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Editorial

Quantum Computing—The Next Frontier in Computational Science: The 21st century has witnessed an unprecedented surge in data generation, scientific complexity, and the demand for faster and more intelligent computation. As classical computing approaches its physical and theoretical boundaries, a revolutionary paradigm “Quantum Computing” has emerged, offering transformative possibilities for science, engineering, and industry.

Quantum computing leverages the fundamental principles of quantum mechanics, that is, superposition, entanglement, and interference, to process information in ways unimaginable to classical systems. Unlike a traditional bit that represents either 0 or 1, a qubit can exist in multiple states simultaneously, enabling quantum systems to explore vast computational spaces in parallel. This extraordinary property positions quantum computing to redefine problem-solving in areas such as artificial intelligence, materials discovery, cryptography, optimization, and climate modelling.

Across the world, research and industry are advancing rapidly in this domain. Recent breakthroughs include superconducting and photonic qubits with coherence times beyond one millisecond and scalable architectures integrating hundreds of qubits. To achieve quantum advantage, where quantum systems outperform classical supercomputers on practical tasks, global technology leaders are investing heavily in hybrid quantum classical approaches.

India, too, is making strategic strides through the National Quantum Mission (NQM), which envisions the development of 50–1000 qubit processors by 2031. The mission focuses on building indigenous capabilities in quantum hardware, algorithms, and secure communication technologies. It emphasizes collaboration among universities, R&D institutions, and industries to create a vibrant national ecosystem that nurtures innovation, education, and entrepreneurship in quantum science.

However, the path forward is challenging. Sustaining coherence, correcting quantum errors, and achieving scalable, fault-tolerant quantum systems remain significant hurdles. Yet, the rapid pace of progress signals that quantum computing will soon transition from experimental study to real-world applications.

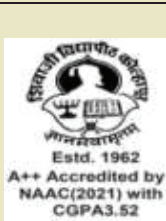
This is a defining moment for academicians and researchers. To secure leadership in this frontier technology, India must integrate quantum science into engineering curricula, promote interdisciplinary research, and develop a skilled quantum-ready workforce. Quantum computing is not merely faster computation, it is a revolution in how technology, matter, and information converge at the quantum level.

Bridging Physics, Engineering, and Computer Science in the Quantum Age

New Delhi

Editor

15th November 2025



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Reliability of Natural Rubber Latex-based Geopolymer Concrete with GGBS

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ABSTRACT

Porosity is one of the most significant elements that directly affects the durability and strength of concrete. Therefore, to attain exceptional durability as well as strength, it is crucial to reduce perviousness in GGBS-based elements. Admixtures of crystalline chemicals are being utilized to decrease the permeability of concrete but quite expensive. Latex from natural rubber has been used as a porous reducing material in geopolymer concrete, per a recent experimental investigation. Variable amounts of fly ash, ground-granulated blast-furnace slag (GGBS), and 2% rubber latex were used to create the concrete cubes and cylinders. The specimens were put through compressive and tensile loading tests to examine how geopolymer concrete affected strength. According to test results, geopolymer concrete has performed better in situations when the proportion of GGBS in the mixture is larger than the quantity of fly ash. Fly ash-based geopolymer concrete has demonstrated less strength increase than geopolymer concrete that includes GGBS. When compared to traditional concrete, geopolymer concrete that contains fly ash and GGBS achieves greater strength. It is also evident that using environmentally friendly elements like fly ash, GGBS, and rubber latex can help reduce porosity in concrete construction.

KEYWORDS: Rubber latex, Fly ash, GGBS, Geopolymer concrete, Strength.

INTRODUCTION

In modern years, there has been a significant global growth in cement output. The replacement of cement with alternative building materials made from industrial byproducts will be one of the major issues facing the construction sector in the years to come. Utilizing industrial waste and lowering greenhouse gas emissions from cement manufacture are two of the primary drivers behind the development of geopolymers. As with traditional concrete, the foundation of geopolymer concrete is comprised of inorganic components; however, these ingredients, which consist of ground granulated

blast furnace slag solvable in solutions of potassium or sodium, fly ash, and silica fume are high in alumina and silica. The alkaline activation of these industrial byproducts results in the formation of a geopolymer binder structure. Geopolymer concrete's usual qualities include geopolymer concrete's usual qualities include low flexural value, and limited longevity. The finely fragmented ashes produced by pulverized coal in power plants are known as fly ash. Usually, silica is found in the range of 40 to 60% and alumina between 20 and 30%. There is a wide variance in the iron content. There is a noticeable concentration of alkalis, with potassium

outweighing sodium. Fly ash's longer life cycle and increased durability are the key benefits of utilizing it in concrete. By reacting fly ash by means of calcium hydroxide to generate calcium silicate hydrate as well as calcium aluminate, the hydration progression lowers the likelihood of calcium hydroxide leaching and the permeability of concrete. Most commonly, sodium silicate (SiO_2) and sodium hydroxide (NaOH) by means of an activator is utilized in geo-polymerization. Rubber latex is extracted in liquid form from the rubber tree. Liquid rubber latex is easily mixed with concrete and can mix homogeneously with water. Rubber latex is incorporated into the micropores of the concrete during mixing. It eventually loses its malleability, solidifies, and completely seals the holes. Rubber latex produced a thin covering around each cement particle when added in cement concrete or geopolymer concrete. Concrete became more workable as a result that rubber sap slowed down the proportion at which the concrete medium shrank because it decreased water absorption. The impact of rubber sap on the carbonation of geopolymer concrete composed of calcined clay was presented by [1]. Rubber latex was mixed to cement concrete with a clay basis to create geopolymer concrete. As per experimental results, it was observed that addition of rubber latex to geopolymer concrete enhanced both the material's workability as well as resistance to carbonation. In an experiment conducted by [2], concrete mixes were made utilizing the absolute volume approach and locally accessible aggregates and mineral admixtures as well as rubber fluid as a base. It was analyzed that when the proportion of rubber sap in concrete mixtures is added up to 0.5%, the compressive capacity rises by means of the rubber dose. The engineering characteristics of latex-modified concrete examined using the GGBS additive, which is one of the byproducts of blast-furnaces adopted to get iron and agricultural products [3]. The modules of elasticity, permeability, durability, etc. were verified through the testing. The experiment's findings demonstrated that chemical attacks on rubber latex resulted in stronger and more resilient materials. The structural response of rubber sap-admixed concrete presented in [4]. To increase the compressive capacity of concrete, portions of the cement in addition to sand are replaced with mineral admixtures such metakaolin and copper slag. To improve tensile strength, a supplementary

reinforcement made of two percent waste tire rubber strip was used. The testing results showed that the concrete with natural rubber latex added had a higher tensile strength and a lower compressive capacity. The GGBS concrete's strength and durability studied in [5]. The concrete grade M20 and M40 that has had 30%, 40%, or 50% of its cement replaced was the subject of the investigation. The cubes and cylinders' compressive, split tensile, and flexural capacities were assessed. Studies on the durability of hydrochloric and sulfuric acid were also carried out. The mechanical properties of GGBS, for example its good acid resistance, fire resistance, high compressive capacity, less creep, and low shrinkage were emphasized by [6]. The ratio of the mixture, its production, the test specimen's curing, and its exposure to acid are some of the techniques used to start the method of examining the features of concrete. The experiment's results showed that under acid attack, the GPS's strength decreased by a less percentage. The majority of earlier studies on fly ash-based geopolymers concrete examined the internal texture of the material and its associated properties, concluding that heat curing is the cause of hardening, which is a disadvantage for cast-in-place applications at low ambient temperatures [7-14]. The purpose of the investigation was to assess how different concentrations of geopolymers and additives affected the strength of geopolymer concrete after ambient curing. The outcomes of the tests also showed that rubber latex might be used to increase the concrete's strength characteristics.

RAW MATERIALS AND METHODOLOGY

Geopolymer concrete as well as conventional concrete with various raw material mixtures, including aggregate, fly ash, GGBS, and rubber latex, are used to create the test samples. To confirm the viability of substituting fly ash, GGBS, as well as rubber latex in geopolymer concrete, the experimental investigation, with a focus on comparing the tensile and compressive capacity of conventional and geopolymer concrete has carried out.

The concrete mix included fine aggregate, which was made of locally accessible sands that were dug out of the riverbed. Coarse aggregate, or crushed stone aggregate, constitutes a single of the ingredients of concrete and is available from the local quarry. Cement concrete of grade M30 is prepared using Portland cement. The water

without turbidity, biological matter, and salts employed for both preparation of concrete specimens. GGBS a byproduct of the blast furnaces used in geopolymer concrete to cast the test specimens. Test specimens are also cast using geopolymer concrete prepared from finely broken coal-pulverized ash from power plants. Sodium silicate also sodium hydroxide as an activator was incorporated in the geo-polymerization procedure to prepare concrete for casting test specimens. Produced rubber latex that was extracted from the bark of rubber trees using a process called tapping and supplied by Siya Scientific Pvt. Ltd. Rubber latex of white colour was utilized in preparation of the test specimens.

The geopolymer concrete was prepared by way of thoroughly mixing fly ash, GGBS, sodium silicate also sodium hydroxide solution, and two percent natural rubber latex. Specific amounts of rubber latex, GGBS as well as fly ash were added as supplements to the mixing process while the concrete was being batch-produced. Geopolymer concrete has been prepared by varying the ratios at which fly ash and GGBS are blended. After adding an alkaline solution with a molarity of 13 M and blending GGBS and fly ash at a proportion of 70:30, geopolymer concrete was made, exhibiting compressive strength when allowed to cure naturally. The test specimens were cast using geopolymer concrete and kept in an ambient curing environment with a temperature of 25 to 35 degrees Celsius so that they would set and become stronger.

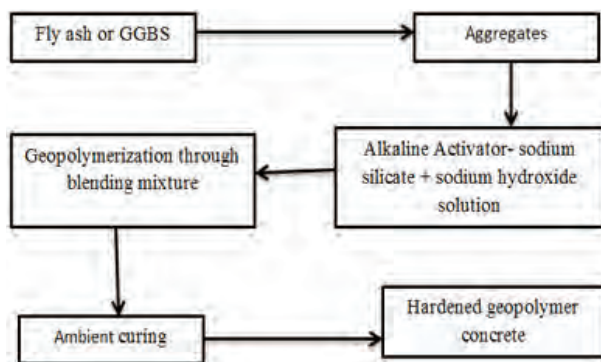


Fig. 1: Flow chart of preparation of geopolymer-concrete

EXPERIMENTAL DESIGN AND TRIALS

For the experiment, the test specimens in the two groups were ready. As seen in Fig. 2, the initial batch of samples were cast as cubes. The second set of cylinder-

shaped specimens, measuring $150 \times 150 \times 300$ mm, was emphasized in Figure 3. The twelve concrete cube test samples and the eight cylindrical test samples are displayed in Table 1. All concrete specimens were cast according to the M30 mix design for the experiment, by means of a set percentage of rubber latex and different quantities of GGBS and fly ash.



Fig. 2: Cubical test samples



Fig. 3: Cylindrical test sample

After curing, all test specimens were kept at ambient temperature. Compressive loading tests were performed on the cube samples in accordance with the evaluation pattern on the loading machine, as highlighted in Fig. 3. Each cube specimen was positioned among the two lips of the machine, and the loading was gradually raised until the specimen shattered. A 2000 kN compression testing apparatus was adopted to check the tensile capacity of cylinder specimens. The machine's two jaws were used to insert the cylinder specimens, as shown in Fig. 4, and a force of $140 \text{ kg/cm}^2/\text{minute}$ was maintained until the test specimen failed entirely. The ultimate tensile and compressive strengths for each test

sample were recorded so as to ascertain the compressive and tensile capacities of concrete. The compressive capability of the concrete was calculated by way of dividing the ultimate load imposed to the specimen by the sample area.

Table 1: The experimental work's test matrix

Test specimen	Type of the sample	Nature of the substance	Number of samples	Rubber latex (2%)	Material in concrete (%)
Size of concrete cube- 150x150 x150 mm	CC	-	3	-	-
	FA	Fly ash	3	-	100
	FG	Fly ash and GGBS	3	Rubber latex	70 and 30
	GG	GGBS	3	-	100
	GF	GGBS and fly ash	3	Rubber latex	70 and 30
Cylinder size - 150x150 x300 mm	FA	Fly ash	3	-	100
	FG	Fly ash GGBS	3	Rubber latex	70 and 30
	GG	GGBS	3	-	100
	GF	GGBS and Fly ash	3	Rubber latex	70 and 30



Fig. 4: Cylinder and cube sample testing on a compression testing apparatus

The tensile capacity of the concrete cylinder for a cylindrical sample was calculated using the following calculations.

- 1 Compressive strength test (MPa): $=P/A$
- 2 Tensile strength test (MPa): $=2P/\pi DL$

Where P denotes the test specimen's ultimate load, L - The specimen's length and A stands for the specimen's area, and D for its diameter.

RESULTS OF THE EXPERIMENT AND A DISCUSSION

Table 2 displayed the differences in recorded ultimate compressive loads that were shared by different concrete cube specimens. The compressive load on all concrete cube specimens varied with increasing the curing period. The ultimate compressive load taken by concrete made of GGBS is higher compared with concrete mixed with fly ash. The compressive load taken by concrete made of combination with GGBS 70% as well as fly ash 30% is much better as compared to concrete made of combination with GGBS 30% and fly ash 70%. As indicated in Table 3, the maximum split load observed is lower for the concrete cube composed of GGBS 30% and fly ash 70% additive mixture than for the concrete cube built of GGBS 70% also fly ash 30% additive mixture. The outcomes of the split load test on cylindrical specimens explored that the concrete made of GGBS densified the test specimen correspond improves the split load capacity as compare to concrete made of fly ash.

Table 2: Compression load test result

Type of specimen	Compressive load taken by specimen after curing, kN		
	7 days	14 days	28 days
M30	450.0	630.0	675.0
GGBS	790.0	1038.8	1151.3
Fly ash	577.1	849.8	971.3
G70%FA30%RL2%	1000.1	1517.9	1630.4
G30%FA70%RL2%	756.9	1285.0	1381.5

Comparative findings of compressive strengths tests on concrete cubes revealed that, as shown in Fig. 5, an increase in GGBS and its percentage when mixed with fly ash strengthened the concrete. Tensile strength is achieved in the concrete cylinder with a significant increase in GGBS doses and its percentage when combined with fly ash, as equated to conventional concrete cylinder specimens. In comparison to both conventional concrete and with 100% fly ash, the 100% GGBS concrete provided a larger compressive load. Even though rubber latex is added to concrete in smaller

amounts than other cubes, as Figure 6 illustrates, it still has a considerable impact on the material's compressive and tensile strengths and lengthens the curing time.

Table 3: Tensile load test result

Type of specimen	Split load taken by specimen after curing, kN		
	7 days	14 days	28 days
M30	60.1	120.2	159.7
GGBS	123.0	142.1	171.8
Fly ash	88.4	101.8	128.6
G70%FA30%RL 2%	154.8	184.5	205.0
G30%FA70%RL 2%	115.2	167.5	187.3

The addition of natural latex altered the internal texture of the concrete, resulting in a decrease in porosity and an increase in density. These changes are what improved the capacity of the concrete cube and cylinder, according to the outcomes of tensile and compressive capacity tests. Additionally, present experimental work outcomes has shown that concrete made entirely of GGBS and fly ash has lower compressive and tensile strengths than concrete made with rubber latex included as well. The achievement of strength to the concrete element is responsible because of hydration process of geopolymer concrete and formation of hydrated products in internal structure of concrete. Mixture of geopolymer concrete GGBS as well as Fly ash dissolved differently based on the category and concentration of the alkali solution. The concentration of alkali has a major impact on the filtering of silica also alumina through fly ash and GGBS particles, the consequent geo-polymerization, as well as the mechanical characteristics of the set geopolymer. The type of activator employed greatly influences the process of polymerization. Reactions occur faster when soluble silicates, like potassium or sodium silicate, are added to the alkaline activator than when alkaline hydroxides are employed alone. The fly ash or GGBS elements begin to bind together as soon as the sodium silicate activator dissolves. The liquid phase rapidly fills with gel when fly ash or GGBS elements comes in contact with it which start reducing porosity on concrete. The reduction of porosity also improved with adding of natural rubber latex. The hydrated structure of cement paste with aggregates developed denser which reflected the through the compression and tensile testing of geopolymer concrete specimens.

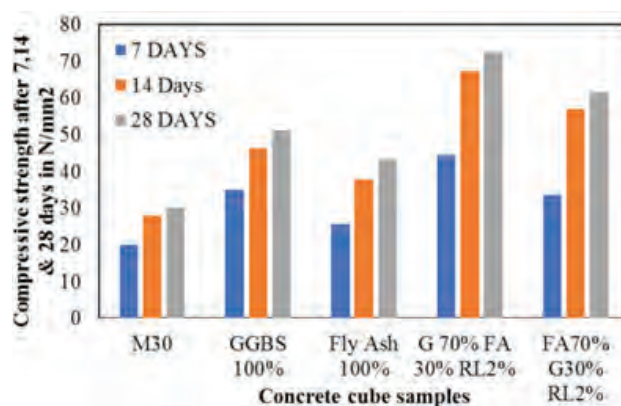


Fig. 5. Failure of conventional and Geopolymer Concrete

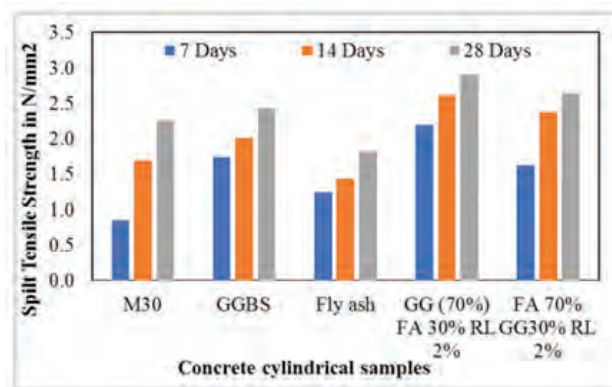


Fig. 6. Failure of conventional and geopolymer concrete

CONCLUSION

On the basis of fly ash as well as GGBS, ordinary concrete and geopolymer concrete are compared. The geopolymer concrete's compressive also tensile capacities were evaluated at different mix doses. These significant outcomes have been examined in the experimental study on GGBS-based geopolymer concrete using natural rubber latex:

- Concrete that contains GGBS 70% and fly ash 30% in addition to 2% natural rubber latex achieves greater load carrying capacity, compressive strength, and tensile strength.
- According to the experimental findings, the roll of rubber sap in geopolymer concrete is crucial for growing density and regulating porosity, both of which have an influence on the material's capacity.
- GGBS-based geopolymer concrete has attained the higher strengths after 28days curing in ambient

temperature as compared to conventional concrete with normal water curing.

- When concrete is combined with 100% GGBS, the contribution of tensile and compressive capacities is more than when the concrete contains 100% fly ash.
- The strengths of concrete cubes and cylinders were found to decrease with decreasing fractions of GGBS and rising proportions of fly ash in concrete, when rubber latex was added in consistent amounts to the mixture.

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Hydrological Models for Flood Mitigation: A Comprehensive Review for Watershed Development

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ABSTRACT

Floods are among the most devastating natural disasters, posing significant risks to both human life and infrastructure. Effective flood mitigation strategies require robust hydrological models that enable accurate prediction, analysis, and management of watershed systems. This review paper explores various hydrological models used in flood mitigation, ranging from empirical and conceptual models to advanced distributed and machine learning-based approaches. It evaluates their applications, advantages, limitations, and suitability for developing integrated watershed management plans. Special emphasis is placed on their role in enhancing prediction accuracy, improving resource allocation, and enabling sustainable development in flood-prone regions. The findings underscore the importance of combining traditional methods with modern computational techniques to build resilient and adaptive watershed systems. This review explores hydrological models for flood mitigation, emphasizing their role in watershed development. It examines model selection, simulation techniques, and effectiveness in predicting and managing flood risks. The study highlights advancements and challenges in integrating these models for sustainable water resource management.

KEYWORDS: *Hydrological models, Flood mitigation, Watershed management, Flood prediction, Distributed models, Machine learning, Sustainable development, Flood-prone regions.*

INTRODUCTION

Floods are among the most destructive natural disasters, causing significant loss of life, property, and infrastructure globally. Their frequency and intensity have been exacerbated by climate change, rapid urbanization, and land-use changes, underscoring the critical need for effective flood mitigation strategies. Hydrological models have emerged as essential tools in understanding, predicting, and managing floods, enabling stakeholders to make informed decisions for watershed development and disaster risk reduction.

Hydrological models simulate the movement, distribution, and quality of water within a watershed, integrating physical, chemical, and biological processes. These models play a pivotal role in flood prediction, early warning systems, and the design of mitigation

measures such as reservoirs, levees, and floodplain zoning. By providing insights into watershed behavior under various climatic and anthropogenic scenarios, they facilitate sustainable water resource management and resilience building.

This comprehensive review aims to explore the diverse range of hydrological models used for flood mitigation, categorizing them based on their methodologies, applications, and capabilities. It examines the strengths and limitations of different modeling approaches, from empirical and conceptual models to advanced physically-based and data-driven models. The review also highlights the integration of emerging technologies such as remote sensing, geographic information systems (GIS), and machine learning in enhancing model performance.

In the context of watershed development, the application of hydrological models extends beyond flood control to encompass water conservation, ecosystem restoration, and socio-economic development. This review underscores the importance of adopting an integrated and adaptive approach, leveraging hydrological modeling as a cornerstone for achieving long-term sustainability and resilience in watershed management.

LITERATURE REVIEW

Numerous studies have explored the application and development of hydrological models for flood mitigation and watershed management. For instance, Smith et al. (2020) analyzed the effectiveness of conceptual models in simulating flood events in small catchments, highlighting their simplicity and computational efficiency. However, the study noted limitations in representing complex physical processes, which may reduce accuracy under extreme conditions.

In contrast, physically-based models, such as those studied by Brown et al. (2019), provide a detailed representation of hydrological processes but often require extensive data and computational resources. These models are particularly useful in evaluating the impact of land-use changes and climate variability on flood dynamics. Similarly, hybrid models combining empirical and physical approaches, as reviewed by Zhang et al. (2021), have demonstrated enhanced flexibility and accuracy, particularly in data-scarce regions.

Data-driven models, including machine learning techniques, have gained prominence in recent years. According to Patel and Kumar (2022), these models excel in pattern recognition and flood forecasting but often lack interpretability and require significant historical data for training. The integration of remote sensing and GIS, as discussed by Lee et al. (2023), has further improved model capabilities by providing high-resolution spatial and temporal data for flood mapping and watershed analysis.

Despite the advancements, challenges remain in model selection, calibration, and validation, as noted by various researchers. The choice of model depends on the specific objectives, data availability, and scale of the study area. Additionally, the need for interdisciplinary

approaches that combine hydrology, climatology, and socio-economic factors is increasingly emphasized in the literature.

Table 1: Summary of Hydrological Models Reviewed

Study	Model Type	Key Features	Limitations	Application Areas
Smith et al. (2020)	Conceptual	Simple, efficient, suitable for small catchments	Limited in extreme conditions	Flood simulation
Brown et al. (2019)	Physically-based	Detailed representation of processes	High data and computational requirements	Land-use and climate impact
Zhang et al. (2021)	Hybrid	Combines empirical and physical approaches	Moderate data needs	Data-scarce regions
Patel & Kumar (2022)	Data-driven	Pattern recognition, flood forecasting	Lacks interpretability, data-dependent	Predictive analytics
Lee et al. (2023)	GIS-integrated	High-resolution spatial and temporal data	Requires technical expertise	Flood mapping, watershed analysis

METHODOLOGY

This review follows a systematic approach to analyzing hydrological models used for flood mitigation in watershed development. The methodology includes:

Methodology

This study follows a systematic approach to analyze and evaluate hydrological models for flood management. The methodology consists of the following key steps:

Literature Review

A comprehensive review of peer-reviewed articles, case studies, and technical reports is conducted to understand the current advancements in hydrological modeling. This step helps in identifying various models used for flood prediction, their applications, and their effectiveness in different hydrological conditions.

Model Classification

Hydrological models are categorized into three primary types based on their structure and application:

- Empirical Models – Data-driven models relying on observed relationships between rainfall and runoff.
- Conceptual Models – Models representing hydrological processes through simplified mathematical relationships.
- Physically Based Models – Models that simulate real-world hydrological processes using fundamental physical equations.

This classification aids in selecting the most suitable model based on study requirements and available data.

Model Evaluation

The selected models are evaluated based on key parameters to determine their reliability and performance:

- Hydrological Parameters: Rainfall intensity, infiltration rate, surface runoff, evapotranspiration, and soil moisture.
- Flood Parameters: Peak discharge, flood duration, flood volume, and inundation area.
- Watershed Characteristics: Land use, slope, soil type, and drainage network.

Model performance is analyzed by comparing simulated results with observed data, ensuring accuracy in flood prediction.

Comparative Analysis

A comparative study is conducted to assess different models based on:

- Accuracy: How well the model predictions match observed data.
- Efficiency: Computational time and resource requirements.
- Applicability: Suitability of models for different watershed scales and flood scenarios.

Real-world case studies are used to validate the effectiveness of each model in various hydrological condition.

CASE STUDY: FLOOD CONDITIONS IN TAMBAVE NEAR KARAD

The Tambave region near Karad has experienced recurring floods due to its location in the Krishna River basin, characterized by heavy monsoonal rainfall and rapid runoff. Comparing this scenario with other case studies reveals significant insights into regional flood dynamics and mitigation measures.

The flood conditions in Tambave can be contrasted with the findings of Brown et al. (2019), who utilized a physically-based model to assess land-use changes. Tambave, similar to the study area in Brown's research, faces challenges related to unplanned urbanization and agricultural expansion, which exacerbate flood risks by reducing natural infiltration and increasing surface runoff.

Moreover, data-driven models like those analyzed by Patel and Kumar (2022) could enhance flood forecasting accuracy in Tambave. The integration of historical flood data with real-time monitoring systems could provide early warnings, enabling timely evacuation and resource allocation.

GIS and remote sensing, as emphasized by Lee et al. (2023), could play a crucial role in Tambave's flood management. High-resolution spatial data can aid in mapping flood-prone areas, designing effective drainage systems, and planning resilient infrastructure. Adopting a hybrid approach that incorporates multiple modeling techniques could optimize flood mitigation strategies for the region.

This comparative analysis underscores the need for tailored hydrological models that consider local geomorphological, climatic, and socio-economic factors, ensuring effective and sustainable watershed development in Tambave.

The Tambave case study refers to a specific hydrological event or region, but without further details, I'll consider general principles that can be applied. In the context of hydrology, when discussing a case study like Tambave, it's critical to understand the hydrological characteristics, such as precipitation patterns, watershed characteristics, soil types, and land use. Based on this, the following hydrological models can be suggested:

SWAT (Soil and Water Assessment Tool) Model

- Use case: For large, rural watersheds with limited hydrological data, SWAT is a robust model that simulates streamflow, sedimentation, and water quality, which are common in cases of agricultural or forested regions.
- Discussion point: The Tambave case study could examine how land use changes (agriculture, deforestation) or different soil types impact water availability and erosion rates. The model could also simulate the impacts of various climate scenarios on the watershed.

HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System)

- Use case: For smaller basins or urban areas with varied precipitation data, HEC-HMS can simulate rainfall-runoff processes effectively. It incorporates infiltration, surface runoff, and routing.
- Discussion point: This model can be used in the Tambave case study to analyze the impacts of urbanization or flood events. It could help in flood forecasting and understanding streamflow response to precipitation events.

MIKE SHE (Integrated Hydrological Modeling System)

- Use case: This model is ideal for cases where both surface and groundwater processes need to be integrated. It includes modules for precipitation, runoff, infiltration, and groundwater interactions.
- Discussion point: In Tambave, if the case involves both surface water management and groundwater recharge or contamination issues, MIKE SHE could model these interconnected processes, providing more comprehensive insights into water management.

NAM (Nordic Association of Hydrology Model)

- Use case: For regions that deal with snowmelt, NAM is useful in cold climates or areas that experience significant seasonal variation in precipitation and temperature.
- Discussion point: If the Tambave case study involves snowmelt runoff or regions with a

significant difference between wet and dry seasons, NAM could be used to assess seasonal variations in river flow or reservoir levels.

Tank Model

- Use case: This simple conceptual model is well-suited for semi-arid regions where water storage and groundwater recharge are key processes. It assumes that water in a watershed is stored in a series of tanks (or reservoirs) and that each tank has a certain drainage and outflow.
- Discussion point: If the Tambave case study is in a semi-arid region or involves water scarcity issues, the Tank Model could be applied to evaluate the effects of rainfall variability, evaporation, and groundwater recharge.

Rainfall-Runoff Models (e.g., Rational Method or Curve Number Method)

- Use case: These are simple empirical methods used for estimating runoff in small, urban watersheds, especially where there's limited data.
- Discussion point: For the Tambave case study, where the area might be urban or small-scale, these models can be used to quickly assess flood risk or runoff under different rainfall events.

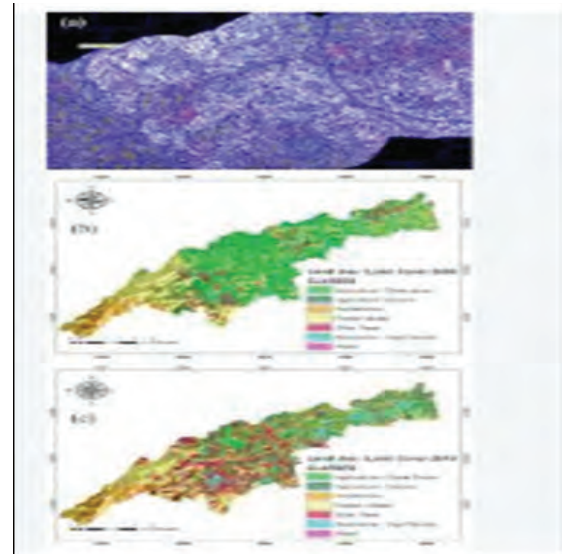
CASE STUDY ANALYSIS AND DISCUSSION

Fig. 1. GIS Map (Source:NHESS)

SWAT is recommended for its balance of process-based simulation and ease of use with available data. If the scope is smaller or focuses on specific issues (e.g., urban floods), HEC-HMS or simple methods like the SCS Curve Number may suffice. For integrated water resource studies involving groundwater, MIKE SHE is the ideal choice, provided the required data and computational resources are available as shown in figure 1.

Quantitative Outputs

- Runoff (mm): Average annual, seasonal, and event-based surface runoff.
- Sediment Yield (t/ha): Total sediment yield at critical points.
- Streamflow (m³/s): Daily, monthly, and annual discharge at watershed outlets.
- Recharge (mm): Groundwater recharge under different conditions.
- Water Balance (mm): Components like evapotranspiration, infiltration, and soil water content.

Expected Visualizations

Maps:

- o Runoff and erosion hotspots.
- o Land-use impact zones.

Graphs

- o Hydrographs (flow vs. time).
- o Seasonal variations in water balance components.

Reports

- o Summaries of scenarios comparing baseline vs. intervention outcomes.

Novelty of Work: Computational Efficiency Compared to Traditional Methods

This study introduces a computationally efficient approach to hydrological modeling for flood management, improving upon traditional methods in the following ways:

Automated Data Processing & Integration

- Traditional models often require manual data input and preprocessing, leading to increased time and potential errors.
- The proposed approach integrates GIS, remote sensing, and real-time hydrological data, automating preprocessing and reducing human intervention.

Improved Computational Speed & Performance

- Physically based models in traditional methods demand high computational resources, making real-time simulations challenging.
- The selected model optimizes parameterization, reducing computational time while maintaining accuracy. Parallel computing techniques and cloud-based simulations further enhance performance.

Enhanced Model Calibration & Validation

- Traditional hydrological models require extensive trial-and-error calibration, making them time-consuming.
- This study employs machine learning techniques and optimization algorithms for automatic calibration, reducing computational overhead while improving model accuracy.

Efficient Flood Prediction & Early Warning Systems

- Conventional methods use static historical data, limiting predictive capabilities.
- By incorporating real-time monitoring and dynamic climate models, the proposed approach enables faster and more accurate flood forecasting, allowing timely decision-making.

Scalability & Flexibility for Different Watersheds

- Traditional methods often struggle with model adaptation across different watershed scales due to fixed parameterization.
- The selected model is adaptable to various watershed sizes and land use conditions, ensuring computational efficiency without requiring extensive reconfiguration.

Optimized Data Storage & Processing

- Traditional models rely on large datasets, requiring extensive storage and processing power.
- Cloud-based data handling and efficient compression techniques minimize memory usage, making the approach suitable for real-time applications.

By addressing these computational challenges, the proposed methodology enhances efficiency, reduces processing time, and improves the accuracy of flood prediction compared to traditional hydrological modeling approaches.

CONCLUSION

When discussing hydrological modeling in the Tambave case study, it is crucial to select a model based on the study area's scale (small vs. large watershed), data availability (precipitation, land use, soil properties), and the specific hydrological processes of interest (e.g., flood forecasting, groundwater recharge, sedimentation). The choice of model should align with the study's objectives, whether for flood management, water quality assessment, or long-term water resource planning.

Applying the SWAT model in the Tambave case study can provide valuable insights into water resource dynamics, identify areas of concern, and assess potential interventions for sustainable watershed management. The model's results can support both short-term decisions, such as flood mitigation, and long-term strategies, including land use planning and climate adaptation.

Challenges & Future Scope

The study identifies limitations in existing hydrological models, including data availability, computational complexity, and model uncertainties. Potential improvements, such as integrating remote sensing data, machine learning techniques, and real-time monitoring systems, are explored to enhance flood prediction and mitigation strategies.

By following this methodology, the study aims to provide a robust evaluation framework for selecting and improving hydrological models for flood management.

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Comparative Study of PRT vs. Existing Bus Transit System in Kolhapur City

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ABSTRACT

Kolhapur city is one of the fastest growing city in Maharashtra, India with an area of 66.82 square kilometers. The population density stands very high at 7261 persons/ square kilometer, Vehicles representing a growth of 16-19% per annum for city since 2003. The increase in number of vehicles impact directly to the public transportation services and increase traffic congestion, hence research designed to find solution, to improve public transportation service, by improving public transportation system to solve traffic congestion problem.

This paper presents a comparative analysis of Personal Rapid Transit (PRT) and existing Bus Transit (BT) system under Kolhapur municipal corporation (KMT) as alternative modes of urban transportation. This paper covers comparison of case study and existing implementations of both systems in various urban contexts worldwide, with reference to advantages, disadvantages, costs, fares, and social impacts examined for each system based on Socio Economic Factors. Comparative performance study with respect to PRT is carried out using Comprehensive Methodology from users, city and operators point of view.

The findings of this evaluation clearly demonstrate that by providing Personal Rapid Transit along existing bus transit routes will significantly enhance commuter satisfaction. This will be accomplished through safety improvements, reductions in travel time, fuel savings, increased capacity, and notable environmental benefits. PRT will alleviate traffic congestion, lower noise levels, and improve air quality on major roads in the city.

KEYWORDS: *Personal rapid transit (PRT), Kolhapur municipal corporation (KMT), Bus transit (BT).*

INTRODUCTION

Kolhapur has greatest importance from tourism point of view. Lakh's of people are visiting Shri. Mahalaxmi temple. Kolhapur is well-connected by road, rail, and air and is seen as a significant religious and commercial hub for the area. It is situated 235 kilometers from Pune and 395 kilometers from Mumbai, the state capital of Maharashtra. Kolhapur is located 412 km from Hyderabad and 549 km from Bangalore. Thus, it is almost halfway between the nation's main IT hubs.

Southern Railways hub is also Kolhapur Terminus Station. It's air port is at Ujalaiwadi, which is close to NH-48. The city is referred to as the "Door of Konkan"

because it is only 135 kilometers from the western shore.

Key issues are, the railway line divides the city in two parts, improper traffic junctions and lane widths, persistent parking issues in central places, such as tararani chowk, C.B.S bus stand, railway station, C.P.R. chowk, etc. are among the main issues. The following factors contribute to traffic jams: Road side parking, Lack of bus bays, Transformers, electric poles, and hoardings blocking roads, High traffic volume compared to road capacity, Narrow bridges and insufficient number of railway overpasses, Invasion of the road by petty shops and foot path vendors, Lack of an integrated terminal for various modes of transportation, Utility ducts lacking

from roads, Absence of truck terminals, [34] all above issues results in traffic congestion, severe air pollution and adverse noise pollution [24]. This research proposal is to solve traffic congestion problem for Kolhapur city.

LITERATURE REVIEW

Vinayak (2022). This paper focuses on understanding passenger satisfaction in the context of public road transport, specifically the Kolhapur Municipal Transport (KMT) system. The study uses the SERVQUAL theory as a guiding framework to evaluate service quality, customer expectations, and satisfaction levels. The research aims to provide insights into the factors that influence satisfaction and to suggest strategies for improving service quality in the KMT system. [02]

Kulkarni(2022).The study mainly looked at traffic jam indices in connection to travel time reliability indicators in order to evaluate the functional effectiveness of the urban road network at Kolhapur. [03]

Sitesh Kumar Singh et al. (2021), The author came to the conclusion that PRT can function well as a local transportation system for individuals to move about locally additionally, it is inexpensive and pollution-free, which will help large cities with dangerously high pollution levels to develop sustainability. In this paper author focused on comparative study of PRT with conventional transport system. [05]

Gurjaret al.(2021),the author focused on Comprehensive methodology to compare the performance of public transportation systems through the perspectives of users, cities, and operators, as well as when integrated with urban areas. [08]

Kim et al. (2020), the study's author offered a practical technique that uses logistic regression models to better understand the factors influencing a short-distance traveler's mode of transportation decision. This study will be crucial in helping to analyze new transportation options that can more readily meet the growing need for short- distance travel. [12]

Jitendra et al. (2020), the main focus of this paper is on significant performance indicators that are applied globally to assess public transportation service performance. [13]

Anuj Sharma et al (2020). The author of this study

came to the conclusion that discussing sustainable transportation systems raises a number of issues. Prior to beginning the planning process, it is crucial to precisely establish the goals and objectives. It requires an integrated approach that considers the effects on the environment, society, and economy. [14]

Scott Cohen et al. (2019). By offering a thorough imaginative approach to the possible far reaching future consequences of connected and autonomous vehicles (CAVs) for urban tourism, this conceptual study sets new standards. This work lays the groundwork for a new area of study on CAVs and tourism, which will also aid in PRT planning from a tourism perspective. [15]

Louis Merlin (2017).This paper explores the potential advantages of automated shared-ride taxi services over traditional bus transit for small cities. The research highlights the ability of these emerging technologies to offer enhanced transit services with benefits such as reduced costs, better service quality, and lower environmental impact compared to conventional bus systems.[20]

Udit Jain et al. (2016) used binary logit models and the expressed preference technique to estimate demand for personal rapid transit (PRT). The author of this paper mostly employed binary logit models and the expressed preference technique to estimate the travel demand for a PRT system within a specific area. [21]

Choudhary et al.The author's research indicates that PRT is a novel integration of computer network, vehicle, and transit technologies that has the potential to be highly economical under the correct conditions. The PRT network proposed in this study is for Varanasi, India, one of the oldest settlements in the world. [23]

A complete framework for reforming and redesigning the bus transit system in Kolkata, India, is presented by Debapratim Pandit (2013) in Case Study Kolkata. The study expands on pre-existing frameworks for reforming bus transit, but it emphasizes the importance of taking into account how users perceive the quality of the current services and how satisfied they are with them at various service levels. By bringing reform efforts closer to the requirements and expectations of passengers, this strategy aims to increase their efficacy. [29]

Shireen Al Suleiman examines the variables that affect public bus service user's overall satisfaction (OS) in a medium-sized metropolis to determine the significance of different service-related qualities and their effect on user satisfaction, the study used an ordinal logistic regression model. The results provide bus operators with insightful information to raise customer happiness, enhance service quality, and draw in more customers. [01]

S. Kharola (2010). This paper investigates the safety concerns related to public transport buses, specifically focusing on fatal crashes with buses in Bengaluru. This study offers several insights into how urban transportation systems can be improved to enhance road safety for both pedestrians and cyclists. [31]

Manish Sharma et al. (2022). An analytical survey of public opinion on the following topics is carried out in this research study: interchange, safety with comfort, walk able accessibility, modal share preference, mode of transportation, socioeconomic status, and travel habits. This paper gives guidelines regarding conducting surveys. [04]

Ran Etgar et al. (2021), In order to assess the capacity of inner-city PRT system and impact of several factors on it, this work involves a thorough discrete-event micro simulation analysis. [06]

Nandan dawda et al. (2021), author focused on the application of moving vehicles rather than people in the creation of India's urban transportation infrastructure. This paper's primary goal was to examine how multimodal transportation was taken into account when developing the infrastructure for urban transportation. [07]

Sheth et al. Focused on use of social benefit cost analysis (SBCA) to analyze assessments of sustainable transportation systems and increase the likelihood of their realization is clarified by this study. This SBCA aids in forecasting the PRT feasibility analysis. [09]

Shanshan et al. An integrated APTS was investigated in this project for metropolitan areas which uses automated vehicles with developing technologies including information and communication technology to service both passengers and freight. The technical difficulties are outlined and Dynamic Autonomous

Road Transit (DART), an exemplary example of an APTS, is presented. [10]

Jonatas Manzolli et al. (2020). The author of paper compares this strategy to more conventional fast transportation options using Multi Criteria Decision and the Preference Ranking Organization Method. [11]

Pomoni et al. (2019). The primary goal of the author's paper was to map the main trends in the transportation work force over the short, medium, and long terms related to behavioral, cultural, and socio economic aspects. [16]

Anasuri et al. (2017). In this essay, personal rapid transit (PRT) is highlighted as viable solution towards the problems of pollution and traffic congestion that has already shown some degree of success. This study explicitly addresses the guide way design for the PRT's pod cars. [19]

Mangalekar et al. (2015). The author of this research concentrated on the air quality index near Mahadwar Road and Dabholkar Corner, where the severe air pollution limit (SAP) is crossed. In this document, remedial steps should also be recommended. [24]

RESEARCH METHODOLOGY

PRT's comparative performance study will be carried out using comprehensive methodology [08]. Comparative performance assessment of public transportation networks from the view point of users. A comparative study of public transportation systems performance from a city perspective. A comparative study of public transportation systems performance from the stand point of operators. Analysis will be performed based on performance indicators. Case studies and current implementations of both systems in diverse global contexts will be used to accomplish everything mentioned above.

Bus Transit System: What Is It?

It is affordable, high-capacity public transportation option that may greatly increase urban mobility. This permanent, integrated system offers the flexibility to fulfill transit demand by swift and efficiently transporting passengers to their destinations via buses.

Major Components of Bus Transit System:

Running ways: Travel times, dependability, and identity are all greatly impacted by running ways.

Stations: Stations are the most important client interface since they serve as the system's entrance point and have an impact on dwell times, the system's reputation, accessibility, dependability, comfort, safety, and security.

Vehicles, Vehicle Configuration: By accommodating a mix of sitting and standing people, buses, have a person capacity of up to 50.

Fare Collection: Traditional pay-on-board techniques, prepayment (bus pass) are among the available options.

This bus oriented system has various Reasons to support vs. reasons to exercise causation [09]

1. Ready availability: Buses doesn't require cutting edge technology to be produced, and many manufacturers across multiple nations can do so.
2. No need for research and development: The introduction of new components and technological advancements for buses happen slowly. No process of evolution and no significant discoveries are planned for the foreseeable future.
3. No specialized labor force or expertise needed: Both the diesel engine and the bus have a lengthy history. With minimal additional training; any truck technician with an understanding of engines can handle bus maintenance. A little instruction and practice can let anyone with a conventional driver's license become a bus driver.
4. Low investment: There is no extra cost associated with building the transit channel because buses nearly usually utilize already-existing city streets.
5. Energy consumption: The bus's efficient power plant and relatively light weight make it possible to save a lot of fuel when compared to other modes.
6. Versatile operations: Buses can go on any level section of pavement because they are not attached to any form of track or guide way.
7. Line-haul capability: Although buses can stop frequently to pick up and drop off people, they can also go quickly between stops.

8. Maneuverability: Despite their size, buses are able to maneuver through practically every type of street arrangement, including ones with tight corners and limited rights of way.

9. Temporary diversions: Unlike rail, buses can go around a disabled bus in front of them and avoid any temporary obstructions that might emerge on city streets.

Reasons to exercise caution

1. Labor-intensive operations: Compared to other modes that rely on huge units and automation, buses have significantly higher operating personnel to passenger ratio.
2. Pollution: Internal combustion engines that run on diesel can do significant harm to the urban environment.
3. Traffic jams: Buses are a major source of traffic jams because they get stuck in them. In these situations, street congestion makes bus service erratic and slow, often completely eliminating its viability.
4. Slow service: In addition to the issue of traffic, fare collection procedures can significantly impede the efficient functioning of buses.
5. Public perception: Many people seem to think that taking the bus would lower their social standing, giving buses a bad public perception.
6. Lower capacity: Compared to rail vehicles, each bus unit is significantly smaller. Running them as a continuous chain is not possible due to loading needs and street conditions.
7. Comfort and trip quality: Compared to buses, rail based modes are naturally preferred by transit users. Rail offers a solid and secure ride. The bus trembles, and vibrates.

Personal Rapid Transit System (PRT) PRT stands for completely automated, grade-separated mass transit. The PRT system consists of a guide way, vehicle, station, power supply apparatus, computer control systems, and facilities for storage and maintenance.

PRTs: Reasons to support vs. reasons to exercise causation [25], [27]1.PRTs are automated, silent,

and nonpolluting. These qualities are shared by most contemporary electrically powered transportation systems operating on rails or a guide way.

2. Safety: There haven't been any significant operating mishaps to date, and the record is incredibly good. Additionally, there has been great personal safety. Systems work in controlled surroundings, and safety professionals and monitors conduct extensive surveillance programs.
3. Constrained space suitability: PRT components all have dimensions that are demonstrably smaller than those of traditional transit, and they produce less noise and vibration. More options exist to run lines through densely populated areas.
4. There is little chance of a car derailing: While other mechanical issues are not ruled out, it is nearly hard for the vehicle to escape the channel.
5. Advanced technology image: PRTs are thought of by the general public as being connected to innovative ideas and technical advances. This might be a very beneficial factor, perhaps leading to a great deal of public and civic support for implementation.
6. Low labour input: There are significant labor cost savings on the people side of the ledger because there are no conductors or drivers on the vehicles, and passengers may not see any operating agency employees.

Reasons to Exercise Causation.

1. System fragility: Automated PRTs are distinguished by extremely sophisticated technology and sometimes delicate parts.
2. Because cross traffic cannot be accommodated on the same level, PRTs can only operate in an elevated design. This means that the lines cannot be put on the surface.
3. The costlier vehicles: Because the suspension systems on these cars are more intricate than those on ordinary cars, they are more expensive.
4. Cost factors: Since advanced technology vehicles must be purchased, complex maintenance facilities must be made available, and a completely new, exclusive guiding route must be developed, capital

investments will be significant and highly costly. Indian scenario point of view following case studies are referred, [19], [23], [25], [30], [37].

1. PRT feasibility study for Gurgaon sector-Delhi
2. PRT feasibility analysis in Lucknow
3. PRT feasibility analysis in Dwaraka
4. PRT feasibility analysis in Varanasi
5. PRT feasibility analysis in Vishakapattanam
6. PRT feasibility analysis in Amrutsar

From world point of view following case studies are referred, [30]

1. PRT at Heathrow air port London
2. PRT at Masdar city Abudhabi
3. PRT at Morgantown
4. Application of PRT in Swedish cities
5. Application of PRT in European cities
6. Application of PRT in china etc.

Novelty of the work: - Personal Rapid Transit (PRT), are novel because of their creative, effective, and adaptable method of urban transportation. PRT systems differ from conventional transit options in the following important ways:

On-Demand, Point-to-Point Service: PRTs provide a more convenient and individualized service by transporting customers straight between stations.

Decreased Traffic Congestion: PRT don't add to traffic congestion because they run separately on designated tracks.

Better Connectivity and Urban Mobility: PRT systems can be easily incorporated into current public transportation systems, enhancing the functionality of buses, trains, and other modes of transportation.

Eco-Friendly: Compared to conventional vehicles, PRT have lower emissions since they employ electric motors and, occasionally, renewable energy.

Upon examining multiple case studies in India and world point of view, there is major gap in previous work that in automated people movers family like metro,

monorail, light rail transit (LRT), rail rapid transit (RRT) comparison between various modes are available but very less work focus on comparison of personal rapid transit (PRT) and other modes of transport.

This paper highlights previous literature review, previous studies, review of existing case studies based on performance indicators in comprehensive methodology.

This paper focus on suitability of PRT system for fastest growing cities in India to avoid traffic congestion.

5. Outcomes and Conversations: Upon examining multiple case studies in India and beyond, the following findings are drawn from the viewpoint of the user, city and operator.

Table 1 Comparative Evaluation of PRT and Bus Transit [02], [03],[05],[08],[25],[37]

Measure of Effectiveness (Performance Indicators)	PRT	Bus Transit	Higher Rated System
Availability	Very Good	Good	PRT
Absolute Travel time	Very Good	Good	PRT
Reliability	Very Good	Good	PRT
Comfort	Good	Poor	PRT
Convenience	Good	Poor	PRT
Safety and Security	Good	Fair	PRT
Area Coverage	Very Good	Very Poor	PRT
Frequency	Very Good	Good	PRT
Investment Cost	Poor	Good	BT
Operating Cost	Good	Fair	PRT
Capacity	Good	Poor	PRT
Passenger Attraction	Very Good	Good	PRT
System Impact	Very Good	Good	PRT
Environmental Impact	Very Good	Very Poor	PRT
Durability	Good	Poor	PRT
Efficient Transport Future	Good	Poor	PRT
Life	Very Good	Good	PRT
Aesthetic appearance	Very Good	Very Poor	PRT

CONCLUSION

So referring back to the first word in the introduction “congestion”, it is the main reason for conducting this research in order to find the appropriate solution to solve this problem, so we believe in the need for a separated mean of transportation on public roads, while keeping in mind that deducting any width from the running way in many areas is not an option due to the narrow width and huge traffic volumes on those roads, also the bottle necks problem in many roads in Kolhapur, this actually will only increase our problem by increasing the Traffic and the congestion on those roads, therefore on one hand, deducting any width from the public roads will make our problem even more complicated .On the other hand , the present and future Volume of transportation sector’s users is huge, Therefore, it’s surely has to be take into consideration in the selection of the most appropriate alternative, when designing any transportation network, it must be able to withstand the expected number of users as required and convenient for the user. I would like to consider the Personal Rapid Transit System (PRT), because it’s the real durable long term solution for Kolhapur.

The findings of this evaluation clearly demonstrate that by providing Personal Rapid Transit along existing bus transit routes will enhance commuter satisfaction through safety improvements.

1. PRT will alleviate traffic congestion though its grade separated.
2. PRT will lower noise levels as it electrically operated.
3. PRT will improve air quality as it not exerts harmful gases.
4. PRT will reduce travel time with constant speed without obstruction.
5. PRT will save fuel as many people accept this new transit.
6. PRT will reduce accidents by running on separate routes.

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A Review of 'Service Life' Prediction of RCC Building Structures

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ABSTRACT

Concrete is one of the most efficient materials of construction owing to its versatile properties. It is the largest manmade material, and its consumption is considered to be next to water. With the advent of modern technology, numerous 'concrete structures' can be built in different environments, however, over time these structures get deteriorated due to several reasons and hence need to be maintained to extend their 'service life'. The 'service life' of a structure is its performance over a long period. Predicting the 'service life' of 'concrete structures' has been one of the challenges before the researchers due to several reasons viz. 'changing exposure conditions, rapidly changing material, inadequate knowledge and predictive models, varying construction quality, etc'. Many approaches have been developed by researchers for predicting 'the service life' of structures. However, these approaches or models do not agree effectively with design and construction defects, and this becomes a major limitation. This paper reviews various approaches developed by researchers for predicting 'the service life' of 'concrete structures' through a rigorous literature survey. The study indicates that 'service life' prediction of 'concrete structures' can be done by developing a model based on the results of non-destructive evaluations.

KEYWORDS: Concrete structures, Service life prediction, Predictive models, Deterioration, Non-destructive evaluation.

INTRODUCTION

Cement concrete (CC) is the most widely used material for the construction of structures in the world over due to its various advantageous properties [1]. It is considered to be the largest manmade material, and its consumption is next to that of water. Cement is an important and expensive ingredient used in concrete production. The manufacturing of concrete is done using various ingredients viz., 'cement', 'fine aggregate', 'coarse aggregate', 'water' and also 'chemical as well as mineral admixtures'. The present scenario shows that, though cement is costlier material due to more energy consumption in its manufacturing, the other ingredients (i.e. 'aggregates and admixtures') are also not easily available at affordable cost for producing the concrete. Further, the available natural resources required for obtaining these materials are depleting at an

alarming rate, it has become an urgent need to conserve these resources for achieving sustainability. Several efforts are being taken to develop sustainable materials by utilizing the industrial waste materials given out in the various processes. The materials like 'fly ash, silica fumes, rice husk ash, and ground granular blast furnace slag' are commonly termed as supplementary cementitious materials [2]. These materials have been tried in the manufacturing of cement as well as other building units like bricks, panels, etc. and thus contribute to sustainable development [3,4].

Almost all types of structures are being constructed using concrete by embedding steel reinforcement commonly termed as 'reinforced cement concrete (RCC)' [5]. With the advent of modern technology in the construction industry, numerous 'RCC structures' have been built in different environmental conditions.

However, over time such structures get damaged due to various processes of deterioration. This fact has led to repair and maintain the structures to extend its useful 'service life' or conserve the heritage structures. The assessment of such structures to predict their remaining 'service life' becomes essential. Several approaches have been developed by researchers for assessing the 'service life' of existing 'RCC structures'. The 'service life' of a structure is considered to be the period during which the structure or any of its parts satisfy design performance requirements without incurring unexpected costs or disruption due to maintenance and repairs [6]. 'The estimation of the service life of RCC structures can be done in two stages, viz. initiation period (t_i), and propagation period (t_p)'. Figure 1 shows, the initiation and propagation periods of 'RCC structures' subjected to corrosion.

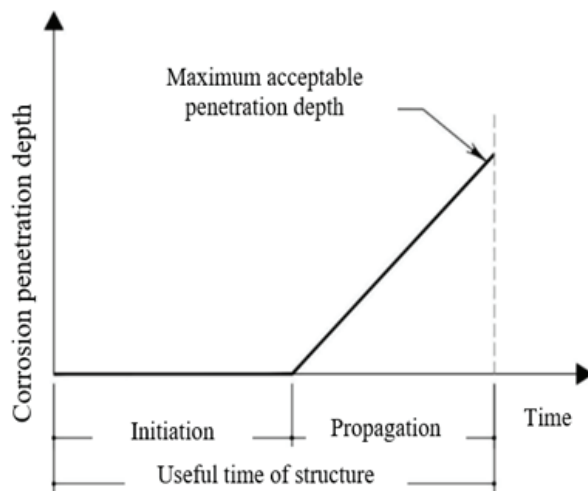


Fig. 1: Initiation and Propagation periods of RC structures subjected to Corrosion [13]

In the 'initiation period', the time is measured from the stage of casting the concrete to the stage when the steel reinforcement becomes no longer passivated, while in the propagation period, the de-passivated steel reinforcement gets corroded. This leads to an increase in 'the probability of the structure's failure' [7].

The 'service life' of 'RCC structures' depends on various factors viz. i) 'Geographic location', ii) Type of structure, iii) 'Nature of exposure', iv) 'One or two-dimensional exposed faces of the structural elements', v) 'Concrete cover to the steel reinforcement'; and vi) 'Corrosion protection methods employed' [8].

Several models have been developed by researchers for prediction of remaining 'service life' of 'RCC structures'. The developed models are mainly based on locations, reflecting local climatic conditions. Some of the models such as the 'European model', 'DuraCrete' and 'the North American', 'LIFE-365' include the ingress of 'chloride' as well as 'carbon dioxide' into the concrete [9]. In 'Spain and South Africa region' 'carbonation and chloride ingress models' have also been developed [10], also in 'Scandinavia', 'ClinConc' [11] and 'DuraCon' [12] model is developed.

One of the most common defects in the 'RCC structures' is the corrosion of steel reinforcement. In many developed as well as developing countries the minimum 'service life' of the 'RCC structures' is considered 50 years by laying down specific regulations. However, under aggressive environments, the concrete that is produced and placed following standard practice can undergo severe deterioration causing corrosion of reinforcement even before the minimum 50 years of its expected 'service life' has been attained. This fact has necessitated; to carry out continuous repairs and maintenance works of 'concrete structures' that have an age of even less than 10 years [13].

The 'service life' prediction of 'RCC structures' is done by various 'approaches' or models. The accurate 'prediction of the service-life of structures' is important for adopting suitable repair strategies in time and cost-effective ways. But, the available prediction models depend on basic assumptions, and may lead to incorrect prediction of serviceable life of 'RCC structures'. Recently, the 'structural health monitoring (SHM)' system has gained importance. The SHM contributes in deriving information about the authentic condition of a structure, or system, with the objective of not just knowing about its structural degradation, but rather to be able to assess remaining performance levels and 'service life' [14].

LITERATURE REVIEW

The research works published by various researchers in the various journals related to the 'service life' prediction of 'RCC structures' have been rigorously reviewed and presented in the following section.

Alexander et al. (2021), have critically explored the

'principles of service life and durability design of RCC structures'. The authors have also highlighted the differences between 'service life (SL) modelling', 'SL prediction', and 'performance-based design' of 'RCC structures', and various aspects related to 'corrosion of steel reinforcement' embedded in concrete. Based on 'Southern African research and practical experience' the authors have focused on the need of achieving the 'performance-based design' for the structure's durability and also recommended the necessity for carrying out supplementary research by updating 'measurable durability indicators' for 'service life prediction modelling and associated design procedure' [7].

Demis et al, (2019) have presented the various case studies relating to the use of concrete 'service life' estimation tools (SLT). Researchers stated that though the use of such tools is important, estimation of 'service life' using such tools is complex process and may lead to confusing results. Hence, the researchers have emphasized on developing organized process of 'design for durability of concrete structures' that can be widely accepted [15].

Various developments are taken place related to the 'service life prediction' for 'concrete structures' which are reviewed by Alexander (2018). The author focuses on various integral difficulties associated in balanced 'service life design' due to the several factors involved in the process. Author also focuses on the benefits of 'performance-based approaches' for the 'prediction of durability' and takes into account 'performance testing' as it is critical in achieving the intended 'service life'. The author explains the concept of 'durability indicators' by giving a practical example. Author concludes with the realistic approach to be used for 'improving durability performance', and also mentioned need for further work at local and hybrid levels [5].

The 'service life' of 'RCC structures' is dependent on 'process of corrosion', predominantly on 'chloride threshold value', which is a distinctive property and be influenced by many parameters viz. use of 'supplementary cementitious material', 'presence of surface cracks', 'water-binder' ratio, 'reinforcement type', 'exposure conditions', etc. Mahima et al. (2018), have broadly reviewed such parameters that affect 'chloride threshold value' [16].

Based on the large experimental data, Neves et al. (2018) presented a model for assessing the residual 'service life' of 'RCC structures' by establishing a correlation between 'the values of air permeability (kT)' and 'the carbonation rate (Kc)'. This correlation between 'kT and Kc' is used to obtain the expected 'corrosion initiation time' without drilling a core sample [17].

Torrent et al. (2014) have determined the 'service life of RC structures' using different methods viz. 'Theorecrete, Labcrete, and Realcrete' and compared their results with the results obtained by using 'Flick's 2nd law'. The results indicate that there is huge variation in the predicted 'service life' of RC structures. From the results, the researchers recommend that for accurate prediction of SLP there is a need to execute long-term research projects by carrying out the investigation of structures under different exposure conditions [18].

Pillai et al. (2013) discussed the merits and demerits of available 'service life' models. The authors compared predicted corrosion initiation time for various conditions. The authors proposed a framework for determining predicted 'corrosion initiation time (Ti)', using simplified 'nomographs'. The author explains the 'parametric sensitivity analysis of various models' [19].

Andrade et al. (2009), The 'inverse of conductivity', 'electrical resistivity (ρ , unit $\Omega.m$)', is a property of a substance that indicates its 'capacity to carry electrical charge'. The authors use this concept. This is a 'volumetric measurement of electrical resistance (Re)', which is 'the ratio of applied voltage to current ($Re = V/I$)' according to "Ohm's Law." Considering the established relations, the suggested model is based on detecting 'electrical resistivity', which is then used as the primary parameter for estimating both 'ti and tp periods', by using resistivity as the NDT parameter for the 'durability definition of reinforcement' [20].

Maaddawy et al. (2007) have developed a simple mathematical model that is useful to practicing engineers and researchers for realistically 'predicting the duration' from the 'initiation of corrosion' to the stage of 'corrosion cracking'. The author describes 'cover cracking' as the end of the 'service life' of a corroding 'RC structure' [22].

Liang et al. (1999) have developed a mathematical

model based on 'Fick's second law of diffusion' for estimating the 'service life' of RC structures considering the time up to the initial period. The study is carried out by considering the concrete's chloride ion diffusion, assuming the process is time-dependent. From the study, the authors conclude that the model is useful for 'the prediction of the service of RC structure'. The model is useful for planning future maintenance and repair work [23].

RESEARCH GAP

From the rigorous literature review, it is observed that several researchers have tried to predict the 'service life of RC structures' considering individual components affecting the durability of structures such as 'carbonation', 'chloride attack', 'diffusion coefficient', and 'permeability'. As RC structures are exposed to a variety of environmental exposures, it is more likely that they will be attacked by several 'durability-affecting components' collectively. However, 'prediction of the service life of structures' considering the combined effects of 'durability affecting components' has not been reported in the literature. Further, few research studies have been carried out to 'predict the service life of the structure' based on the 'non-destructive testing' (NDT) data of structures by establishing the nomographs considering the parameters namely, diffusion coefficient, age of the structure, chloride content, concrete cover thickness, etc. Most studies concerning 'the prediction of the service life of RC structures' are carried out by determining the 'corrosion initiation period' by developing models considering the period required for 'CO₂' or 'Cl-' ions to diffuse to the steel-concrete interface.

CONCLUSION

From the rigorous literature review, the study concludes that the 'service life' prediction of 'RCC structures' needs to be carried out not only considering the individual durability affecting components viz. 'carbonation, chloride attack, diffusion coefficient, and permeability' but also considering their combined effects. Additionally, the precise assessment and proper measurement of the 'chloride threshold value' is essential for the 'service life prediction of RCC structures'.

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Role of Use of Recycled Asphalt Pavement and Recycled Aggregate in the Construction of Rigid Pavements

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ABSTRACT

The recycling or reuse of pavement material is a very simple but powerful concept. In many parts of the world, recycling of infrastructure construction and demolition waste is a major point of discussion. Thus demolition waste obtained from old roadways has been investigated thoroughly in many studies as sustainable approach. In this research paper an attempt is being made to develop sustainable concrete mixes for rigid pavements comprising bulk utilization of waste materials such as reclaimed asphalt pavement (RAP) and recycled aggregate (RA) with varying percentage replacements of natural aggregates with RAP and natural coarse aggregate (NCA) with RA. All 17 concrete mixtures were prepared and tested with constant water to cementitious ratio of 0.48. The experimental work was split into two phases. The first phase was investigated with RAP content (0%, 20%, 40%, 60%, 80%, and 100% of NA replaced by RAP) and the second phase was investigated with RA content: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of NCA replaced by RA. The workability test on concrete mixes for RAP & RCA are carried out by slump test. The hardened properties of concrete such as compressive strength and flexural strength were studied. The results showcased that the mechanical properties decreased as the replacement ratios of RAP and RA increased with reference to control mix. Thus, even while the reduction in mechanical characteristics is not that great in comparison to the attempts to lessen the negative impacts of RAP and RA on the environment and human health, they still have the potential to be added to concrete mixtures.

KEYWORDS: *Recycled asphalt pavement (RAP), Recycled aggregate (RA), Recycling.*

INTRODUCTION

Concrete has been used extensively due to the increase in population and expansion of cities. Recent years have seen a number of environmental problems because of the massive consumption of natural aggregate (NA), which makes up about 75% of concrete mixes, and the production of massive amounts of construction and demolition waste, which have an adverse effect on the environment due to landfill areas that pollute the environment and runoff into rivers and streams. A number of studies have been conducted to

examine alternative, economical, and environmentally sustainable alternatives for protecting natural resources and enhancing environmental consciousness. The employ of recycled materials in concrete pavements has gained significant attention in last few years due to the growing need for sustainable construction practices and resource conservation. Among the various recycled materials, Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA) have emerged as viable options for enhancing the sustainability of concrete pavements. Along with lessening their negative effects on the environment, these materials

provide financial advantages as well, like lower raw material procurement costs.

The current study aims to develop sustainable concrete mixes for rigid pavements by using waste materials in large quantities, such as recycled aggregate (RA) with different percentages of natural coarse aggregate (NCA) and reclaimed asphalt pavement (RAP) with different percentages of natural aggregates. A total of 17 concrete mixtures were prepared and tested with constant water to cementitious ratio of 0.48. The experimental work was split into two phases. The first phase was investigated with RAP content (0%, 20%, 40%, 60%, 80%, and 100% of NA replaced by RAP and the second phase was investigated with RA content: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of NCA replaced by RA. The fresh properties of concrete such as slump, compaction factor and vee-bee consistometer were investigated. The hardened properties of concrete such as compressive strength and flexural strength were studied.

LITERATURE REVIEW

Today one of the main obstacles is focusing on protecting natural resources for upcoming generations while bringing industrial operations into a more stable, long-term balance between costs and environmental protection. Some of the literature survey work have been made on this investigation is being discussed. RAP is one of the major alternative resources which can be used in concrete pavements. RAP is specified as the reprocessed pavement materials, which are asphalt and aggregates used in road building. When asphalt pavements are removed to make way for subsurface utilities or to perform reconstruction, resurfacing, and rehabilitation activities, these materials are generated [1-3]. Using RAP decreases the quantity of waste product and helps with the disposal problems of highway construction materials. Using RAP has been favoured over virgin materials in terms of cost-effectiveness and preserving the environment based on the technique of sustainable development [4,5].

RAP has been used in different forms such as coarse fractions, fine fractions, and mixed fractions for the production of concrete mixes [6]. The various fractions of RAP can be used in portland cement concrete pavements (PCCP), pervious concrete pavements

(PCP) and self-consolidating concrete (SCC) [7–8]. The higher percentages of RAP are being utilized to reduce the cost and natural resources [9]. According to Singh et al. [7], the application of RAP minimizes the need for conventional aggregates, which in turn lowers transportation costs. This lowers project costs for making concrete on building sites. [10] Most of the researchers suggested that 50% of coarse RAP is suitable for concrete pavements.

In general, compressive strength is the main emphasis of concrete pavement mechanical performance. This is also true for general concrete applications [11] The minimal compressive strength requirements for concrete pavement range between 20—30 MPa[12], usually within 7 days of age, for adequate abrasion resistance on the pavement surface.

When RCA completely replaced by NA in the concrete pavement, there is reduction in strength depending on the mixture parameters. Chan et al. included hooked-end steel fibres in RCA pavement to enhance the compressive and flexural strengths [13]. However, when compared to fiber-reinforced NA pavement, 100% RCA pavement had a decrease in strength of up to 50%. Thus the increase in the fibre content will increase in the flexural strength of RCA pavement, which was not the case for NA pavement.

Tavaakoli and Soroushin [14] have presented the study on, regular concrete's strength, aggregate content compared to RCA, and the proportion of fine to coarse particles in regular concrete, to determine the strength characteristics of RCAs.

Crushed inorganic particles from construction and demolition materials have been investigated by Manasa et al. [15] as components of recycled coarse aggregates (RCA). When used in place of natural aggregates in high strength concrete, recycled aggregates' strength characteristics are examined in this study. It contrasts the workability, compressive strength, tensile strength, elastic modulus, and flexure strength of RCA concrete with those of natural aggregate concrete at 0%, 25%, 50%, 75%, and 100%. Moderately decreasing parameters are found as the percentage of recycled aggregates rises.

MATERIALS & METHODOLOGY

The specifications and sources of materials used in the project are as mentioned in below table 1.

Table 1: Materials description

Material	Description	Source
Cement	OPC 43 grade	JK Cement
CA	20mm down size	Nearby quarry plant, Belagavi
FA	Zone-II	
RAP	Milled Asphalt Waste from NH-4	Collected waste from Ashoka Buildcon
RCA	Construction & Demolished waste	Collected waste from Belagavi City



Fig. 1 Milled RAP



Fig. 2 Recycled Concrete Aggregates

PHYSICAL PROPERTIES OF MATERIALS

The physical properties of the materials are assessed in accordance with IS codes and are determined to be

satisfactory. The material properties are as shown in below table 2

Table 2: Physical Properties of materials

Material	Tested Property	Value
Cement	Specific Gravity	3.10
FA	Specific Gravity	2.63
	Water Absorption	1.66%
CA	Specific Gravity	2.72
	Water Absorption	0.81%
RAP	Sieve Analysis	Confirms to IS - 383
RCA		

The mix design for the current work is carried out for M25 grade of concrete for control mix in accordance with IS 10262:2019 and the quantities of materials per cubic meter are as mentioned in table 3.

The design mix includes six mix percentages of RAP concrete (0%, 20%, 40%, 60%, 80% & 100%) and eleven mix proportions of RCA concrete (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% & 100%). The trial mix quantities for RAP concrete & RCA concrete are depicted in table 4 & table 5.

Table 3: Mix proportions

Material	Quantity (kg/m ³)
Cement	400
Sand	666
Coarse Aggregate	1132
Water	192
Water-cement ratio	0.48

Table 4: Trial quantities for proposed RAP mixes

Mix ID	Cement (%)	Fine Aggregate (%)	Coarse Aggregate (%)	RAP (%)
M1 (0%)	100	100	100	0
M2 (20%)	100	80	80	20
M3 (40%)	100	60	60	40
M4 (60%)	100	40	40	60
M5 (80%)	100	20	20	80
M6 (100%)	100	0	0	100

Table 5: Trial quantities for proposed RCA mixes

Mix ID	Cement (%)	Fine Aggregate (%)	Coarse Aggregate (%)	RCA (%)
M1 (0%)	100	100	100	0
M2 (10%)	100	100	90	10
M3 (20%)	100	100	80	20
M4 (30%)	100	100	70	30
M5 (40%)	100	100	60	40
M6 (50%)	100	100	50	50
M7 (60%)	100	100	40	60
M8 (70%)	100	100	30	70
M9 (80%)	100	100	20	80
M10 (90%)	100	100	10	90
M11 (100%)	100	100	0	100

Casting, Curing & Testing

For each mix, 3 cubes of size 150x150x150 mm and 3 beams of size 100x100x500mm are casted. The cast specimens were left at room temperature for 24 hours, after which they were demolded and cured for 28 days in water.

TEST RESULTS

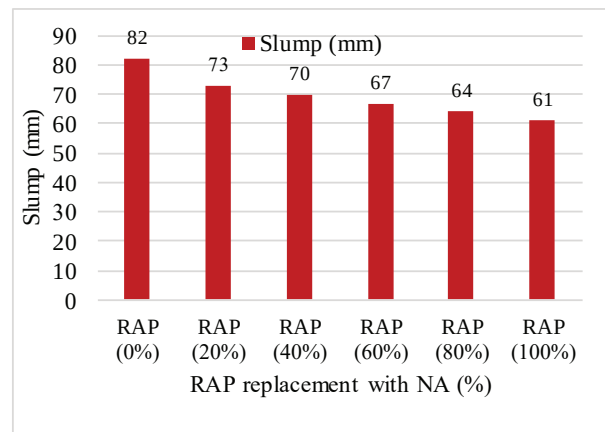
Workability

All concrete mixtures were maintained with a constant water–cement ratio of 0.48 without chemical admixture. From the table 6, the resulting slump values ranging from 25 to 82 mm. To obtain the required strength and durability in low workability it is crucial to ensure thorough mixing and proper compaction. Since the study is conducted without chemical admixtures, the current slump values are a reflection of this constraint. Therefore inclusion of chemical admixtures would enhance the workability of the concrete.

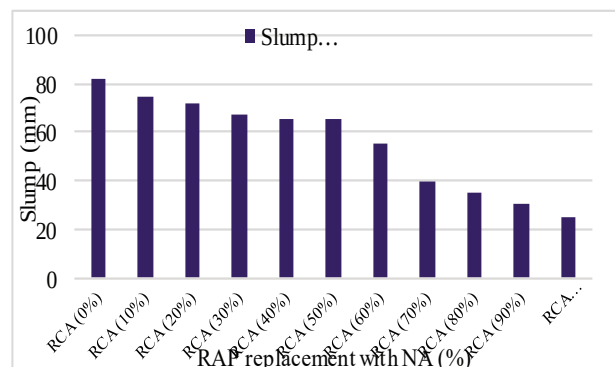
Table 6: Slump test results on RAP mixes

Mix ID	Slump (mm)
M1 (0%)	82
M2 (20%)	73
M3 (40%)	70
M4 (60%)	67

M5 (80%)	64
M6 (100%)	61

**Fig. 3 Test results on Slump – RAP mixes****Table 7: Slump test results on RCA mixes**

Mix ID	Slump (mm)
M1 (0%)	82
M2 (10%)	75
M3 (20%)	72
M4 (30%)	67
M5 (40%)	65
M6 (50%)	65
M7 (60%)	55
M8 (70%)	40
M9 (80%)	35
M10 (90%)	30
M11 (100%)	25

**Fig. 4 Test results on Slump – RCA mixes**

Compressive & Flexural Strength

The RAP & RCA specimens are examined for compressive strength and flexural strength at the age of 28 days curing. The test results are represented in table and respective graphs are represented in fig.

Table 8: Test results on Strength - RAP mixes

Mix ID	Compressive Strength (MPa)	Flexural Strength (MPa)
M1 (0%)	27.70	11.23
M2 (20%)	26.37	10.35
M3 (40%)	24.15	9.91
M4 (60%)	15.70	6.85
M5 (80%)	15.70	6.53
M6 (100%)	15.41	6.16

From the above table it can be observed that the compressive strength of RAP mixes goes on reducing with the increase of RAP replacement. This is because due to the weak bonding of cement and bitumen film on aggregates in concrete matrix. As RAP replacement increases, it is also seen that the flexural strength of RAP blends continues to decline. This might result from the bitumen and cement films' poor adhesion to the particles in the concrete matrix.

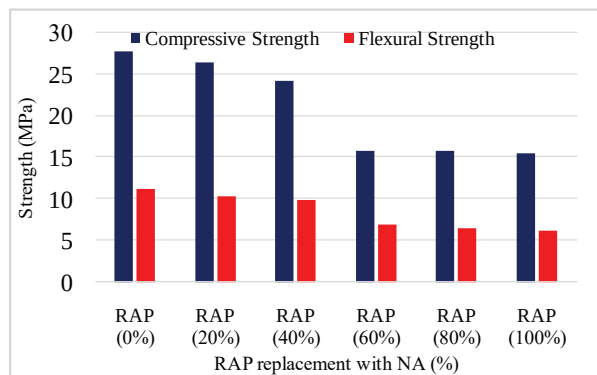


Fig. 5 Test results on Strength – RAP mixes

Table 9: Test results on Strength - RCA mixes

Mix ID	Compressive Strength (MPa)	Flexural Strength (MPa)
M1 (0%)	28.07	8.32
M2 (10%)	36.59	9.00
M3 (20%)	46.59	9.59
M4 (30%)	47.19	10.48

M5 (40%)	44.89	10.04
M6 (50%)	43.7	9.51
M7 (60%)	41.63	9.08
M8 (70%)	29.71	6.04
M9 (80%)	25.53	5.77
M10 (90%)	23.11	5.52
M11(100%)	21.48	5.16

As observed from the above table, the compressive strength of RCA mixes goes on increasing upto 30% with compared to reference mix and decreases as RCA replacement increases. This is because due to the weak bonding of cement and mortar film on aggregates in concrete matrix. It was noticed that the flexural strength of RCA mixes goes on increasing upto 30% with respect to reference mix and decreases as RCA replacement increases. This results from the cement and mortar film's poor adhesion to the particles in the concrete matrix.

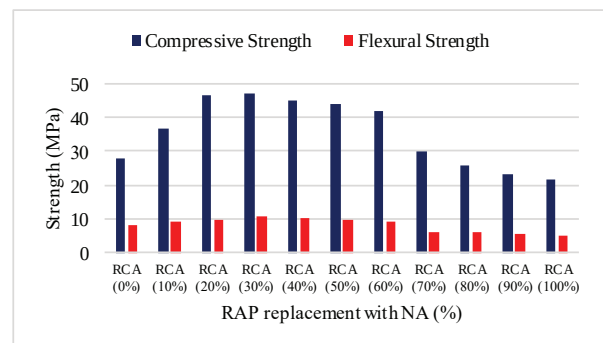


Fig. 6 Test results on Strength – RCA mixes

CONCLUSION

This paper studies the effect of incorporating RAP with natural aggregates and RCA with natural coarse aggregates on the mechanical properties of concrete. From the experimental results, the following are key findings:

1. The workability of a produced concrete mixes reduces as the percentages of RAP & RCA increases.
2. The compressive strength reduces as percentage level of RAP increases in concrete mixes.
3. The flexural strength decrease when the replacement levels of RAP increases in concrete mixes.

4. The compressive strength increases upto 30% replacement and decrease when the percentage of RCA increases in concrete mixes.
5. The flexural strength increase upto 30% replacement and decrease when the percentage of RCA increases in concrete mixes.

FUTURE SCOPE

In future additional experiments can be taken up out to enhance the properties of concrete mixes and additional properties can be evaluated.

1. The properties of concrete mixes can be studied separately with coarse fraction of RAP and fine fractions of RAP.
2. The workability property of RAP & RCA concrete mix can be studied with the inclusion of admixtures.
3. The economical evaluation of using RAP and RCA material versus fresh mix on pavement can be carried out.

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Sustainable Building Solutions: Transforming Agricultural Waste into Biodegradable Construction Materials

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ABSTRACT

The growing demand for sustainable construction solutions has led to innovative approaches that incorporate waste materials into building designs. This paper explores the potential of agricultural waste as a source of biodegradable building materials. Agricultural by-products such as rice husks, straw, and coconut shells, traditionally considered waste, offer a unique opportunity to create environmentally friendly alternatives to conventional construction materials. Through advanced processing techniques, these agricultural wastes can be transformed into composite materials with desirable structural properties, such as thermal insulation, durability, and fire resistance. The biodegradability of these materials ensures they are less harmful to the environment, reducing the ecological footprint of the construction industry. This study presents a comprehensive analysis of the properties of various agricultural waste-based materials, investigates their performance in building applications, and proposes methods for large-scale implementation. Additionally, the paper discusses the economic feasibility of using agricultural waste in construction, highlighting its potential to reduce costs while promoting sustainable building practices. The innovative use of agricultural waste in biodegradable building materials presents a transformative solution for the future of eco-friendly construction, aligning with global sustainability goals and contributing to a circular economy.

KEYWORDS: *Agricultural waste, Sustainable construction, Circular economy, Eco-friendly materials.*

INTRODUCTION

The construction sector is a cornerstone of economic development but also a significant contributor to environmental degradation. Conventional building materials such as cement, concrete, and bricks rely heavily on finite natural resources and generate substantial greenhouse gas emissions during production. This scenario underscores the need for innovative,

sustainable alternatives to conventional construction materials. Agricultural waste, an abundant and renewable resource, emerges as a promising candidate in addressing these challenges.

The environmental impact of conventional construction materials

The production of traditional construction materials accounts for nearly 11% of global carbon emissions,

driven by energy-intensive processes and the extraction of raw materials [1], [2]. Additionally, the extensive use of non-biodegradable materials contributes to long-term environmental pollution and waste management challenges. Addressing these issues requires a paradigm shift towards biodegradable and renewable building solutions.

Agricultural Waste as a Sustainable Resource

Agricultural residues such as rice husks, wheat straw, sugarcane bagasse, and coconut coir are generated in large quantities globally, often leading to disposal problems [3], [4]. Transforming these wastes into construction materials not only mitigates environmental pollution but also reduces dependency on non-renewable resources. For instance, rice husk ash, rich in silica, has been effectively utilized as a partial replacement for cement, enhancing the strength and durability of concrete [5]. Similarly, wheat straw composites have demonstrated excellent thermal insulation properties, making them suitable for energy-efficient buildings [6].

Aligning with Circular Economy Principles

The integration of agricultural waste into construction aligns with circular economy principles, promoting the reuse and recycling of materials within the production lifecycle [7]. This approach fosters resource efficiency, minimizes waste, and reduces the environmental footprint of the construction industry. Moreover, the valorization of agricultural residues can provide economic incentives to farmers, creating a win-win scenario for both agriculture and construction sectors [8].

The following table presents a comparative analysis of materials derived from agricultural waste and their applications in construction. It outlines different types of agricultural waste, such as rice husks, straw, corn stalks, and wheat chaff, and compares their suitability for use in various construction applications, including insulation, wall panels, biocomposite materials, and concrete reinforcement. Key factors such as material properties, environmental benefits, and performance metrics like durability and cost-effectiveness are also highlighted. This analysis serves to inform sustainable building practices by showcasing the potential of agricultural waste as an eco-friendly alternative to traditional construction materials.

Table 1: Comparative Analysis of Agricultural Waste-Based Materials

Material	Key Properties	Advantages	Limitations
Rice Husk Ash	High silica content, lightweight	Enhances strength and durability	Requires energy-intensive processing
Wheat Straw	Low thermal conductivity	Excellent insulator	Susceptible to moisture
Coconut Coir	High tensile strength	Renewable and biodegradable	Variability in fiber quality
Sugarcane Bagasse	Low density, high cellulose content	Cost-effective and lightweight	Limited mechanical strength
Maize Stalks	Biodegradable, eco-friendly	Reduces carbon footprint	Limited industrial uptake

LITERATURE REVIEW

The utilization of agricultural waste in biodegradable construction materials has been explored extensively in recent years. The following review highlights significant contributions from researchers, summarizing their findings and identifying research gaps.

Smith et al. (2020) investigated the potential of rice husk as a partial replacement for cement in concrete. Their study demonstrated a 20% enhancement in compressive strength, attributed to the high silica content of rice husk ash. However, they noted the need for scalability studies to translate laboratory findings to industrial applications.

Zhang and Li (2021) examined the thermal insulation properties of wheat straw composites. Their results showed a 15% reduction in thermal conductivity, emphasizing its suitability for energy-efficient construction. The authors highlighted a lack of durability analysis as a critical research gap.

Patel et al. (2022) focused on the feasibility of producing particleboards from sugarcane bagasse. Their findings underscored the cost-effectiveness and lightweight nature of these panels. Nonetheless, optimization of the manufacturing process was identified as a challenge for large-scale production.

Gupta et al. (2023) explored the reinforcement potential of coconut coir in biocomposites. The study reported

a 25% improvement in tensile strength, making it a viable option for sustainable construction. Variability in fiber quality was noted as a limitation, necessitating standardization protocols.

El-Sayed and Ahmed (2023) developed biodegradable binders using maize stalks. Their research demonstrated the eco-friendliness of these binders and their potential to reduce the carbon footprint of construction projects. However, long-term performance data remain insufficient.

Brown et al. (2019): Analyzed rice straw as an alternative to traditional construction aggregates, revealing its potential in reducing material costs but highlighting process inefficiencies.

Cheng and Wong (2020): Studied banana fiber composites, identifying their excellent mechanical properties, though challenges in industrial adoption persist.

Kim et al. (2021): Researched the use of corn cob ash in mortar, observing enhanced water resistance but limited tensile properties.

Lee and Park (2022): Investigated oil palm ash in concrete mixes, achieving improved durability but noting high energy requirements for processing.

Ramesh et al. (2023): Examined groundnut shell powder in construction composites, showing better dimensional stability but requiring improvements in compressive strength.

Rahman et al. (2020): Utilized jute fiber as reinforcement in geopolymer composites, with positive effects on flexural strength, though environmental assessments were incomplete.

Singh et al. (2021): Explored hempcrete applications, demonstrating enhanced insulation and moisture regulation properties but limited structural strength.

Mehta et al. (2022): Studied sawdust-based panels for interior applications, highlighting affordability and lightweight characteristics, with concerns over moisture susceptibility.

Olu et al. (2022): Investigated cassava peel in lightweight bricks, reporting reduced environmental impact but inconsistent material quality.

Wei et al. (2023): Developed rice bran-based bio-admixtures, demonstrating their role in reducing water permeability but requiring further chemical stability testing.

LITERATURE GAP

The literature reveals several promising applications of agricultural by-products in construction materials, but significant research gaps remain. While studies on rice husk, wheat straw, sugarcane bagasse, and coconut coir emphasize their potential in enhancing concrete, composites, and biocomposites, challenges such as scalability, durability, manufacturing optimization, and variability in material properties persist. Notably, long-term performance data, environmental assessments, and standardization protocols are frequently cited as critical gaps. Moreover, although several studies report improvements in specific properties like thermal insulation, compressive strength, or water resistance, issues such as inconsistent material quality, process inefficiencies, and limited structural strength in certain materials (e.g., hempcrete, sawdust, and cassava peel bricks) underscore the need for further investigation and optimization for industrial adoption.

OBJECTIVES OF THE RESEARCH

The aim of this research is to investigate the potential for converting agricultural waste into biodegradable materials for use in the construction industry. The study seeks to evaluate the environmental, economic, and practical benefits of utilizing agricultural by-products such as rice husks, straw, corn stalks, and wheat chaff. By examining their properties and performance in construction applications, the research intends to contribute to reducing waste, lowering carbon emissions, and advancing the adoption of sustainable, renewable materials in building practices.

CONCLUSION

The use of agricultural waste as biodegradable construction materials offers a promising solution to both environmental and resource challenges in the construction industry. By harnessing the potential of materials such as rice husks, straw, and corn stalks, we can significantly reduce waste and the carbon footprint associated with traditional construction methods.

Innovative approaches, such as the development of bio-composites and natural insulation materials, can not only provide sustainable alternatives but also enhance the efficiency and affordability of green building practices. This research highlights the importance of further exploration and investment in agricultural waste as a key resource for driving a circular economy and creating eco-friendly, resilient, and cost-effective construction solutions.

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Effect of Waste Plastic on Concrete Characteristics and Development Android Application of Mix Design

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ABSTRACT

The increasing cost of construction materials has become a significant challenge in the construction industry, affecting project budgets and timelines. At the same time, plastic waste continues to accumulate in large amounts, posing serious environmental and health hazards. An attempt has been made to utilize waste plastic as an aggregate substitute in concrete production of the M20 grade concrete which is proportioned as per IS:10262-2019. However, the manual procedure of mix design is laborious and more time-consuming. Hence, the Android application for designing the mix has been developed which will help to save the time required for designing the mix. The effect of the incorporation of waste plastic on the properties of fresh and hardened concrete has been investigated and compared. The compressive strength of concrete is acceptable up to 10% replacement of fine aggregate by plastic aggregate as per IS: 456-2000.

KEYWORDS: Waste plastic, Concrete, Mix design, Android application.

INTRODUCTION

Discarded plastic bags, fragments of plastic sheets, and bottles of various sizes, colors, and textures are often seen drifting through the air, littering the streets, and accumulating in gutters. Their presence not only pollutes the environment but also leads to sewer blockages, creating a significant ecological hazard. Plastic dispersed in the water resources for many years. Some recent instances such as the Kerala flood of 2018 and, the Maharashtra flood of 2019 and 2021 (Kolhapur, Sangli and Satara districts) have experienced that these water resources are sending back all the plastic that was thrown into the rivers or oceans. Numerous efforts have been made to reduce the use of plastic bags and other plastic products, but their widespread utility in daily life has hindered success.

Each year, over 500 billion plastic bags are consumed globally, averaging nearly one million per minute. The improper disposal of these plastics poses a severe threat to wildlife, with hundreds of thousands of

marine creatures, including sea turtles and whales, perishing annually after mistakenly ingesting plastic waste. Terrestrial animals also face similar dangers. The collection, transportation, and disposal of plastic waste further contribute to environmental challenges. In landfills or natural settings, plastic bags take thousands of years to break down. With a population exceeding 1 billion, India alone consumes approximately 4 million tons of plastic annually. Recycle practice and reuse of waste plastic products engage huge labour and processing costs, resulting very small quantity of plastic waste being recycled and reused while the remaining go into landfills, incinerators and dumps [2]. Now the question arises how to effectively minimize the impact of plastic waste at a reasonable cost? Many researchers have attempted to utilize plastic waste in concrete in many forms as well as in the construction of roads. The plastic waste in fabriform shapes equal to 30kg has been used in terms of a partial replacement for fine aggregate in concrete mixtures which enhances resistance against the propagation of micro-cracks,

reduces the cost of concrete ingredients and solves some of the solid waste problems posed by plastics [3]. A comprehensive analysis has been conducted on waste and recycled plastics, various waste management strategies, and the impact of recycled plastic on both the fresh and hardened properties of concrete [4]. To overcome environmental problems, recycled plastic i.e. melt-densified used as a lightweight coarse aggregate which result in not only reduced weight of structures but also contributes to ecological sustainability [5,6]. Plastic waste, polyethylene terephthalate and high-density polyethylene plastic have been used as partial replacements for coarse aggregate to investigate the properties of concrete through experimental investigations [7,8,9,10,11]. The recycled plastic can be used as a fine aggregate by substitution of sand in variable quantity [12,13,14,15,16,17,18,19]. The partial replacement of more than 10% of sand by recycled aggregate resulted in a reduction in compressive strength [20, 21, 22, 23, 25]. The manufactured concrete can be used in non-structural concrete due to decreased compressive stress as compared to normal concrete [26]. However, the achieved strength has been between 12MPa to 15MPa which has been useful for non-structural elements such as sidewalks, low-rise concrete wall building, cementitious backfill, ramps and the construction of lightweight structures [27,28,29]. The incorporation of plastic materials into concrete enhances its ductility, allowing it to undergo substantial deformation before failure. This property is particularly beneficial in environments with extreme weather conditions, such as temperature fluctuations that cause expansion and contraction, as well as freeze-thaw cycles. Additionally, utilizing recycled aggregates in the concrete of the studied buildings has demonstrated energy efficiency benefits. The presence of plastic aggregates contributes to improved thermal performance by keeping the interior cooler as external temperatures rise, in comparison to conventional concrete [30].

Hence, in this study, an attempt has been made to utilize waste plastic in concrete which is not recyclable so as to reduce the waste and save the earth. The properties of concrete have been determined by using waste plastics in granulated form as partial replacement of fine aggregates in concrete. The android application has

been developed which provide handy tool for design the mix of any grade of concrete.

METHODOLOGY

Material collection and preparations

1. First of all plastic bags have been collected.
2. They have been thoroughly cleaned before use to ensure that the dirt, dust, debris and other forms of impurities have been removed which could alter the hydration and bonding with cement paste.
3. Melting of plastic has been done at controlled temperature at 160°C to 180°C. Melting of polyethylene, polystyrene, polypropylene at temperature less than 200°C do not produce any harmful products.
4. The molten plastic has been transformed into wires.
5. Finally, set and cooled plastic crushed into crusher to obtain fine particles of size less than 4.75mm which has been used as partial replacement of the natural sand. Figure 1 presents flow chart to obtain recycled waste plastic aggregate of size less than 4.75mm.



Fig. 1: Recycled waste plastic aggregate of size less than 4.75mm

MATERIALS

The ordinary portland cement 43 grade confirming to IS:8112-1989 [31] has been used to design M20 grade of concrete. Table 1 present the details of physical properties of OPC 43 Grade cement.

Locally available natural sand and crushed angular coarse aggregate have been used in concrete mix. Table 2 represents the details of physical properties of fine, coarse and plastic aggregates. Potable water has been used for manufacturing and curing of specimens.

MIX DESIGN

M20 grade of concrete has been designed as per IS:10262-2009 [34]. However, the analytical procedure of mix design is laborious, cumbersome and more time-consuming.

Hence, it is essential to develop an android application for concrete mix design which will provide a handy tool and drastically reduce the time required for the design of the mix.

Table 1: Physical characteristics of OPC 43 grade cement

Sr. No.	Physical Properties	Results Obtained	IS: 8112-1989 requirements
1.	Specific Gravity	3.15	--
2.	Normal Consistency	32.5%	--
3.	Fineness	340 m ² /kg	225 m ² /kg (minimum)
4.	Initial Setting Time	125 minute	30 minutes (minimum)
5.	Final Setting Time	415 minute	600 minutes (maximum)
6.	Soundness	2 mm	10mm (maximum)
7.	Average Compressive strength of cement (28 days) of 3 cubes of size 7.07cm	43.05 MPa	43 MPa (minimum)

Table 2: Physical properties of fine aggregates

Sr. No.	Characteristics	Fine Aggregate	Requirement of Fine Aggregate as per IS:2386-1963 [32]	Plastic Aggregate of size less than 4.75mm	Coarse Aggregate	Requirement of Coarse Aggregate as per IS:2386-1963 [32]
1.	Specific Gravity	2.66	2.6-2.8	1.1	2.76	2.6-2.8
2.	Fineness Modulus	2.83	2.6-2.9	2.8	7.13	5.5-8.0
3.	Silt Content	1%	3% (Max.)	0%	--	--
4.	Water absorption	3.44%	--	0%	1.66%	--
5.	Free surface moisture	2%	--	0%	0%	--
6.	Zone	III	--	--	--	(IS:383-1970) [33]

Mix Design

The detail of concrete mix proportion for M20 grade of concrete designed according to IS: 10262-2019 [34] is indicated in Table 3.

Mix Design Android Application

The entire procedure of performing the mix design is carried out through application developed on the android studio software using the java language.

Fig. 2 indicates the result obtained for the M20 grade of concrete designed according to the Android Application method.

Table 3 presents a comparison of mixed design results obtained from the IS method and Android application.



Fig. 2: Mix Design Result from Android Application

Table 3: Comparison of mix design results

Ingredients of Concrete	IS Method Quantity (kg/m ³)	IS Method proportion	Android Application Quantity (kg/m ³)	Android Application proportion
Cement	413.33	1.00	413.33	1.00
Fine aggregate	509.35	1.23	509.36	1.23
Coarse aggregate	1248.28	3.02	1248.29	3.02
Water	193.79	0.47	193.78	0.47

From the results of Table 3, it is concluded that both mix design methods i.e. IS and Android Application show good coherence with each other.

EXPERIMENTAL RESULTS

The required amount of all ingredients of concrete has been batched by the weigh batching technique.

First concrete mix of conventional concrete has been manufactured with natural sand (0% plastic aggregate). Other concrete mixes have been obtained by 5%, 10%, 15%, 20% and 25% weight replacement of fine aggregate by plastic aggregate.

Properties of Fresh Concrete

The workability of concrete has been determined by using the slump cone test and compaction factor test for each % of replacement fine aggregate by plastic aggregate. These tests have been carried out for each batch of concrete and the average value is tabulated in Table 4.

Table 4: Workability of fresh concrete

% Replacement of Fine Aggregate by Plastic Aggregate	Slump Value in mm	Compaction Factor
0%	190	0.8870
5%	270	0.9570
10%	285	0.8680
15%	280	0.8478
20%	220	0.8630
25%	Collapse	0.8631

From Table 4, it is seen that the workability goes on increasing up to the 10% replacement of the

sand by plastic aggregate. Further, with increase in % replacement of the sand by plastic aggregate, workability starts decreasing due to the bulking of the plastic aggregate in the concrete.

Properties of Hardened Concrete

Cube specimens for compressive strength testing, measuring 150mm×150mm×150mm have been casted using concrete in which fine aggregate has been partially replaced with plastic aggregate at varying percentages. The concrete mixture has been poured into moulds and compacted using a table vibrator. The specimens have been then stored in a vibration-free environment, maintaining a minimum relative humidity of 90% and a temperature of 27°±2°C for 24½ hours from the time water has been added to the dry materials. After this curing period, the specimens have been labeled, carefully removed from the moulds, and immediately submerged in clean, fresh water, where they remained until testing. The water used for submersion has been replaced every seven days and maintained at a constant temperature of 27°±2°C. At no point have been the specimens permitted to dry before testing.

Dry Density

The dry density has been noted prior to destructive testing. It is the ratio of the weight of concrete to the volume occupied in dry conditions or during testing.

The dry density of concrete cubes is indicated in Table 5.

Table 5: Dry density

% Replacement of Fine Aggregate by Plastic Aggregate	Average Weight of Cubes (kg)	Density (kg/m ³)
0%	8.9970	2666
5%	8.5995	2548
10%	8.2990	2459
15%	7.6980	2281
20%	7.2960	2162
25%	6.4970	1925

From Table 5, it is observed that the density of the concrete reduces with increase in the plastic content due to the weight of plastic aggregate is less than that of the sand.

Compressive Strength Test

The compressive strength test has been performed as per IS:516-1959 [35]. The cube specimens have been positioned in the testing machine so that the load has been applied to the opposite cast faces, rather than the top and bottom surfaces. The load has been gradually increased at a consistent rate of approximately 140kg/cm² per minute without sudden impact until the specimen could no longer withstand the increasing force and ultimately failed. A compression testing machine with a 3000kN capacity has been used for this procedure. The maximum load sustained by each specimen has been recorded, along with observations of the concrete's appearance. Fig. 3 indicates a compression testing machine with a cube specimen.



Fig. 3: Compression test of cube specimen

Fig. 4 presents compressive strength variation at different plastic percentages.

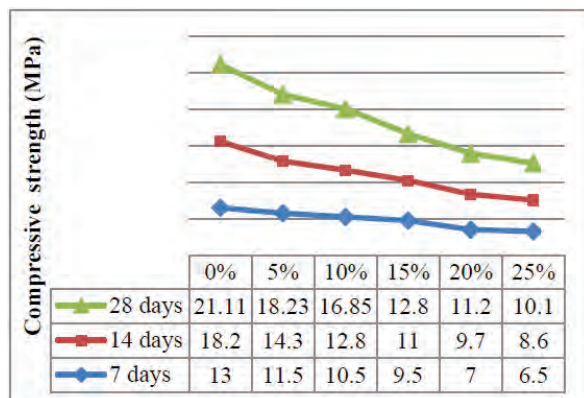


Fig. 4: Compressive strength variation

From Fig. 4, as the percentage replacement of fine aggregate by plastic aggregate increased, the compressive strength of the concrete decreased. At 5%, 10%, 15%, 20% and 25% replacement of sand with plastic aggregate, the compressive strength of the concrete decreased by 13.64%, 20.18%, 39.37%, 46.94% and 52.16% at 28 days concerning conventional concrete. Here, it is seen that the compressive strength of concrete is acceptable up to 10% replacement of sand by plastic aggregate as per IS: 456-2000 [36].

Spilt Tensile Strength

The split tensile strength test on cylindrical concrete specimens, as per IS: 5816-1999 [37] as shown in Fig. 5, determines the indirect tensile strength of concrete. A standard cylindrical specimen (typically 150mm diameter×300 mm height) is placed horizontally in a compression testing machine, and a uniform load is applied along its length through two parallel steel strips. This loading induces tensile stress perpendicular to the vertical diameter, causing the specimen to split along its length.



Fig. 5: Split tensile strength of cylindrical specimen

The results of Spilt Tensile Strength are presented in Fig. 6.

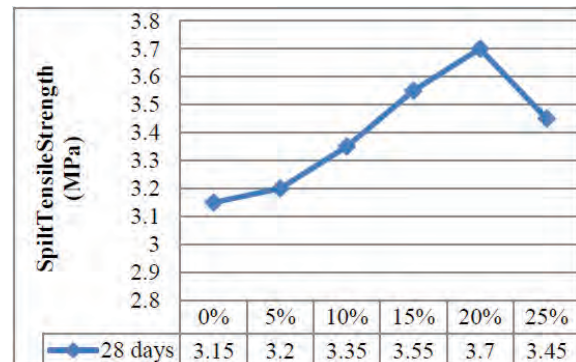


Fig. 6: Split tensile strength variation

From Fig. 6, split tensile strength has illustrated a different trend than compressive strength results. Compressive strength showed a reduction in strength with the increase in the replacement of sand by plastic aggregate. While split tensile strength show an increase in strength even with a 20% replacement of sand by plastic aggregate. It may be due to the internal shear and tensile reinforcement provided by plastic aggregate. During the testing of conventional concrete cubes, spalling was observed. In contrast, concrete containing plastic aggregates exhibited bulging in the transverse direction. The incorporation of plastic aggregates altered the failure mode from brittle to ductile, demonstrating increased deformation capacity before failure. The plastic aggregates behave in a similar manner as that of steel and synthetic fibres which helped the concrete in bridging the cracks. Additional research and testing are required to determine the optimum percentage of replacement of fine aggregate by plastic aggregate. The optimum quantity of plastic aggregate cannot be directly related to tensile strength because it is dependent on two components i.e. compressive strength of concrete and the amount of plastic aggregate in the mix.

The tensile strength tended to decrease as the proportion of waste plastic aggregate exceeded 20% replacement. This trend is believed to result from a reduction in the adhesive strength at the interfacial transition zone between the waste plastic aggregate and the cement paste.

COST COMPARISON

The cost comparison between conventional concrete and concrete with 20% amount of fine aggregate by plastic aggregate is illustrated in Table 6.

Table 6: Cost Comparison

Ingredients of Concrete	Conventional Concrete (0% Qty. Plastic Aggregate)	Cost (Rs.)	Concrete (20% Qty. Plastic Aggregate)	Cost (Rs.)
Cement	413.33 kg	2935/-	413.33 kg	2935/-
Sand	509.35 kg	1800/-	407.48 kg	1440/-
C.A.	1248.28 kg	1081/-	1248.28 kg	1081/-
Water	193.79 lit	25/-	193.79lit	25/-
Plastic Processing	0 kg	0/-	101.87 kg	204/-
Total		5,841/-		5,685/-

The Table 6 represents that, the replacement of sand by 20% of plastic aggregate resulted into decrease in cost of concrete by 2.7%.

CONCLUSIONS

The study has been intended to develop an android application to design concrete mixes and to investigate the effective ways to utilize the plastic waste aggregate in the concrete. From the analysis of strength characteristics of concrete utilizing plastic aggregate the following conclusions are quoted.

1. The android application helps to design a mix of any grade of concrete within a fraction of a second.
2. The dry density of the concrete reduces with increase in the plastic content due to the weight of plastic is less than that of the sand.
3. The workability increased up to the 10% replacement of the sand by plastic aggregate. Further, with increase in % replacement of the sand by plastic aggregate, workability start decreasing due to the bulking of the plastic aggregate in the concrete.
4. The compressive strength of concrete is acceptable up to 10% replacement of sand by plastic aggregate as per IS: 456-2000. The compressive strength of concrete is reduced due to the lesser binding properties of plastic aggregate in concrete.
5. The split tensile strength showed increase in strength even with 20% replacement of sand by plastic aggregate because of the internal shear and tensile reinforcement provided by plastic aggregate. The tensile strength has been prone to decrease with the increase of waste plastic aggregate beyond 20% replacement due to decrease in adhesive strength at the interfacial transition zone of waste plastic aggregate and cement paste.
6. Lesser production cost compared to other materials because the plastic is totally waste material.
7. The concrete with plastic aggregate can be used for non-structural members like partition walls to reduce the dead load on the structure and hence the cost. It can also used for manufacturing the paving blocks and has superior aesthetic appeal if colored pigments are used.

8. Ultimately, reduction in solid wastes results in better use of land than landfills.

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Analysis of the Structural Response and Sensitivity of Skewed Bridges

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ABSTRACT

A structural response with respect to skewed highway bridges is point of uncertainty significantly due to the criticality of the bridge. Objective of the present study is to understand the impact of skew angles on the structural behaviour and free vibration behaviour of existing skewed bridge located between Charni Road – Grant Road Station, Mumbai, India. A study was made for different skew angles of the bridge. Skew angles of 0 degree (straight bridge), 100, 200, 300, 400, 500 were considered for the study. An attempt was made to understand the variation of structural responses of the bridge for different skew angles under dead load, wind load and moving loads. A comparison was made between the results for different skew angles for a same span. This parametric study was performed by finite element modelling software of bridges in MIDAS Civil. Plate elements were used for defining Main Girders, Cross Girders and Road Beams of the skewed bridge. Based on the free vibration frequency, the dynamic behaviour of the bridge was also investigated in this research paper. From the analysis of all the bridge models, it was observed that with the increase of skew angle, the support reactions, bending moment for the main girder and deflection of the bridge at the centre span length were decreased but the torsional moment values increased considerably. The free vibration analysis showed that with the increase of skew angle the natural frequency of the bridge was increasing for all the modes of vibration. The analysis of different models for structural behaviour and free vibration analysis is discussed in this paper.

KEYWORDS: *Skew angle, Structural behaviour, Parametric free vibration analysis.*

INTRODUCTION

Skew bridges are very common in urban areas, in mountainous regions, river crossings etc. due to practically difficulty to normal bridges. In straight bridges, the bridge deck is exactly perpendicular to abutments or pier. But in skewed bridge it is other than 90°. Hence the analysis and design of skewed bridge becomes essential criteria as it differs than that of normal non-skewed bridge.

In past studies Bae H. and Michael G. (2012) provided load distribution factor for moment and shear to study their effects on multi girder bridges and observed that there was an inverse relationship between skew angle and load distribution factor. Guangyang H. and Suren

P. (2012) studied the behaviour of wheel loads of truck on skewed bridges with concrete deck on the steel superstructure using finite element software DIANA with the skew angles varying as 0°, 30° and 60°. The study showed that with the increase in skewed angle the service truck loads induced strains and stresses in the decks, responsible to initiate the cracking in concrete deck. The graphs of micro strains vs. distance from steering axle of the vehicle were plotted showing comparison of test and FEA model results for the different skewed angle for top longitudinal strain, bottom longitudinal strain, top transverse strain and bottom transverse strain. The conclusions made were that the modelling of skewed bridges required measurement data for verification. Gholamreza N.

and Zahed A. (2012) presented the 3D finite element analysis of the skewed bridge on a composite girder bridge by using seventy two bridge models with different span ratios and skew angle varying from 0° to 60° by using AASHTO loadings and the results obtained were compared with straight bridge model. The results concluded that with the increased skew angle of the bridge, moment of interior and exterior girder decreased by about 10% for skew angle less than 20° but this decrease was about 33% for skew angle more than 20° . Kar A. et. al. (2012) studied the effect of change of skew angle on the structural behaviour of the bridge and observed that maximum deflection occurred nearer to obtuse angled corner but as aspect span was more it came nearer to the middle of the span and shifts towards obtuse angled corner as skew angle increased". Theoret P. et. al. (2012) determined the bending moment and shear force values required for designing the skew bridge using the equivalent beam method. The analysis showed that non orthogonal grillages satisfactorily predicted the amplitude and the transverse distribution of longitudinal bending moments and shear forces and were used for the analysis of skewed slab bridges. Alaa H. and John B. (2015) determined the ultimate load carrying capacity of the skewed bridge for different loading for the most probable failure pattern and concluded that skew angle and aspect ratio of the bridge affected the crack length of the bridge but the critical location of the load was affected the most. Patel P.(2016) summarized the analysis of skew angles by using a single span T beam RC girder under IRC loading with a loading considered as dead load, vehicular load and the combination of dead load and vehicular load. It is concluded that bending moment decreased with increase in skew angle for about 40% and 37% as compared to the right angle bridge for class- A loading and for class 70- wheel loading respectively. Shahu A. and Joshi S. (2016) included various techniques and methods for skew bridge analysis by using IRC loadings with different skew angles. The torsional moment value played a major role as it can directly affect the bending moment and shear force values. Study concluded that for live loads, bending moment increased gradually, significant increase in torsional moment. Dicleli M. and

Fatih O. (2018) developed the correction factor for loads acting on different structural members such as girders, abutments and piles of skewed integral bridges to adjust the readily available live load distribution formulae for integral bridges and observed that as the skew angle decreased then the live load effects in the girder also in abutment and pier supports were decreased. Razzaq M. (2018) developed the loading sequence for different stages of construction of the skewed bridge to check the structural behaviour during these stages in the sequence as before the concrete hardening, after placing the asphalt layer and the barrier wall and it was concluded that as the number of lane increased, the moment and shear distribution factors in the girders also increased mostly for skew angle greater than 30° .

SKewed BRIDGE MODEL AND DATA

Software and its features

MIDAS Civil finite element analysis software is used for the parametric analysis of the structural behavior of the bridge and free vibration analysis. It can create nodes, elements and solid plates for different models. One end of main girder was kept fixed and the other end was supported on a roller to simulate the support conditions. The finite element analysis results for a single span skewed bridge with clear span of 24.50 m with varying skew angles (0° to 50° with existing skew angle 18°) were obtained and reported in terms of bending moment, torsional moment and deflection.

Bridge Modeling in Midas Civil

A single span simply supported existing skewed bridge consisting of main girders, cross girders and road beams with overall span length 24.50m and width 14.50m was considered in the present study. Fig.2 shows the plan of the bridge. Fig.1 shows the actual site photos of the existing skew bridge located between Charni Road – Grant Road Station, Mumbai, India. The model of the existing skewed bridge and bridge with varying skew angles were developed in FEA software MIDAS civil. A detailed cross section of main girder, cross girder and road beam is shown in fig.3. General parameters of the existing skew bridge and sectional properties of the bridge are shown in table 1 and 2 respectively.



Fig.1. Actual site photo of the existing skew bridge located in Mumbai, India



Fig.2. Plan showing dimensions of Main Girder, Cross Girder and Road Beam

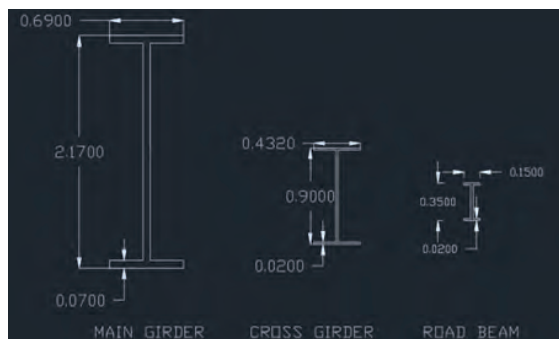


Fig.3. Cross Section of Main Girder, Cross Girder and Road Beam

Table 1. General parameters of the existing skew bridge

Sr. No.	Parameter	Details of parameter
1.	Location	Between Charni Road – Grant Road Station, Mumbai, India
2.	Year of Construction	1921
3.	Owner	MCGM
4.	Span Length (m)	24.50
5.	Width (m)	14.50
6.	No. of Spans	1
7.	Type of Deck	RCC Slab with Steel Plate
8.	Existing skew angle	180
9.	Material	Fe500 (main girder, cross girder and road beams)
10.	Support conditions	One end of main girder was fixed and the other end was supported on a roller

Table 2. Sectional properties of the bridge

Sr. No	Section	Property
1	Skew Angles considered	00, 100, 200, 300, 400, 500
2	Main Girder	$0.69 \times 2.17 \times 0.69$
3	Cross Girder	$0.15 \times 0.35 \times 0.15$
4	Road Beam	$0.432 \times 0.9 \times 0.432$
5	2 L stiffener at the end	ISA $150 \times 150 \times 20$
6	4 L stiffener at the end	ISA $150 \times 150 \times 12$
7	2 L stiffener at the mid span	ISA $150 \times 150 \times 20$
8	4 L stiffener at the mid span	ISA $150 \times 150 \times 12$

LOADING ON BRIDGE

Dead Load and moving load

The structural members of the bridge are made up of carbon steel of density 78.5 KN/m^3 which comprises for the self-weight of the bridge. A RCC deck slab is of 270 mm thick including 20mm asphalt layer as finished road surface over the deck slab. This, in total comprises of the static loading of the bridge. The vehicle loading was considered as per IRC: 6 - 2016.

Dynamic Load

Wind load intensity as per IRC: 6 –2016 has been considered. In order to assess the stability and functionality of the bridge, Eigen value analysis was also been performed. The dynamic properties of the bridge such as natural modes (or mode shapes), natural periods (or frequencies) and modal participation factors were obtained.

RESULTS AND REVIEWS

Structural behavior of the bridge

In the present work, different skew bridge models are prepared in MIDAS Civil with the skew angle varying from 00 to 500 with the increment of 100 with the existing skew angle of 180. Under Dead load, wind load and moving loads the results obtained for all different bridge models are axial force, shear force, torsional moment and bending moment. These parameters are further interpreted to get maximum bending moment, maximum shear force, bending moment due to torsion, design equivalent bending moment, shear force due to torsion, and design equivalent bending moment.

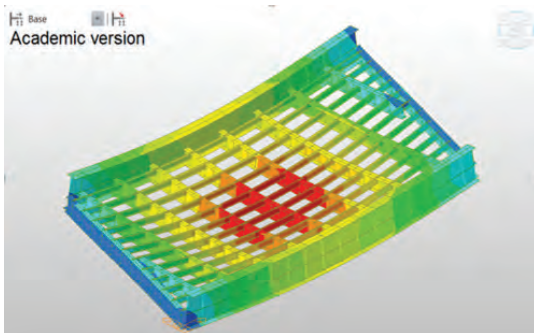


Fig.4. Maximum Displacement in X - direction due to Live Load

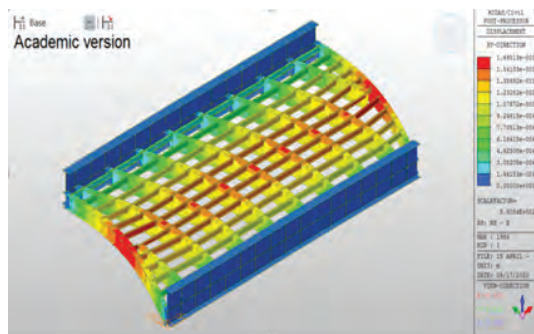


Fig.5. Horizontal deformation due to Seismic Force in X direction

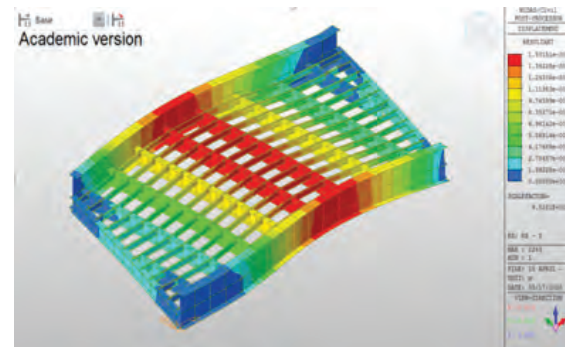


Fig.6. Horizontal deformation due to Seismic Force in Y direction

Reaction

General behavior of the bridge indicates that the reactions at the supports in the skewed bridge decreases with the increase of skew angle. Fig. 7 shows the variation of skew angle with the support reactions of the bridge.

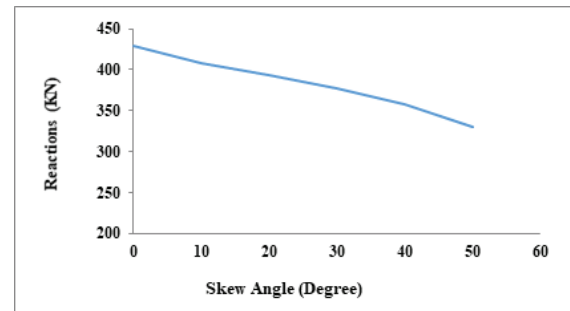


Fig.7. Reaction vs. skew angle

Maximum Bending Moments

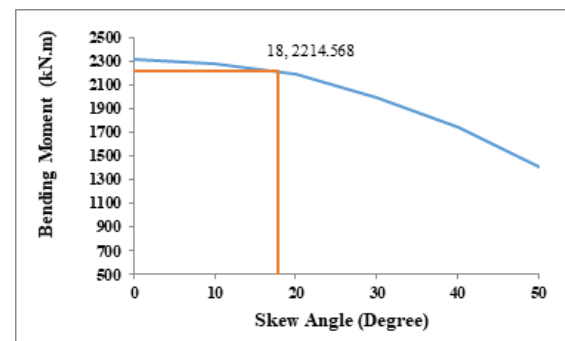


Fig. 8. Maximum bending moment vs. skew angle

General behavior of the bridge indicates that the maximum bending moment value in skew bridge compared with that of straight bridge decreases with

increase of skew angle. The behavior of skew angle for maximum bending moments at the main girder is shown in Fig. 8 and the maximum bending moment value was decreasing from 2321 kN.m at 00 skew angles to 1410 kN.m at 500 skew angle and a sudden fall was observed after skew angle of 200.

Maximum Torsional Moment

General behavior of the indicates that the maximum torsional moment value in skewed bridge compared to that of straight bridges increases with increase of skew angle and a sudden increase was observed after skew angle of 200. The behavior of skew angle for maximum torsional moments at the main girder is shown in Fig. 9 and the maximum torsional moment value was increasing from 53.88kN.m at 00 skew angle to 207.12kN.m at 500 skew angle.

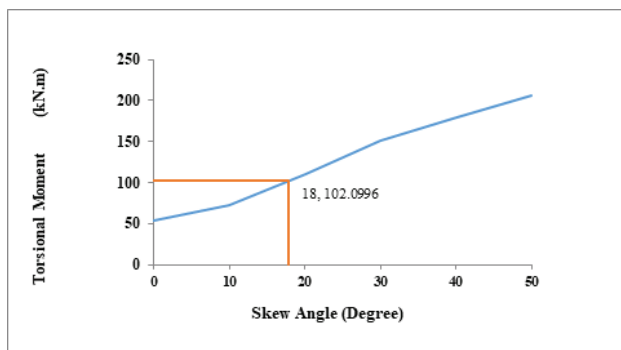


Fig. 9. Maximum torsional moment vs. skew angle

Maximum Deflection

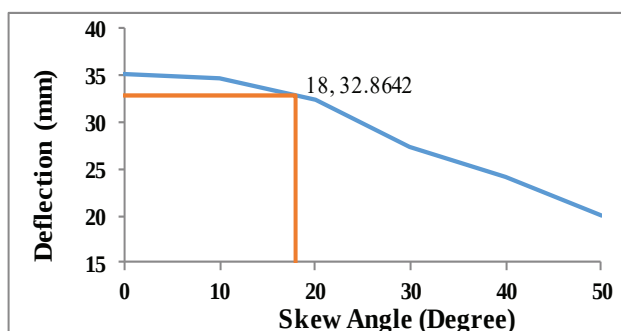


Fig.10. Maximum deflection vs. skew angle

General behavior of the bridge indicates that the deflection in the skewed bridge to that of the normal bridge decreases with the increase of skew angle and a considerable change in deflection values were observed after skew angle of 200. The behaviour of skew angle

for maximum deflection at the centre of the span of the bridge is shown in Fig. 10 and the maximum deflection value at the centre span of the bridge was decreasing from 35.16mm at 00 skew angles to 21.09mm at 500 skew angles.

FREE VIBRATION ANALYSIS

The effect of skewness of skewed bridge on natural frequency was also investigated. Free vibration analysis was performed. The effect of higher modes shall be included by considering missing mass correction by adopting well established procedures. For purpose of discussion, only the first five dominating modes are considered in the analysis. Fig. 11, 12 and 13 shows the mode shapes for mode number 1,2 and 3 respectively. Mode shape 1 and 2 are translational mode of vibration along X and Y direction respectively while as third mode is a torsional mode of vibration. It was observed that with the increase in skew angle, the frequencies were also been changing.

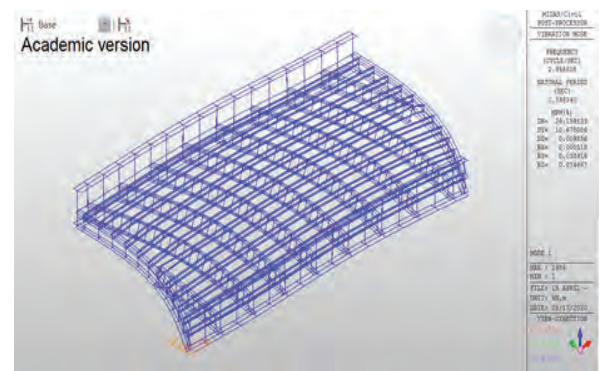


Fig.11. First mode shape along longitudinal direction (translational)

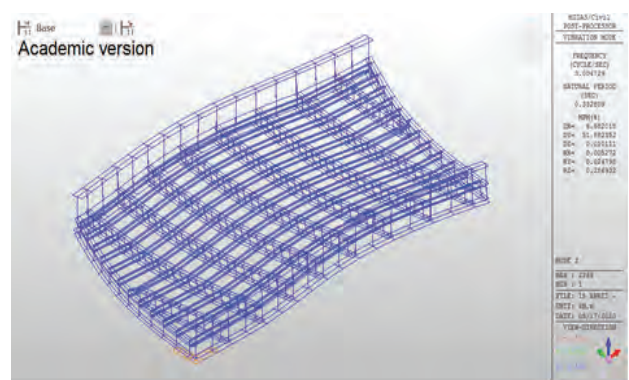


Fig.12. Second mode shape along transverse direction (translational)

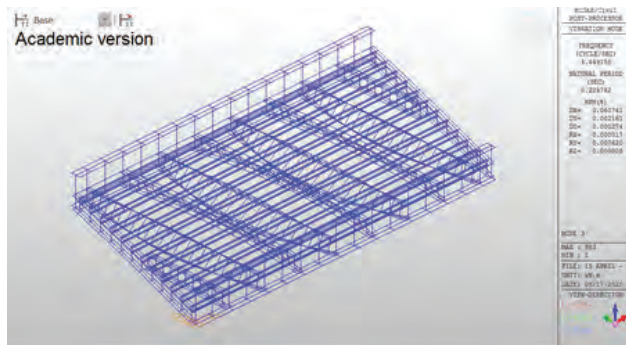


Fig. 13. Third Mode Shape along twisting mode of vibration (torsional)

Variation of frequency

It has been observed that the frequency of each mode increases with the increase in skew angle of the bridge. The variation of natural frequency upto 5 modes of vibration is shown in Fig. 14.

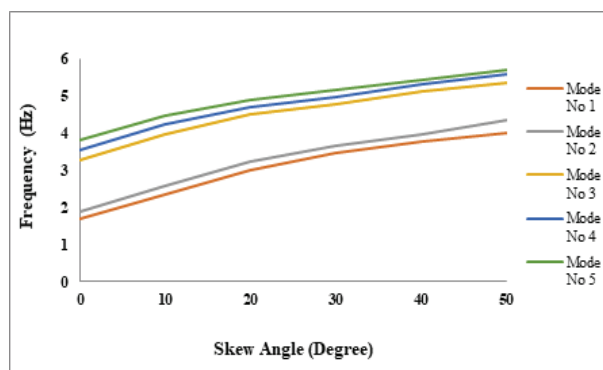


Fig. 14. Frequency vs. Skew Angle

CONCLUSION

The finite element models of skewed bridge with varying skew angles were studied in MIDAS Civil. The structural behavior of the bridge and natural vibration frequencies were explored thoroughly. The conclusions from the study are as below:

The reactions at the supports in the skewed bridge decreases with the increase of skew angle.

- Torsional moment played a major role in skewed bridge as it was observed that with the increase of skew angle, torsional moment increases and it increases considerably after 200 skew angles. This increase is therefore affected on equivalent bending moment.

- The value of bending moment is decreased in all main girders, cross girders and road beams with increasing skew angle from 00 to 500.
- Maximum deflection decreased with the increase in skew angle of the bridge for all girders of the bridge.
- The fundamental frequency of the skewed bridge is increased with the increase in skew angle of the bridge for all modes of vibrations.

Abbreviations

MIDAS: Modular Interactive Data Acquisition System

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Estimation of Aquifer Parameters Using Pumping Tests of Kavalapur Area, Miraj Taluka, Sangli District, Maharashtra, India

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ABSTRACT

Groundwater condition of the area depends on the aquifer parameters such as Storativity, Transmissibility and Coefficient of permeability. Geological formation of an area controls the porosity and permeability. These aquifer parameters are important for excavation and design of dug-wells. Applicability of results from laboratory results has limitations while in-situ, pumping tests gives the representative aquifer parameters. The aquifer yield can be estimated through a pumping test. In this method, water is withdrawn from the well by adjusting pumping rate to maintain a constant water level in the well. This established an equilibrium condition where the percolation rate into the well matches the pumping rate. Test results include recording drawdown in both the pumping well and observatory wells. Utilizing the Thiems and Dupuits equilibrium formula for unconfined aquifer conditions, the coefficient of permeability (k) and Transmissibility (T) can be computed. The fractured and weathered basalt behaves as a good aquifer whereas massive basalt doesn't. The value of Radius of influence in the study area is 140m. The paper ends with compressive results of hydraulic parameters, which may be helpful in the outlook of sustainable groundwater resource in the region.

KEYWORDS: *Pumping test, Aquifer parameters, Groundwater resource.*

INTRODUCTION

The aquifer's yield can be ascertained using a pumping test. With this technique, water is pumped out of the well at a high pace while being constantly adjusted to keep the well's water level constant. By doing this, an equilibrium state is created where the rate of percolation into the well and the rate of pumping are equal. This test, which is often carried out in the summer, gives a precise indication of the yield of the well. The test results include recording drawdown in both the pumping well and an observatory well, which are then used to calculate aquifer characteristics. Utilizing the Thiems and Dupuit's equilibrium formula for unconfined aquifer conditions, the coefficient of permeability (K) and discharge capacity of the aquifer (Q) can be computed. This approach allows for a

comprehensive assessment of the aquifer's properties and potential.

STUDY AREA

The study area is in the Miraj taluka of the Sangli district of Maharashtra. It is included in Survey of India toposheet 47 L/9 and bounded by latitude $16^{\circ}53'7''$ N to $16^{\circ}57'7''$ N and longitude $74^{\circ}33'45''$ E and $74^{\circ}37'30''$ E. The area under study is about 57 km².

METHODOLOGY

Pumping test data obtained from main pumping dug well (Kv1) along with two observatory wells Kv2 and Kv3 respectively. The calculations involve applications of two methods, viz. Thiems and Dupuits methods, for unconfined aquifer conditions.

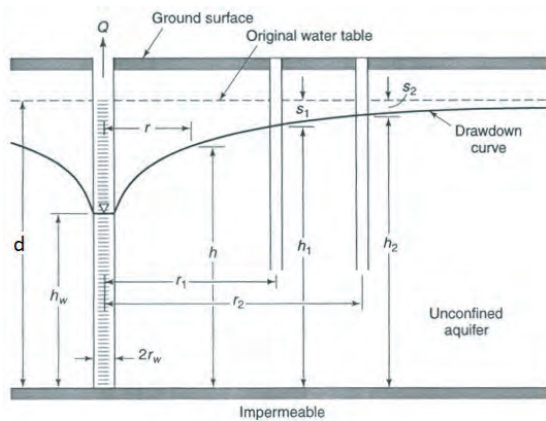
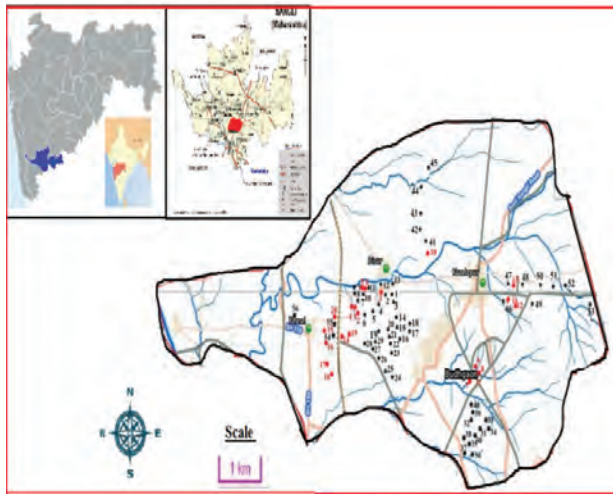


Fig. 1: Unconfined aquifer cases

Where,

Q = Discharge

d= Aquifer's saturated thickness

R= Radius of cone of depression

r_w = Radius of well

h_w = Thickness of saturated aquifer below equilibrium water table

k= Coefficient of permeability

h_1 = Height of water table in first observatory well

h_2 = Height of water table in second observatory well

s_1 = drawdown in first observatory well

s_2 = drawdown in second observatory well

r_1 = distance of first observatory well from pumping well

r_2 = distance of second observatory well from pumping well

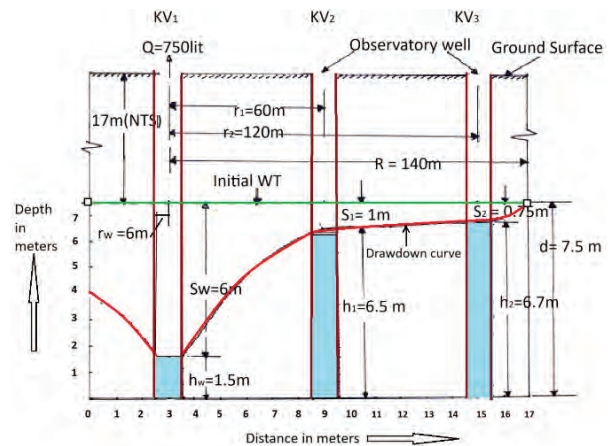


Fig. 2: Unconfined aquifer case study

Table 1: Wells spatial locations

	Well no.	Well depth (m)	Water table	Time (hr)	Depleted water table(m)
Pumping well	Kv1	24.5	17.00	8	6.0
Observatory well	Kv2	23.0	17.00	8	1.0
Observatory well	Kv3	23.5	17.00	8	0.75

Thiems formula for unconfined aquifer case

$$K = \frac{Q \log_e \left(\frac{r_2}{r_1} \right)}{\pi (h_2^2 - h_1^2)}$$

$$Q = \frac{\pi K \pi (h_2^2 - h_1^2)}{2.3 \log_{10} \left(\frac{r_2}{r_1} \right)}$$

Coefficient of transmissibility,

$$T = kd$$

d = Thickness of saturated aquifer

$$Q = \frac{2\pi T (S_1 - S_2)}{\log_{10} \left(\frac{r_2}{r_1} \right)}$$

Assumptions in Thiems formula

Following are the assumptions made in its derivation.

Aquifer is homogeneous, isotropic, infinite, and areal extent, so that coefficient of Permeability and Transmissibility remains constant.

The well has been excavated up to the full depth of aquifer.

Pumping is continuous up to the getting equilibrium stage.

Laminar flow with radial and horizontal flow lines.

For hydraulic gradient, tangents of the water's surface's inclination are utilized rather than sine.

2. Dupuits Formula for Unconfined Aquifer case.

$$K = \frac{Q \log_{10}(R/r_w)}{\pi (d^2 - h_w^2)}$$

$$Q = \frac{\pi K (d^2 - h_w^2)}{\log_{10}(R/r_w)}$$

To find out the permeability and transmissibility of a aquifer a pumping test is conducted in the study area. A suitable site of dug well KV1, KV2 and KV3 is selected which is in northern part of the Kavalapur area. Depth of dug well KV1, KV2 and KV3 is about 24.5m. Pumping of water started from KV1. Observatory well KV2 and KV3 are located 60m and 120m away from KV1 where pumps were not started. Pumping of water from KV1 was continuously for 8hr, after that equilibrium condition is formed. From observatory well, KV2 and KV3 lowering of water table by 1m in KV2 and 0.75m in KV3. Drawdown curves are formed which are shown in the fig. After 8hr pumping a radius of influence of circle is measured which is about 140m. Values of S_w , S_2 , h_w , h_1 , h_2 , r_1 , r_2 , d , and Q are measured and shown in the fig. Water table from KV1 is lowered from 17m. to 23m. To attain the same static water level 17 m in KV1 requires 12hr after stopping the pumps.

Unconfined aquifer case study

Calculations of coefficient of permeability by using Thiems formula for unconfined aquifer

$$K = \frac{Q \log_e (r_2/r_1)}{\pi (h_2^2 - h_1^2)}$$

Where,

$$Q = 750 \text{ lit/m} = 12.5 \text{ lit/sec} = 1.25 \text{ cm/sec}$$

$$r_1 = 60\text{m}$$

$$r_2 = 120\text{m}$$

$$h_1 = 6.5\text{m}$$

$$h_2 = 6.75\text{m}$$

$$K = \frac{1.25 \times \log_e (120/60)}{3.142(6.75^2 - 6.5^2)}$$

$$K = \frac{1.25 \times \log_e (120/60)}{0.7855}$$

$$K = \frac{1.25 \times 0.693}{0.7855}$$

$$K = 1.10 \text{ cm/s}$$

Calculations of coefficient of permeability by using Dupuits formula for unconfined aquifer

$$K = \frac{2.3 Q \log_{10}(R/r_w)}{\pi (d^2 - h_w^2)}$$

Where,

$$Q = 1.25 \text{ Cm/s}$$

$$R = 140\text{m}$$

$$r_w = 6\text{m}$$

$$d = 7.5\text{m}$$

$$h_w = 1.5 \text{ m}$$

Putting the values in Dupuit's formula,

$$K = \frac{2.3 \times 1.25 \log_{10}(140/6)}{3.142(7.5^2 - 1.5^2)}$$

$$K = \frac{2.3 \times 1.25 \times 1.368}{3.142(56.25 - 2.25)}$$

$$K = \frac{3.933}{169.66}$$

$$K = 0.02318 \text{ cm/s}$$

The value of coefficient of permeability by using Thiems formula for unconfined aquifer is, $K = 1.10\text{cm/s}$.

The value of coefficient of permeability by using Dupuits formula for unconfined aquifer is, $K = 0.02318 \text{ cm/s}$.

Calculation of transmissibility by using the formula,

$$T = k \cdot d$$

where,

k = coefficient of permeability

d = thickness of saturated zone

$$T = 0.0002318 \times 7.5$$

$$= 0.0017385 \text{ m}^2/\text{s}$$

$$= 0.10431 \text{ m}^2/\text{m}$$

$$= 150.192 \text{ m}^2/\text{day}$$

The value of transmissibility $T = 150.192 \text{ m}^2/\text{day}$

(The standard value of transmissibility for basalt is 32 to $100 \text{ m}^2/\text{day}$)

RADIUS OF INFLUENCE OF CONE OF DEPRESSION

Groundwater, or the water found in rock fissures and soil pores below the surface of the Earth, is a crucial part of our water supplies. An aquifer is a unit of underground rock or deposit that can produce sufficient water for daily consumption. The water table is the depth at which rock cracks or soil pores are completely saturated with water.

Case studies

Pandurang E Gurav's well:

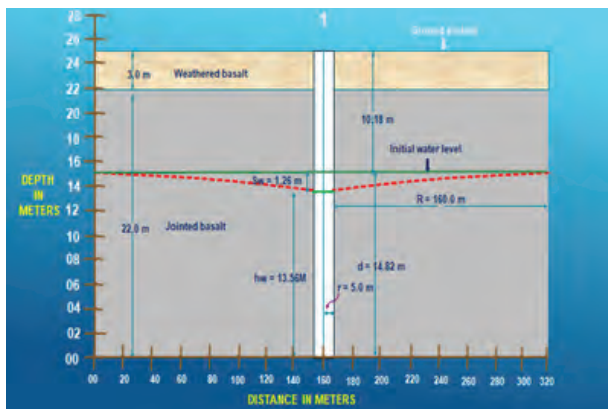
Diameter: 10 meters, Depth: 25 meters, Pump Power: 3 HP

Area under Irrigation: 8 acres, Scheme: No

Initial Water Level: 14.82 meters

Water Level after 1 hour: 13.56 meters

Radius(R) of the cone of depression: 160 meters



Gajanan S. Bandgar's well:

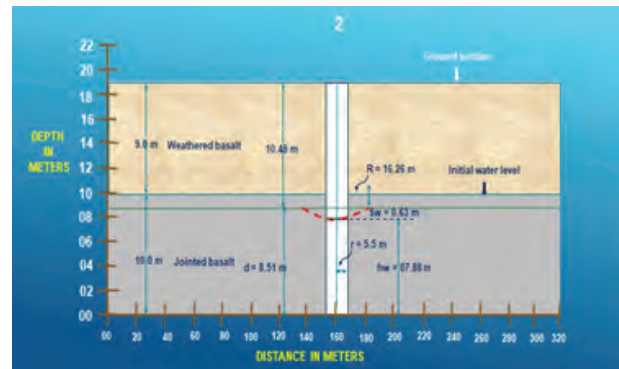
Diameter: 11 meters, Depth: 19 meters, Pump Power: 5 HP

Area under Irrigation: 5 acres, Scheme: No

Initial Water Level: 8.51 meters

Water Level after 1 hour: 7.88 meters

Radius (R) of the cone of depression: 16.26 meters



Jairam B. Patil's well:

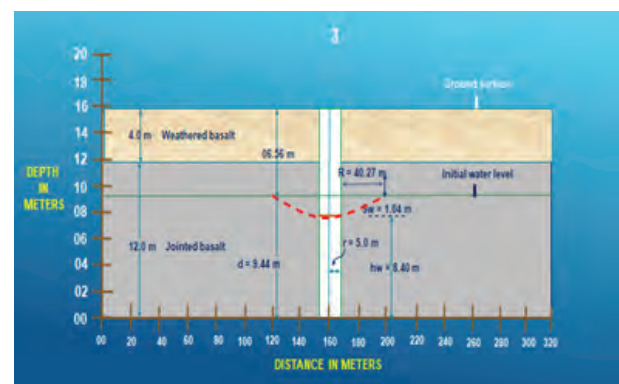
Diameter: 10 meters, Depth: 16 meters, Pump Power: 3 HP

Area under Irrigation: 4 acres, Scheme: No

Initial Water Level: 9.44 meters

Water Level after 1 hour: 8.4 meters

Radius (R) of the cone of depression: 40.27 meters



Ananda Bandgar's well:

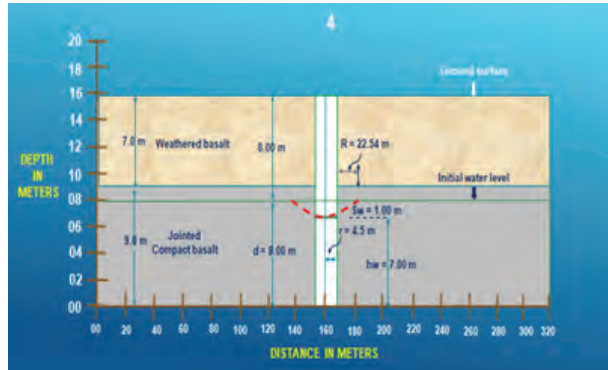
Diameter: 9 meters, Depth: 16 meters, Pump Power: 3 HP

Area under Irrigation: 2 acres, Scheme: No

Initial Water Level: 8 meters

Water Level after 1 hour: 7.0 meters

Radius (R) of the cone of depression: 22.54 meters



Ramjan A Mulani's well:

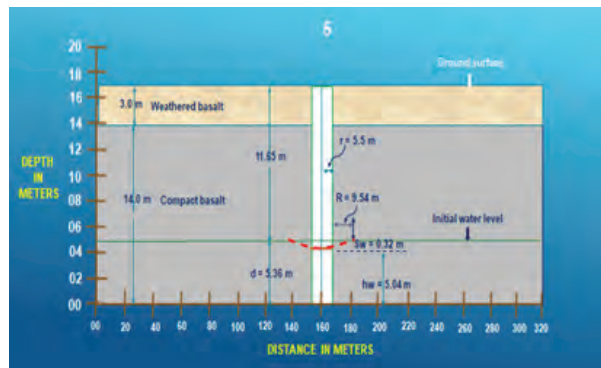
Diameter: 11 meters, Depth: 17 meters, Pump Power: 5 HP

Area under Irrigation: 5 acres, Scheme: No

Initial Water Level: 5.36 meters

Water Level after 1 hour: 5.04 meters (Well appears to have run dry)

Radius (R) of the cone of depression: 9.55 meters



Rangrao L Patil's well:

Diameter: 9 meters, Depth: 18 meters, Pump Power: 3 HP

Area under Irrigation: 4 acres, Scheme: No

Initial Water Level: 8.83 meters

Water Level after 1 hour: 7.9 meters

Radius (R) of the cone of depression: 42.07 meters

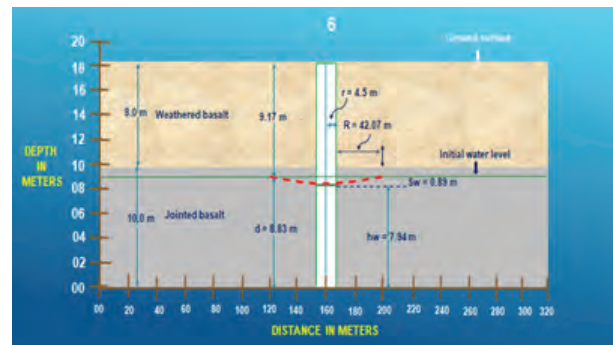


Table 2: Radius of Influence of Dug wells (After 1 hour)

Radius of Dugwell (m)	5	5.5	5	4.5	5.5	4.5
Depth of dugwell (m)	25	19	16	16	17	18
Pump Capacity (HP)	3	5	3	3	5	3
Discharge (m ³ /s)	0.32	0.3	0.28	0.28	0.20	0.21
Thickness of saturated aquifer below equilibrium (hw)- in (m)	13.56	7.88	8.40	7.09	5.04	7.94
Sw = d - hw	1.26	0.63	1.04	0.91	0.32	0.89
R in (m)	160	16.26	40.27	22.54	9.55	42.07

CONCLUSION

Pumping test's results of the site KV1, KV2 & KV3 shows that, radius of influence is 140 m.

After 8 hrs. pumping from KV1, the measured value of Sw is 6 m, hw is 1.5 m, S1 is 1 m & S2 is 0.75 m

The value of coefficient of permeability (K) is calculated by using Thiem's formula is 1.10 cm/sec & by using Dupuit's formula is 0.02318 cm/sec.

Despite the fact that all of the parameters are the same, the assumptions made by the Thiem's and Dupuit's formulas account for the discrepancy in the coefficient of permeability value.

In comparison to Thiem's formula, Dupuit's formula is more practical in basaltic rocks because its coefficient of permeability, which is equal to 0.02318 cm/sec, is closest to the conventional value of K, which is 0.01 cm/s.

The comparison of the radius (R) of the cone of depression for each well indicates variations in the impact of groundwater pumping on the water table.

Wells with larger radii have a wider area of influence and may affect neighbouring wells over a broader region.

Wells with smaller radii experience more localized drawdown, which could lead to a faster depletion of groundwater in the immediate vicinity of the well.

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Application of AI for Saving Power in a Conveyor: A Case Study by Design of User Interface for Material based Automatic Belt Speed Selection for a Conveyor

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ABSTRACT

The conveyor plays an important role in the industry transportation of raw or finished goods from one place to the other. The belt and the idlers are the important components of a Conveyor. The capacity of a conveyor is nothing but the volume of material transported per unit of time. The standard formula used for the calculation of LCC (Load-carrying capacity) deviates from the practically obtained values due to vibrations in the conveyor. The conveyor's capacity is dependent on factors like belt speed, a width of the belt, Surcharge angle, material density, inclination angle, troughing angle, etc. This study deals with designing a User Interface or an application that would automatically select an optimum speed based on the selection of material. The relation between various parameters required for the selection of the speed is obtained by using Multiple Linear Regression to create a mathematical model that will be close to the practical values. The data required for regression has been obtained from the standard handbook. The mathematical model has been experimentally tested to find out the errors in the mathematical model. The User Interface would help in selecting an optimum speed based on the properties of the material to be carried.

KEYWORDS: User interface, Belt width, Trough angle, Surcharge angle, Multiple regression, Idlers.

INTRODUCTION

Mechanical devices called conveyors are used to transfer items from one location to another. In addition to being utilized in industrial contexts, they are also seen on farms, in warehouses, and in the processing of goods. Conveyors can be fixed or movable, motorized, or driven by gravity.

Belt Conveyors: One of the most basic kinds of conveyors is a belt system. It transfers components between its ends. A variable speed drive allows for changeable speed.

A typical belt conveyor has the following components.

- a) Belt: Tightly woven cloth forms the “carcass” of the belt, which is encircled by a multi-layered rubber or comparable substance. Steel cables or

one or more layers of cloth can also be used in the belt.

The material, size, and purpose of the belt might change according to the use. A typical roller conveyor used in industry for carrying material is shown in Fig 1. (Entracker, 2017) [8].



Fig. 1: A typical industrial roller conveyor

- b) Head Pulley: This pulley, which is attached to an actuator and electric motor, is in charge of pulling the conveyor.
- c) Tail Pulley: On the conveyor bed, the belt is coiled around this pulley.
- d) Idler Rollers: These rollers are positioned to support, lessen, and preserve the alignment of the belt along the conveyor. Generally speaking, idlers are made up of a shaft, shell, rolling bearings, and sealing groups.
- e) Frames: The conveyor system is fixed to a frame for alignment and stability. The system elements in a belt conveyor is shown in Fig 2.(Alharbi, 2023) [5] [9].

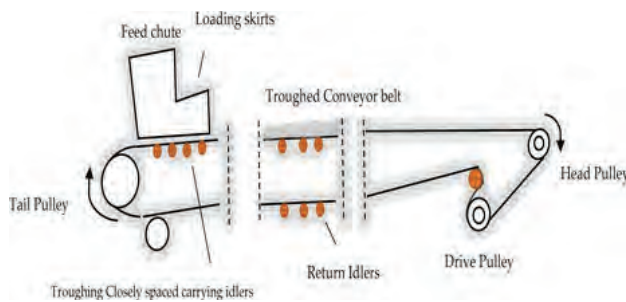


Fig. 2: A schematic sketch to show the components of a Belt conveyor

LITERATURE REVIEW: CAPACITY OF A BELT CONVEYOR

Provision of a trough could increase the Load Carrying Capacity(LCC) of a flat belt conveyor. A comparison of the cross-section of belt is shown in Fig 3 (RINA, 2024) [10].

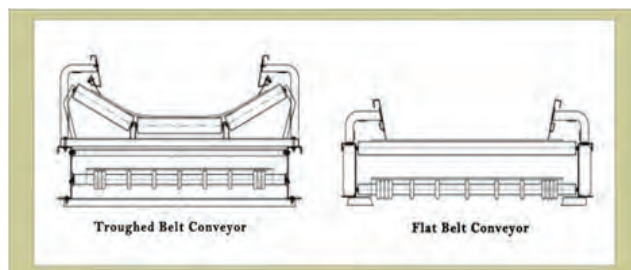


Fig. 3: Comparison of flat belt and troughed belt

Conveyors should be run at the fastest suggested speed while fully loaded for the highest haulage efficiency. The following parameters determine the belt's LCC.

- a) Belt width: The material lump size and the need for loading or transfer points may have an impact on the minimum belt width. The ultimate choice of belt width will also be influenced by load support limitations and troughability.
- b) Belt speed: Numerous elements, most notably the discharge, loading, and transfer arrangements, lump sizes, maintenance standards, etc., affect the maximum belt speed.
- c) Surcharge angle and bulk density of the substance: Material's natural angle of repose is reduced as a consequence of the belt's undulations as it travels over the conveyor idlers. A critical factor in determining the carrying capacity is the reduced angle, which is also referred to as the angle of surcharge. The cross-sectional area of the material on the belt is directly influenced by this angle, which in turn affects the volume being transported.

It is advisable to use a smaller surcharge angle to determine the capacity when handling materials that have a tendency to slump easily, such as fine powders or dust, or when dealing with long conveyors where the load may settle. This may require the use of additional factors, such as increasing the width of the belt or the speed, to meet the required capacity.

- d) Inclination Angle :Carrying capacity depends on conveyor inclination. In a vertical plane, the cross-sectional area of an inclined load diminishes as the surcharge angle falls relative to the belt. Multiply the horizontal capacity by the cosine of the slope angle to estimate reduced capacity.
- e) Troughing Angle: The predominant trough angle for standard three-roll idlers is 35° , although trough angles between 20° and 45° are also observed. While steeper trough angles can increase capacity, they can also have adverse effects on transition zones as well as convex and concave curves.
- f) Idler Configuration: The idlers' most prevalent configuration is shown below in Fig 4 (Fenner, D., 2009) [4].



Fig. 4: A three-roll trough idler belt Conveyor

The general formula for the calculation of a belt capacity is

$$Q = 3.6 \times A \times V \times M \quad (1)$$

Where

Q is the Capacity of the three roll trough idler belt pulley in T/hr

A is Load Cross Section Area* (m²) V is speed of the belt in meters/second.

M represents the material density in kilograms per cubic meter. [4]

DATASET OF LOAD CARRYING CAPACITY OF A BELT CONVEYOR BASED ON SURCHARGE ANGLE, AND BELT WIDTH

The Data book of Fenner Dunlop, Australia shows the various values of LCC at different belt speeds for a material bulk density of 1000 Kg/ m².

The sample data for various conditions is provided below in Table 1.

Table 1. Sample Dataset for Conveyor belt capacity at various values of parameter for a material with bulk density. 1000 Kg/ m²

Belt Width (mm)	Belt Speed m/s	Capacity (T/hr)	Surcharge Angle	Trough Angle
2800	1	3240	5	45
2800	1	3520	10	45
2800	1	3800	15	45
2800	1	4090	20	45
2200	0.5	1029	20	35
2200	0.75	1543	20	35
2200	4.5	9258	20	35

2200	5	10287	20	35
2200	1	1920	5	45
2000	0.5	846	20	35
2000	0.75	1268	20	35
2000	1	1691	20	35
2000	1.25	2114	20	35

APPLICATION OF AIML FOR DECIDING THE BELT SPEED

The technology known as artificial intelligence, or AI, is essentially what makes computers capable of thinking like humans and solving problems. Data is the foundation of artificial intelligence (AI); this data is used to teach the system by producing correlations or patterns the procedure in depicted in Fig 5 (Drawn in open board).

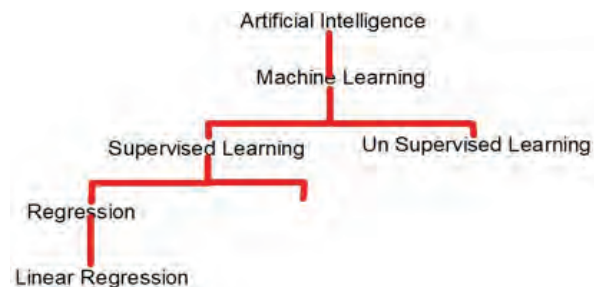


Fig 5: Artificial Intelligence-Tree Diagram applicable for this research.

In supervised Learning, the algorithm is based on a labeled dataset, which means the dataset whose respective target value is already known. Regression predicts then continuous output depending on the input variable, the prediction is based on various parameters. Linear regression is a type of supervised ML that entails the calculation of a linear equation to represent the connection among dependent as well as independent factors.

The study involves the use of Multiple regression the equation is given below

$$Y = m_0 + m_1X_1 + m_2X_2 + m_3X_3 + m_4X_4 \quad (2)$$

In the above equation

Y denotes the dependent variable

X1 X2 X3 X4 are independent variable m0 represents the intercept

m_1, m_2, m_3, m_4 are the slopes For the study under consideration

Y is the Load Carrying capacity of a three equal roll trough idler belt Conveyor in T/hr

X_1, X_2, X_3, X_4 are independent variables, Belt Width(mm), Belt Speed m/s, Surcharge Angle, and Trough Angle.

The objective of the algorithm is to determine the most accurate equation that can forecast the Gear oil temperature based on given values of the independent variables. The term “best fit” refers to the equation with the lowest amount of error in its predictions.

THE OBJECTIVES OF THE RESEARCH

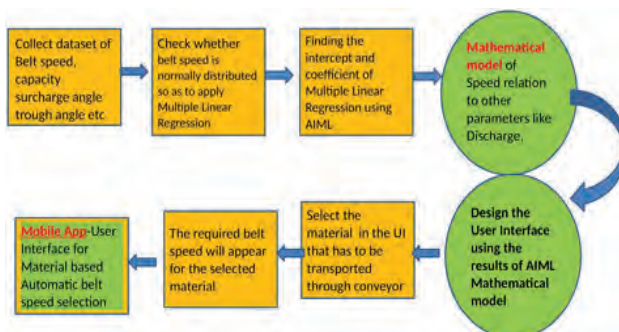
The research aims at

- 1) Finding the best fit multiple linear regression equation for predicting the Belt speed of a three equal roll trough idler belt Conveyor (using the variables, Belt Width(mm), Belt Capacity T/hr, Surcharge Angle, and Trough Angle.
- 2) Using Python Programming in the Google Colab Platform. The mathematical modeling will help to get an equation close to the practical values.
- 3) Design a User Interface or an App that would give the values of the Belt speed just by selecting the material

METHODOLOGY

The User Interface for Material based Automatic belt speed selection for a conveyor is developed using the following two methods

- 1) Computational Method(AIML)
- 2) Design and Analysis of UI using Figma software



Machine learning of the practically available data's, of the belt conveyor speed against the design parameters and generating a mathematical model of the same.

Comparing the results of belt conveyor speed obtained through AIML mathematical model with that of the standard formulas and comparing the results and validating the results of AIML generated equations.

Creating a Database for Design of User Interface(UI) for Material based Automatic belt speed selection from the Validated results of AIML based Multiple Linear Regression Model

Design of User Interface(UI) for Material based Automatic belt speed selection from the results of AIML based Multiple Linear Regression Model using Figma.

COMPUTATIONAL- APPLICATION OF AIML- MATHEMATICAL MODEL OF SPEED OF A BELT CONVEYOR

Google Colaboratory allows to execution Python Programs without any pre-requirement and also gives access to GPU.

```

from google.colab import drive
drive.mount('/content/drive')
import numpy as np
import pandas as pd
#basic visualisation package-bar, line,
pie, chart
import matplotlib.pyplot as plt
#descriptive plots-kernel density
estimator, boxplot
import seaborn as sns
  
```

	Belt Width(mm)	Belt Speed m/s	Capacity(T/hr)	Surcharge Angle	Trough Angle
0	400	0.5	26	20	35
1	450	0.5	34	20	35
2	500	0.5	44	20	35
3	600	0.5	66	20	35
4	650	0.5	78	20	35
...	...	...	...	...	...
346	2000	1.0	2240	25	60
347	2200	1.0	2750	25	60
348	2400	1.0	3320	25	60
349	2600	1.0	3940	25	60
350	2800	1.0	4610	25	60

351 rows x 5 columns

```

CP_data
pd.read_csv('/content/drive/MyDrive/Research Data/Base Data - REV UP.csv')
CP_data.describe()
  
```

	Belt Width(mm)	Belt Speed m/s	Capacity(T/hr)	Surcharge Angle	Trough Angle
count	351.000000	351.000000	351.000000	351.000000	351.000000
mean	1470.940171	1.897436	1798.643875	18.076923	42.051282
std	676.490080	1.354419	1652.962136	5.021930	9.735513
min	400.000000	0.500000	26.000000	5.000000	35.000000
25%	900.000000	1.000000	573.000000	20.000000	35.000000
50%	1500.000000	1.000000	1280.000000	20.000000	35.000000
75%	2000.000000	3.000000	2625.000000	20.000000	55.000000
max	2800.000000	5.000000	10287.000000	25.000000	60.000000

```
from scipy.stats import norm
plt.figure(figsize = (12,7))
sns.distplot(CP_data['Belt Speed m/s'],
fit = norm, color = 'darkviolet')
plt.show()
```

The linear Regression can be run only if the belt speed is normally distributed as shown in Fig. 6 (Arackal, 2024)[11].

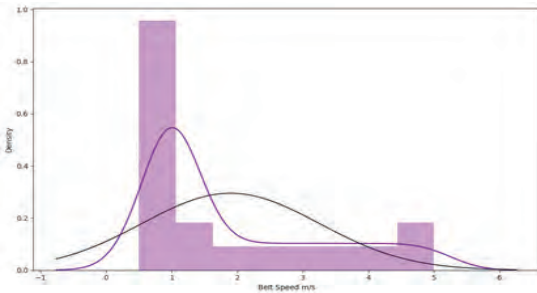


Fig. 6. The frequency distribution of Belt speed of a three equal roll trough idler belt Conveyor in m/s, is normally distributed

```
plt.figure(figsize = (7,3))
sns.heatmap(CP_data.corr(), annot = True, cmap = 'RdPu')
plt.show()
```

The correlation between various parameters showing range of correlation is shown in Fig 7. (Arackal, 2024) [11].

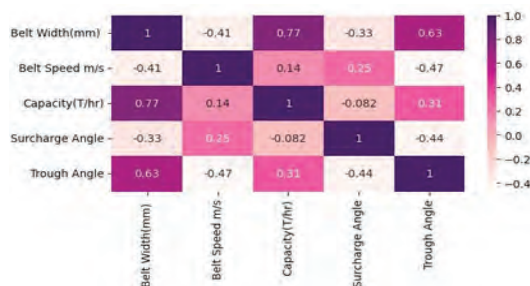


Fig. 7. Heat map showing Correlation between all the parameters, dependent as well as independent

```
plt.figure(figsize = (3,9))
sns.heatmap(CP_data.corr()[['Belt Speed m/s']], annot = True,
cmap = 'RdPu')
plt.show()
```

The relation between independent and dependent variable is shown in Fig 8 (Arackal, 2024) [11].

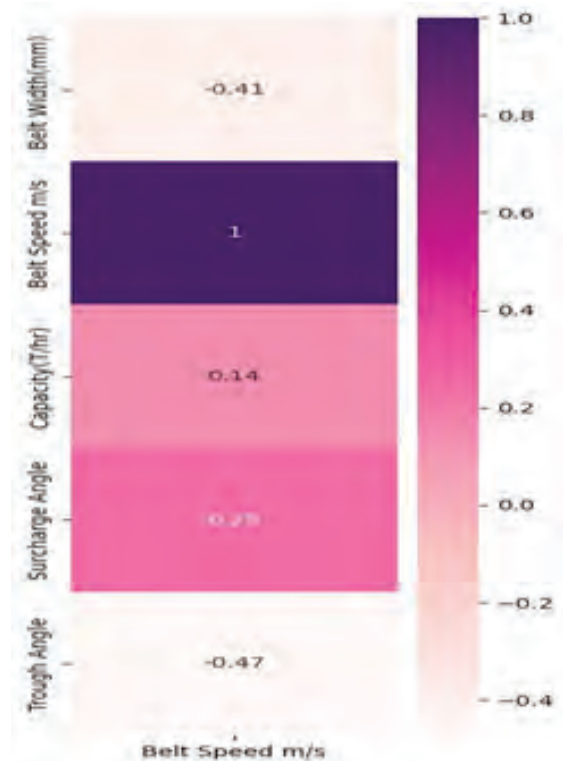


Fig. 8: Heat map showing the Correlation between all the Independent variables to the dependent variable

```
x = CP_data.drop(['Belt Speed m/s'],
axis = 1)
y = CP_data['Belt Speed m/s']
from sklearn.model_selection import
train_test_split
#splits features and targets and test
sinze is 20% and training size is 80%
x_train, x_test, y_train, y_test =
train_test_split(x,y,test_size = 0.2,
random_state = 8)
x_train
```

	Belt Width(mm)	Capacity(T/hr)	Surcharge Angle	Trough Angle
69	1800	1701	20	35
248	2200	2430	20	45
3	600	66	20	35
249	2400	2940	20	45
13	1500	466	20	35
...	...	...	...	...
194	1600	4796	20	35
347	2200	2750	25	60
136	1200	1754	20	35
133	900	953	20	35
348	2400	3320	25	60

```
from sklearn.preprocessing import
MinMaxScaler # scaling all from 0 to
100
scaler= MinMaxScaler(feature_range =
(0,100))
scaler.fit_transform(x_train)
x_train_scaler=
scaler.fit_transform(x_train)
x_test_scaler=
scaler.transform(x_test)
pd.DataFrame(x_train_scaler)
```

	0	1	2	3
0	58.333333	27.158684	75.0	0.0
1	75.000000	39.035516	75.0	40.0
2	8.333333	0.521342	75.0	0.0
3	83.333333	47.344412	75.0	40.0
4	45.833333	7.038123	75.0	0.0
...	...	...	...	...
2 69	50.000000	77.614858	75.0	0.0
270	75.000000	44.248941	100.0	100.0
271	33.333333	28.022157	75.0	0.0
272	20.833333	14.972304	75.0	0.0
273	83.333333	53.535354	100.0	100.0

274 rows x 4 columns

Linear Regression

```
from sklearn.linear_model import
LinearRegression
lr_model = LinearRegression()
lr_model.fit(x_train_scaler, y_train)
y_test
Belt Speed
m/s00.502971.00781.501824.50250.75 ..... 721.5032
61.001804.50962.001463.50
lr_model.intercept_
3.0775604549963864
#beta 1, beta 2....
lr_model.coef_
array([-0.05771908, 0.06630417, -0.00562217, -
0.0027801 ])
```

MAKE A NEW PREDICTION

Prediction of Belt speed for Iron Filing with angle of surcharge of 30 degree

```
x_iron = [[400, 4610, 30, 35]]
x_iron_scaler =
scaler.transform(x_iron)
np.round(lr_model.predict(x_iron_scaler
))
array([7.])
```

Prediction of Belt speed for Coal with angle of surcharge of 35 degree

```
x_coal = [[600, 4610, 35, 35]]
x_coal_scaler =
scaler.transform(x_coal)
np.round(lr_model.predict(x_coal_scaler
))
array([7.])
```

Prediction of Belt speed for Sugarcane with angle of surcharge of 39 degree

```
x_sc = [[2800, 4610, 39, 35]]
x_sc_scaler = scaler.transform(x_sc)
np.round(lr_model.predict(x_sc_scaler))
array([1.])
```


OUTPUT OF THE PYTHON PROGRAM- MULTIPLE LINEAR REGRESSION

Running the python program in the Google colab, the value of the intercept and the slopes are put in equation 2 we get

$$Y = 3.07 - 0.058 X_1 + 0.066 X_2 - 0.006 X_3 - 0.0027 X_4 \quad (3)$$

Where

Y is the Conveyor Belt Speed in m/s

X1 is the Belt width in mm

X2 is the Load Carrying capacity of a three equal roll trough idler belt Conveyor in T/hr

X3 is the Surcharge angle in degrees X4 is the Trough angle in degrees.

VALIDATION OF THE EQUATION OBTAINED BY AIML

The table 2 below shows the values of the calculation done by

- Standard formulas (equation 1)
- Equation modeled using AIML

The values obtained by the above two formulas are compared with the practical values. The percentage of the variation in speed is shown in Table 2.

Table 2. Result Validation

Result Validation						
Belt Width (mm)	Load Carrying Capacity as per Standard Formula T/hr	Surcharge Angle	Trough Angle	Belt Speed as per formula	Belt Speed as per AIML	Practically obtained Belt Speed
2800	4610	25	60	0.67	1	1
			Percentage variation	-33	0	

It is observed that the values calculated through AIML formula closely matches to that of the Practically obtained values.

DATABASE FOR UI

The AIML Multiple Regression model generated in equation no (3) is used to design a User Interface in

which a set of database is created or in fact predicted from the Mathematical model equation (3) by using the material property of Surcharge angle.

To explain the Design three material are selected namely Iron Filings, Coal and Sugar cane and their Surcharge angle is put in the equation and the Belt speed required for transmission is predicted for a Capacity of 4610 T/Hr, and a trough angle of 350 the results are tabulated in Table 3.

Table 3. Belt speed values based on Surcharge Angle Material Property

S No	Material	Surcharge Angle (Material Property) in Degrees	Belt Speed based on the Material in m/s calculated from AIML Model
1	Iron Filing	30	7
2	Coal	35	7
3	Sugarcane	39	1

The values of belt speed evaluated in Table 3 is used for the design of UI using Figma, the design of the UI is shown in Fig 9 (Arackal, 2024) [7].



Fig. 9: Prototype of Design of UI for Material based Automatic belt speed selection from the results of AIML based Multiple Linear Regression Model using Figma

The link of the App is provided in the Reference [7]

THE MOBILE APP FOR MATERIAL BASED SPEED DETECTION OF A BELT CONVEYOR

The stage wise illustration of the speed selection based on the properties of material is illustrated in the Fig 10 (Arackal, 2024) [7].

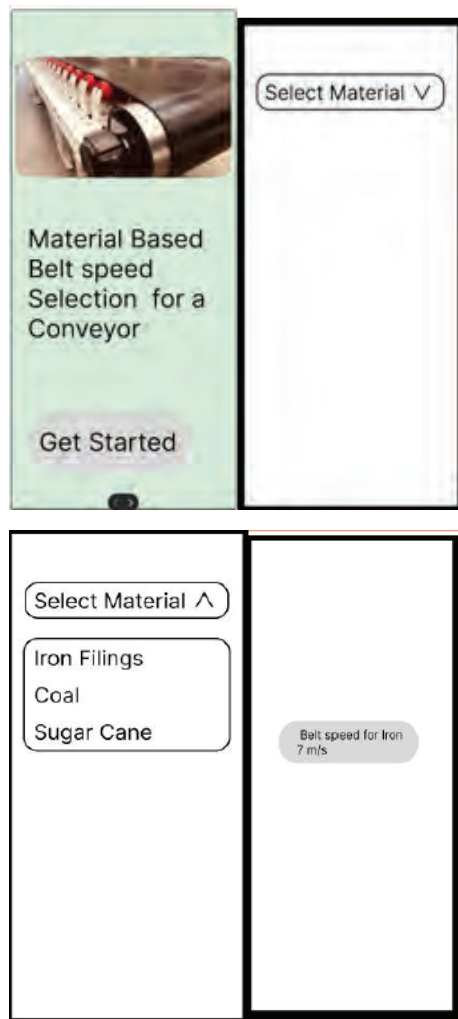


Fig. 10: Frames while using the app of Material based speed selection for a conveyor

RESULTS AND CONCLUSION

- 1- The Mathematical equation generated is close to the practical values
- 2- The factors LCC (Load Carrying capacity) plays a major role in deciding the belt speed
3. Based on the surcharge angle of the material to be transported, the User Interface can directly determine the speed.
4. The User Interface can help in deciding the optimum speed for a particular material to be transported using a belt conveyor, thereby saving power.

5. The selection of Optimum speed and running the conveyor at an optimum speed will reduce the vibration in the system thereby saving power.
6. The methodology can be used for different topographical regions

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Damping Force, Ride and Handling Characteristics of the Vehicle Equipped with Rack and Pinion based Energy Harvesting Shock Absorber

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ABSTRACT

Collection of energy from source is called as energy harvesting process. Energy harvesting shock absorbers represent an innovative solution for improving energy efficiency in passenger vehicles. It converts vibrational energy from suspension systems into usable electrical energy. The rack and pinion based energy harvesting shock absorber (RPEHSA) is designed and developed for harvesting the energy from the vehicle suspension. The proposed RPEHSA utilises a rack and pinion gear to transform linear suspension motion into rotary motion. This motion is then transformed into electrical energy through an electromagnetic generator. This research investigates the determination of damping force in energy harvesting shock absorbers designed for passenger vehicles. A detailed mathematical model of the RPEHSA was developed and relationship between damping force and displacement was determined. This research also investigates ride and handling characteristics using a quarter car model. This model offers a simplified and effective approach to simulating the vehicle suspension system. The study focuses on analysing characteristics such as sprung mass and unsprung mass displacement, vertical acceleration, suspension travel, and tire force. The RPEHSA is designed to offer a dual benefit of improving energy efficiency while maintaining vehicle dynamics. This research establishes the practicability of incorporating innovative energy-harvesting shock absorbers in vehicle suspension.

KEYWORDS: Rack and pinion based mechanism, Energy harvesting shock absorber, Damping force, Ride and handling characteristics.

INTRODUCTION

The technique of extracting a small quantity of energy from different source and transforming it into useful electricity is known as energy harvesting. Energy harvesting shock absorbers are primarily used for harnessing the kinetic energy produced by suspension vibrations, which would otherwise be lost as heat and dissipated into the surroundings. It is observed that only 14–30% of fuel energy is effectively utilised, with the remainder being wasted into the environment [1]. A significant portion of energy is dissipated by vehicles in the form of kinetic energy through suspension systems and braking mechanisms. The concept of energy harvesting shock absorbers was introduced around two

decades ago, aiming to convert this lost energy into a usable form.

Energy harvesting from suspension systems has been extensively studied to improve energy efficiency in vehicles. Lei Zuo et al. developed a mathematical model to estimate potential power generation, considering road roughness and speed variations. Their study revealed that 100–400 W of energy could be harvested at 60 mph, with tyre stiffness significantly influencing energy output despite compromising ride comfort [2]. Zhang Jin-qi et al. highlighted the regenerative shock absorbers can recover up to 10% of fuel efficiency from suspension systems, demonstrating that only ten to twenty percentage of fuel energy is utilised for

moving vehicle ahead [3]. Zhongjie Li et al. tested electromagnetic energy-harvesting shock absorbers on a Chevrolet Suburban SUV.

Researcher found that a 68 W power can be generated at 48 km/hr [4]. Zutao Zhang et al. utilised super capacitors in high-efficiency shock absorbers, recovering 44.24% mechanical efficiency and delivering an average output of 4.302 W [5]. Md. Emran Hossain et al. designed a rack-and-pinion system for harvesting energy dissipated over speed breakers, converting rotational energy into electrical energy [6]. Yilun Liu et al. developed a mechanical motion rectifier (MMR) mechanism in the shock absorber. This MMR consists of a ball-screw and one-way clutches. [7]. In railway systems, Xingtian Zhang et al. demonstrated energy harvesting using a mechanical vibration rectifier, incorporating gears and one-way bearings. Super capacitor was utilized to store the harvested energy [8]. Waleed Salman et al. developed a helical gear based mechanism to harvest energy from suspension, achieving a maximum power output of 270 W through MATLAB simulations and bench tests [9]. Zhanwen Wang shows that a system combining vibration input, transmission, generator, and power storage, achieving 36.44% efficiency by employing a ball screw mechanism [10]. S. Hegazy and A. M. Sharaf studied ride comfort at various vehicle speeds by mathematical modelling and experimentation. A two degrees of freedom quarter car model has been developed [11].

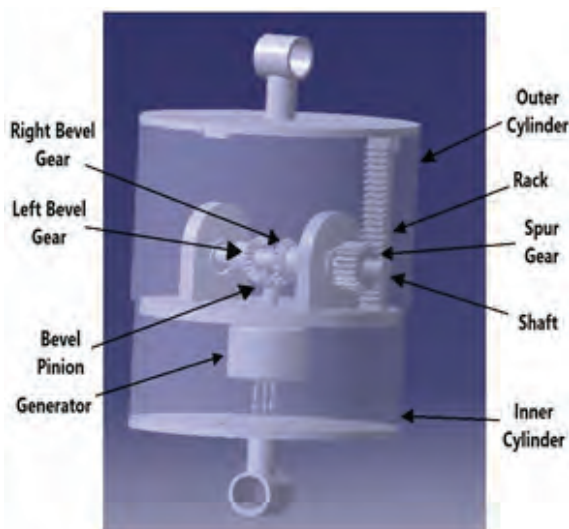


Fig. 1: CAD Model of RPEHSA

This study proposes rack and pinion based energy harvesting shock absorber (RPEHSA). Figure 1 shows computer aided design model of RPEHSA. The suspension system exhibits linear upward and downward motion during vibrations, it is required to convert this motion into rotary motion. Table 1 shows technical specification of the designed prototype of the RPEHSA.

Table 1: Technical Specifications of the RPEHSA

Parameters	Value
Module of the spur gear (pinion)	1.25
Radius of spur gear (pinion) r	20 mm
Length of the rack	100 mm
Module of bevel gear	1.25
Pitch circle radius of bevel gear	24 mm
Pitch circle radius of bevel pinion	20 mm
Shaft diameter	10 mm
Inertia of spur gear (J_p)	23.68 Kg-mm ²
Inertia of shaft (J_s)	7.9 Kg-mm ²
Inertia of bevel gear (J_b)	9.8 Kg-mm ²
Inertia of bevel pinion (J_{bp})	4.8 Kg-mm ²
Inertia of planetary gearbox (J_{pg})	0.16 kg-cm ²
Rotor inertia of generator (J_g)	0.4 kg-cm ²
Mass of outer cylinder (m_c)	1.67 kg
Mass of rack (m_r)	0.13 kg
Internal resistor of phase of the generator R_i	0.45 Ω
Back electromotive voltage constant k_e	0.0458 V s/rad
Gear ratio of the planetary gearbox i	1:18

During the vibration of the shock absorber, the rack moves linearly in an upward and downward direction, while the spur gear rotates alternately in clockwise and anticlockwise directions. By incorporating a one-way clutch bearing, two bevel gear and bevel pinion, the bidirectional motion is converted into single directional rotary motion. This motion drives the generator which will produce power.

MATHEMATICAL MODELLING OF ENERGY HARVESTING SYSTEM

This study focuses on the analysis of the damper in the shock absorber, which is influenced by friction damping between meshing gears and electromagnetic damping in the motor.

The function of a shock absorber is to deliver a damping force. In the proposed RPEHSA, the linear damping force is derived from the rotary damping generated by the generator.

The total instantaneous electrical power PE [5],

$$P_E = \frac{1.5 \cdot k_e^2}{R_e + R_i} \omega_g^2 \quad (1)$$

Where, R_e is the controllable external resistor and C_R is the rotary damping coefficient of the generator which is given by [5],

$$C_R = \frac{1.5 \cdot k_e^2}{R_e + R_i} \quad (2)$$

The linear damping coefficient (C_L) of the RPEHSA is determined by subjecting the energy-harvesting shock absorber to a displacement excitation (x).

Input Power is considered as [2],

$$P_{input} = C_L \cdot \dot{x}^2 \quad (3)$$

Where $\dot{x}$ is the excitation velocity.

The input power consists of power lost due to friction in the gear element, planetary gearbox, and generator (P) and power output of the generator (PE) [5].

$$P_{input} = P_f + P_E \quad (4)$$

Let,

η_p = Mechanical efficiency of the rack pinion = 0.97,

η_b = Mechanical efficiency of the bevel gear = 0.96,

η_{pg} = Mechanical efficiency of the planetary gearbox = 0.92

η_g = Mechanical efficiency of the generator = 0.90

$$P_E = \eta_{rp} \cdot \eta_b \cdot \eta_{pg} \cdot \eta_g \cdot P_{input} \quad (5)$$

$$\eta_{rp} \cdot \eta_b \cdot \eta_{pg} \cdot \eta_g \cdot C_L \cdot \dot{x}^2 = \frac{1.5 \cdot k_e^2}{R_e + R_i} \omega_g^2 \quad (6)$$

The rack and pinion system transforms linear to rotary motion based on the following relationship [15].

$$\omega_p = \frac{\dot{x}}{r} \quad (7)$$

$$\omega_p = i \cdot \omega_g \quad (8)$$

Here, ω_p represents the rotational speed of the pinion.

Thus, the linear damping coefficient (C_L) is shown as below:

$$C_L = \frac{1.5 \cdot K_e^2}{\eta_{rp} \cdot \eta_b \cdot \eta_{pg} \cdot \eta_g \cdot i^2 \cdot r^2 (R_e + R_i)} \quad (9)$$

The exciting force (F) is defined, and the system's equation of motion is derived using the Lagrangian formulation [15], as shown below:

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{x}} \right) - \left(\frac{\partial T}{\partial x} \right) + \frac{\partial D}{\partial \dot{x}} = F \quad (10)$$

Here, x represents the excitation displacement, while T and D denote the energies associated with kinetic and damping effects, respectively. The term T can be written as follows [15]:

$$T = \frac{1}{2} \cdot m_c \cdot \dot{x}^2 + \frac{1}{2} \cdot m_r \cdot \dot{x}^2 + \frac{1}{2} \cdot J_p \cdot \omega_p^2 + \frac{1}{2} \cdot J_s \cdot \omega_p^2 + \frac{1}{2} \cdot 2J_b \cdot \omega_p^2 + \frac{1}{2} \cdot J_{bp} \cdot \omega_p^2 + \frac{1}{2} \cdot J_{pg} \cdot \omega_p^2 + \frac{1}{2} \cdot J_g \cdot \omega_g^2 \quad (11)$$

By substituting equations (7) and (8) into equation (11), the resulting expression can be simplified as follows:

$$T = \frac{1}{2} \left(m_c + m_r + \frac{J_p + J_s + 2J_b + J_{bp} + J_{pg} + \frac{J_g}{i^2}}{r^2} \right) \cdot \dot{x}^2 \quad (12)$$

The damping effect D is as follows [15]:

$$D = \frac{1}{2} \cdot C_L \cdot \dot{x}^2 \quad (13)$$

Therefore, substituting (12) and (13) in (10) leads to

$$\left(m_c + m_r + \frac{J_p + J_s + 2J_b + J_{bp} + J_{pg} + \frac{J_g}{i^2}}{r^2} \right) \cdot \ddot{x} + C_L \cdot \dot{x} = F \quad (14)$$

$$F_D = \left(m_c + m_r + \frac{J_p + J_s + 2J_b + J_{bp} + J_{pg} + \frac{J_g}{i^2}}{r^2} \right) \cdot \ddot{x} + \left(\frac{1.5 \cdot K_e^2}{\eta_{rp} \cdot \eta_b \cdot \eta_{pg} \cdot \eta_g \cdot i^2 \cdot r^2 (R_e + R_i)} \right) \cdot \dot{x} \quad (15)$$

QUARTER CAR MODEL

This model is widely utilised for analyse and design suspension systems for passenger vehicles. It primarily examines the vertical motion of a single wheel and its associated components. This model allows researchers to study essential factors such as ride comfort, road grip, and vibration isolation [12]. This modelling technique is vital for assessing suspension performance under controlled scenarios, with the objective of balancing ride comfort and handling stability [13].

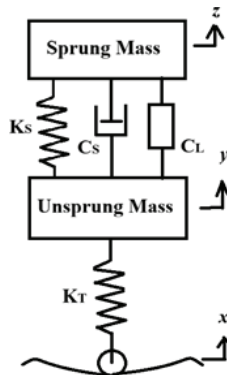


Fig. 2: Quarter Car Model with RPEHSA

Figure 2 demonstrates quarter car model with RPEHSA.

Taking force equilibrium at sprung mass m_s ,

$$-K_s(z-y) - C_D(\dot{z}-\dot{y}) = m_s \ddot{z} \quad (16)$$

$$\ddot{z} = \frac{1}{m_s} [-K_s(z-y) - C_D(\dot{z}-\dot{y})] \quad (17)$$

Taking force equilibrium at for unsprung mass (m_u).

$$K_s(z-y) + C_D(\dot{z}-\dot{y}) - K_T(y-x) = m_u \ddot{y} \quad (18)$$

$$\ddot{y} = \frac{1}{m_u} [K_s(z-y) + C_D(\dot{z}-\dot{y}) - K_T(y-x)] \quad (19)$$

The damping force is calculated by,

$$F_T = C_T(\dot{z}-\dot{y}) \quad (20)$$

Table 2 shows specification of different parameters used in quarter car modelling.

Table 2: Input Parameters for quarter car model

Parameter	Notation	Value
Sprung mass	m_s	350 kg
Unsprung mass	m_u	50 kg
Stiffness of the spring	K_s	15000 N/m
Stiffness of the tyre	K_T	160000 N/m
Damping Coefficient of Viscous Damper	C_s	2000 N-s/m
Damping Coefficient of RPEHSA	C_L	958 N-s/m

Total (Equivalent) coefficient of damping is:

$$C_T = C_s + C_L \quad (21)$$

Ride and Handling in Quarter Car Modelling of Passenger Car:

1. Ride Comfort: Ride comfort refers to a vehicle's

capability to shield passengers from road-induced vibrations and uneven surfaces. Parameter used for ride comfort are:

- Sprung Mass Displacement: The root mean square value serves as statistical indicators of vibration exposure over time and are utilised to assess long-term ride comfort.
 - Acceleration of the Sprung Mass: This parameter gauges the accelerations experienced by the vehicle body (sprung mass) due to road surface irregularities.
 - Suspension Travel (Stroke): Suspension travel refers to the vertical range of movement permitted by the suspension system to accommodate road surface irregularities.
- Handling Characteristics: Handling refers to a vehicle's capability to maintain control and stability. Handling characteristics as follows:
 - Unsprung Mass Vertical Displacement: The vertical movement of the unsprung mass affects tire-road contact.
 - Tire Deflection: It is defined as the difference between road input and unsprung mass displacement.
 - Tyre Force: It is the force developed at the contact between tyre and road. This force responsible for transmitting the required forces for steering, braking, and acceleration.

RESULT AND DISCUSSION

The numerical simulation is performed to determine damping force at various excitation and frequencies and ride and handling characteristics at sinusoidal displacement in quarter car model.

Determination of damping force

Force vs Displacement graphs are plotted for different excitation (2.5 mm to 10 mm) and different frequencies (1 Hz to 4 Hz) which are shown in the Figure 3 to Figure 6 respectively. Maximum damping force is also recorded for respective condition.

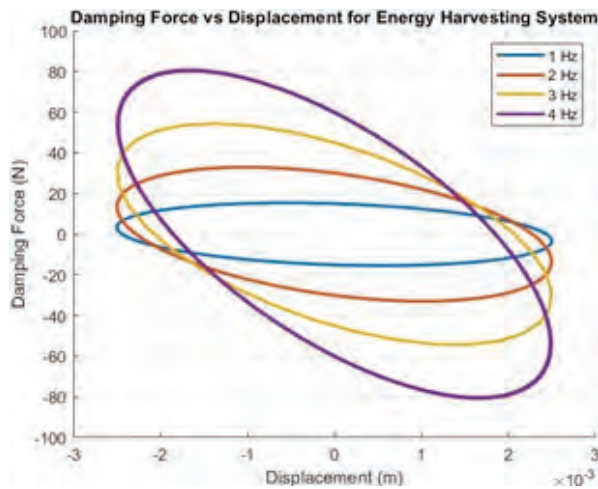


Fig. 3: Numerical Simulation Result for 2.5 mm Excitation

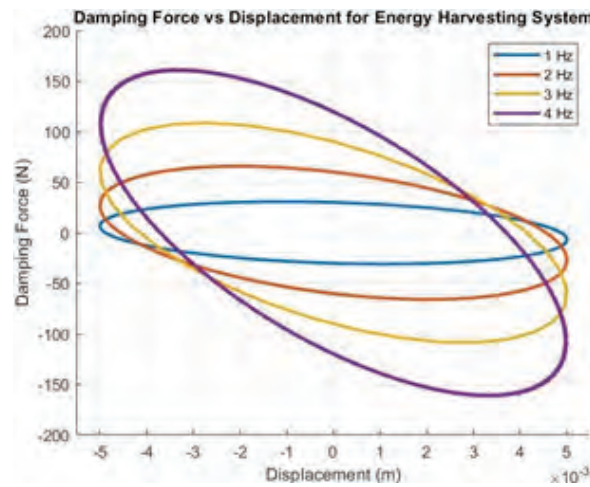


Fig. 4: Numerical Simulation Result for 5 mm Excitation

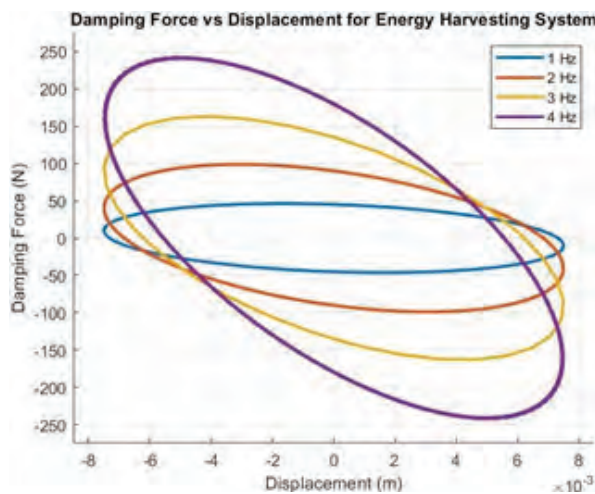


Fig. 5: Numerical Simulation Result for 7.5 mm Excitation

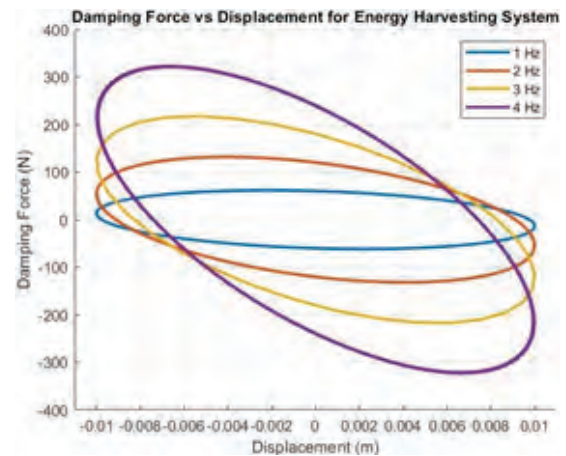


Fig. 6: Numerical Simulation Result for 10 mm Excitation

Figure 7 illustrates the relationship between damping force, excitation amplitude, and frequency. It is seen that at 0 Hz, the damping force is negligible, as no dynamic excitation occurs. However, as the frequency increases, the damping force shows a significant rise across all excitation levels. At 1 Hz, the damping forces for 2.5, 5, 7.5 and 10 mm excitations are 15.42 N, 30.83 N, 46.25 N, and 61.67 N, respectively. At 4 Hz, these values increase to 80.84 N, 161.67 N, 242.51 N and 323.35 N. The trend suggests that both frequency and amplitude of excitation contribute to an increase in damping force, indicating a strong dependence on dynamic input conditions.

The graph demonstrates a quadratic relationship between damping force and frequency, which aligns with the theory that power dissipation in a damping system is proportional to the square of velocity.

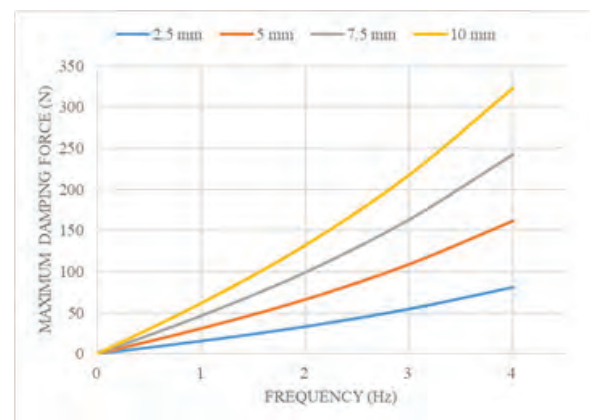


Fig. 7: Graphical Representation of Damping Force at Different Excitations and Frequencies

Similarly, for constant excitation, the force increases progressively with frequency. This behaviour aligns with theoretical expectations, validating the system's performance under varying dynamic conditions. The increasing damping force with excitation amplitude and frequency suggests that the system is well-suited for applications requiring adaptable damping characteristics.

ii) Determination of ride comfort and handling characteristics:

Ride comfort and handling characteristics are determined by providing sinusoidal excitation of 10 mm excitation and 1 Hz frequency as standard road condition. Figure 8 shows obtained graphs through numerical simulation.

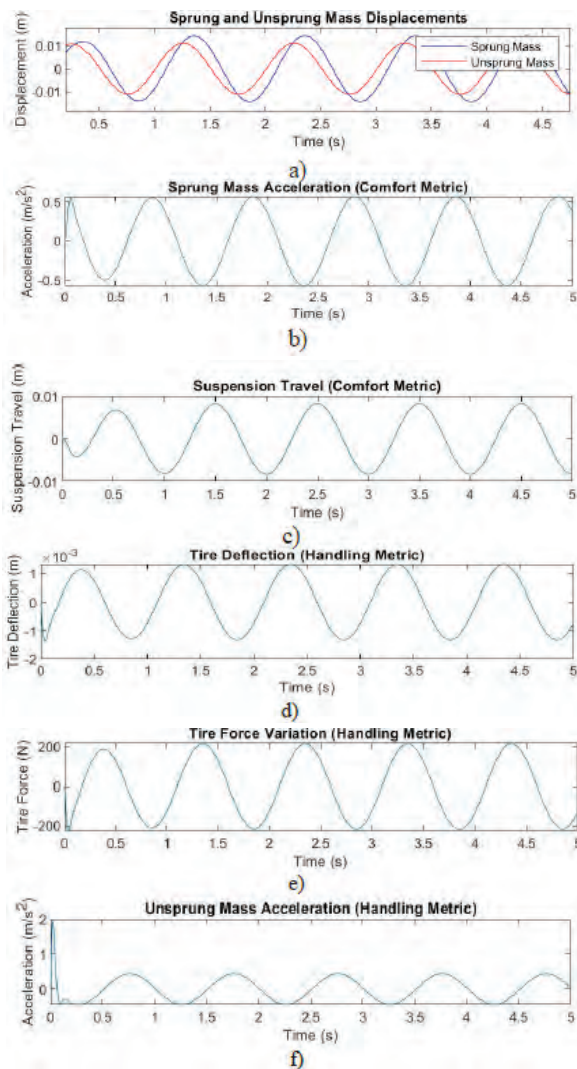


Fig. 8: Ride and Handling Characteristics Graphs

Table 3 provides observed values of ride comfort and handling characteristics parameters through graphs.

Table 3: Observation of Ride comfort and handling parameters

Parameter	RMS	Peak
Sprung mass displacement in m	0.0099	± 0.012
Unsprung mass displacement in m	0.0078	± 0.011
Sprung mass acceleration in m/s^2	0.3941	± 0.5
Suspension travel in m	0.0056	± 0.01
Tyre deflection in m	0.0009	± 0.001
Tyre force variation in N	151.02	± 200
Unsprung mass acceleration in m/s^2	0.3443	1.5

As per ISO 2631-1:1997, the values recorded from simulation of quarter car model of passenger car with RPEHSA were in the acceptable limit.

CONCLUSION

This research studied the energy harvesting shock absorber. The design parameters and technical specification of energy harvesting shock absorber was presented.

CAD prototype of RPEHSA and rack and pinion based energy harvesting system were discussed. Mathematical modelling of the RPEHSA was performed and expressions for evaluating the linear damping coefficient and damping force were derived. Damping force for different excitation and frequency levels were determined by using numerical simulation. Quarter car model with RPEHSA also discussed. Numerical simulation was carried out to determine different ride comfort parameters and handling characteristics. RMS and Peak values of the standard parameters were discussed which were found within acceptable limit. This research shows that RPEHSA can be used in passenger car.

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Development and Performance Evaluation of Viscous Jaggery Filling Low-Cost Automation Workstation

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ABSTRACT

Jaggery, a natural sweetener made by heating fresh sugarcane juice, is vital to India's agro-processing industry, especially the MSME sector. A major challenge in this sector is labor scarcity due to the physically demanding nature of the work. Filling hot, viscous jaggery into molds is particularly challenging, requiring swift wrist and finger movements, heat exposure, and quick execution. This study recommends adopting Low-Cost Automation (LCA) to enhance efficiency, safety, and hygiene in the jaggery filling process. The study introduces a novel approach by integrating LCA with custom-designed molding mechanisms tailored to the jaggery production process, optimizing production efficiency for small-scale manufacturers. To evaluate the productivity of manual jaggery molding, and LCA system the observations are made using two industrial engineering techniques: multiple activity charts and two-handed process charts. Inferences on reduced labor involvement and cycle time are drawn from summary sheets of these charts. The chart results revealed that implementation of the LCA system reduced left-hand acts from nine to seven and right-hand acts from fourteen to seven. The time study calculations indicated that the standard time for jaggery filling process decreased from 30.89 Seconds to 9.5 Seconds with the LCA system. The LCA system increased jaggery molding productivity by three times and brought other automation benefits. The developed automation solution is unique and found worthy for small scale jaggery manufacturers.

KEYWORDS: *Low-cost automation, Time study, Method study, Cycle time.*

INTRODUCTION

Maharashtra is well-known in India for producing high-quality jaggery that is popular around the world. India is the top producer of jaggery globally, contributing over 70% of the world's supply. [1]. Jaggery is regarded as a healthier alternative to sugar because it preserves the natural minerals and vitamins present in sugarcane juice [2]. As health consciousness grows, consumers are increasingly drawn to fresh, nutritious foods, enhancing the appeal of jaggery. It also holds importance in Ayurvedic medicine, further enhancing its value. With its rich medicinal and nutritional benefits, jaggery holds significant potential to serve as a healthier alternative to sugar and to expand its presence in the global export market in the future.

Traditional jaggery production plants in India struggle with inefficiencies, high labor requirements, and difficulties meeting international market standards, leading to the closure of many units. [3]. Key challenges include the use of outdated juice extraction technology, inefficient open pan furnaces, reliance on manual molding and packaging processes, inadequate quality control, hygiene concerns, limited technical expertise, and insufficient financial support [4]. Modernizing these plants is crucial to protect the economic wellbeing of sugarcane farmers and rural workers who rely on jaggery production. Tasks like feeding sugarcane, removing scum, stirring syrup, filling molds, and extracting solidified jaggery demand substantial effort and skilled labor.

The jaggery molding process is physically demanding and time-sensitive, exposing workers to high temperatures and placing strain on the hands and wrists. Furthermore, cleanliness and hygiene standards are often inadequate, significantly impacting the quality of the final product. Fig. 1 illustrates the process of manual jaggery molding.



Fig. 1: Process of manual jaggery molding

Automation systems for filling viscous jaggery, developed by specialized consultants, utilize extrusion screws to facilitate the flow of the thick jaggery. These systems may consist of conveyors for moving molds and manual control valves to regulate the flow of jaggery. However, jaggery manufacturers consider these systems costly and primarily suitable for fully automated plants. Low-Cost Automation (LCA) combines hydraulic, mechanical, and electrical technologies with existing production processes to enhance productivity [5]. LCA-based equipment can be operated by semi-skilled or unskilled workers with minimal physical effort, using standardized parts to facilitate machine automation [6]. Research indicates that traditional jaggery manufacturing is highly labor-intensive, highlighting the need for automation for performing repetitive and laborious tasks [7].

The repetitive production tasks performed in the industry are monotonous, boring, fatiguing, and demotivating and consequently affect satisfaction and productivity [8]. Thus developing a flexible, automated LCA system for the jaggery molding process is crucial. This system should include the necessary automation capabilities and technical features to meet the specific needs of jaggery manufacturers. This paper assesses the labor productivity of the manual jaggery molding process and introduces a proof-of-concept of an LCA system designed for automated jaggery molding. It also

presents a performance analysis and field test results of the automated jaggery filling workstation which developed as per the proof-of-concept.

METHODOLOGY

The proposed methodology for implementing LCA solution for considered problem consist four steps - first step is to perform a Quality Function Deployment (QFD), second step is preparation of prototype, third step is development of actual workstation and the final step is performance evaluation.

Quality Function Deployment (QFD)

QFD converts customer requirements into engineering characteristics for proposed products [9]. It reduces the time required and the resources saving from all stages of product development [10]. In this study QFD tool is used to map Customer Requirements and Engineering Characteristics of proposed LCA system for viscous jaggery filling. The relevance between the raised Customer Requirements and selected Engineering Characteristics is shown in Table 1.

Table 1 Relevance between the Customer Requirements and Engineering Characteristics

Engineering Characteristics	Customer Requirements
Implement Low-Cost Automation	Reduce labor dependency
	Minimal investment
	Easy maintenance
	Easy operation
Dedicated setup for jaggery filling	Ability to integrate into existing setup
	High production rate
Predefined dispensing quantity setting	Exact control on quantity of jaggery to be filled
Fixed and low cycle time	Reduction in number of labors
	Reduce supervision
Human contactless filling	No exposure to hot jaggery
Use food-grade material parts	Compliance as a food processing norms
	Easy to clean
Piston filler technique	Capability to carry wide variety viscosity fluid

	No contact with moving parts
Remotely located control panel	Ease of maintenance
	Easy to operate
	Within reach controls

Prototype Preparation

Prototyping provide all possibilities for users to gain hands-on experience before final application is built. In this step the prototype of proposed viscous jaggery filling workstation is prepared as a proof of concept. This prototype is designed based on the Engineering Characteristics identified through QFD results. This prototype is designed to fill viscous fluids using a pneumatic piston filler mechanism as its core working principle. The developed prototype equipped with hopper in which the viscous fluid to filled in container is poured. The prototype is equipped with two cylinders; the first cylinder is provided to receive the fluid from the hopper whereas the second cylinder defines the quantity of fluid to be received from the hopper. The photograph of prepared prototype is shown in Fig. 2.

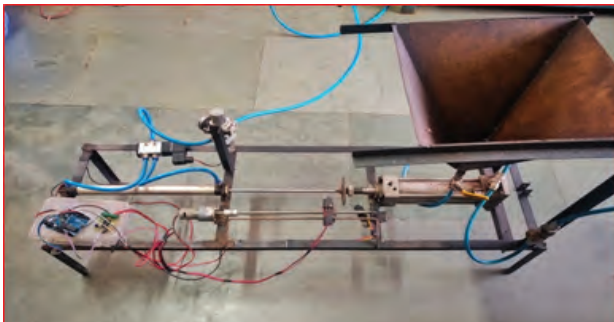


Fig. 2 Prototype Photograph

Control System

The electromechanical control system designed and developed to fill the viscous fluid in predefined quantity. The system consists of power screw mechanism to adjust the positions of limit switch. According to the position of limit switch the stroke of pneumatic cylinder can be adjusted which in turn adjust the amount of liquid sucked in cylinder of filling system. The control system is also capable of check the delivered output of viscous fluid against the input. If there is any error it will be displaced on display panel. The block diagram of the control system is shown in Fig. 3.

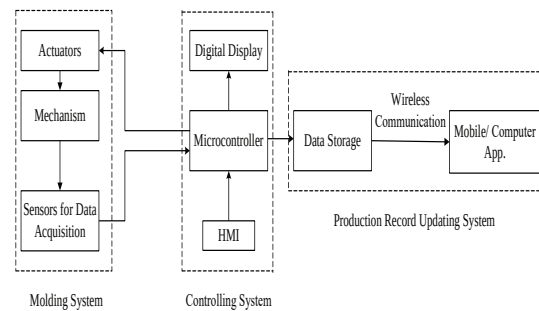


Fig. 3 Control system

Automated LCA Workstation

A prototype demonstration was organized for the owners and workers of traditional jaggery manufacturing units to provide them practical insights of the system's operation. Three different grades of viscosity-rated lubricating oils are utilized as viscous fluids during the demonstration. It is confirmed from end users that the Customer Requirements raised during the QFD field survey can be effectively addressed through the identified Engineering Characteristics of the proposed LCA system. The design and fabrication of the actual jaggery filling LCA workstation have been assigned to a specialized machine-building organization. The system is designed to efficiently fill viscous jaggery into two molds simultaneously. All components of the system that may come into contact with the jaggery were fabricated using food-grade stainless steel. The mechanism's custom-designed hardware components are fabricated to meet precise functional requirements, while standard parts are sourced from reliable suppliers. The electronic, pneumatic, and electrical components of the control system were carefully chosen and properly configured. The photograph of the actual jaggery filling LCA workstation is shown in the Fig. 4.



Fig. 4 Jaggery filling LCA workstation

OBSERVATIONS

The Two-Handed Process Chart, also referred to as the Operator Process Chart, is used to document the activities of a worker's hands in relation to each other. This chart offers a synchronized, graphical representation of the sequence of manual activities carried out by workers in repetitive industrial tasks. The comprehensive Two-Handed Process Charts are created to compare worker involvement in the jaggery filling process before and after the implementation of the LCA. A multiple activity chart is a visual representation that uses a series of bars (columns) aligned with a common time scale. Each subject is assigned a specific bar, and the activities associated with each subject are depicted within the corresponding bar. A multiple activity chart has been developed to assess the relationship between the physical activities of operators and the machine operations during the automated jaggery filling process.

Two Handed Process Charts

In the manual jaggery filling process, workers use their right hand to collect and fill the viscous jaggery while using their left hand to hold and position the mold. To ensure the jaggery settles properly within the mold, it is necessary to shake or strike the mold against the floor between successive filling stages. Table-2 presents the two-handed process chart for manually filling jaggery to prepare 1-kilogram jaggery cakes.

In an automated jaggery filling machine, the system independently handles all physical tasks involved in filling viscous jaggery into molds. The operator's responsibility is limited to loading the empty mold and unloading the filled mold. In the LCA system, as active participation of the operator is reduced, it makes possible them to handle the multiple workstations simultaneously. The LCA system is designed with two dispensers, programmed to simultaneously dispense viscous jaggery in precise, predefined quantities into two molds. Table 3 presents the two-handed process chart for the automated filling process used to prepare a 1-kilogram jaggery cake.

Table 2 Two handed process chart for manual jaggery filling process

Left Hand			Right Hand		
Description of activity	Avg. Time	Symbol	Description of activity	Avg. Time	Symbol
Reach for mold	1	←	Hold the spatula		▽
Carry mold to center position	1.5	←			
Hold the mold		▽	Reach for jaggery	1	←
			Collect jaggery on spatula	1.5	○
			Carry spatula to center position	1	←
			Fill jaggery into mold	1.5	○
Shake the mold	1.5	○			
Hold the mold		▽	Reach for jaggery	1	←
			Collect jaggery on spatula	1.5	○
			Carry spatula to center position	1	←
			Fill jaggery into mold	1.5	○
Shake the mold	1.5	○			
Hold the mold		▽	Reach for jaggery	1	←
			Collect jaggery on spatula	1.5	○
			Carry spatula to center position	1	←
			Fill jaggery into mold	1.5	○
Shake the mold	1.5	○	Hold the spatula		▽
Keep the filled mold sideways	2	←			

Table 3 Two handed process chart for automated jaggery filling process

Left Hand			Right Hand		
Description of activity	Avg. Time	Symbol	Description of activity	Avg. Time	Symbol
Reach for mold	1		Reach for mold	1	
Load the mold on machine	1.5		Load the mold on machine	1.5	
Wait till mold get half filled	5		Wait till mold get half filled	5	
Shake the mold	1.5		Shake the mold	1.5	
Wait till mold get full filled	5		Wait till mold get full filled	5	
Shake the mold	1.5		Shake the mold	1.5	
Unload mold from machine	1.5		Unload mold from machine	1.5	

Multiple Activity Chart

The process of automated jaggery filling is broken down into smaller components called as elements, and the time required for each element is recorded using a stopwatch. The elements are subsequently recorded in the chart, with corresponding information placed in the appropriate columns for each element. The chart uses two symbols: a hatched column to represent "Working" and a blank column to represent "Idle." A multiple activity chart prepared for the automated jaggery filling process to prepare 1 kilogram of jaggery cake is shown in Table 4.

Table 4 Multiple activity chart for automated jaggery filling process

	Operator	Avg. Time	Symbol	Machine	Avg. Time	Symbol
3	Collect 2 molds	1		Idle		
6	Load the 2 molds on machine	1.5		Idle		
12	Idle			Half filling in 2 molds	5	
14	Shake the mold	1.5		Idle		

20	Idle			Full filling in 2 molds	5	
22	Shake the mold	1.5		Idle		
25	Unload the mold from machine	1.5		Idle		

RESULTS AND DISCUSSIONS**Two Handed Process Charts Inferences**

The summaries of the two-handed process chart for the manual and automated jaggery filling processes are presented in Tables 5 and 6, respectively. The summary sheets show that in the automated jaggery filling process, the left hand performs three movements, which is the same as in manual filling, while the right hand's movements are reduced from six to three. Since the jaggery filling process is automated, both hands of the operator are in an optimal rest position twice per cycle, allowing for a 10-second break each time. In automated jaggery filling, the number of operations performed by the left and right hands is limited to two each, compared to three and six operations, respectively, in manual filling. By implementing the LCA system, the total number of left-hand actions is reduced from nine to seven, while the right-hand actions decrease from fourteen to seven.

Table 5 Two handed process chart summary for manual jaggery filling process

Left Hand				Right Hand		
SYMBOL	FREQ.	Avg. Time	DIST.	FREQ.	Avg. Time	DIST.
	3	4.5	1-2 feet	6	6	1-2 feet
	3	8	—	2	15	—
	3	4.5	—	6	9	—

Table 6 Two handed process chart summary for automated jaggery filling process

SYMBOL	Left Hand			Right Hand		
	FREQ.	Avg. Time	DIST.	FREQ.	Avg. Time	DIST.
	3	4	1-2 feet	3	4	1-2 feet
	2	10	--	2	10	--
	2	3	--	2	3	--

Multiple Activity Chart Inferences

The automated jaggery filling process has a cycle time of 17 seconds for producing 1 kilogram of jaggery. Out of the total 17 seconds, the operator needs to be attentive for only 7 seconds, as the system takes 10 seconds to fill the viscous jaggery into the two molds simultaneously. The filling time can be reduced by increasing the stroke speed of the filling cylinders. However, due to the hygroscopic nature of jaggery, this may adversely affect its quality. The Table 7 presents a summary of the multiple activity chart for the automated jaggery filling process.

Table 7 Multiple activity chart summary

Subject	Cycle Time (Sec.)	Time Worked / Cycle	Utilization %
Operator	17	7	41.18
Machine	17	10	58.82

Cycle Time Comparison

The cycle times of manual and automated jaggery filling processes are analyzed to assess and compare their efficiency and performance. The time recorded in the observation section of this paper represents the average duration of each activity or element, determined from fifty manual and automated jaggery filling cycles. These observed time values are converted into the normal time values, which will indicate the time to be taken by the worker if he performs the same element at a normal pace. The performance rating factor for this normalization is set at 110% based on the Westinghouse Method of Rating. As jaggery filling demands the repetitive motions of fingers and wrists, the worker

is also required to sit in the awkward position. The fatigue and personal allowance values are decided as 10% and 5%, respectively. The unavailability of empty molds may cause a delay in the jaggery filling process. To account for this potential disruption, a contingency allowance of 2% is included to offset the expected time loss. The cycle time calculations of the manual jaggery filling process are given below.

Observed time = 24 Seconds

Performance rating factor for normalization = 110 %

Normal time = $24 \times (110/100) = 24 \times 1.1 = 26.4$ Seconds

Considering fatigue and personal allowance = 15 %

Time considering fatigue and personal allowance = $26.4 \times 0.15 = 3.96$ Seconds

Considering contingency allowance = 2 %

Time considering contingency allowance = $26.4 \times 0.02 = 0.53$ Seconds

Standard time = Normal time + rest and personal allowance time + contingency allowance time = $26.4 + 3.96 + 0.53 = 30.89$ Seconds

The cycle time calculations of the automated jaggery filling process are given below.

Observed time for manual elements = 7 Seconds

Performance rating factor for normalization of manual elements = 110 %

Normal time for manual elements = $7 \times (110/100) = 7 \times 1.1 = 7.7$ Seconds

Considering rest and personal allowance for manual elements = 15 %

Time considering rest and personal allowance = $7.7 \times 0.15 = 1.15$ Seconds

Considering contingency allowance = 2 %

Time considering contingency allowance = $7.7 \times 0.02 = 0.15$ Seconds

Standard time = Normal time + rest and personal allowance time + contingency allowance time = $7.7 + 1.15 + 0.15 = 9$ Seconds

Observed Time for machine elements = 10 Seconds

Therefore, Cycle time for automated jaggery filling = Standard time for manual elements + Observed time for machine elements = $9 + 10 = 19$ Seconds (for simultaneous filling in two molds)

Therefore, cycle time for automated jaggery filling in one mold = $19/2 = 9.5$ Seconds.

Thus, the saving in time to prepare 1 kilogram of jaggery mold by implementing LCA = $30.89 - 9.5 = 21.39$ Seconds.

CONCLUSION

A solution based on LCA has been proposed and successfully implemented to address low labor productivity and minimize workers' active participation in the jaggery molding process. The nine key engineering characteristics of an automated jaggery filling workstation are identified and aligned with the end-user requirements through the application of the QFD tool. The prototype of the proposed viscous jaggery filling workstation has been developed, and its operation has been demonstrated to the laborers and owners of the jaggery manufacturing plant. The summary sheets of the two-handed process chart for both manual and automated jaggery filling processes highlighted a reduction in manual activities. The number of left-hand activities has decreased from nine to seven, while the number of right-hand activities has decreased from fourteen to seven. The cycle time analysis conducted to assess the efficiency of the developed LCA workstation revealed a time reduction of 21.39 seconds in the preparation of each 1 kilogram of jaggery cake. In conclusion, the developed LCA system has the potential to enhance productivity while minimizing labor involvement in the jaggery filling molding process. For future work, it is suggested to utilize the prepared LCA workstation over an extended period to evaluate its additional performance factors, such as return on investment, reliability, and the reduction of labor fatigue.

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Experimental Investigation of RCCI Engine with a Design of Experiments (DOE) Approach for Split Injection and Ethanol-Butanol Energy Share

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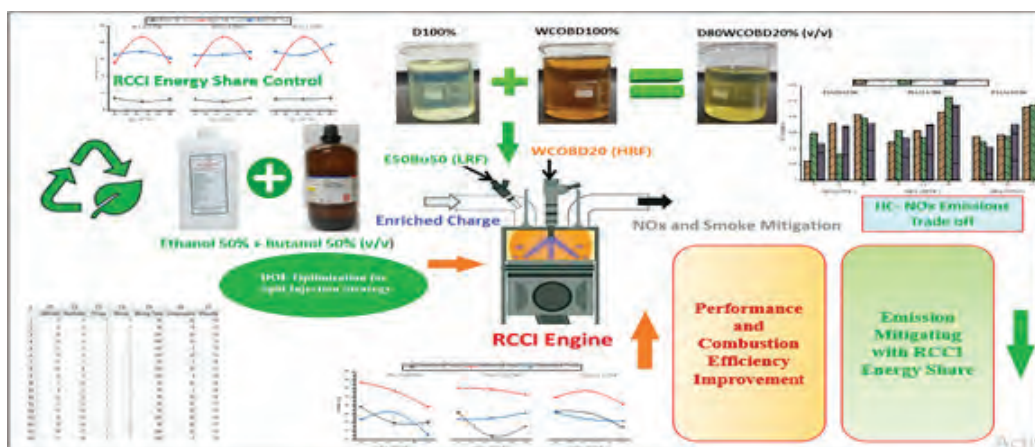
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ABSTRACT

CI engines are continuously developing to mitigate emissions like NO_x , smoke, UHC, & CO up to a major extent. Researchers use green biofuels, CNG, and newer innovative techniques like LTC to achieve this. HCCI is a well-known LTC method for reducing NO_x and smoke, although it is limited to part-load operation & increases HC-CO emissions. RCCI technology uses LRF (high octane fuel) & HRF (high cetane fuel) for controlled combustion. In this regard, a split injection strategy for HRF, WCO–diesel 20% blend is used. While the energy share effect for LRF E50%+B50% blend fuel is used. This combustion process with RCC is achieved using the DOE L81 test parameters, which include 4 factors and 3 levels. Fuel injection strategy parameters like main injection angle variation of 180, 230 & 280 bTDC and pilot injection angle variation of 280, 310 & 340 bTDC. Also, for energy share, the LRF equivalent fraction of ethanol-butanol blend fuel injector open time varies from 3 ms, 4 ms & 5 ms, which contributes 0.28, 0.36, and 0.44 kg/h ethanol-butanol blend (LRF) flow rates, respectively, at 3 bar operating pressure. The operating load or power was varied in 33%, 66%, & 100% of full load or peak power operation. From rigorous experiments with the L81 array from DOE, ANOVA analysis, and validation of the experiment, it was obtained that the injector open time of 4 ms with 230 MIA and 310 PIA shows better thermal efficiency (34.5%), and NO_x HC emissions are reduced at 38% energy share of LRF.

KEYWORDS: Split injection strategy, Design of experiments, Reactivity-controlled combustion. Ethanol-Butanol, Energy share.

GRAPHICAL ABSTRACT



INTRODUCTION

Traditionally, ICEs have been the preferred power source globally due to their higher power density, reliability, and effectiveness when compared to other energy systems. However, the considerable emissions that take place from these engines had a drastic effect on the environment, thus leading to a variety of health issues and reduced fossil fuel reserves due to increasing energy consumption. These emissions pose significant barriers to the long-term global usage of ICEs. Therefore, the focus of current large-scale research studies is on enhancing fuel efficiency and lowering emissions from these engines. The Reactivity Controlled Compression Ignition combustion strategy has recently become one of the most promising ways to make combustion processes cleaner and more efficient. However, despite its merits, numerous challenges remain before the concept can achieve full commercialization.

The RCCI paradigm represents one of the low-temperature combustion approaches that aim to reconcile the best characteristics of traditional diesel engines and spark-ignition systems while simultaneously reducing some of their associated limitations, such as elevated emissions of nitrogen oxides and particulate matter. The most important characteristic of RCCI is its use of two fuels with different reactivity characteristics, thus allowing for very precise control of the combustion process.

WORKING PRINCIPLE OF RCCI

RCCI works by mixing low-reactivity fuel, like gasoline, ethanol, or isobutanol, with air first, then letting the mixture into the cylinder. This is similar to how a normal gasoline engine works. Then, in the compression stroke, the high-reactivity fuel, such as diesel or biodiesel, is directly injected into the combustion chamber. The low-reactivity fuel creates a lean, homogeneous mixture, and the high-reactivity fuel is injected into specific zones within the combustion chamber. High-reactivity fuel self-ignites under compression, and the controlled ignition of the high-reactivity zones helps ignite the premixed low-reactivity fuel.

LITERATURE REVIEW

According to Mojtaba-Ebrahimi et al. (2019), adding hydrogen to landfill gas and diesel cut fuel use, raised

peak pressure, shortened combustion time, and removed knock.

Jeongwoo Lee et al. (2017) found that 26% cooled EGR using methanol-diesel increased thermal efficiency, lowered NO_x and smoke emissions, and decreased cycle-to-cycle fluctuations.

Ganesh Duraisamy et al. (2019) further verified that cooled EGR with 76–81% methanol outperformed hot EGR at 3.4 and 5.1 bar BMEP in emissions and efficiency.

With ideal CNG shares at 30–45%, Jamrozik et al. (2019) investigated dual-fuel diesel/CNG operation and observed greater ignition delay, higher peak pressure, enhanced combustion rate, and notable decreases in CO₂ and CO emissions.

With spark help required at low loads, Legrottaglie et al. (2019) found gasoline improves RCCI performance at 150 and 300 Nm, hence supporting ignition delay and mixing. Kumbhar et al. (2021) examined RCCI's potential for BSVI compliance, revealing decreased NO_x/PM and improved thermal efficiency without sophisticated exhaust treatment. Reviewing hydrogen and alcohol utilization in RCCI diesel engines, Szamrej et al. (2021) discovered advantages in efficiency, emissions, and combustion. Rajkumar et al. (2021) proposed that increased latent heat and oxygen content cause alcohol and biodiesel to enhance CI engine emissions. Dempsey et al. (2014) found all three produced minimal NO_x/soot and good efficiency (~47%) when HCCI, RCCI, and PPC were compared without EGR; RCCI and HCCI showed more adaptability to intake conditions. Yabin Dong et al. (2016) looked at methanol use in RCCI for CO₂, NO_x, and PM reduction. Emphasizing fuel optimization for FFVs depending on load and AFR, Ayat Gharehghan et al. (2019) evaluated LTC engines using natural gas, ethanol, and methanol.

To maximize RCCI combustion and emissions, Jing Li et al. (2017) stressed flexible fuel utilization and modification of injection timing, EGR, CR, and piston design. Under different loads, Yifeng Wang et al. (2016) concentrated on operational parameters and control measures to improve RCCI performance and emissions.

A thorough review of RCCI developments meant to increase diesel engine fuel economy was given

by Reitz et al. (2016). Using electronic injection during the suction stroke, Gharehghani et al. (2015) investigated B100 biodiesel and CNG dual-fuel combustion and found positive outcomes. Shukla et al. (2021) underlined the possibility of ethanol in dual-fuel configurations to satisfy emission criteria while enhancing thermodynamic performance.

Kokjohn et al. (2009) looked at PCCI and HCCI combustion techniques' fuel reactivity control.

Kalsi et al. (2017) observed that HCNG blends (18%) with B100 pilot fuel greatly enhanced thermal efficiency (up to 64%) and reduced CO/HC emissions, albeit NO_x increased marginally.

Noting combustion and efficiency gains, Kakooe et al. (2019) evaluated RCCI performance utilizing hydrogen-natural gas and other dual-fuel techniques by combining modeling and experimentation.

EXPERIMENTAL SETUP AND METHODOLOGY

The goal of this research is to reduce NO_x -smoke emissions. To reduce NO -smoke emissions, the RCCI combustion process with split injection, LRF energy share effect, and experiment design are used. This study blends 99.9% pure LR grade ethanol with 50–50% (v/v) n-butanol as low reactive fuel (LRF) and injects it into the intake manifold at 40–60 PSI with a saturated injector. The injector open time is adjusted by 3 ms, 4 ms, and 5 ms to change LRF quantity and energy share. Furthermore, leftover cooking oil is widely available. Standard two-step transesterification is employed in the lab. First comes esterification, then transesterification. The temperature is 60°C for 60 minutes. A split injection approach is employed to directly inject a diesel-WCOBD20% blend (v/v) at 8000–8500 PSI (60 MPa) as a pilot fuel and highly reactive fuel (high cetane number). An orthogonal L81 matrix array is created for the experiment. This examines three stages for the four-factor (parameter) fuel system functioning for RCCI combustion. Split injection parameters include main injection timing, pilot injection timing, energy share (injection length), and load. See figure 1 Kirloskar's TV1 engine with a programmable open ECU for RCCI operation is employed. A water-cooled, single-cylinder, four-stroke TV1 3.5 kW, 1500 RPM, with VCR.



Fig. 1: Engine setup to run the RCCI combustion process

Also, as seen from the below figures 2 and 3, AVL444N five gas analyzers and smoke meters are used, respectively. The figure 4 below illustrates the use of a saturated injector to inject ethanol butanol liquid fuel into the intake manifold.



Fig. 2 AVL 444N Five gas analyzer



Fig. 3 AVL437C smoke meter



Fig. 4 Saturated Port/manifold (LRF) Liquid Injector

RESULTS DISCUSSIONS

Combustion Analysis

RCCI combustion process cylinder pressure maximum, rate of pressure rise, neat heat release, and mean gas temperature are shown in figures 5–8. Split injection approach and injector open time (energy sharing) affect LRF. Figure 5 shows that ethanol-butanol LRF cylinder pressure peaks at 3 ms, followed by 4 and 5 ms injector open time. The injector's open time and ethanol-butanol energy share may increase. Increased LRF fuel quantity decreases WCOBD20% HRF energy share (high cetane) fuel quantity. In addition, main and pilot injection time improvements produce exciting outcomes. For equal 3ms injector open time operation, cylinder pressure maximum reduces from 55 bar to 50 bar away from TDC. Advanced injection lowers in-cylinder pressure and compressed air temperature, reducing cylinder pressure by 10%. Latent heat from pilot and main fuel vaporization lowers charge pressure and temperature, reducing maximum combustion pressure. The quickest rate of pressure rise (RPRR) occurs when the HRF energy share is higher or lower while the injector is open for 3 ms. This may be due to more high-cetane fuel. By increasing quick and spontaneous combustion, WCOBD20 raises pressure per degree crank angle. RPR enhanced with advanced injection timing and mild PFI (LRF) fuel injector open time increases neat heat release rates. Mean gas temperature rises with HRF and falls with pilot and main injection timing.

The figure below 7 shows that heat release rate increases with injection advance, including pilot injection to 34 0bTDC and main injection to 28 0bTDC. Due to charge enrichment and reactivity-controlled combustion, PFI (LRF) fuel injector open time increases neat heat release rates. Mean gas temperature rises with HRF and falls with pilot and main injection timing.

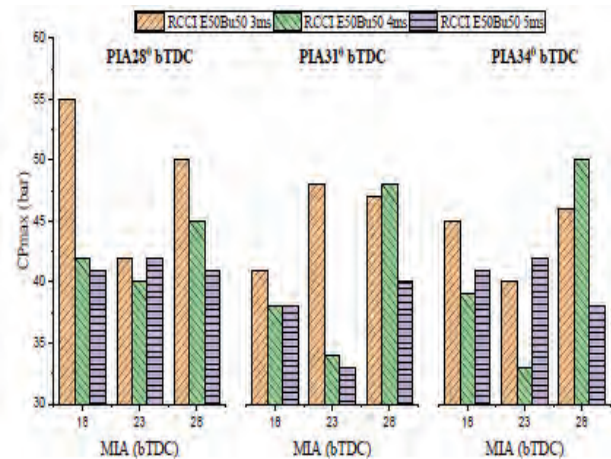


Fig. 5 Effect of split injection strategy and LRF injector open time on combustion pressure maximum

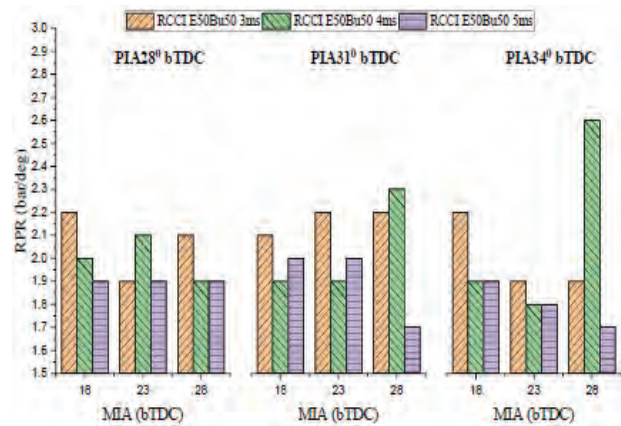


Fig. 6 Split injection approach and LRF injector open time affect pressure rise (combustion noise).

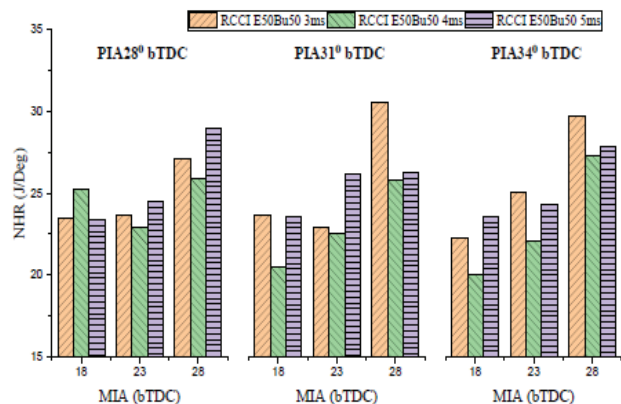


Fig. 7 Effect of split injection strategy and LRF injector open time on neat heat release rate

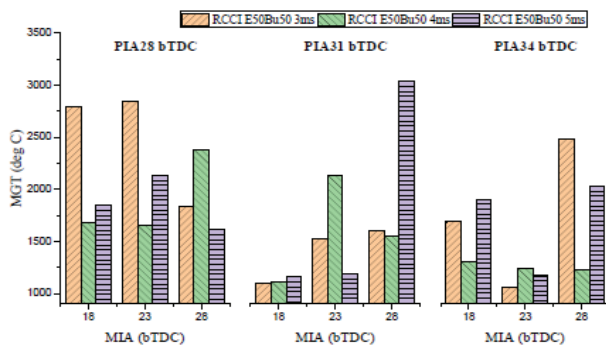


Fig. 8 Effect of split injection strategy and LRF injector open time on mean gas temperature

Performance Analysis

LRF energy comes from ethanol-butanol equivalency. It contributes to WCOBD20% and HRF+LRF's energy needs. Figure 9 shows that LRF energy share increases with injector open time from 3 to 5 ms. The energy share of 3ms, 4ms, and 5ms injector open time is 20%, 30-40%, and 50%. Energy share was 50% at the highest injector open time of 5 ms for all split injection strategy operations. LRF flow rates of 0.28, 0.42, and 0.58 kg/h for 3 ms, 4 ms, and 5 ms injector open durations may explain this. Increased LRF reduces HRF. The graphic below demonstrates that LRF injector open duration increases 5.6 brake thermal efficiency. We find that brake thermal efficiency peaks at 5ms injector open time, topping all others. A 5 ms injector open time averages 36% BTHE. This exceeds BTHE by 19% over a 3-ms injector's open duration. Homogenous and regulated combustion may improve BTHE. BTHE rises due to ethanol-butanol's enhanced charge. Higher LRF flow rates may enhance HC-CO emissions. It's crucial to balance BHTE performance with HC-CO-NO_x-smoke emissions.

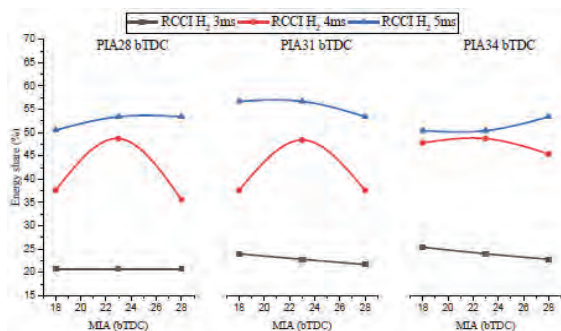


Fig. 9 Effect of split injection strategy and LRF injector open time on energy share of LRF

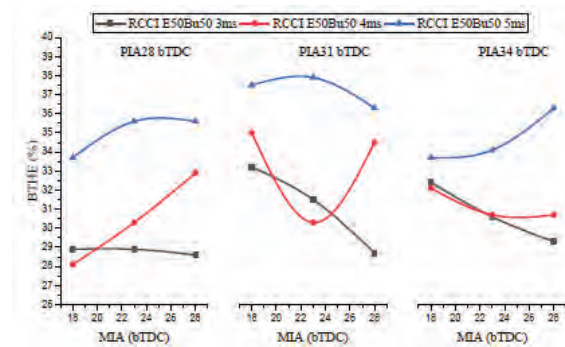


Fig. 10 Effect of split injection strategy and LRF injector open time on brake thermal efficiency

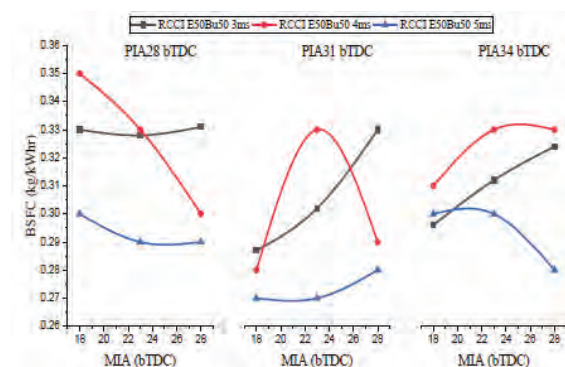


Fig. 11 Effect of split injection strategy and LRF injector time on brake-specific fuel consumption

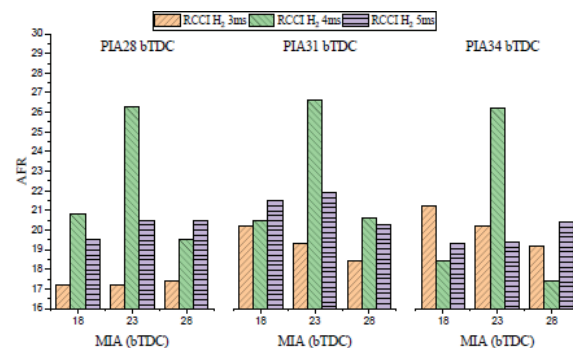


Fig. 12 Effect of split injection strategy and LRF injector open time on air fuel ratio

Also, BSFC required to create power is lower for 5 ms injector open time, followed by 4 ms and 3 ms. Figure 5.8 of the air-fuel ratio indicates greater AFR at 4 ms injector open time than 5 or 3 ms. This shows that a 4 ms injector open duration can produce lean combustion and reduce HC-CO and NO_x smoke. Since constant-speed diesel uses roughly the same air, all activities have somewhat lean AFR. AFR was better at 4 ms with

230 bTDC main injection angle. Maximum air-fuel ratio is 26, about 23% greater than 5 and 3 ms open time operating.

Emissions Analysis

Figures 13–16 show carbon monoxide, unburnt hydrocarbons, nitric oxides, and smoke opacity emissions. Nearly 0.1–0.2% vol. CO emissions. Increased LRF energy share (injector open time) reduces CO emissions by 25%. This may be because LRFs are more oxygenated, promoting complete burning and converting CO output into CO₂. CO emissions are highest at 3 and 4 ms.

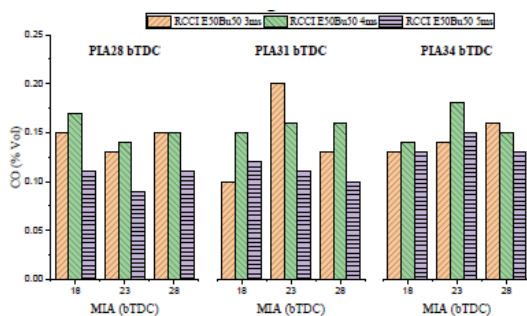


Fig. 13 Effect of split injection strategy and LRF injector open time carbon mono-oxides emissions

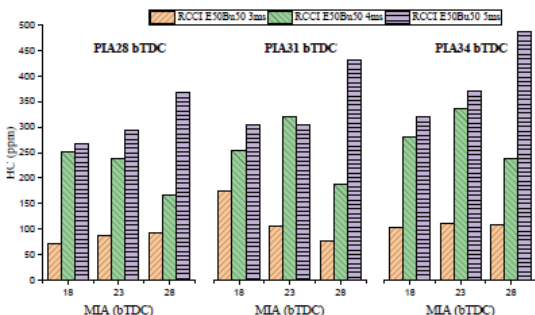


Fig. 14 Effect of split injection strategy and LRF injector open time un-burnt hydrocarbon emissions

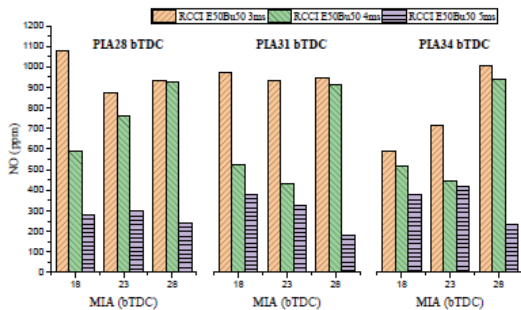


Fig. 15 displays NO_x emissions changes based on split injection technique and LRF injector open time

However, a 5-ms injector open time increased HC emissions. Ethanol-butanol fuel's high octane number and almost 0.58 kg/h of LRF fuel enhanced ignition delay and combustion duration, causing most of the fuel to be injected unburned into the exhaust. In contrast to 3 ms, HC emissions increase fourfold at 5 ms. Thus, 5 ms open time HC emissions are unacceptable. It shows an upper injector open time cutoff for LRF because high-octane fuel resists burning.

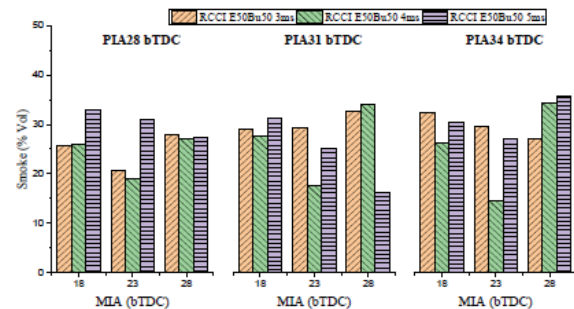


Fig. 16 Effect of split injection strategy and LRF inject or open time smoke emissions.

Nitric oxides (NO_x) and smoke emissions, as expected, show interesting results in favor of a 5-ms injector open time. It can be seen from figure 5.11 below that NO_x emissions decrease with an increase in LRF energy share. It can be seen that almost 3.5% fewer NO_x emissions are recorded for all injections with a 5-ms injector open time compared to a 3-ms injector open time. This may be due to higher LRF decreases in cylinder combustion pressure and temperature; hence, fewer NO_x emissions are reported. Additionally, reports have indicated that an injection strategy with an advanced injection time and a shorter dwell period has resulted in more NO emissions. Injection open time of 4 ms with MIA23 and PIA31 has reported less NO_x emissions trade-off with HC emissions. Smoke emissions showed superior results at MIA230bTDC.

CONCLUSIONS

In rigorous tests, we used the L81 array from DOE, conducted an ANOVA, and confirmed the results. The injector open time of 4 ms with 230 MIA and 310 PIA has a higher thermal efficiency (34.5%), and the NOG and HC emissions are lower at 38% of the LRF energy share.

1. The energy sharing in LRF increases with an

increase in injector opening time, from 3 ms to 5 ms. Energy share reported by 3ms, 4ms and 5ms injector open time are 20%, 30-40% and 50% respectively. At the highest injector open time of 5 ms for all split injection strategy operations, it has shown the highest energy share of 50%.

2. As WCOBD20% HRF energy share (high cetane) fuel quantity and energy share decrease with an increase in LRF fuel quantity. We observe intriguing results as we advance both the main and pilot injection timings. As we move away from TDC, cylinder pressure maximum decreases from 55 bar to 50 bar for the same 3 ms injector open time operation.
3. A 5-ms injector's open time records 36% of BTHE. This is almost 19% higher than BTHE compared to a 3 ms injector's open time. On the other hand, BTHE 34.5% recorded by 18 MIA-31PIA with 4 ms injector open time at 38% energy share seems to be the best balance between performance combustion and emissions.
4. Note that HC emissions are at 5 ms, increased up to 4 times compared to 3 ms. Nitric oxides (NO_x) and smoke emissions, as expected, show intriguing results in favor of a 5-ms injector open time.

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Impact of Alcohol-Gasoline Fuel Blends Affect Engine Performance and Exhaust Emissions - A Review

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ABSTRACT

Alcohol is an attractive substitute fuel for SI engines because of its many unique qualities, such as its high octane number, limitless supply, and capacity to lower greenhouse gas emissions. By examining the findings of earlier studies, the present article seeks to inform people about how alcohol affects the operation, combustion, and pollution characteristics of SI engines. The fuel qualities of methanol, ethanol, and butanol are examined in this article. Fuel consumption, coefficient of variation, mean effective pressure, thermal efficiency, braking torque, and volumetric efficiency are all examined in relation to the performance of SI engines running on gasoline mixed with butanol, ethanol, and methanol under varied circumstances. When gasoline was mixed with methanol, ethanol, or butanol, fuel consumption increased and the thermal efficiency of spark-ignition engines decreased; most studies on the subject found that better combustion resulted in lower emissions of CO, NO_x, and UHC when gasoline was mixed with alcohol. The article also discusses exhaust gas temperature and pollutant emissions, including CO, CO₂, NO_x, and UHC.

KEYWORDS: *Alcohol, Ethanol, Methanol, Butanol, Spark-ignition engine, Alternative fuels.*

INTRODUCTION

The world's population growth has led to a sharp rise in the use of fossil fuels, which are becoming more and more expensive. Currently, about 80% of the energy used worldwide comes from fossil fuels, and one of their main drawbacks is that their emissions pose serious environmental risks, such as global warming. Alternative fuels have been proposed to replace or reduce the use of fossil fuels in order to protect the environment. Another issue is the depletion of fossil fuel resources, which is expected to happen within 40 years. As a result, there is a growing demand for renewable energies, and environmentally friendly fuels for cars and other applications are sought after worldwide. Globally, biomass-based, environmentally benign, and renewable fuels can be obtained from waste, agriculture, and forests. Numerous fuel types, including ethanol, methanol, butanol, biodiesel, dimethyl ether, diethyl ether, artificial natural gas (SNS), straight vegetable

oils (SVO), and hydrogen, are being studied as fuel alternatives for diesel and gasoline engines. Thus, this review paper's primary goal is to learn more about the potential of methanol, ethanol, and butanol as alternative fuels in SI engines. This article discusses the operation and emissions characteristics of SI engines that run on a gasoline mixture with methanol, ethanol, or butanol. Additionally, this looks at the exhaust emissions from SI engines that use gasoline that has been diluted with methanol, ethanol, or butanol. [1, 2, 3, 4, 7, 8].

LITERATURE REVIEWED

In order to investigate the performance and exhaust emissions of SI engines that are driven by alcohol-gasoline mixes, a thorough literature review is conducted. The literature review is divided into three categories i.e., (i) Ethanol Blends with Gasoline (ii) Methanol Blends with Gasoline (iii) Butanol Blends with Gasoline. The review is presented in the following sections.

Ethanol Blends with Gasoline

Ali Murtaza Ansari [1] studied the effects of various gasoline-ethanol fuel mixtures on engine performance and noise emissions. A four-stroke, single-cylinder engine was used to evaluate blends with different ethanol contents (G90E10, G80E20, and pure gasoline). The findings demonstrated that a higher ethanol concentration increased power, decreased brake-specific fuel consumption, and increased thermal efficiency. In particular, the G80E20 showed the lowest fuel consumption and the best thermal efficiency (25%) of any vehicle. Pure gasoline generated more noise emissions, but ethanol mixtures significantly decreased harmful exhaust particles.

Atul Verma et al. [2] have studied the effectiveness of ethanol-premium gasoline mixes on a four-stroke, four-cylinder, multi-point fuel injection (MPFI) spark-ignition (SI) engine. With all loads and fuel samples, the maximum brake mean effective pressure (BMEP) was achieved at about 3000 rpm. In comparison to other sample fuels at all loads, it is evident that fuel sample F2 (ethanol 6.25%) has the highest BMEP. At all loads and fuel samples, the maximum brake torque (BT) was recorded at 3000 rpm. In comparison to other sample fuels at all loads, it is evident that fuel sample F2 (ethanol 6.25%) has the highest BT. For every gasoline sample, the brake power rose as engine speed and load increased. At 4200 rpm and under all operating loads, the greatest braking power was achieved with gasoline sample F2 (ethanol 6.25%), and brake power decreases as the ethanol content rises.

According to Muhammad Usman et al. [3], a gasoline engine with four strokes and four cylinders that is water cooled. The current study focuses on how various gasoline alcoholic fuel mixtures affect engine performance and emissions at engine speeds between 1200 and 4400 rpm. First, pure gasoline was used in the experiments, followed by several fuel blend compositions, including gasoline with ethanol (E) and gasoline, ethanol, and methanol (EM). BP was found to be lowest for pure gasoline and greater for E than EM. For E10 and E5M5, the greatest gains in brake power were 5.70% and 4.91%, respectively. Because ethanol has a larger calorific value than methanol, the ethanol fuel blend increased more than the methanol-ethanol

fuel blend. Furthermore, the increased heat of ethanol vaporization, which cools the air-fuel charge inside the cylinder and raises the charge density, is responsible for the increase in brake power for E blends when compared to pure gasoline. The piston surface is under increased pressure because of the high air-fuel charge density, which raises the BP. BSFC for E and EM is clearly more than just pure gasoline. When compared to pure gasoline, the BSFC for E5M5 and E10 in the current investigation increased by 3.67% and 1.97%, respectively.

Although it has a lower heating value for pure gasoline, Mortatha K. Mohammed et al. [4] showed a considerable rise in RON (research octane number) and MON (motor octane number) for all blending fuels. When comparing the E40 combination to gasoline, the greatest increase in thermal efficiency was 25.8%. As engine speed increases, volumetric efficiency shows negative behaviour, and the percentage of ethanol blended drops. As combining fuel (E40), the highest reduction in brake specific fuel consumption was equal and showed drops of 17.21% as compared to gasoline fuel. When ethanol ratios rise relative to gasoline fuel, exhaust gas emissions in (HC, NO_x, CO₂, CO) are significantly reduced. The largest decrease in CO emissions was observed in E30 at 26.33%, CO₂ emissions at E40 at 25%, HC emissions at E40 at 31.05%, and NO_x emissions at E40 at 20.91%.

Waste plastic, a significant disposal problem, can be transformed into useful energy, according to S. Padmanabhan et al. [5]. In order to evaluate the environmental effect of converting energy recovered from lower-density and higher-density polyethylene trash into a substitute plastic fuel, ethanol was mixed into a diesel engine. Ternary (3) fuel mixes were evaluated that contained 10%, 15%, and 20% ethanol and 20%, 30%, and 40% waste plastic fuel with regular diesel. In comparison to basic diesel, the study discovered that mixing 10% ethanol with 20% plastic fuel reduced fuel usage by about 7.9%. By employing the same ternary blend, emissions of hydrocarbons are reduced by approximately 13.43% and carbon monoxide by approximately 10.2%. Because of the ternary blend's high oxygen content ethanol, the combustion process was enhanced, resulting in a reduction in emissions.

In an attempt to reduce carbon and pollutant

emissions, Yanshuai Ye et al. [6] used response surface methodology (RSM) to study the process of combustion and exhaust of gasoline-cassava bioethanol fuel blends in electronic fuel injection engines. Tests were carried out to ascertain the effects of various gasoline-cassava bioethanol mixing ratios (G100, G90E10, G80E20, and G70E30) on engine efficiency and other performance characteristics.. According to the results, the gasoline-cassava bioethanol fuel blend outperforms G100 in terms of total hydrocarbon emissions and carbon monoxide emissions, but it falls short of G100 in terms of torque, braking power, and fuel consumption related to brakes.

According to research by Yusuf Abdulfatah Abdu et al. [7], the benefits of ethanol or methanol addition to gasoline include lower engine-out emissions and improved efficiency, and the effect varies depending on the mix ratio. Using ethanol-gasoline blend fuels lowers the BSFC while increasing brake power and torque output. In comparison to gasoline, methanol- gasoline mix fuels exhibit a modest increase in brake power and torque output as well as a higher BSFC. Additionally, because ethanol has a higher density than gasoline, a small amount of ethanol poured into the cylinder enhances brake power and torque output. Particularly at low engine speeds, ethanol-gasoline has outperformed methanol-gasoline in terms of engine power, torque output, and exhaust pollutants. According to several studies, NOx emissions from ethanol-gasoline mixtures can either rise or fall. Numerous causes contribute to these discrepancies. First, the flame temperature rises as the combustion process approaches stoichiometry, which in turn causes an increase in NOx emissions.

Methanol Blends with Gasoline

A study by Ehtisham Ahmed et al. [8] Using methanol-gasoline mixes of 0%, 3%, 6%, 9%, 12%, 15%, and 18%, the current study examines and contrasts the emissions and performance of four- stroke, single-cylinder SI engines with those helped by artificial neural networks (ANNs). With gasoline denoted as M3, M6, M9, M12, M15, and M18, respectively, methanol was utilized in quantities of 3%, 6%, 9%, 12%, 15%, and 18% by volume. The small-scale SI engine's usage of methanol-gasoline blend (M12) increased torque, BP, and BTE (14.9%, 15.4%, and 13.4%, respectively)

while maximizing energy conversion into usable work. Compared to M0, the BSFC dropped by 4.7%. Because of the oxygen content and lower carbon to hydrogen ratio, the emissions of CO₂, CO, and HC were reduced as the amount of methanol in the fuel mixes increased. Comparing M18 to M0, the CO, CO₂, and HC dropped by 28.4%, 16.5%, and 19.4%, respectively. The increased hydrogen and oxygen content enhances burning, producing more heat and the related NO_x and EGT emissions. As a result, EGT and NO_x emissions increased by 23.2% and 43.1%, respectively.

According to İlker Örs et al. [9], the experiments were carried out in a four-stroke, single-cylinder SI engine at varying engine speeds when the engine was fully loaded. By mixing 10% methanol and ethanol with gasoline, they conducted an experiment on a SI engine. Because of its low calorific value, they discovered that adding methanol raised the brake specific fuel consumption (BSFC) values by 10.3% when compared to adding ethanol, while lowering the brake thermal efficiency (BTE) by 6.12%. Methanol has a larger oxygen content than ethanol, which results in higher oxygen emission values by 15.3%. These findings demonstrate that, like ethanol, methanol may be used as an additive in gasoline.

According to Muhammad Ali Ijaz Malik et al. [10], fuel has an impact on engine performance, emissions, and lubricating oil degradation. It may be concluded that, after 100 hours of engine operation, the rate at which lubricating oil deteriorates is higher when M12 is utilized as fuel rather than gasoline. However, M12 is a good fit for engine performance (power, torque, and BTE) and environmental emissions (CO and HC). Following 100 hours of engine running with gasoline

(G) and M12 in succession, the lubricating oil samples were removed from the engine oil sump. When compared to G, M12's brake power was found to be greater. For M12, the maximum BTE of 23.69% was noted at 2800 rpm and lower load. At lower and higher loads, respectively, M12 was shown to reduce HC emissions by an average of 6.05% and 6.31% when compared to G.

Research was conducted by Nuthan Prasad B. S. et al. [11]. The best findings for an optimal compression ratio are displayed from an experimental research

(combustion, performance and emission analysis) of methanol combined gasoline-fuelled in a single-cylinder, four-stroke VCR engine. Various compression ratios (8, 9, and 10) were tested. Comparing M50-fueled SI engines to compression ratios, the former performs exceptionally well at CR10. The findings indicate that a larger compression ratio improves combustion with a higher fraction of methanol blend, and the chemical characteristics of methanol contribute to a good agreement of improvisation in brake specific energy consumption (BSEC) and brake thermal efficiency (BTE). Comparing CR10 to gasoline fuel, a 30–40% decrease in NO_x, CO, and HC emissions was noted. Higher CR raises the ratio of fuel to air in the cylinder and creates turbulence, which enhances the quality of fuel atomizing. As a result, CO₂ rises when methanol is added, which is credited with better burning.

Through a novel integration of experimental and statistical techniques, Ijaz Malik MA et al. [12] investigated the effects of different test fuels (M0, M6, M12, and M18) on engine performance and emissions as well as their influence on lubricant oil degradation. When compared to gasoline at low load, BP had noticeably better performance, with M6 and M12 exhibiting 6.84% and 8.85% higher power, respectively. At greater loading conditions, BTE increased by an average of 19%, 20%, and 22% for M6, M12, and M18 in comparison to base fuel. With 8.68%, 18.62%, and 28.78% lower carbon monoxide emissions for M6, M12, and M18 compared to M0, methanol blending proved advantageous in terms of a clean atmosphere. Similarly, compared to gasoline, the average reduction in greenhouse emissions for M12 and M18 was 9.85% and 14%, respectively. When compared to M0 during straight 120 hours of engine operation, the lubricating oil degradation rate for methanol blended fuels was greater. In comparison to M0, the TAN of damaged lubricating oil for M6, M12, and M18 was 8.09%, 16.20%, and 24.02% higher at higher loads, respectively.

This study by Silvana Di Iorio et al. [13] examines how ethanol/methanol mixtures affect a turbocharged direct injection spark ignition engine's emissions and performance. 10% ethanol (E10), 25% ethanol (E25), 5% ethanol with 15% methanol (E5M15), and balancing gasoline were the three blends that were taken into consideration. Ethanol blends have a high

fuel consumption, and when adding methanol to the fuel, the fuel consumption increases even more, with the exception of the early part of the cycle, where E5M15 uses less gasoline than E25. Because methanol reduces combustion efficiency, CO₂ emissions rise for E10 and E25 while falling for the ternary blend. Even though their weight varies according to the particular stage of the cycle, CO, THC, and NO_x emissions for E10, E25, and E5M15 exhibit a linear decline. The study's findings have demonstrated that alcohol blends are a viable fueling option for SI engines because they lower pollutants at the expense of a minor increase in fuel consumption.

Butanol Blends with Gasoline

According to Muhamad Norkhizan Abdullah et al. [14], most researchers found that when alcohol was mixed with gasoline, the best combustion resulted in lower CO, NO_x, and UHC emissions. Because there was not enough oxygen in the engine to convert all of the carbon to CO₂, CO was created when the engine was running with a fuel-rich equivalency ratio. Consequently, alcohol's oxygen concentration can both increase and decrease the generation of CO₂. Lastly, according to the review, butanol is the most promising of the three alcohols. alcohol for vehicle fuels, resulting in improved efficiency and reduced emissions. The characteristics and proportion of that alcohol to gasoline, however, have an impact.

Acetone-butanol-ethanol (ABE) impacts on HCCI-DI (Homogeneous Charge Compression Ignition-direct injection) engine performance, combustion, and emission were examined by Ibham Veza et al. [15]. This study looked into how ABE affected the combustion, emission, and performance of HCCI-DI engines. The presence of oxygen in ABE was discovered to have the potential to encourage full combustion and ultimately reduce emissions of CO and HC. CO₂ and NO_x emissions were successfully reduced by the addition of ABE. Additionally, better engine performance was noted in terms of reduced brake specific fuel consumption (BSFC), increased brake thermal efficiency (BTE), and EGT. All things considered, ABE has the potential to develop into a promising alternative biofuel given its pleasingly enhanced engine performance.

Tan Tien Huynh et al. [16] studied how butanol- gasoline mixtures affect a four-cylinder spark-ignition engine's emissions, fuel consumption, and performance.

Several butanol mixture ratios (10% to 50% by volume) were evaluated in the study at engine speeds of 2250 and 4250 rpm and throttle settings of 30% and 70%. Particularly at higher engine speeds, a larger butanol percentage slows the rate of flame propagation. When the butanol mix is less than 30% at low throttle, engine brake torque and power increase; at higher throttle levels, these values drop. When the butanol percentage falls below 30%, specific fuel consumption falls. Butanol blends reduce CO, HC, and CO₂ emissions as compared to pure gasoline. All butanol-gasoline mixtures result in higher NO_x emissions.

CURRENT TRENDS AND FUTURE DIRECTIONS

Current Trends

The increasing global focus on reducing fossil fuel dependency has led to significant research on alcohol-gasoline fuel blends. Some of the key emerging trends include:

- **Higher Alcohol-Gasoline Blends:** Because of their higher energy density, better combustion efficiency, and fewer emissions when compared to methanol and ethanol, higher alcohols like butanol and acetone are becoming more and more popular, according to recent studies.
- **Engine Modifications and Optimization:** Multiple-point fuel injection (MPFI) systems and variable compression ratio (VCR) engines are examples of engine improvements that have advanced to make SI engines more adaptable to alcohol-gasoline mixes.
- **Artificial Intelligence and Predictive Models:** Researchers can now more precisely forecast engine performance and emissions because of the combination of Artificial Neural Networks (ANNs) with optimization strategies like Response Surface Methodology (RSM).
- **Ternary Fuel Blends:** Ternary mixes (such as ethanol, methanol, and gasoline) have been demonstrated during research to further maximize

combustion efficiency while reducing emissions, making them a possible alternative fuel source.

Future Directions

As research on alcohol-based fuels progresses, several promising directions are emerging:

- **Hybrid and Flex-Fuel Vehicles:** A key factor in lowering carbon footprints will be the creation of hybrid automobiles and flexible fuel vehicles (FFVs) that can handle greater alcohol mix percentages.
- **Sustainable Bio-Derived Alcohols:** An increasingly popular sustainable alternative to gasoline is the creation of alcohol fuels from waste biomass, polymers, and agricultural wastes.
- **Long-Term Impact on Engine Durability:** Evaluation of the long-term impacts of alcohol-gasoline blends on engine longevity, including component wear and tear and lubricating fluid deterioration, requires more investigation.
- **Additive and Nanotechnology Enhancements:** Research is now underway to increase the performance, lower emissions, and improve combustion properties of alcohol-based fuels through the use of nanoparticles and fuel additives.

By addressing these trends and future directions, Blends of gasoline and alcohol can promote sustainability and engine efficiency while making a substantial contribution to greener energy sources.

CONCLUSION

Alcohol's characteristics closely mimic those of regular gasoline, making it the most viable solvent as an alternative fuel. Methanol, ethanol, and butanol are three alcohol families that are frequently utilized as alternative fuels. Fuel characteristics, engine conditions, and engine design all affect engine performance, combustion behavior, and exhaust emissions. This review covered all of those topics, and the results are summed up as follows.

- Alcohol is the most practical solvent as an alternative fuel since its properties are quite similar to those of ordinary gasoline. Three alcohol families that are commonly used as alternative fuels include

methanol, ethanol, and butanol. The findings are summarized as follows.

- Because alcohol shares many characteristics with regular gasoline, it is the most promising solvent as an alternative fuel. Methanol, ethanol, and butanol are three alcohol families that are frequently utilized as alternative fuels.
- The majority of the investigations came to the conclusion that as engine speed increased, so did fuel consumption and braking power. The reason behind this is that alcohol has a far lower calorific value than regular gasoline.
- It has been observed that raising the compression ratio enhances combustion efficiency or thermal performance.
- Because alcohol improves combustion, most study found that blending it with gasoline reduced CO, NO_x, and UHC emissions.

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Performance Analysis of Developed Water Cooler Test Rig

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ABSTRACT

Water coolers are commonly utilized in commercial establishments located in sub-tropical and tropical regions, such as India, particularly during the summer or in warm climates. When a person drinks water from the water cooler, freshwater from the building's storage tank is supplied through a float valve attached to the tank. When a substantial number of individuals rapidly consume the chilled water from the water cooler, the newly introduced fresh water does not cool down promptly. The individuals listed below do not receive cold water; instead, they are provided with warm water. It is necessary to reduce the time it takes for water to cool down, which requires studying the water cooler. A test rig is created to investigate the heat exchange occurring within the water tank of the cooler. The temperature distribution of the water cooler is measured using a temperature probe and then analyzed. It has been found that when the water is consumed at a rate of 10 liters every 20 minutes and replaced with freshwater, there is no noticeable cooling effect within the water. The starting and end temperature of the water will have negligible differences. The water cooler has an experimental coefficient of performance of 2.95 and a theoretical coefficient of performance of 4.65. The developed test rig will be used to analyse the heat transfer in water with different water consumption rate.

KEYWORDS: *Watercooler, Refrigeration.*

ABBREVIATION

m = Mass flow rate of fluid in kg/hr

Cp= Specific heat in of fluid in kJ/kgK

dT= Difference between temperatures

BPM = Beeps per minute

INTRODUCTION

Refrigeration is the process of controlling the temperature of an object (material) to make it fit for further usage. Water coolers are used in subtropical and tropical countries such as India during the summer or in warm climates. Water coolers/dispensers are installed in every commercial establishment to satisfy

the thirst of visitors. Any improvement in water cooler performance will not only save energy but also raw material consumption like the refrigerant used, copper pipe requires.

Water is held in a tank in a standard water cooler (Fig.1) and cooled through indirect contact with refrigerant. The evaporator walls (water tank) are chilled by refrigerant tubes (Conduction), and the water is cooled by convection. The refrigerant tube configuration solely cools the evaporator walls. Water begins to cool as a result of convection. Cooled water molecules will move to the bottom and settle down due to the buoyancy effect, whereas hot molecules will rise upward. Warm water will build in the centre upper region as a result of

this convection stream. The evaporator's (water tank's) central upper portion (Fig. 2) is relatively hot.



Fig.1. A Typical Water Cooler

If the centre upper warm zone is reduced in any way, heat transfer will rise, and cooling time will be reduced. The parameters involved in this heat transfer include refrigerant, refrigerant tube arrangement, surface area exposed for heat transfer, refrigerant velocity in tube, inlet and outlet temperature of water, rate of water consumption, refrigerant inlet and outlet temperature, and so on. These characteristics must be investigated to reduce the central upper warm region and achieve faster cooling in the evaporator.

Storage water coolers are utilized for drinking in commercial establishments. When the temperature rises above 40°C, people drink more water than usual. As a result, water use rises throughout the summer. The rate of water cooling cannot keep up with the rising rate of water demand. As a result, the cooler was unable to cool the appropriate amount of water, and the drinkers (or thirsty individuals) were unable to obtain chilled water. The sole aim of the water cooler is not met. This occurs even when a properly selected water cooler is used.

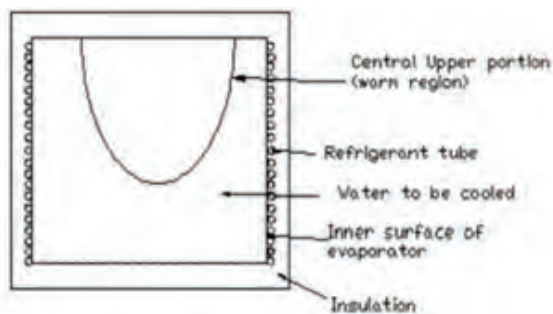


Fig. 2. Water Cooler Evaporator

PERFORMANCE MEASUREMENT OF WATER COOLER TEST RIG

The water cooler test rig is developed using a typical water cooler available in the market. The major specifications are mentioned in Table 2. The schematic diagram of the developed test rig is shown in Fig. 3 and simple vapour compression refrigeration cycle on P-h plot in Fig.4.

The two experiments were performed, one for measurement of performance of the refrigeration system and second experiment to obtain the temperature distribution of water within the watertank. For both experimentation, the water temperature was different.

For calculating the Coefficient of performance COP of the system, the test was conducted for 2 hours for 80 liters of water and the COP is calculated. The initial temperature of water was The Table 3 shows observations recorded while calculating the coefficient of performance (COP) of the refrigeration system when the water was not removed from the watertank.

Table 1: Water consumption pattern used for the experimentation

Water Consumption Pattern	Water Consumption Pattern for 2 hr	
Pattern 1	No water is removed from the water tank so 80 liters of water is cooled within 120 min,	
Pattern 2	1st to 20th min	10 litres
	21th to 40th min	10 liters
	41st to 60th min	10 litres
	61st to 80th min	10 liters
	81st to 100th min	10 liters
	101st to 120th min	10 liters

Table 2: Major specifications of a typical water cooler

Title	Specifications
Power Supply	1Ph AC, 230V, 50Hz
Refrigerant	R134a
Water Storage Capacity	80 Liters
Water Cooling Capacity	40 Liters / hr
Mass of Refrigerant	280 gms

Compressor Type

Hermetically sealed
Reciprocating**EXPERIMENTAL COP CALCULATION
(WITH NO ADDITION/REMOVAL OF
WATER) :**

Actual refrigeration effect (Water side)

$$= m \times C_p \times dT = 40 \times 4.186 \times (35-16) = 3181.36 \text{ kJ/hr} = 53.02 \text{ kJ/min} = 0.884 \text{ kW} = 0.25 \text{ TR}$$

Actual refrigeration effect (Refrigerant side)

$$= m \times C_p \times dT = 12.1 \times 1.2 \times (27.3-7.1) = 527.95 \text{ kJ/hr} = 8.80 \text{ kJ/min} = 0.146 \text{ kW}$$

Capacity of the test rig i.e. Output = 884 Watt

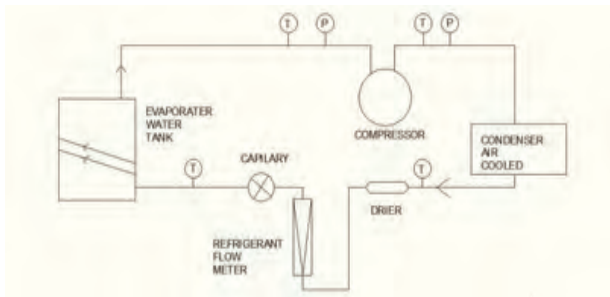
Compressor work i.e. Input = $(60/(\text{imp./kWh})) \times \text{BPM}$
 $= (60/3200) \times 16 = 0.3 \text{ kW} = 300 \text{ Watt}$ Experimental COP = Refrigeration effect / Compressor work
 $= 884/300 = 2.95$ with respect to initial water temperature 35°C.

Fig. 3. Schematic diagram of the water cooler test rig

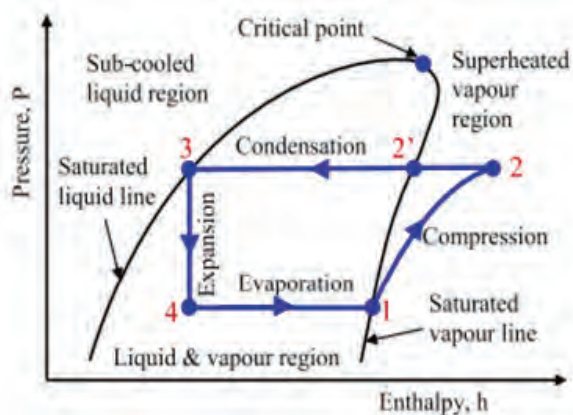


Fig. 4. Simple vapour compression refrigeration cycle on P-h plot [13]

Table 3: Observation Table

Observations (with no addition/removal of water)	
Refrigerant temperature at evaporator inlet (T1)	7.1°C
Refrigerant temperature at compressor inlet (T2)	27.3°C
Refrigerant temperature at condenser inlet (T3)	80.1°C
Refrigerant temperature at expansion valve (capillary tube) inlet (T4)	35.2°C
Water inlet temperature	35°C
Water outlet temperature	16°C
Refrigerant suction pressure	5 PSI (2.9 Bar)
Refrigerant discharge pressure	105 PSI (12.76 Bar)
Refrigerant flow	18 Liters per hours
Energy meter reading (3200 imp./kWh) in BPM	16 Beeps per minute
Mass of water	40 Kg/hr
Time for cooling 40 Liter water	60 min

THEORETICAL COP CALCULATION:

h1=enthalpy of refrigerant at inlet of compressor = 425.92 kJ/ kg

h2=enthalpy of refrigerant at outlet of compressor = 464.77 kJ/ kg

h3=enthalpy of refrigerant after condensation = 245.13 kJ/ kg

h4=enthalpy of refrigerant after expansion = h3 = 245.13 kJ/ kg

Refrigeration effect= h1-h4 = 180.8 kJ/kg

Compressor work = h2-h1 = 38.85 kJ/Kg

Theoretical COP = $(h1-h4) / (h2-h1) = 4.65$

The calculated coefficient of performance is within the range of refrigeration system.

**TEMPERATURE DISTRIBUTION
WITHIN THE WATERTANK**

Due to the acceptable operating range (-55°C to 125°C) and accuracy ($\pm 0.5^\circ\text{C}$), DS18B20 Water Proof Temperature sensors are used in the test rig. To measure the temperature within the water, DS18B20 sensor (quantity 14) were mounted on the two rods. Figure 5a & 5b shows the arrangement done for measuring the temperature within the water tank.

Table 4 clarifies the locations of probe within the tank. Probe T1 & T2 are mounted at the bottom of the tank (L1 location, 0 cm) whereas T13 & T14 are placed at the L7 at the vertical distance of 38cm once 80 liters water is placed in the tank. All these probes were connected to computer via Mega Arduino and the data was recorded continuously for 2 hours.

In experimentation, the water cooler was considered with there is no any water drawn for drinking i.e the water usage was considered zero for two hours (Pattern 1 mentioned in Table 1) and the temperature was measured across the tank. In this experiment, the initial temperature of water at L7 (at top) was measured to be 25°C and at L1 (at bottom) was 21.62°C. The test was conducted for continuous for 2 hours and after that temperature was recorded. After 120 minutes, the temperature at the top 23.89°C and at the bottom was 11.31°C.

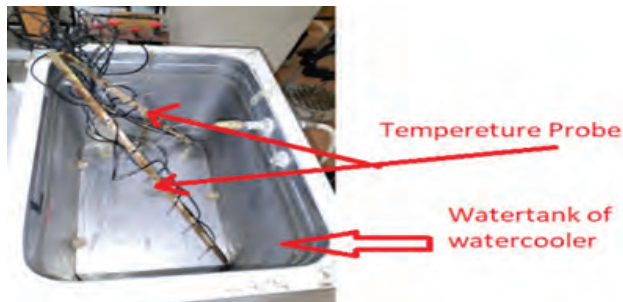


Fig. 5a: Arrangement of probe inside the water

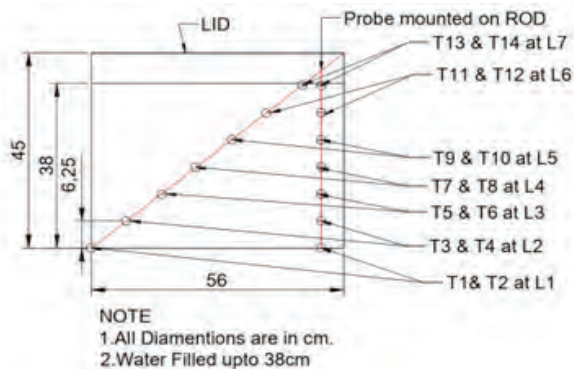


Fig. 5b: Location of temperature probe (from the bottom)

Table 4: Location of temperature probe and its location

Location from bottom	Temperature Probe No.
0 cm	T1 & T2

6.25 cm	T3 & T4
12.5 cm	T5 & T6
18.75 cm	T7 & T8
24 cm	T9 & T10
32.25 cm	T11 & T12
38 cm	T13 & T14

At L1 (at bottom) at 0th min, the water temperature was 21.62°C and it reduces to 11.31°C as the cooling takes place. After 120 minutes, the temperature at the bottom reaches to 11.31°C but at the same time, the temperature at the L7 (at top) the temperature was 23.87°C.

From, this it is clear that even after 2 hours of cooling in water cooler, the water is not cooled at top. The table 5 clears the reading recorded (with 3- colour scale) and the graph 1 and 2 shows the temperature distribution in water tank as per the time and location when no water is removed from tank.

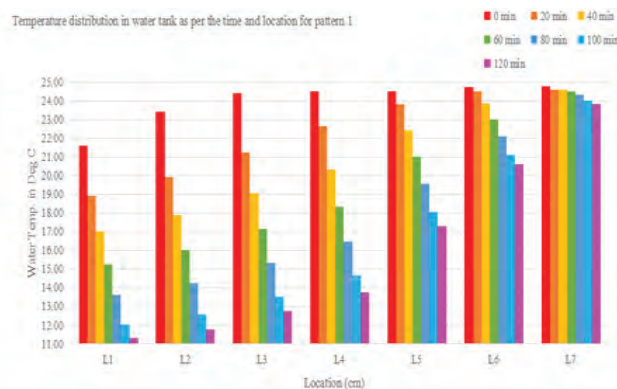
From graph 1 & 2 once can see that from the start of experiment, there is sharp decrease in the temperature of water at L1 (at bottom) due to refrigeration effect. At L2 (i.e at 6.25cm from bottom), withing first 20 minutes, there is sharp decrease in temperature but this rate of cooling decreases as the time passes. The rate of cooling decreases at once moves towards the top of the tank. There is only drop of almost 20°C at L5, L6 and L7. In the upper region of water, the heat transfer rate is very slow and the temperature of water is almost constant. There is significant heat transfer is recorded at the bottom region of water tank.

In water consumption pattern 2, after every 20 minutes, the 10 litres of water were removed and makeup hot water of 40°C (to simulate the real-life situation) was added into the tank. So, in all experiment, the new water was added 6 times and hence it is seen that the lowest temperature of water (28.5°C) was unchanged in 2 hours. The graph 3 & 4 shows the variation of temperature within the water as per the time and location for this pattern.

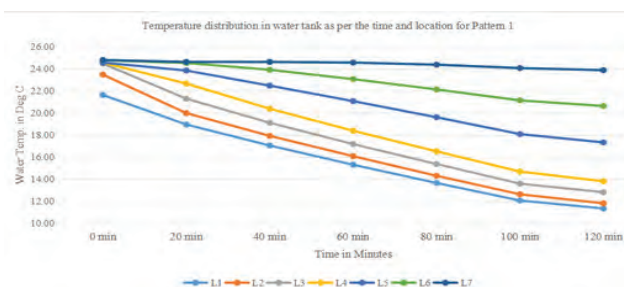
Table 5: Temperature (in °C) distribution across the water tank with respect to time and location when no water is removed from tank (pattern 1)

Time/ Location	0 min	20 min	40 min	60 min	80 min	100 min	120 min
L1	21.62	18.94	17.03	15.28	13.63	12.03	11.31
L2	23.47	19.97	17.91	16.06	14.28	12.80	11.78
L3	24.47	21.28	19.10	17.16	15.35	13.57	12.79
L4	24.56	22.66	20.37	18.37	16.50	14.86	13.78
L5	24.56	23.84	22.47	21.06	19.60	18.07	17.31
L6	24.78	24.53	23.91	23.06	22.12	21.13	20.62
L7	24.79	24.62	24.62	24.56	24.37	24.06	23.87

As after every 20 mins, the hot water was added in the tank and there is no sufficient time to cool the available water in the tank, there is no any cooling effect observed in the water. The initial temperature and final water were marginally changed. From this second experimentation with this pattern, one can conclude from the table 6 that if the water consumption pattern is like after every 20 minutes if 10 liters of water is removed and makeup water is added then there is no cooling effect will be seen. There will not be much change in the initial and final temperature of water. From these graphs, one can observe that the at all level of water, the temperature of water is increasing from the start to the end of experiment.



Graph 1: Temperature (in °C) distribution of water with respect to time and location for pattern 1 (bar graph)



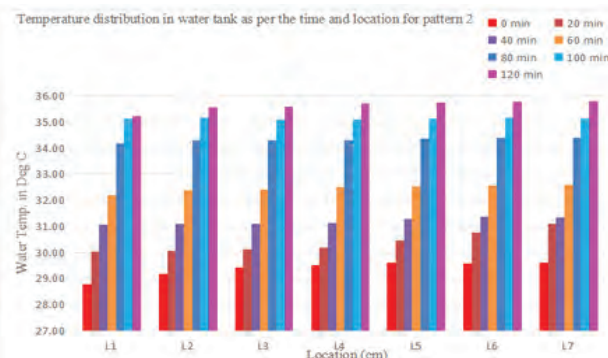
Graph 2: Temperature (in °C) distribution of water with respect to time and location for pattern 1 (line graph)

CONCLUSIONS

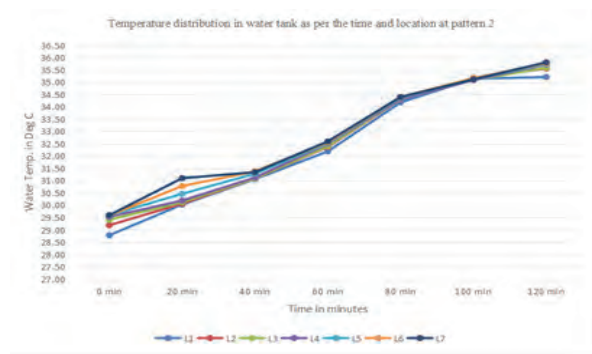
As per the literature review, very few researchers have worked on the evaporator side of water cooler (refrigeration system). There is need to study the water cooler for minimizing the chilling time of water and the water cooler test rig developed. For measuring the temperature of water, special arrangement is done and data was record on computer using temperature probe - Arduino system, for a specific water consumption pattern. The temperature data was analysed.

Table 6: Temperature (in °C) distribution across the water tank with respect to time and location when after every 20 mins 10 liters of water is removed and makeup water of 40°C is added into tank (pattern 2)

Time/ Location	0 min	20 min	40 min	60 min	80 min	100 min	120 min
L1	28.78	30.03	31.06	32.19	34.19	35.14	35.22
L2	29.19	30.07	31.09	32.38	34.31	35.17	35.57
L3	29.41	30.13	31.09	32.41	34.31	35.09	35.60
L4	29.53	30.19	31.13	32.50	34.31	35.09	35.72
L5	29.60	30.47	31.28	32.53	34.38	35.14	35.75
L6	29.59	30.78	31.38	32.56	34.41	35.17	35.78
L7	29.60	31.10	31.35	32.60	34.41	35.12	35.82



Graph 3: Temperature (in °C) distribution of water with respect to time and location for Pattern 2 (bar graph)



Graph 4: Temperature (in °C) distribution of water with respect to time and location for Pattern 2 (line graph)

From above discussion, following conclusions can be drawn.

- The developed rig is developed and used for studying the water cooler performance and temperature distribution within the water.
- For measuring the coefficient of performance of water cooler, the 80 litres of water without addition/removal of makeup water were considered.
- The water cooler's experimental and theoretical coefficients of performance are found to be 2.95 and 4.65, respectively.
- For getting the temperature distribution with in the tank, the two-water consumption patterns were used.
- From graph 1 and 2, for pattern 1 (when no water is removed from the tank), it is clear that the as the time passes, the temperature of water decreases rapidly at the bottom whereas the water temperature is almost unchanged at top.
- In pattern 1, as there is no addition/removal of water from the tank, the heat transfer process is uninterrupted and hence cooling takes place quickly.
- From graph 3 and 4, for pattern 2 (when 10 liters of water is removed after every 10 minutes), it is clear that the as the makeup water of 40°C is added after 10 minutes, no cooling impact is noticed inside the water.
- In pattern 2, from the graph 3 & 4, at all level of water, at all times, the initial and final temperature of the water was almost same.
- In pattern 2, after every 10 minutes, the make-up water of 40°C is added, the temperature of water is increasing from the start to the end of experiment.

FUTURE SCOPE

The developed test rig is used to study the temperature distribution within the water with different water consumption pattern.

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11. Experimental and Theoretical Analysis of Integrated AC with Water Cooler, Sandeep Enakoti, Kasuba Sainath, Dr. T.K.K Reddy, Dr. Suresh Akella
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Sustainable Drilling Optimization of A286 Stainless Steel Using the Taguchi Method for Eco-friendly Manufacturing

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ABSTRACT

The drilling process for high-performance materials such as A286 stainless steel plays a critical role in manufacturing industries, especially those requiring superior strength, corrosion resistance, and heat tolerance. Optimizing machining processes becomes essential for lowering the effect on the environment, saving resources, and encouraging environmentally conscious procedures as global enterprises work to achieve the sustainability goals set forth in the UN Sustainable Development Goals (SDGs). This study focuses on the sustainable optimization of drilling parameters for A286 stainless steel using the Taguchi method, a robust statistical technique for design of experiments (DOE). The parameters examined include coating, cutting speed, feed rate, point angle, and helix angle, with a focus on minimizing material waste, energy consumption, and enhancing tool longevity. A well-designed experimental setup, based on Taguchi's orthogonal array (OA), reduces the number of trials while allowing for comprehensive analysis of multiple factors. The study investigates key performance metrics such as material elimination rate and cycle time for both operational efficiency and sustainability. According to the findings, spindle speed and feed rate optimization can greatly lower energy usage, prolong tool life, and increase drilled hole quality—all of which are consistent with sustainable production standards. This work offers useful insights for sectors looking to support SDG targets like Industry, Innovation, and Infrastructure (SDG 9) and Sustainable Consumption and Production (SDG 12) by encouraging more intelligent machining techniques and eco-friendly material usage.

KEYWORDS: A286 stainless steel, Drilling, Sustainable manufacturing, Taguchi technique, Eco-friendly materials, ANOVA.

INTRODUCTION

A286 stainless steel was mainly created for uses needing high strength and good resistance to corrosion. Compared to AISI 304 and AISI 316 austenitic stainless engines, fasteners, superchargers, and high temperature applications like turbine wheels, frames, casings, and after burner parts. Despite having strong toughness, ductility, and corrosion resistance, this steel has a low hardness because to the alloy's low carbon concentration.

These steels are difficult to machine because of their

hardness and non-availability of suitable cutting tool materials. The machining of these material results in increased heat production, high cutting forces, reduced surface quality, extreme wear, and residual stresses. Therefore, it would appear to be very difficult to use standard cutting tools and ordinary machining methods. According to previous studies, when super alloys are machined, optimal cutting conditions lead to longer tool life, lower energy consumption, less wear, production of heat, residual stresses, and improved machining ability. The integration of advanced coatings and eco-friendly

materials with optimized machining strategies plays a vital role in promoting sustainable manufacturing. Productivity is a key factor in the success of any industry, as it directly influences profitability, competitiveness, and long-term sustainability.

In order to maximize productivity, modern engineering industries require steel to be machined at higher feed rates and faster cutting speeds. In addition to productivity, the industry's need to lower production costs and adhere to stringent environmental regulations has prompted research institutions to try to extend the life of cutting tools. One of the most basic and widely used material removal processes in manufacturing sectors, drilling operations have an impact on well integrity, equipment life, and drilling efficiency. The success of the drilling operation depends on the proper circulation and removal of cuttings, which in turn requires the effective use of drilling fluids, specialized equipment, and careful operational control. Optimizing the material removal process helps increase the rate of penetration, minimize downtime, and reduce environmental impact, ultimately improving the overall success of the drilling project. Such drilling operations can be carried out by various cutting point angle, coating by PVD techniques, flute angles of drilling bit, and coating hardness for tool used for machining. Therefore, more research is required to examine how parameters in traditional drilling techniques for A286 stainless steel superalloy affect the removal of material rate, machined surface finish, and time to machining. The PVD-coated inserts are more suitable for drilling and turning A286 alloy compared to uncoated materials. The use of PVD-coated inserts effectively reduced the chip compression ratio and friction coefficient, indicating improved performance in the drilling process. Sabana Azim, Soumya Gangopadhyay [7] used CrAlN and TiAlN PVD coatings to improve the performance and sustainability of micro-drilling in Ni-based superalloys which helps to improve their effectiveness in enhancing tool wear resistance and surface integrity. P. Haja Syeddu Masooth, V. Jayakumar [3] Compared TiAlN, TiN, and AlCrN PVD coatings from that TiAlN coating provided the best surface finish, followed by AlCrN and TiN For dry drilling. M. Venkata Ramana, G. Krishna Mohan Rao [1] optimized the surface finish and rate of tool wear in sustainable turning operation by applying

the Taguchi technique. For that experimental work utilized the PVD coating in combination of titanium aluminum nitride (TiAlN) and titanium nitride (TiN), which was chosen for their ability to withstand the high temperatures and stresses encountered during machining operations of A286 stainless steel. These TiAlN/TiN coatings enhanced the durability and wear resistance of the tool, resulting in improved machining performance and a higher quality surface finish. These findings are valuable for manufacturers and researchers seeking to optimize machining processes and achieve desired surface quality when working with A286 stainless steel alloy. The experimental results conducted for machining A286 superalloy by B. Davoodi, SH. Musavi, [5] shown that the Minimum Quantity Lubrication (MQL) has a practical and sustainable substitute for conventional flood lubrication. MQL significantly reduced cutting fluid consumption (over 90%) while achieving comparable surface roughness under certain conditions. The machining properties of A286 stainless steel alloys for turning, milling, and drilling operations were examined by Viddya S. Patil and L.Y. Waghmode [6] in terms of their chemical composition, their applications, and different machining parameters. The results reveals that the optimized cutting parameters for manufacturing super alloys increases the life span of the tool, uses less energy, lessens the effect of residual stresses, wear, and heat generation, and improves the ability to be machine.

Optimization of machining parameters leads to a balance between productivity, quality, and cost-effectiveness. The specific conclusions depend on the target priorities, such as maximum MRR, best surface finish, or longest tool life. Advanced techniques like statistical modeling (e.g., Taguchi method or RSM) or machine learning can enhance the precision of such optimizations. Taguchi analysis is an approach to statistical analysis that systematically examines how various factors affect a response variable in order to optimize procedures and enhance quality. This method identifies the combination of factors that maximizes Material removal rate (MRR) and minimizes Cycle Time (CT) while considering interactions among factors. This analysis enhances efficiency, reduces machining time, and provides guidelines for future operations. In this research, the Design of Experiment (DOE) method is used to analyses data. Because A286

stainless steel is difficult to machine, AlTiN and AlTiSiN coatings are used on cutting instruments. When PVD coatings are applied to drilling tools, the resulting drills offer superior durability, high temperature, outstanding impact strength, exceptional resistance to abrasion, and increased corrosion resistance compared to drills without coating. The goal of the study was to better understand how different coated material, point and helix angles affect output responses like removal of material and surface finish, in order to increase machinability. Within the experimental parameter domain, a statistical model was built to estimate the material removal rate (MRR) and machining time. The variables of response are removal rate of material (MRR) and Cutting Time (CT), and process parameters under consideration are coating, cutting speed, feed rate, point angle, and helix angle. The combination of process parameters were selected to optimize the drilling process performance.

MATERIALS AND METHODS

Work piece material

A286 stainless steel material plate of Size: 10*200*200 mm and weight- 3.9 kg is selected for experimentation shown in Fig.1. Table 1 displays the wt.% of A286 stainless steel's chemical composition.

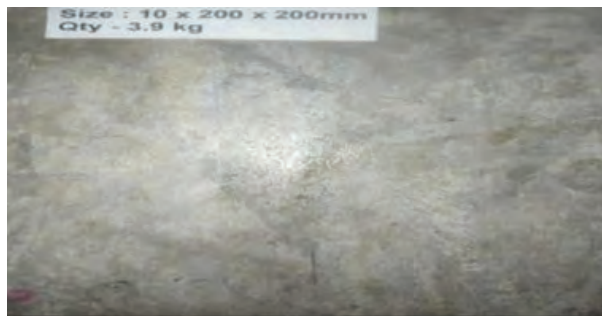


Fig 1: Image of A286 Stainless steel plate

Table 1 chemical composition of A286 stainless steel

C	0.035	V	0.31
Ni	25.4	Si	0.5
Cr	15	S	0.002
Ti	2.23	B	0.005
Al	0.24	P	0.008
Mn	1.54	Fe	Bal
Mo	1.3		

Drilling tool

Carbide material drilling tool of Length: 70 mm and Diameter: 6 mm. is taken for experimental work. Figure 2 represents AlTiSiN Coated tool and Figure 3 represents AlTiN Coated tool.



Fig 2: Tool Coated with AlTiSiN



Fig 3: Tool coated with AlTiN

Selection of Machining parameters and levels

In this study, machining parameters are selected using statistical three-level full factorial experimental approach. Experiments are conducted considering Coating, Cutting speed (m/min), Feed (mm/rev), Point angle (degree) and Helix angle (degree). Overall 18 experiments were carried out. Table 2 shows values of various machining parameters used for experiment:

Table 2: Machining variables and levels

Sr. No	Variables	Levels		
		1	2	3
1.	Coating	AlTiN	AlTiSiN	---
2.	Cutting Speed (m/min)	55	60	65
3.	Feed (mm/rev)	0.05	0.06	0.07
4.	Point angle (degree)	127	130	133
5.	Helix angle (degree)	28	30	32

Experimental procedure

Drilling operation is carried out on Vertical Machining Center (VMC) machine shown in Fig.4. A stopwatch was used to record the machining time. The following relation is used to compute the material removal rate.

$$MRR = \frac{\pi \times D^2 \times F \times N}{4} \text{ mm}^3/\text{Sec}$$

Where, D= Drill Diameter (mm), F= Feed Rate (mm/rev), N= Spindle speed (rpm)



Fig 4: Vertical Machining Center (VMC) machine

METHODOLOGY

The Taguchi technique is a systematic procedure to improving quality by optimizing process parameters and ensuring robustness against variability. It uses a loss function to quantify deviations from desired performance, emphasizing that even small deviations can lead to significant long-term impacts. The signal-to-noise (S/N) ratio evaluates robustness by maximizing desirable outputs (signal) while minimizing unwanted variability (noise), with performance categorized as lower-the-better, nominal-the-better, or higher-the-better based on the application. The optimal parameter levels are identified by selecting the settings with the highest S/N ratios. Additionally, analysis of variance (ANOVA) is employed to determine the statistical significance and contribution of each variable, highlighting the most influential factors.

Ratio of Signal to Noise: Smaller is preferable

$$\eta = -10 \log \sum_{i=1}^n y^2 \quad (1)$$

Ratio of Signal to Noise: Larger is preferable

$$\eta = -10 \log \frac{1}{n} \sum_{i=1}^n \frac{1}{y^2} \quad (2)$$

Where, y = Observed data, i = Trial, n = No. of trials

The S/N ratio evaluates process robustness by maximizing desirable output (signal) while minimizing undesired variability (noise). A maximal rate of material removal and a minimum drilling time are the objectives of this experiment. Since better performance is indicated by higher material removal rate (MRR) values, the larger-the-better quality characteristic is applied to MRR. On the other hand, as shorter machining time values indicate higher productivity, the smaller-the-better quality characteristic is applied to machining time.

Table 3 Machining observations and outcomes

S.N	Coating	Point angle	Helix angle	Cutting Speed	RPM	Feed	Cycle Time	Hole Dia.	MRR
1	AlTiN	127	28	55	2917	0.05	22	6	68.33
2	AlTiN	130	30	55	2917	0.06	23	6	83.33
3	AlTiN	133	32	55	2917	0.07	22	6	96.66
4	AlTiN	127	30	60	3182	0.05	22	6	75
5	AlTiN	130	32	60	3182	0.06	19	6	90
6	AlTiN	133	28	60	3182	0.07	18	6	105
7	AlTiN	130	28	65	3447	0.05	20	6	81.66
8	AlTiN	133	30	65	3447	0.06	17	6	98.33
9	AlTiN	127	32	65	3447	0.07	20	6	113.33
10	AlTiSiN	133	32	55	2917	0.05	27	6	68.33
11	AlTiSiN	127	28	55	2917	0.06	22	6	83.33
12	AlTiSiN	130	30	55	2917	0.07	20	6	96.66
13	AlTiSiN	130	32	60	3182	0.05	26	6	75
14	AlTiSiN	133	28	60	3182	0.06	23	6	90
15	AlTiSiN	127	30	60	3182	0.07	21	6	105
16	AlTiSiN	133	30	65	3447	0.05	24	6	81.66
17	AlTiSiN	127	32	65	3447	0.06	18	6	98.33
18	AlTiSiN	130	28	65	3447	0.07	18	6	113.33

RESULTS AND ANALYSIS

The experimental analysis was conducted using Minitab statistical software, which processes the experimental data and calculates the signal-to-noise ratio results. This study focuses on optimizing the drilling process by reducing machining time while increasing the material

removal rate (MRR). As the parameters vary at different levels, the impacts of various process parameters on MRR and machining time are assessed and plotted. To assess the influence of each parameter and its levels, the average S/N ratios are calculated.

Analysis of Signal-to-Noise ratio

The larger-the-better performance characteristic is chosen for material removal rate to achieve higher values, while the smaller-the-better performance characteristic is selected for machining time to achieve lower values.

Table 4 Response table for MRR

Level	Speed	Cutting Feed	Helix Angle	Point angle	Coating
1	37.48	38.27	38.99	39.00	39.00
2	39.12	39.00	39.02	39.01	39.00
3	40.41	39.73	38.99	39.00	
Delta	2.93	1.46	0.04	0.01	0.00
Rank	1	2	3	4	5

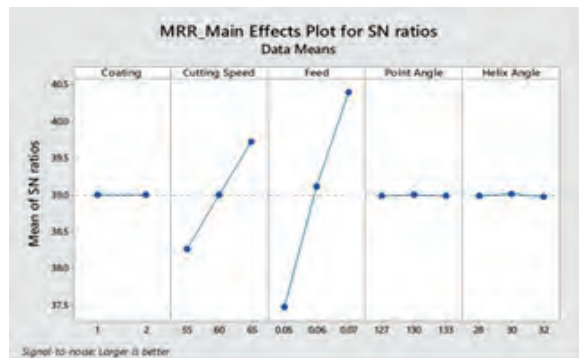


Fig. 5: Main effect plot for MRR

It is clear from response Table 4 and Fig. 5 that the most important factors affecting MRR are cutting speed and feed, which are followed by helix angle, point angle, and coating. A feed rate of 0.07 mm/rev, a cutting speed of 65 m/min, a helix angle of 320, a point angle of 1330, and an ALTiSiN coating are suitable for MRR.

Table 5 Response table for Machining Time

Level	Feed	Cutting Speed	Helix Angle	Point angle	Coating
1	-27.37	-27.07	-26.12	-26.19	-26.35
2	-26.10	-26.58	-26.81	-26.46	-26.38
3	-25.92	-25.74		-26.75	-26.67

Delta	1.45	1.33	0.69	0.55	0.32
Rank	1	2	3	4	5

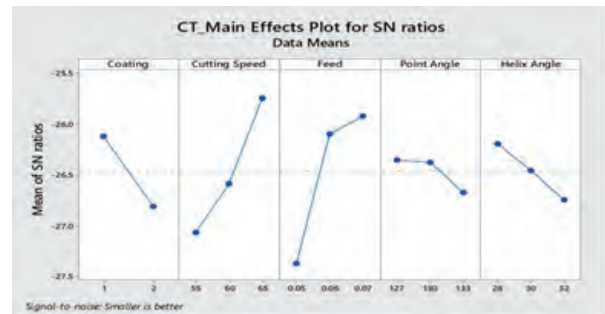


Fig 6: Main effect plot for Machining Time

Cutting speed and feed have the greatest impact on MRR, followed by helix angle, point angle, and coating, as can be shown from response Table 5 and Fig. 6. Feed rate of 0.05 mm/rev, cutting speed of 55 m/min, helix angle of 320, point angle of 1330, and ALTiSiN coating are the most suitable for machining time.

Analysis of Variance (ANOVA)

Analysis of variance is a statistical method for assessing the importance of variables influencing a system or process. The ANOVA module of Minitab 17 software can be used to examine the impact of parameters.

Table 6 ANOVA results for MRR

Source	DOF	SS	MS	F-Value	P-Value	% CON
Coating	1	0.00	0.00	0.00	1.000	0.00%
Cutting Speed	2	675.30	337.65	581.13	0.000	19.96%
Feed	2	2701.24	1350.62	2324.56	0.000	79.88%
Point angle	2	1.24	0.62	1.07	0.388	0.04%
Helix angle	2	0.31	0.15	0.27	0.772	0.01%
Error	8	4.65	0.58			0.14%
Total	17	3382.74				
S = 0.7622 R-Sq = 99.86 % R-Sq (adj) = 99.71%						

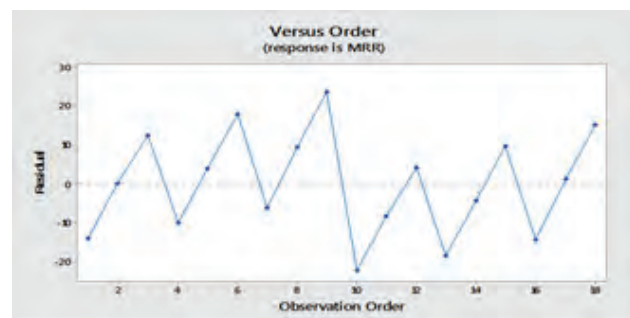


Fig. 7: Residual plot for MRR

From Table 6 and Fig.7 it is clear that Feed contributes the most to the total variation (79.88%), followed by Cutting Speed (19.96%), while other factors contribute negligibly for material removal rate (MRR) and from Table 7 and Fig.8 feed rate has the highest contribution to the total variation (36.19%), followed by Cutting Speed (23.47%) and Error (21.70%). Other factors have relatively smaller contributions for machining time.

Table 7 ANOVA results for Machining Time

Source	DOF	SS	MS	F-Value	P-Value	% CON
Coating	1	14.22	14.22	4.00	0.081	10.85
Cutting Speed	2	30.77	15.38	4.33	0.053	23.47
Feed	2	47.44	23.72	6.67	0.020	36.19
Point angle	2	3.44	1.722	0.48	0.633	2.63
Helix angle	2	6.77	3.389	0.95	0.425	5.17
Error	8	28.44	3.556			21.70
Total	17	131.1				
S=1.885 R-Sq = 78.31% R-Sq (adj) =53.90%						

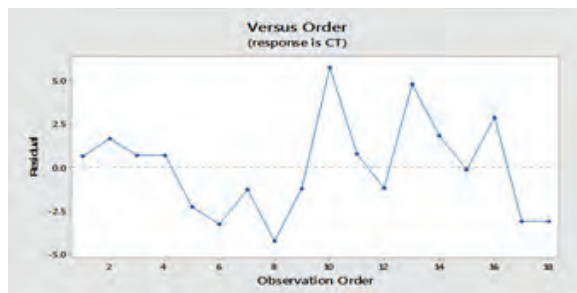


Fig. 8: Residual plot for Machining Time

CONCLUSION

A sustainable and cutting-edge technology-driven approach to machining is demonstrated by the Taguchi method's optimization of Material Removal Rate (MRR) in drilling A286 stainless steel. The results highlight that feed rate (79.88% contribution) and cutting speed (19.96% contribution) are the most influential factors in achieving higher MRR, while factors such as helix angle, point angle, and coating have minimal impact. For machining time, feed rate and cutting speed also dominate, contributing 36.19% and 23.47%, respectively. By prioritizing these key parameters, this

optimization approach promotes resource efficiency, reducing energy consumption and machining time while maintaining quality. Incorporating advanced technologies like precision tooling and coatings such as AlTiSiN further enhances tool life and process stability, supporting sustainability. This data-driven methodology not only aligns with productivity goals but also reflects a commitment to reducing environmental impact, optimizing resource use, and guiding future machining processes toward eco-efficient advanced practices.

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Application of Artificial Intelligence and Machine Learning in Foundry for Improvement of Casting Quality

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ABSTRACT

Artificial neural networks (ANNs) are a powerful predictive tool for process parameters and their optimisation in green sand systems leading to generation of sound castings. This research paper presents a case study of ANN along with an assessment of the literature of other AI-ML tools predicting casting defects and manipulating various mould characteristics. Notably, back-propagation neural networks have been popularly employed in the training by moisture, permeability and mould hardness to predict defects, including blowholes and porosity. In addition, forward and reverse mappings have also been reported in the literature for ANNs to map the properties of the mould as functions of input variables to obtain castings with improved quality. Although comparative studies report that genetic algorithm have the potential to outperform neural networks for optimising green sand mixtures, both approaches yielded efficient results. The paper also presents the other techniques such as sensitivity analysis used to estimate permeability and demonstrated the complex relationships of mould parameters on the output. Overall, ANNs provide a solid basis for improving the process and quality of green sand moulds.

KEYWORDS: *Artificial neural networks, Green sand mould, Process parameters, Casting defects, Back-propagation, Genetic algorithms, Permeability, Sensitivity analysis.*

INTRODUCTION

Predicting process parameters in green sand moulding using neural networks is one of the best areas under research because of the precision and utility required for casting and related processes. Green sand moulding, also a standard foundry process, has complex interactions between parameters, like moisture content, permeability, and mould hardness, which serially affects the quality of the final casting product. Conventional parameter optimisation approaches cannot deal with the non-linearity between the parameters and the mechanism.

Because ANNs can represent complex and nonlinear

relationships, they have been increasingly used to overcome these challenges. For example, ANNs were applied in casting defect predictions. The training parameters which were included are moisture, permeability, and mould hardness. It showed highly effectiveness in forecasting casting process related defects. [1]. Further, the potential of back-propagation neural networks (BPNN) and genetic algorithms (GA-NN) in reverse and forward mapping of mould properties was demonstrated. It indicated the capability of determining the inputs required to produce desired qualities in castings [2]. Some of the comparative studies could enlist the superior performance of ANNs compared to the classical methods. For instance, the

ANN have been proven better than linear regression models for predicting the permeability of green sand moulds, which is a key property to consider in the casting process [3].

It has also been used together with genetic algorithms to optimise green sand mixture formulation [4]. Increase in the accuracy of the casting process was observed. In general, neural networks in green sand moulding predict the process parameters, precisely and further aid in establishing efficient and dependable casting processes. Introducing new technology to the foundry industry, namely where quality and consistency of cast products are essential.

LITERATURE REVIEW

A literature review covers NN applications to extract process parameters from high-volume and high-variability processes in green sand moulding, driven by the desire to increasingly use artificial intelligence to derive or optimise aspects of the foundry process (i.e. logging or analysing data) based upon the established commercial relationship between the foundry and the customers that provide foundries with a higher likelihood of receiving supplementary work from customers. Neural networks are one of the most applicable prediction methods for predicting an essential process parameter, like temperature, humidity, the compaction of sand, the mix and the quality of green sand moulds & it is also analysed statistically & computationally. By examining ten significant research papers, a trend towards feedforward neural networks, backpropagation algorithms and recurrent neural networks for complex process input-to-output relationships becomes apparent. The use of experimental data (typically obtained from foundries) and training and validating NN models associated with performance metrics (mean squared error (MSE), R2 values, etc.) are some of the commonly utilised techniques. The results include neural networks that can predict the best practical process parameter limits to optimise process quality and sustainability and reduce defects and production costs in moulds. Neural networks studied in this literature review have shown efficiency in working with nonlinear and noisy data, which can be obtained from the nature of green sand moulding processes. Here are some popular ML technologies used in Foundry, as illustrated in Fig. 1.



Fig. 1. AI ML Technologies

1. Artificial Neural Networks (ANN) and Back Propagation: Several researchers have used ANN, mainly backpropagation of neural networks for casting defect detection based on the data from green sand moulds and optimisation circular on the various process parameters. For example, Parekh used an L27 orthogonal array as an input matrix to train the network to predict defects such as misrun, blowholes, and porosity with parameters such as moisture and permeability as key inputs[1]. A similar study used backpropagation to model the relationships between mould properties and input parameters and proved its effectiveness in forward and reverse mappings[2].
2. Genetic Algorithms (GA) and Hybrid Models: Few studies have combined neural networks with genetic algorithms to improve prediction accuracy. A performance comparison was performed between the genetic neural network (GA-NN) and back-propagation neural network (BPNN). The study revealed that GA- NN performed better in reverse mapping tasks than BPNN[2]. A different investigation showed that genetic algorithms have a superiority over neural networks to predict controlling parameters for desired properties of the mould [3].
3. Neuro-fuzzy Systems: The integration of neural networks with fuzzy logic has been investigated in neuro-fuzzy systems to increase the accuracy of predictions. Studies found that standalone neural network models are less efficient than neuro-fuzzy

models for predicting properties such as green compressive strength [4, 5].

4. Sensitivity Analysis: Sensitivity analysis has been implemented for neural networks to assess the effect of different process parameters on output variables such as permeability. It aids in determining the ideal process window for aspects like clay and moisture content [6].

MAJOR FINDINGS

The following are some of the significant findings of AI-ML application in foundry, as shown in Fig. 2.



Fig. 2. AI ML Application in Foundry

1. Prediction of Casting Defects: Neural networks have successfully predicted significant casting defects by examining process parameters. ANN, which is used in this study, is a powerful tool to detect defects such as porosity and blowholes and can help improve casting quality. [1, 7]
2. Optimization of mould properties: Neural networks are used to optimise the properties of moulds. Neural networks accurately predict green compression strength, permeability, etc., and optimise mould properties. This is accomplished by forward and reverse mappings so that the casting process can be done more explicitly process [2, 3]
3. Improved Accuracy with Hybrid Models: The combination of genetic algorithm and neuro-fuzzy systems integrated with neural networks results in minimised errors. Hybrid models of this type have been incredibly effective in predicting complex relationships between input parameters and mould properties [2, 4, 5].

4. Influence of Training Data: The neural networks' prediction quality is very much related to the training data set. Some studies have shown that the performance of a network will change with variations in the content of the training set, which further suggests there is a need for comprehensive and representative training of the data [8].

In conclusion, neural networks in predicting process parameters of green sand moulds have been achieved with some degree of accuracy, mainly when applied together with genetic algorithms and neuro-fuzzy systems. It was seen that by use of other technologies the precision of forecasts and the refinement of mould characteristics have been achieved, leading to improved specifications for cast and process operations.

CASE STUDIES

Optimization of Green Sand Casting Process Parameters by Artificial Neural Network

In this study, the researcher used artificial neural networks (ANN) to predict casting defects in green sand moulds. The study uses an L27 orthogonal array input matrix to train a back-propagation neural network. Using essential process parameters like moisture, permeability, and mould hardness, defects like misrun and porosity are predicted, establishing the working ability of the ANN to optimise casting processes. [1]

Forward and Reverse Mappings in Green Sand Mould System Using Neural Networks

The paper presents the author's recent work demonstrating the complex interactions between mould properties and input parameters such as sand grain size and binder content. The GA- NN model is superior to the BPNN model in determining the proper range of input parameters to obtain desired mould characteristics, confirming the utility of neural networks in the optimisation of manufacturing processes [2]

Estimation of Permeability of Green Sand Mould by Performing Sensitivity Analysis on Neural Networks Model

The proposed neural network model was designed to predict the permeability of green sand moulds. We use a back-propagation learning algorithm to train the

model to replicate the effects of various parameters (e.g., grain fineness, clay content, and moisture) on permeability. Performing a sensitivity analysis to ascertain the interdependencies of these parameters can shed light on the value maximisation of the process towards optimised permeability [6]

CONSTRUCTION OF NEURAL NETWORK

Quality castings are produced by proper control of process parameters. It is required to establish the values of process parameters for individual moulds. [9] Green sand moulding grey cast iron defects are influenced by process parameters, which change over time and temperature, with permeability and mould hardness increasing as moisture and compressive strength decrease [10]. Proper data collection, conceptualization and assessment of process parameters is a prime requirement.[11].

An Artificial Neural Network (ANN) model was developed using mould quality data to predict defect presence based on key parameters like moisture, GCS, mould hardness, and permeability. The model aims to identify patterns and relationships influencing defects, enabling better quality control in mould production. By training on past observations, the ANN learns to classify defect-prone conditions with high accuracy. This predictive approach enhances process optimization, reducing defects and improving manufacturing efficiency.

As Fig. 3 shows, the ANN implemented in a research work using MATLAB proves to be robust and practical in solving the problem. The architecture includes an input layer of four features, a hidden layer with 20 neurons, and an output layer configured for regression generating one continuous value. The Levenberg–Marquardt optimisation algorithm was used to train the network, with MSE being the appropriate performance metric. Achieving a minimum of 0.0164 mean test VAE squared error (death) at epoch 67 suggests that the model learnt well without overfitting. The R-values found for training, validation and test datasets (>0.95) suggest a robust predictive capacity of the model and the correlation between predicted and real values of the model, as shown in Fig. 4. The error histogram also revealed in Fig. 5, verifies that the predictions are

correct, with most errors close to zero. Fig. 6 shows the reliability of the ANN model as it captures complex patterns in the dataset and its scalability to future predictions and applications. 4.

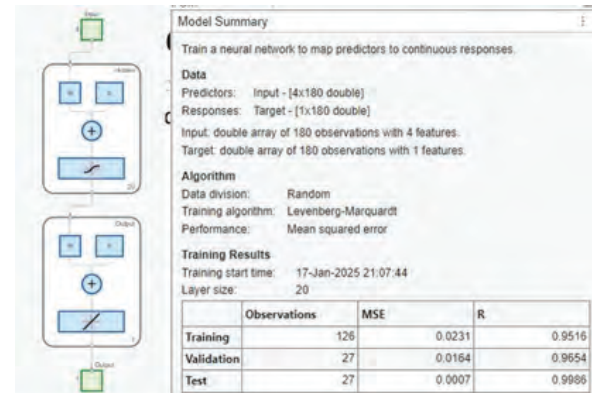


Fig. 3. ANN Model details

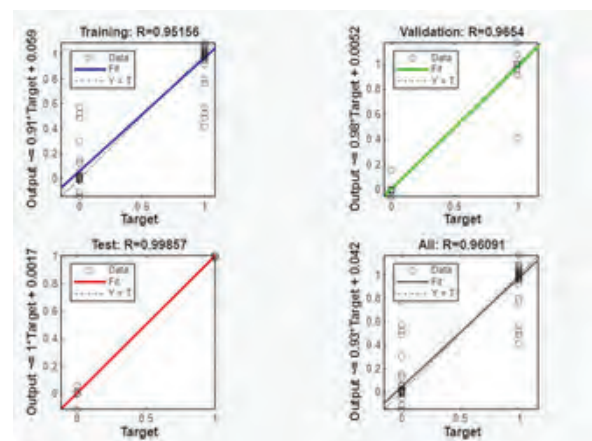


Fig. 4. ANN Model R values for training, validation and testing

QUANTITATIVE VALIDATION

The current ANN model showed high accuracy with R values of 0.9516 (training), 0.9654 (validation), and 0.9986 (test), indicating strong predictive capability, as observed. Meanwhile the low MSE values (0.0231, 0.0164, and 0.0007) confirm minimal error. The error histogram showed errors concentrated around zero, thus validating precision. The model achieved optimal performance at epoch 67, ensuring effective learning without overfitting. The similar results are observed as the model was applied to a green sand moulded cast iron casting. The model predicted the occurrence of the casting defect by 0 or 1.

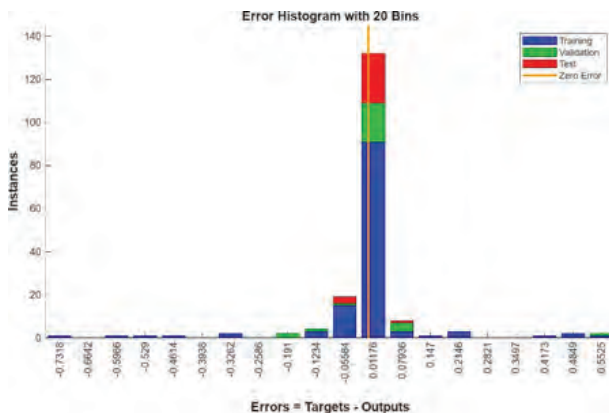


Fig. 5. Error Histogram

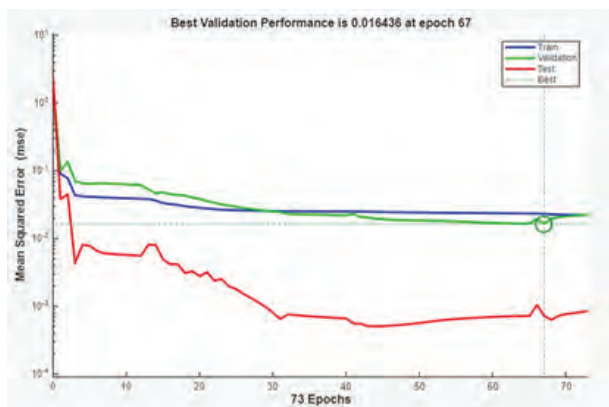


Fig. 6. ANN model validation performance

MODEL EVALUATION METRIC OF ANN

Based on the evaluation of the ANN model, following are some of the key performance metrics.

Model Accuracy & Performance: The high correlation coefficients (R values) for training (0.9516), validation (0.9654), and test (0.9986) indicate a strong predictive capability of the ANN model.

The test dataset shows an almost perfect fit ($R = 0.9986$), suggesting excellent generalization to unseen data.

Error Analysis

The mean squared error (MSE) values are low across all datasets, which indicate that, with the test dataset having the lowest error (0.0007), confirming model reliability.

The error histogram, shown above, demonstrates that the majority of errors are close to zero, thus, further validating the model's accuracy.

Training Process & Convergence

The best validation performance is achieved at epoch 67, as shown in the training performance plot. This indicates that the model stops training at an optimal point, preventing overfitting.

The decreasing trend of MSE over epochs confirms effective learning.

Potential Improvements

Although the model performs exceptionally well, further testing with a larger dataset can help validate its robustness. Regularization techniques or dropout layers could be explored to enhance generalization further.

Additional hyperparameter tuning may further refine the model's predictive capability.

Overall, the ANN model exhibits excellent performance with high correlation and low error, making it suitable for accurate predictions.

RESULT AND DISCUSSION

Artificial neural network (ANN) training can accurately predict casting defects and optimise the process parameters for green sand casting, thereby avoiding misruns, blowholes, inclusions and porosity. The main contribution of this work: Compared to the back-propagation neural network (BPNN), the genetic-neural network (GA-NN) performs superior on forward and reverse mappings in green sand mould systems, improving casting quality. Artificial neural networks can assist in rebounding decisions of green moulding sand and be used to predict compactibility value without testing. Conversion of the process window from deterministic to stochastic using neural network models and fuzzy logic enhances the optimisation of the process parameters for predicting significant casting defects.

Machine Learning Models for Prediction of Moisture Content of Green Molding Sand to Enhance Green Rebounding Process Neuro-fuzzy models perform significantly better than neural network models in predicting the green compressive strength of clay bonded moulding sand mixtures. The neuro-fuzzy model better predicted clay-bonded moulding sand mix properties than the neural network model, empowering individual

foundries to control green sand properties based on their raw materials. An artificial neural network can adequately control the bentonite moulding sand quality over individual parameters at particular points in time. However, a slight change in the quantity of the training sets may result in changes in the network quality, requiring a switch to the other types of networks.

AI IMPLEMENTATION CHALLENGES IN INDUSTRIAL SETTINGS

The implementation of artificial intelligence (AI) in manufacturing, including foundries, presents several challenges that span technical, organizational, and human factors.

1. **Technical Challenges:** The complexity and variability of manufacturing processes, especially foundries, where large amount of data is generated, which are often non-linear, stochastic, are one of the technical challenges. It calls for advanced AI systems capable of processing massive amounts of data and adapting to dynamic conditions. Moreover, pairing AI with pre-existing manufacturing systems is complex due to compatibility issues and infrastructure limitations.
2. **Organizational Challenges:** Such organizations, especially foundries, must have sufficient resources and manpower in the digital department to enable the adoption of AI.
3. **Human Factors:** Equally important to the successful rollout of AI is a consideration of human factors. Employees can be resistant to change, as they fear not only job displacement, but also that they may lack the skills needed to work alongside AI systems.

In foundries, the challenges are more as because of its stringent and variable working conditions, which can affect the reliability and accuracy of AI systems significantly. The need for precise control over production parameters in foundries requires the implementation of AI particularly challenging, as it calls for highly specialized algorithms and robust data collection systems.

SCOPE FOR FUTURE WORK

Neural networks have been applied successfully in several studies to predict the process parameters in green

sand mould systems. In particular, back-propagation neural networks (BPNN) and neural networks (GA-NN) have been successfully used to approximate the complex interactions of input parameters and their mould properties. NNs have been shown to do both forward and reverse mappings and, in some cases, generalise better than BPNN (GA-NN). [2, 3]

Prior studies have used artificial neural networks (ANNs) to optimise green sand casting process parameters and prediction of casting defects, including misrun porosity defects and blowholes. Using orthogonal arrays and back-propagation techniques has facilitated accurate predictions of defects from critical process parameters such as moisture, permeability, and mould hardness.

[1, 7]. Applying deep learning techniques, particularly neural network sensitivity analysis, has also been beneficial in estimating permeability by demonstrating the complex relationships among variables, including clay and moisture content. [6].

In addition, neural networks have been utilised to aid decision- making for moulding sand control systems to forecast features such as compatibility without physically testing the material.[12]. The use of genetic algorithms in combination [7] with neural networks has improved the prediction accuracy of controlling parameters, and it has shown advantages over ordinary neural networks by using data from organisational structures during training.[3].

This study highlights the effectiveness of artificial neural [8] networks in predicting/optimising process parameters in green sand mould systems. The ability of ANN to model complex, nonlinear relationships and screen by performing sensitivity analyses is why they have become well-known tools for improving casting quality and efficiency. Neural networks can be enhanced using genetic algorithms and [9] developed into neuro-fuzzy models, leading to performance improvements that offer several significant advantages for the foundry industry.

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A Review on Casting Process Optimization

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ABSTRACT

Foundry industries are the most significant sector of the casting manufacturing industry. Foundry industries in developing countries have the problem of poor quality and productivity because of number of process parameters are involved in the casting process which needs to be controlled. Even after a completely controlled process, the defects in the casting process are unavoidable and that is the reason to call this casting process as the process of uncertainty where it is difficult to explain the exact reason behind the cause of the casting defects. If we consider the today's competitive global market in the sector of automobiles OEM's (Original Equipment Manufacturers), then there is the requirement to launch the new product rapidly with maintaining the quality of the product and all this is required to maintain their position with the original equipment manufacturers. To meet these demands the automobile manufacturing original equipment manufacturers should improve their process and also they have to manage their suppliers and vendors. One of the prime suppliers of original equipment's manufacturers is the foundry industries.

To maintain the quality of the casting, it requires to do the casting defects analysis which is the process of finding the root causes of occurrence of defects involved in rejection of the casting and also it requires to take the necessary action to minimize the defects and to make the improvements in the yield of the castings also. For reduction of the defects and making an improvements in the process the several techniques are used like cause-effect diagrams, if- then rule (expert systems), design of experiments (DoE), casting simulation, Grey Relational Analysis (GRA), artificial neural networks (ANN), and AI tools etc. can be used to optimize the existing process. Simulation of the casting process is useful to visualize the mould filling, casting solidification, cooling of the metal, and to find the possible locations of internal defects of the castings such as shrinkage, sand inclusion, cold shuts, and porosity. This method of simulation helps in troubleshooting the existing castings and to develop the new castings without having the shop floor trials which ultimately helps to launch the product in the market in minimum time span with optimum cost of the product.

KEYWORDS: Casting defect, Simulation, Taguchi method, ANOVA, GRA, ANN, Parameter optimization.

INTRODUCTION

The metal casting is one of the basic manufacturing process. This is the very primary manufacturing process from past few centuries and today also it is seen that it is very important process of manufacturing. Applications of casting process includes many auto parts, machinery parts, domestic used appliances, etc. The manufacturing a casting predicts preparing mould

cavity of required shapes to be made for that liquefied metal is allowed to enter in to the mould cavity of desired shape and size and it is allowed to solidify.

Process development and methoding is designed to enhance the quality characteristics of process parameters which will greatly minimize the defects. The optimized methoding design is obtained through experimentation, which purpose is to minimize the defects and process

variation by setting the appropriate level of process parameters. It is very important to find the factors affecting the performance of the process and quality of the product. To reduce the process variation it is needed to set the appropriate levels of the process parameters which will reduce the defects [1].

Foundries in developing countries represent the significance in developing countries and these industries having problem of the ban quality and productivity. Main reason of this quality and productivity is that process is having large number of process parameters. Even if the process is completely controlled, the defects in the casting are observed hence this process is also called as uncertain process.

Casting process is used for mass production of the items, which are large in size, with intricate shapes. The major steps required to be followed manufacturing of a castings are moulding of sand, melting of metal, pouring of molten metal, solidification of molten metal, cooling of casting, fettling of casting, cleaning of casting, quality check of casting and elimination of defective casting. For production of sound castings, user should have the knowledge related to following aspects:

- i. Manufacturing of patterns and moulds
- ii. Skill of melting and pouring of molten metal
- iii. Solidification of the casting
- iv. Quality check and inspection of casting

Today's global market is competitive and Automobiles OEMs (Original Equipment Manufacturers) have to launch the new product rapidly with better quality and to maintain their position with other OEMs. To fulfil this demand the automobile manufacturing OEMs should improve their processes, manage their suppliers and vendors. The one main supplier for OEMs is foundry industries. In automobile, the numbers of parts are manufactured from foundry and OEMs buyers' demand defect free casting and strict to deliver on time [8].

LITERATURE REVIEW

Ravi [2] has given the guidelines for effective implementation and use of casting simulation technology. The guidelines are based on a review of about 200 industrial projects carried out by using

simulation software in consultation with the IIT Bombay. The projects considered for analysis are of two types: (a) Yield or quality improvement of existing castings and (b) Rapid development/ improvement of new castings. The guidelines cover all major metals processes and deal with five stages of simulation projects: data gathering, methods design, numerical simulation, methods optimization and project closure.

Kumar et al. [3] analysed that study on various sand casting parameters those affecting the quality of the casting. The most influencing parameters which affects the quality of the casting are Moisture, Green strength, Pouring temperature all this parameters affect the casting defects and also shows the optimal settings of each parameter to reduce the casting defects and improves the quality of castings at low cost. By the application of Taguchi's method to the green sand casting process, the productivity of the castings produced increases and maintains the stability of the casting process. Before the application of Taguchi's method it is observed that the parameters involved in the process of casting were more arbitrary levels which was difficult to maintain their appropriate level and because of this, the product quality had instability problems. Taguchi's method yielded optimized control factors, resulting in superior product quality and stability.

Choudhari et al.[4] stated that the process of casting solidification is complex in nature and the simulation of such process is required in industry before it is actually undertaken. The defects like shrinkage cavity, porosity and cold shuts can be minimized by designing an appropriate feeding system to ensure directional solidification in the casting, leading to feeder. Major parameters of a feeding system are like feeder locations, shape and size of feeders and feed aids. In this study, the component suffered from shrinkage porosity defect leading to premature failure. It also was subjected to incomplete fill due to sudden variation in thickness. Hence, it was necessary to redesign and redevelop the component. Component geometry has been modified without affecting its functionality by providing sufficient draft and radius at the junction.

Renukananda et al. [5] have studied in this work that flow of water and LM6 aluminium alloy through a multi-gate gating system have been compared using

numerical simulation. As water, whose kinematic viscosity is of the same order as common molten metal, so can be used for experiments. This was followed by experimental observations of water flow in horizontal modular transparent multi-gate gating system developed in the lab, which showed similar trends as the numerical simulations.

Saravana and Jeya [6] have minimized the casting defects such as Shrinkage, sand drop, sand blow holes, scabs and pinholes by using Taguchi optimization technique. The parameters considered are moisture content, green strength, mould hardness and practical size. The Taguchi approach is used to capture the effect of signal to noise ratio of the experiments based on the orthogonal array used to find the optimum condition. The outcome of this paper leads to select suitable process parameters in casting industry to produce defect free castings. The improvement expected in reduction of casting defects is 20-30%.

Gondkar and Inamdar [7] studied that, casting simulation which helps to Casting simulation is helpful to experience the filling of the mould, solidification of casting and to find the position of hidden defects such as shrinkage defects, blow holes, hard zones, etc. Simulation process can be used to troubleshooting existing casting, and is used for creating new casting without any of the trials on shop floor and it also helps to launch their product in the market as soon as possible with optimum cost. Use of simulation software, shrinkage defects optimized.

Patil and Inamdar [9] have studied defects in casting like shrinkage porosity, blow holes, cold shuts. To reduce these defects he has used artificial neural network (ANN) as well as AutoCAST simulation. Casting simulation is helpful to experience the filling of the mould, solidification of casting and to find the position of hidden defects such as shrinkage defects, blow holes, hard zones, etc. Simulation process can be used to troubleshooting existing casting, and is used for creating new casting without any of the trials on shop floor and it also helps to launch their product in the market as soon as possible with optimum cost. ANN is used for prediction of casting defects, it is used for optimization of sand and mould related parameters such as GCS, permeability, moisture percent, metal

composition, and metal temperature. ANN is used for optimization of casting parameters by using MATLAB software and back propagation algorithm is used.

Patil and Inamdar [10] ANN is used for prediction of casting defects, it is used for optimization of sand and mould related parameters such as GCS, permeability, moisture percent, metal composition, and metal temperature. ANN is used for optimization of casting parameters by using MATLAB software and back propagation algorithm is used. The ANN technique is an effective method to model the complex relationship between the process condition and the quality index of casted parts. ANN can be employed for casting process starting from moulding to final inspection method. ANN appeared to be successful in identifying possible sources of casting defects made in whole process.

S. K. Singha and S. J. Singh [11] have stated that use of ANN methods for optimization of casting process is one of the new techniques which industries are using now a days. It is difficult to predict the most optimized parameters to have defects free castings but defects in the castings can be minimized by optimizing the process parameters. There are many forms of algorithms in Artificial Neural Network (ANN) but mostly used and famous for the purpose of optimization is Back Propagation Algorithm. The obtained data is applied in the toolbox of ANN in the MATLAB and optimization is carried out. Validation of the results with the actual shop floor trials, it can be inferred that it is possible to minimize the percentage of the casting defects by using ANN.

OPTIMIZATION OF CASTING PARAMETER BY USING ADVANCE TOOLS:

Several new statistical techniques have been introduced by Dr. Taguchi, which has proved that tools in the field of improving quality are valuable. His approach have been used by many Japanese manufacturing industries for process and quality improvement successfully. Taguchi has stated that there is 85% of the poor quality due to manufacturing process and remaining 15% is because of labors.

This methods states about the input process parameters of optimum levels or on the basis of statistical analysis

the control factors are decided and experimental results makes process insensitive to effect of variations because of uncontrollable or the noise factors like surrounding temperature, humidity and vibration, etc.[7]. In this method the S/N ratio (Z) is applied to represent the quality characteristics for the observed data or responses. This is signal to noise ratio where signal represents the desirable value noise represents the undesirable value and ratio expresses the scatter around the desired value. The large S/N ratio represents smaller will be the scatter. The experimental values represents the quality loss values for each quality characteristic in the experimental trial runs. Based on the nature of quality characteristics the quality loss function is of several types:

- i. Smaller the better
- ii. Larger the better
- iii. Nominal the best

Techniques like cause-effect diagrams, design of experiments (DoE), casting simulation, if-then rules (expert systems), Grey Relational Analysis and artificial neural networks (ANN), AI tools, etc are used for optimization of the process parameters [8, 10].

GREY RELATIONAL ANALYSIS FOR MULTI OBJECTIVE OPTIMIZATION

Optimization of multiple process parameters is different from that of single performance parameters. The larger S/N ratio for one process parameter may related to a lower S/N ratio for another. Hence, total evaluation of the S/N ratio is necessary for the optimization of multiple performance parameters. To provide the solution to this problem, the grey relational analysis (GRA) is used. The grey relational analysis (GRA) was used for the solution to this problem. As a way to express the correlation between the desired and actual experimental data, the gray relational coefficient is computed from the normalized experimental data after the experimental findings have been normalized. The grey relational coefficient corresponding to each process respond to get is then summed to get the grey relational grade. The grey relational grade serves as a basis for the overall assessment of the multiple process answers. The optimization of a gray relational grade thus gets converted from the optimization of the

complicated multiple process responses. In the end, the gray relational grade is regarded as the total evaluation of the multi-reaction process's experimental data. The optimization factor is considered as the level with highest grey relational grade [8].

PREDICATION AND OPTIMIZATION OF DEFECTS BY CASTING SIMULATION TECHNIQUE

Employing a simulation model helps the study of actual systems that are not yet in reality. Quantifying the performance of a system under study for different values of its input parameters is of particular importance. In deciding at the managerial level, such numerical performance metrics can be very useful. The extra effort and time needed to alter the setup configurations in the manufacturing system is the main source of the metal casting company's expenses. The different customer orders, which differ in material kind, make, and dimension, necessitate a change in the machine setup. The goal is to create the methoding system and optimize it with the help of simulation and minimize the cumulative total cost incurred in changing of machine set-up. The simulation model is built In order to determine the setup expenses of all possible order combination, an explanation of the Computer Applications in Simulation of Metal Casting Process is necessary. The following are the software used for casting simulation in table 1 [2-12].

Table 1: List of simulation Software and its methods

Sr No	Software Name	Methods for Simulation
1.	AutoCAST	Vector element method
2.	ProCAST	Finite element method
3.	MAGAMAsoft	Finite volume method
4.	SolidCAST	Finite Difference method

IMPLEMENTATION OF ANN

The foundry industries integrated with an ANN-based predictive model into its manufacturing process. The ANN system can be used to:

1. Analyze Historical Data: Data from previous casting operations, including temperature, pouring time, alloy composition, and defect rates, were fed into the ANN.

2. Predict Defects: The trained ANN model identified patterns and predicted defects before casting.
3. Optimize Process Parameters: ANN suggested optimal values for critical process parameters, reducing human error and inconsistencies.
4. Automate Quality Control: The system automatically flagged high-risk batches, allowing for corrective actions before defects occurred.

Validation Techniques:

1. Train-Test Split Validation
2. Cross-Validation
3. Sensitivity Analysis

CONCLUSION

It is concluded that the non-value added time in the process of casting methoding can be reduced by adopting simulation technologies. This has been successfully experienced in industries, and now many industries are using such kind of valuable soft wares. This software is easy to use and handle by a person having learning edge of engineers with less time. Today many foundries are also turning towards the use of such kind of software.

The methoding optimization for casting process shows that the most influencing parameters which affects the casting quality resulting in defects. The use of Taguchi method shows that it helps to improve the process by optimizing the process parameters. Optimizing the process parameters also helps to improve the yield of the casting. ANN is used for optimization of casting parameters by using MATLAB software and back propagation algorithm is used.

Quantitative validation of ANN models in the foundry industry ensures that these models are accurate, reliable, and capable of improving operations. By using key performance metrics, robust validation techniques, and

real-world testing, foundries can integrate ANN models with confidence to optimize production, minimize defects, and reduce costs.

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Development of Iron Rich Multi-millet Cookies Fortified with Moringa Powder to Combat Iron Deficiency Anemia

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ABSTRACT

The study aimed to develop multi-millet cookies fortified with moringa leaves powder to be rich in iron content and other nutrients which will benefit the population with iron deficiency anemia. Multi-millet cookies were developed with key ingredients such as moringa leaves powder, amaranth millet flour, pearl millet flour and refined wheat flour. The Response Surface Methodology (RSM) was used for the optimization and the Central Composite Design of response surface methodology of Design-Expert software was used to formulate flour blends. 30 runs (flour blends) were generated. The formulation used to prepare the multi-millet cookies was moringa powder 1.12%, pearl flour 23.60%, amaranth flour 21.68% and refined wheat flour 53%. Physical parameters of multi-millet cookies recorded as diameter 44mm, thickness 14mm, weight 8.5gm, spread ratio 3.14 and hardness 7564.223N. Colour values (L^* , a^* , b^*) were 50.88, 4.2, 34.26 respectively. The sensory values recorded the overall acceptability score as 8.2. Moisture content as 4.2%, ash content 2.6%, total fat 15.51%, protein 9.12%, crude fiber 0.10%, and carbohydrates 68.47%. Iron 8.43mg/100gm, potassium 13.50mg/100gm, and calcium 220mg/100gm. The shelf life recorded was for 45 days in room temperature. Multi-millet cookies fortified with moringa leaves powder are healthy, tasty and rich in nutrients and minerals.

KEYWORDS: Response surface methodology, Iron-rich, Multi-millet cookies, Moringa powder, Iron deficiency anemia.

INTRODUCTION

In India, cookies are widely consumed and highly regarded as a convenient and inexpensive snack. They are popular among individuals of all ages and social classes. Bakery products are recognized for their nutritional value, and efforts are being made to enrich them with high-quality non-wheat flours, such as cookies, which are ready to eat, convenient, inexpensive, and one of the most popular processed food products in India (Kulthe et.al., 2017). Millets,

also known as “Gods own crops”, “belong to the grass family (Gramineae). They have been found to possess high nutritional and medicinal properties, with low-releasing carbohydrates that lower the risk of diabetes and are rich in dietary fibers, minerals like iron, magnesium, phosphorus, and potassium. Millets are also gluten-free and millet proteins are rich sources of essential amino acids and phytochemicals, as well as micronutrients. (Kulkarni et.al., 2021). Moringa oleifera is a species of vegetable belonging to the Brassica order and the Moringaceae family. The plant is rich source

of important minerals, protein, vitamins, β -carotene, amino acids, phenolics, antioxidants, anti-inflammatory nutrients, omega 3 and 6 fatty acids. Also a rare combination of zeatin, quercetin, kaempferol, and other phytochemicals (Haneen et.al., 2015).

Amaranth plants, belonging to the Amaranthaceae family. It is gluten-free nature, high-quality protein, and abundant fiber and minerals such as calcium and iron (Chauhan et. al., 2016). They also contain high concentrations of essential amino acids and minerals such as P, Ca, Fe, K, Zn, Mg, Cu, and Mn (Iftikhar et.al., 2019). Pearl millet is a good source of energy, protein, essential minerals, and dietary fiber (Kulkarni et.al., 2021). Pearl millets are rich in B-vitamins, potassium, phosphorus, magnesium, iron, zinc, copper, and manganese (Krishna et.al., 2020). Iron-deficiency anemia is a pressing public health issue in many developing nations. In India, almost 90% of adolescent girls are affected by anemia. Unfortunately, about half of all pregnant women in underdeveloped countries struggle with anemia. Iron deficiency and anemia can cause fatigue and weaken the immune system. As a result, there is a pressing need to develop iron-rich biscuits that can be used to combat anemia effectively (Nisha et.al., 2014).

METHODS AND MATERIAL

Materials

The raw materials like amaranth seeds, pearl seeds, refined wheat flour, powdered sugar, ghee, baking powder, baking soda, skimmed milk powder, salt, Maharashtra, India. The amaranth seeds and pearl seeds were dried and subjected to processing like sorting, cleaning, grading and milling. Uniformly dried amaranth seeds and pearl seeds were milled using a mixer grinder (Philips HL Mixer Grinder). The moringa leaves were plucked from tree and shadow dried for 3 days. Further leaves were powdered and packed in air tight container.

Formulation of cookies

Cookies with 100% refined wheat flour were served as control. 40gm of refined wheat flour was used to prepare control. The multi-millet cookies were prepared using following ingredients – pearl flour (9gm), amaranth flour (9gm), refined wheat flour (21gm), drumstick

(moringa) powder (1gm), powdered sugar (28gm), ghee (16gm), baking powder (2gm), baking soda (1gm), skimmed milk powder (6gm), salt (0.5gm), milk (8gm). Experimental design for flour blends and optimization of cookies

The Central Composite Design (CCD) of response surface methodology (Design-Expert software version 12.0.1.0 Stat-Ease) was used for the formulation of flour blends. The constraint levels ranged between 10gm to 30gm for pearl millet flour, 10gm to 50gm for amaranth millet flour, 10gm to 80gm for refined wheat flour and 1gm to 4gm of drumstick (moringa) leaves powder. 30 runs (flour blends) were generated (Table 1).

Raw material analysis – Pearl millet flour, amaranth millet flour and moringa powder were analyzed. The proximate analysis of these ingredients i.e. Moisture content, ash content, fat, protein were analyzed. Physical properties like colour and density were analyzed.

Physical parameters of cookies-The diameter (mm), thickness (mm), spread ratio, weight (gm) and hardness (N) of cookies were measured and values were recorded. Colour values of cookies- A Hunter Lab colorimeter (Colour Flex EZ) was employed to assess the color of the multi-millet cookie. After calibration, the biscuit sample was placed in the designated cup, and measurements of L^* , a^* , and b^* values were taken. The colour deviation from the standard was observed and recorded.

Proximate analysis of cookies- Moisture content, ash content, total fat, crude fiber, and protein were analyzed per AACC (2000). Carbohydrate was calculated by using following formula.

Carbohydrate (%) = 100 - % (moisture content + ash content + protein + fat + fiber) Sensory analysis of cookies- Ten panelists made up of males and females were selected. The panelists were requested to evaluate the various cookies samples for appearance, colour, taste, flavour, texture, crispiness and overall acceptability using a 9-point Hedonic scale.

Mineral analysis of cookies- The Atomic Absorption Spectrophotometer (AA 800 Perkin-Elmer Germany) was used to analyze the micronutrients content of the multi-millet cookies by the AOAC method (2005).

Shelf life analysis of cookies-The total bacterial count was determined using Nutrient Agar, following standard procedures. Laboratory tests were conducted to assess the bacterial, fungal, and yeast presence in millet biscuits.

RESULTS AND DISCUSSION

Raw material analysis of cookies

Moringa powder is high in ash content due to a high percentage of inorganic, volatile materials and high in crude protein content which indicates high mineral content. The average particle diameter of moringa powder was 500-750 μm . The lower the particle size, the higher the percentage of ash content (Lori et.al.,(2010)). The fat content in moringa powder is low due to low lipid content and has more dietary polyunsaturated and saturated fatty acids (Sultana et. al., 2020). Carbohydrate level was highest following crude protein content. Bulk density values of flour decreases with increase in moisture content as reported in Ojediran et. al., (2010).

Table1. Preparation of cookie samples using Response Surface Methodology (RSM)

Standard order	Run order	Moringa powder	Pearl flour	Amaranth flour	Refined wheat flour
1	5	1	10	10	10
2	10	4	10	10	10
3	23	1	30	10	10
4	25	4	30	10	10
5	26	1	10	50	10
6	2	4	10	50	10
7	6	1	30	50	10
8	27	4	30	50	10
9	28	1	10	10	80
10	24	4	10	10	80
11	7	1	30	10	80
12	12	4	30	10	80
13	3	1	10	50	80
14	1	4	10	50	80
15	13	1	30	50	80
16	22	4	30	50	80
17	21	2.5	20	30	45
18	16	2.5	20	30	45
19	17	-0.66228	20	30	45
20	15	5.66228	20	30	45

21	20	2.5	-1.082	30	45
22	11	2.5	41.082	30	45
23	9	2.5	20	-12.1637	45
24	4	2.5	20	72.1637	45
25	14	2.5	20	30	-28.786
26	18	2.5	20	30	118.79
27	19	2.5	20	30	45
28	8	2.5	20	30	45
29	29	2.5	20	30	118.79
30	30	2.5	20	30	118.79

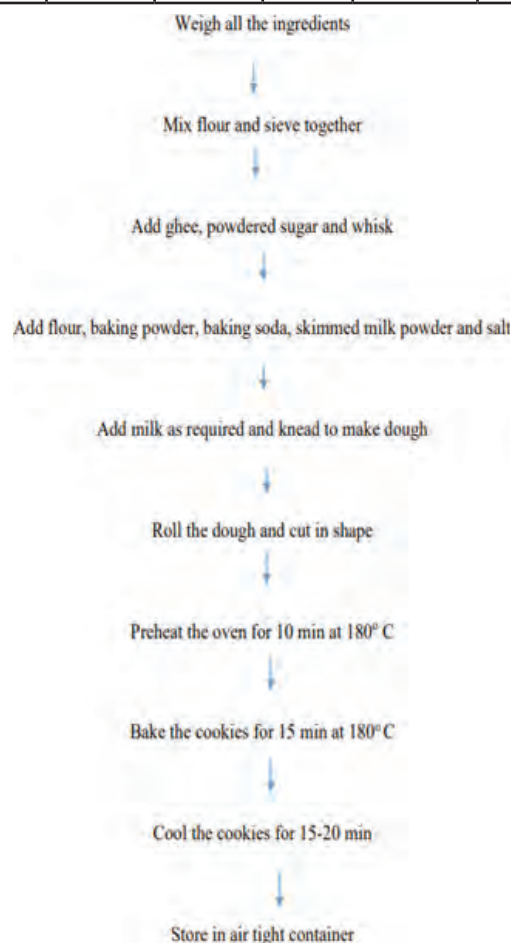


Fig. 1. Flow chart of cookies

Values in the table are presented as mean $\pm$ deviation (n=3), 3 is the repetition times of measuring the relevant indexes.

Bulk density of flour is affected by moisture content, particle size and air content present (Raigar et. al., 2015). Pearl millet flour had comparatively lower L value while refined wheat flour had higher L value.

Positive 'a' value represents redness while negative 'a' values represents greenness therefore moringa powder has negative 'a' value which represents dark green colour while pearl, amaranth and refined wheat flour

showed positive 'a' value. The L values of flours were highest compared to moringa powder due to whiteness colour of flours (Table 2).

Table 2. Proximate analysis and physical properties of raw materials

Sr. No.	Parameter	Drumstick leaf Powder(moringa)		Pearl Millet Flour		Amaranth Millet Flour		Refined wheat flour	
1	Moisture (%)	18.0±0.12		12.2±0.05		11.4±0.07		11.6±0.11	
2	Ash (%)	14.5±0.08		1.2±0.02		2.4±0.06		1.6±0.27	
3	Fat (%)	0.2±0.02		7.8±0.11		4.2±0.20		2.2±0.17	
4	Protein(%)	3.0±0.16		13.6±0.02		16.0±0.09		11.2±0.18	
5	Fiber(%)	6.8±0.19		2.8±0.07		3.2±0.04		1.3±0.02	
6	Carbohydrate(%)	57.5±0.33		62.4±0.25		62.8±0.27		72.1±0.32	
7	Density(gm/ml)	0.40±0.02		0.50±0.07		0.50±0.11		0.40±0.04	
8	Color	L*	37.78±0.18	L*	68.76±0.23	L*	80.54±0.31	L*	93.75±0.22
		a*	-5.89±0.02	a*	0.71±0.05	a*	1.92±0.02	a*	1.18±0.08
		b*	15.96±0.12	b*	9.53±0.08	b*	11.86±0.11	b*	11.15±0.05

Optimization of cookies and experimental design for flour blends-A central composite design (CCD) was employed to assess the combined impact of independent variables using Design Expert 12.0.1.0 (Stat-Ease. Inc. U.S.A.) (Table 3).

Model analysis of diameter-The ANOVA of this model was quadratic. The p-value was 0.0168 ($p < 0.05$) which represents the model was highly significant. The f-value was 1.64, the lack of fit was 0.3898 which was insignificant ($p > 0.05$) hence the model was highly acceptable. Model analysis of thickness-The ANOVA of this model was linear. The p-value was 0.0349 ($p < 0.05$) which represented the model was significant. The f-value was 3.06, the lack of fit was 0.0594 which was insignificant ($p > 0.05$) hence the model was highly acceptable.

Model analysis of spread ratio- The ANOVA of this model was linear. The p-value was 0.0010 ($p < 0.05$) which represented the model was highly significant. The f-value was 6.51, the lack of fit was 0.1340 which was insignificant ($p > 0.05$) hence the model was highly acceptable.

Model analysis of weight- The ANOVA of this model was linear. The p-value was 0.0170 ($p < 0.05$) which represented the model was highly significant. The f-value, the lack of fit was 0.1086 which was insignificant ($p > 0.05$) hence the model was highly acceptable.

Model analysis of hardness- The ANOVA of this model was quadratic. The p-value was 0.0279 ($p < 0.05$) which represented the model was highly significant. The f-value was 2.81, the lack of fit was 0.2748 which was insignificant ($p > 0.05$) hence the model was highly acceptable.

Effect of independent variables - Figure 2 shows the relationship between the independent variables and the dependent variable i.e. diameter, thickness, spread ratio, weight and hardness. The final equations are as follows-
Diameter = $46.2359 + 0.236725 * A + -0.584234 * B + -0.262805 * C + 0.257315 * D + 0.625 * AB + 0.375 * AC + -0.25 * AD + 0.125 * BC + -0.5 * BD + -0.5 * CD + 0.298146 * A^2 + 0.298146 * B^2 + 0.0731464 * C^2 + -1.11971 * D^2$

Thickness = $9.21001 + 0.0358318 * A + 0.124882 * B + -0.285597 * C + -0.545518 * D$
Spread ratio = $5.1165 + 0.0297897 * A + -0.194251 * B + 0.116789 * C + 0.432825 * D$

Weight = $8.16045 + -0.0101339 * A + -0.0534364 * B + -0.323246 * C + -0.475163 * D + 0.443125 * AB$
Hardness = $6,550.19 + 201.582 * A + -251.03 * B + -153.16 * C + -2,177.15 * D + -265.437 * AB + -359.454 * AC + -590.125 * AD + 925.535 * BC + -49.9847 * BD + 218.111 * CD + -684.879 * A^2 + 246.93 * B^2 + 1,676.41 * C^2 + 752.842 * D^2$

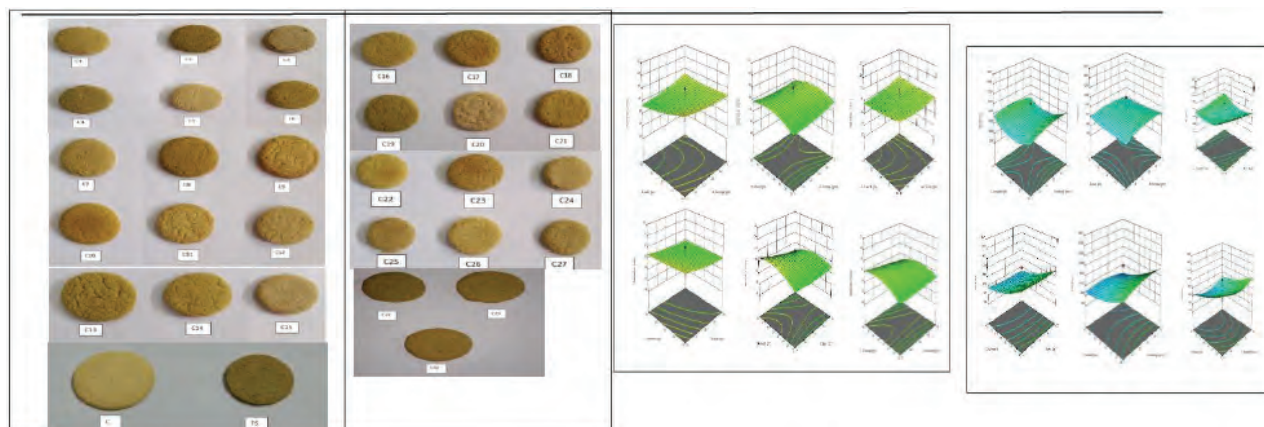


Fig. 2. Effect of moringa powder, pearl flour, amaranth flour, refined wheat flour on diameter, thickness, spread ratio, weight and hardness of multi- millet cookies

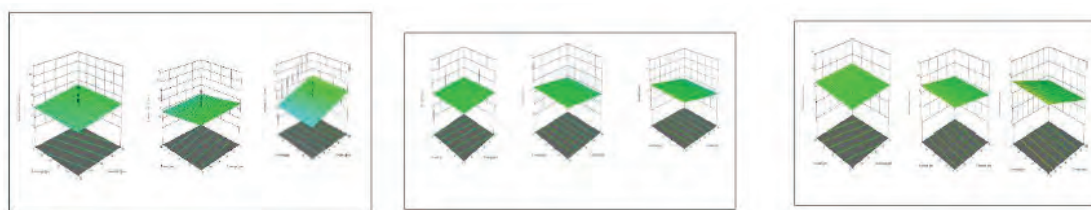


Fig. 3. Mult-millet cookie samples

Table 3. Analysis of variance (ANOVA)

Source	Diameter		Thickness		Spread ratio		Weight		Hardness	
	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
Model	1.64	0.1768	3.06	0.0349	6.51	0.0010	2.13	0.0170	2.81	0.0279
A	0.2736	0.6085	0.0318	0.8600	0.0765	0.7844	0.0021	0.9635	0.1367	0.7167
B	1.67	0.2162	0.3860	0.5400	3.25	0.0834	0.0595	0.8092	0.2120	0.6518
C	0.3373	0.5700	2.02	0.1677	1.18	0.2887	2.18	0.1524	0.0789	0.7826
D	0.3838	0.5438	9.82	0.0044	21.52	< 0.0001	6.28	0.0191	19.03	0.0006
AB	1.23	0.2856							0.1524	0.7017
AC	0.4414	0.5165							0.2795	0.6048
AD	0.1962	0.6641							0.7533	0.3991
BC	0.0490	0.8277							1.85	0.1935
BD	0.7848	0.3897							0.0054	0.9424
CD	0.7848	0.3897							0.1029	0.7528
A ²	0.4916	0.4940							1.79	0.2012
B ²	0.4916	0.4940							0.2324	0.6367
C ²	0.0296	0.8657							10.71	0.0051
D ²	9.21	0.0084							2.87	0.1110
Lack of Fit	1.35	0.3898	4.19	0.0594	2.73	0.1340	3.07	0.1086	1.77	0.2748
R ²	0.3046		0.3290		0.5101		0.2541		0.7243	
Adjusted R ²	0.2356		0.2216		0.4317		0.1348		0.4669	

Table 4. Formulation of flour for final sample

Moringa powder	Pearl flour	Amaranth flour	Refined wheat flour
1.38 gm	29.04 gm	26.67 gm	66 gm

Table 5. Physical parameters of multi-millet cookies

Sample	Diameter (mm)	Thickness (mm)	Spread ratio	Weight (gm)	Colour			Hardness (N)
					L*	a*	b*	
1	46	11	4.18	9.94	50.81	4.46	33.98	11990.314
2	44	10	4.4	9.78	44.46	4.17	37.58	14994.496
3	44	10	4.4	9.68	53.3	2.99	28.87	11334.612
4	45	11	4.09	10.15	48.22	2.62	33.77	8647.057
5	45	9	5	8.48	56.86	5.13	30.64	8491.03
6	46	11	4.18	9.02	49.11	4.25	43.89	8683.699
7	44	9	4.88	7.03	51.68	4.6	35.22	6861.736
8	50	11	4.54	10.23	44.54	6.9	37.25	14783.033
9	53	9	5.88	8.48	50.62	9	37.24	5691.065
10	48	10	4.8	7.9	51.12	4.83	46.08	10868.542
11	46	10	4.6	7.54	51.84	7.62	35.3	6067.183
12	48	10	4.8	9.01	56.77	5.72	35.54	7158.304
13	55	10	5.3	9.95	50.48	4	41.56	7552.271
14	48	8	6	7.28	53.86	4.43	40.69	5011.049
15	46	9	5.11	8	56.15	3.98	33.43	8651.667
16	46	9	5.11	7.08	53.81	3.74	39.33	3912.718
17	48	8	6	7.31	50.82	4.86	41.37	5748.038
18	48	9	5.33	6.5	50.82	4.86	41.37	5019.205
19	47	9	5.22	7.36	50.27	2.01	43.91	3621.941
20	50	8	6.25	6.8	60.42	2.7	30.35	2482.712
21	49	8	6.125	7.64	50.76	5.7	43.46	7284.189
22	44	9	4.88	8.01	55.67	3.47	38.95	7103.222
23	48	10	4.8	8.79	48.49	5.71	35.68	11414.162
24	43	9	4.77	7.54	52.91	6.14	34.36	15679.713
25	42	9	4.66	8.03	49.71	4.78	34.8	14971.563
26	47	8	5.875	8.14	57.74	2.77	37.66	6804.999
27	43	8	5.375	6.98	54.53	3.56	37.26	10102.122
28	45	8	5.625	7.06	54.7	3.62	37.18	4927.599
29	46	7	6.57	6.45	58.01	2.85	37.75	4350.065
30	46	7	6.57	6.45	58.32	2.7	37.69	3370.881
C	50	10	5	10.2	65.24	5.12	28.32	7421.36
FS	44	14	3.14	8.5	50.88	4.2	34.26	9564.223

Table 6. Sensory parameters of multi-millet cookies

Sample code	Appearance	Colour	Taste	Flavour	Texture	Crispiness	Overall acceptability
C1	7.8	8.5	7.6	7.6	7.2	7.1	7.5
C2	7.6	8.2	6.5	7.2	7.4	7.5	6.8
C3	8.2	7.6	7.6	7.8	7.5	7.4	7.6
C4	7.6	8.2	6.2	6.8	7.2	7.6	7.8
C5	8.2	7.5	8.8	7.2	7.6	7.2	8.2
C6	7.6	8.6	7.2	7.8	7.6	8.4	7.4
C7	7.4	8.3	8.8	8.4	7.2	8.5	8.6
C8	7.5	7.6	7.7	7.2	7.6	7.2	7.4
C9	7.6	8.2	8.2	7.6	7.2	8.2	8.2
C10	7.5	8.3	7.2	7.4	7.6	8.2	7.3
C11	7.2	8.2	8.2	7.2	7.6	8.2	7.6
C12	7.6	8.4	7.4	7.6	7.4	7.2	8.2
C13	7.6	7.6	7.4	7.8	7.9	8.4	7.7
C14	7.5	7.2	7.3	7.2	7.3	7.2	7.4
C15	8.2	8.6	8.3	7.4	7.4	8.2	8.6
C16	8.6	7.6	7.2	7.4	7.6	8.2	7.2
C17	7.2	7.6	7.6	7.2	7.1	8.4	7.9
C18	7.6	7.2	7.4	7.4	7.2	8.3	7.2
C19	7.1	7.6	7.4	7.6	7.2	7.4	7.6
C20	8.5	7.3	7.6	7.5	7.6	8.2	7.3
C21	7.2	8.5	7.6	7.2	8.4	8.2	7.5
C22	8.5	7.2	7.6	7.2	8.3	8.4	8.2
C23	7.2	8.8	7.2	7.4	7.5	8.2	7.8
C24	8.4	8.6	7.7	7.8	8.3	8.2	8.6
C25	7.2	7.8	6.4	7.3	7.5	7.4	6.9
C26	6.4	7.6	7.4	7.6	8.4	8.1	8.2
C27	7.2	7.6	7.4	8.2	7.6	7.9	7.8
C28	7.6	7.4	7.6	7.5	7.4	7.6	7.6
C29	7.7	7.2	7.2	7.4	7.4	8.6	8.4
C30	7.4	7.2	7.4	7.6	8.2	8.6	7.8
C	8.5	8.4	8.3	8.4	8.8	8.2	8.4
FS	8.2	8.8	8.1	7.4	8.8	8.6	8.8

Table 7. Proximate and mineral analysis of multi-millet cookies

Proximate	Control (C) (%)	Final Sample (FS) (%)
Moisture content	5.4±0.12	4.2±0.02
Ash content	1.3±0.08	2.6±0.06
Total fat	16.63±0.11	15.51±0.08
Protein	9.08±0.14	9.12±0.18
Crude fiber	0.2±0.04	0.10±0.02
Carbohydrates	67.59±0.22	68.47±0.19
Mineral	Control (C) (mg/100gm)	Final sample (FS) (mg/100gm)
Iron	0.53±0.07	8.43±0.04
Calcium	145±0.22	220±0.28
Potassium	0	13.50±0.30

Values in the table are presented as mean± deviation (n=3). 3 is the repetition times of measuring the relevant index.

Table 8. Total plate count (cfu/g) values of multi-millet cookies

Sample	Storage period (days)			
	15	30	45	60
Control (C)	3.1x10 ⁴	3.9x10 ⁴	4.2x10 ⁴	4.7x10 ⁴
Final sample (FS)	3.5x10 ⁴	3.8x10 ⁴	4.6x10 ⁴	4.8x10 ⁴

Physical parameters of cookies- It was observed that diameter of millet cookies decreased as the incorporation of millet flour increased and vice versa. The thickness of cookies increased as the diameter decreased due to fiber in millet cookies. As reported in Ashoush et.al., (2019) the replacement of wheat flour with an increasing level of moringa leaves and spirulina powder significantly decreased the spread ratio compared to control sample. This decrement was due to the decrease and increase in diameter and thickness, respectively. As reported by Ashoush et.al.,(2019) cookies with 2% spirulina and 3%

moringa powder showed the weight of cookie samples with different levels spirulina and moringa powders significantly higher compared to the control cookie samples. According to Ajibola et al., (2015) observed a significant reduction in cookie weight fortified with moringa leaf samples. It showed that the Control sample made from refined wheat flour had greater diameter, thickness and spread ratio compared to final sample. Millet cookies had incorporation of moringa leaf powder which had fiber content. The addition of fiber content impeded cookie spreading, resulting in a decrease in diameter and a corresponding increase in thickness. The hardness of cookies increased as incorporation of millet flour increased. All millet-based cookies exhibited lower L* values compared to the control sample, indicating a darker hue due to the nature of the ingredients. According to Ashoush et. al., (2019) report increase in the darkness of cookie reflected in L* values, as incorporation of moringa and spirulina powders increased colour of cookie became darker (Table 5).

Sensory parameters of cookie-The sensory parameters of cookies were analyzed by 10 panelists using a 9-point Hedonic scale. The mean score of 10 panelists are calculated. The overall acceptability of cookies ranged from 6.8-8.8. The Control sample (C) and Final sample (FS) were rated nearly for 8.2-2.4 points for overall acceptability. Similar study was reported by Igbabul et.al.,(2018) the appearance was rated.

6.13, aroma 5.60, crispiness 6.40, taste 5.46, texture 6.26 and overall acceptability 5.96 and were most acceptable sample. the texture and crispiness of FS was highly rated due to incorporation of millet which made cookies crispy. The flavour of FS observed was of moringa leaves powder which thus gave green colour to cookies. The taste of FS observed was earthy and slightly bitter due to incorporation of moringa leaves powder. The overall appearance of FS was acceptable due to flavour, colour, texture and crispiness of cookies. As a result it was observed that the appearance and overall acceptability of cookies were rated by high points. The overall acceptability of FS was highly rated and could be acceptable (Table 6).

Proximate and Mineral analysis of cookies- As reported by Igbabul et. al., (2018) moisture content of control

cookies (100% refined wheat flour) was high while ash content, fat, protein and crude fiber are low. As a result, carbohydrate level was highest while crude fiber level was lowest. The moisture content of Final sample (FS) low compared to control sample.

Nisha et. al., (2014) reported that iron rich biscuit made from moringa powder contain carbohydrate 26.4 %, protein 19.4%, fat 14%, fiber 8.5 % and ash content 9%. Low fiber content in cookies can be due to incorporation of flour which was finely refined because the process removes the bran which contains fiber. In Control (C) sample, iron content is 0.53 ± 0.07 mg/100gm, calcium is 145 ± 0.12 mg/100gm and potassium is not detected. As reported in Igbabul et. al., (2018) iron, potassium, calcium level is are low in cookies. Potassium is not detected in control sample and calcium content is high in control sample. Iron content is lowest. In final sample (C) iron content is 8.43 ± 0.04 mg/100gm, calcium is 220 ± 0.28 mg/gm and potassium is 13.50 ± 0.30 mg/100gm. According to findings in Igbabul et. al., (2018) iron, potassium, calcium levels increased as addition of moringa powder increased in cookies. As a result, iron and calcium content in FS was high while potassium content was low (Table 7).

Shelf life analysis of cookies- Total plate count (TPC) was recorded using nutrient agar. The Total plate count of control sample varied from 3.1×10^4 cfu/g to 4.7×10^4 cfu/g for 60 days. The total plate count increased significantly with the increase in storage period. Fungal growth was observed on cookies on the 60th day. As reported by Kumari et.al., (2021) in a shelf life evaluation of biscuits and cookies incorporating germinated pumpkin seed flour, the total plate count of control whole wheat flour biscuits varied from 3.20 to $4.32 \log$ cfu/g over 75 days of storage. The total plate count of Type-I and Type-II whole wheat flour biscuits ranged from 3.44 to $4.25 \log$ cfu/g and 3.55 to $4.20 \log$ cfu/g, respectively, whilst that of Type-III whole wheat flour biscuits spanned from 3.67 to $4.21 \log$ cfu/g. As a result, the total plate count increased gradually as the storage period increased. The FS can be stored for 45 days at room temperature (Table 8).

CONCLUSION

The formulation used to prepare the final sample of millet cookies was moringa powder 1.12%, pearl

millet flour 23.60%, amaranth millet flour 21.68% and refined wheat flour 53%. The final goal was to develop iron-rich multi-millet cookies fortified with moringa powder of good quality and rich in iron content which will benefit iron deficiency anemia. Millet flours such as amaranth and pearl were rich in iron content while moringa powder was rich in iron and other minerals like potassium and calcium. The multi-millet cookie sample developed in this study had successfully obtained iron content upto 8.43 ± 0.04 mg/100gm. The multi-millet cookie has a greenish colour, earthy flavour, sweet and slightly bitter taste. The texture of the multi-millet cookie was smooth and crisp. The shelf life of the cookie was upto 45 days at room temperature. The overall acceptability of multi-millet cookies was high in appearance, taste and crispiness. Compared to cookies developed from refined wheat flour, multi-millet cookies were healthy, tasty and rich in minerals and nutrients. Recommended Daily Allowance for iron for men is 8mg/day and 18mg/day for women. The intake of multi-millet cookies can contribute from 10-20% of the recommended daily iron intake. Multi-millet cookies fortified with moringa powder contain 8.43 ± 0.04 mg/100gm hence the iron-rich multi-millet cookies can be suggested for the population with iron deficiency anemia.

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Development of Carbonated Whey Protein Drink

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ABSTRACT

This research introduces the intent and significance of developing carbonated whey protein beverages, highlighting their potential to meet consumer convenience demand for nutritious beverages, utilize whey by-products sustainably, and offer unique market differentiation. It outlines the objectives, which include understanding the physico-chemical properties of raw materials, optimizing preparation methodologies, evaluating quality parameters, and assessing shelf life. For optimization, we have taken values of WPI from 1gm to 5gm. For CO₂ optimization, we optimized from 1gm to 4gm. The optimization of preservatives, malic acid, color and flavor was carried out at variable percentages. The finalization was done on basis of sensory evaluation and the analysis was done using AOAC methods. The process of making drink is mixing of all ingredients followed by refrigeration, while studying significance of maintaining ideal levels of acidity, pH, and carbonation for quality of final product. The carbonated whey protein drink comprising 4g CO₂, 0.1g potassium sorbate, 0.02g sodium benzoate, 0.015g stevia, 0.35g malic acid, 95ml water, and 5g WPI, 0.20g flavor, and 0.002g color at 5°C exhibited the highest tactile score among all samples. The drink was packed in the PET bottle and kept at refrigeration temperature which was acceptable over a period of 30 days.

KEYWORDS: Carbonation, Convenience, Food additives, Shelf life, Whey protein beverage.

INTRODUCTION

Carbonated beverages (CBs) have been a staple in the beverage industry for decades, offering a wide range of flavors and formulations. These beverages are characterized by means of the presence of dissolved carbon dioxide, which offers rise to effervescence and enhances the sensory attraction. The carbonation process, to begin with inspired through clearly gassy mineral water, has superior to embody a various array of flavors and formulations, catering to various purchaser options. The development of a carbonated whey protein drink combines the dietary blessings of whey proteins

with the smooth tendencies of carbonated beverages (Love et al., 2021).

Whey proteins and amino acid supplements have a strong position in the sports nutrition market based on the purported quality of proteins and amino acids they provide. Recent studies employing stable isotope methodology demonstrate the ability of whey proteins or amino acid mixtures of similar composition to promote whole body and muscle protein synthesis. Other developing avenues of research explore health benefits of whey that extend beyond protein and basic nutrition. Many bioactive components derived

from whey are under study for their ability to offer specific health benefits (Ewan Ha, Michael B. Zemel, 2003). There are many types of whey based beverages containing plain, carbonated and fruit flavored that have been successfully developed and marketed everywhere. The benefits of whey proteins will simply be increased by the beverages producers into various products i. e. the pH value ranged from 2 to 10 (Gottschalk, 2005).

The beverage market of today is vast and varied. Just a generation or two ago, carbonated beverages (CBs) could have been considered a rare treat, but today they are widely available and drunk by nearly everyone. The fact that more than 200 million liters of CBs were consumed worldwide in 2013 is evidence of this. Even though the amount of carbonated beverages drunk has decreased recently, it is evident that carbonated drinks are still a highly popular form of refreshment. (Abu-Reidah, Imam, 2020)

Consumer preferences are shifting toward more nutritious beverage options that offer dietary advantages without sacrificing taste or comfort. Milk's whey protein is well-known for having a full amino acid profile and being highly bioavailable, which makes it a fantastic option for anyone looking for dietary supplements that are high in protein. In keeping with this trend, whey protein is being added to carbonated drinks to provide a silky substitute for traditional protein shakes or powders. The allure of fizzy drinks is their bubbly feel and aroma, which can enhance the acceptance of protein-rich dietary supplements (Kadyan et al., 2021).

For today's busy consumers, ready-to-drink beverages offer the benefits of portability and convenience. Both chilled and shelf-stable beverages fall under the carbonation category; shelf-stable items are more in demand since they are convenient to distribute and store. For ready-to-drink protein beverages, whey proteins are the frequently recommended source due to their superior nutritional value, flavorless nature, ease of digestion, and special ability to work in beverage systems. Since 1985, the following five broad trends have shaped food and beverage innovations: convenience, enjoyment, ethnic fusion, tradition, and—most importantly—health and wellness. Sales of ready-to-drink and energy drink products have increased to \$23 billion. Whey beverages can be broadly categorized into four types: “thick”

dairy- type beverages (fermented or unfermented); thirst- quenching carbonated beverages (the “Rivella-type”); and alcoholic beverages (beer, wine, or liqueurs) combined with fruit or (rarely) vegetable juices. (Chavan, et. al., 2015)

MATERIALS AND METHODOLOGY

Collection of Raw Material

The acquisition of vital ingredients, such as Whey protein isolate, stevia, orange flavor, sunset yellow color adheres to rigorous quality standards at a nearby superstore or supermarket. This meticulous approach ensures that raw materials meet specific criteria for quality and purity, crucial in scientific research. Additionally, essential chemical reagents for raw materials like potassium sorbate, sodium benzoate, and malic acid are easily obtained from the Food Technology Laboratory at Shivaji University, Kolhapur. This centralized source guarantees access to necessary analytical tools, facilitating a systematic examination and assessment of the materials and products under investigation.

Proximate analysis

Moisture content (MC)

The Moisture content (MC) was measured using the oven drying method. Known wt. of each material's sample was kept in an empty petri - dish, pre-weighed, and to remove moisture in an oven at 105°C until a steady weight was reached (6 -7 hrs.) (Ranganna, 1986).

Ash content

To determine ash content sample was drawn into pre-weighed crucible which was further completely charred by heating it on low flame, cooled and situated in muffle furnace, ignited for about 4 hours at 550 °C. (A.O.A.C., 1990)

Fat content

Fat content of product was analyzed by Soxhlet method. Fat was calculated with the help of AOAC method (A.O.A.C., 1990).

Protein content

Percentages of protein in product were calculated with the help of kjeldahl method. This method was

divided into 3 steps. For digestion step, weigh 2gm of sample. Add sample into test tube with reagent powder (Potassium sulphate & Copper sulphate) and 10ml conc. H_2SO_4 . Then put it on hot Plate for digestion at $300^{\circ}C$ - $400^{\circ}C$ for 4 to 5hrs. After cooling add some amount of distilled water into the test tube. Final point of digestion was recorded when sample color turned into greenish or bluish. Second step was Distillation. Steam Distillation was carried out with the help of addition of acid & alkali in Distillation tube. Boric acid & 45% NaOH (sodium Hydroxide) was used to rising the pH. In this method, Ammonium (NH_4^+) ions were changed to Ammonia (NH_3), which is gas. Titration of collected solution was done in flask with the help of 0.1 N H_2SO_4 . At the end of titration process, blue color of solution is turns into Pink. (A.O.A.C., 1990) Protein will be finding by using given formula $6.25 \times N$.

Total Carbohydrate Content

Percentage of Carbohydrates = $100 - (\text{percentage of moisture} + \text{Percentage of Ash} + \text{Percentage of Protein} + \text{Percentage of Crude fat})$. (Suman 2008)

Crude Fiber

Acid and Alkali wash method was used to analyses the Crude fiber percentage in product as per method given in A.O.A.C., 1990.

Methodology

Carbonated whey protein drink will be prepared by methodology prepared by Silva e Alves et al. (2018) with slight modifications.

Optimization of carbonation in whey protein drink

Many fruit juices and beverages contain different food additives such as malic acid as acidulant, stevia as a sweetener, sodium benzoate and potassium sorbate as preservatives. The selection was based on their compatibility with the product. These preservatives are allowed as long as they stay within the bounds. Legal limits as per FSSAI for stevia, potassium sorbate and sodium benzoate in carbonated drinks with water basis are 200mg/kg, 500 mg/kg and 600 mg/kg, respectively. Samples PS1, PS2, PS3 and PS4 were prepared. A nine-point hedonic scale was used to analyze and rate each sample. Whey protein drink sample made with whey protein isolate (5 gm), malic acid (0.35 gm), stevia

(0.015 gm), orange flavor (0.15 gm), and orange color (0.01 gm) in 95 milliliters of water, sodium benzoate (0.02g) and potassium sorbate (0.10) and carbon dioxide was added in varying ranges from 1gm to 4gm.

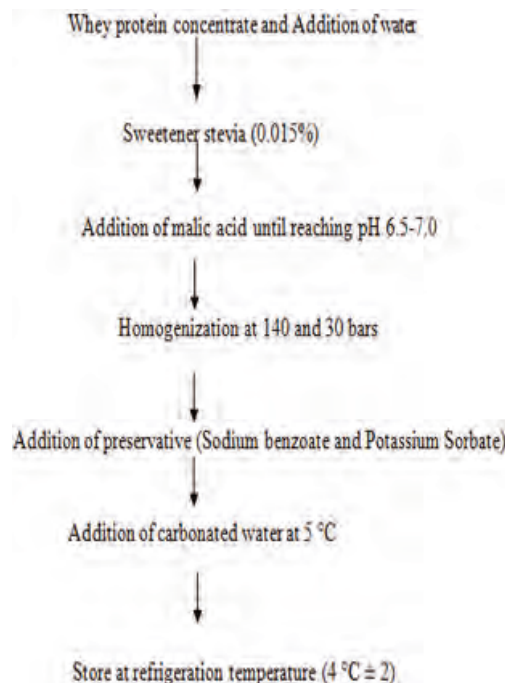


Fig. 1. Manufacturing of carbonated whey beverage (Silva e Alves(2018))

Table 1: Optimization of Carbonation in Whey protein drink

Sample Code	CO ₂ (gm)	Potassium sorbate (gm)	Sodium Benzoate (gm)	WPI (gm)	Malic Acid (gm)	Orange Flavor (gm)	Water (ml)	Stevia (gm)	Orange color (gm)
PS1	1	0.10	0.02	5	0.35	0.20	95	0.015	0.01
PS2	2	0.10	0.02	5	0.35	0.20	95	0.015	0.01
PS3	3	0.10	0.02	5	0.35	0.20	95	0.015	0.01
PS4	4	0.10	0.02	5	0.35	0.20	95	0.015	0.01

RESULT AND DISCUSSION

Sensory evaluation of carbonated whey protein drink at various temperature ranges

The sensory evaluation was conducted at various temperature ranges such as $5^{\circ}C$, $15^{\circ}C$, $25^{\circ}C$ and $35^{\circ}C$.

The sample at 5°C resulted better than other samples. Below table no. 2 shows the sensory evaluation results the sample.

Table 2: Sensory evaluation of carbonated whey protein drink at 5°C

Attribute	Sensory score			
	Temperature 5°C			
	F1	F2	F3	F4
Color	8	8	8	8
Consistency	7	7	7.5	8
Taste	7	7	7	8
Flavor	8	8	7.5	8
Mouth feel	7	7	8	8.5
Overall acceptability	7	7	7.5	8

By above tactile process in table no. 2, Sample F4 was selected (4gm CO₂, 0.10 gm potassium sorbate, 0.02gm sodium benzoate, 0.015gm stevia, 0.35gm malic acid, 95ml water, 5gm WPI, 0.20gm flavor, 0.002gm color) which was kept at 5 degree Celsius F1= 1gm CO₂, 0.10 gm potassium sorbate, 0.02gm sodium benzoate, 0.015gm stevia, 0.35gm malic acid, 95ml water, 5gm WPI, 0.20gm flavor, 0.002gm color at 5°C.

F2= 2gm CO₂, 0.10 gm potassium sorbate, 0.02gm sodium benzoate, 0.015gm stevia, 0.35gm malic acid, 95ml water, 5gm WPI, 0.20gm flavor, 0.002gm color at 5°C.

F3= 3gm CO₂, 0.10 gm potassium sorbate, 0.02gm sodium benzoate, 0.015gm stevia, 0.35gm malic acid, 95ml water, 5gm WPI, 0.20gm flavor, 0.002gm color at 5°C.

F4= 4gm CO₂, 0.10 gm potassium sorbate, 0.02gm sodium benzoate, 0.015gm stevia, 0.35gm malic acid, 95ml water, 5gm WPI, 0.20gm flavor, 0.002gm color at 5°C.

The F4 sample was chosen because it had improved mouth feel, texture, flavor, and appearance. Because carbon dioxide was less soluble at higher temperatures, the results were not satisfactory for other samples. The F4 sample was ultimately approved as carbon dioxide

was dissolved properly giving fizzy consistency to the final product. The final choices about texture, acceptability overall, and nice aroma have been made based on sensory evaluation.

Chemical parameters of final product

Table 3: Chemical parameters of control sample and final product

Parameter	Final product
Total solid	8.5±0.3
Protein (%)	4.46±0.3
Fat (%)	0.12±0.1
Ash (%)	1.3±0.003
Crude fiber (%)	0.44±0.18
Carbohydrate (%)	1.06±0.08
Acidity	0.19±0.1
pH	6.5±0.5

The table no. 3 provides an overview of the carbonated whey protein drink's chemical composition. The product is characterized by a total solid content of 8.5%, with a notable protein concentration of 8.63%, indicating a protein-rich formulation. It is extremely low in fat, containing only 0.12%, and has a carbohydrate content of 1.06%, making it low in calories from fats and sugars. The ash content is 1.3%, reflecting the mineral content of the product. The crude fiber is 0.44%, contributing to the dietary fiber intake. The product has an acidity level of 0.19, suggesting it has a mild acidic taste, while the pH of 6.5 indicates that it is close to neutral, which is generally favorable for consumption. Overall, the product appears to be designed as a high-protein, low-fat, and low-carbohydrate option, with a balanced pH and mild acidity.

STORAGE AND MICROBIAL STUDY OF CARBONATED WHEY PROTEIN DRINK

Effect of Storage study on microbial analysis of carbonated whey protein drink

In table no. 4, microbial parameters were observed after specific period of time for 30 days. The carbonated whey protein drink is stable for 30 days. The microbial results are within the FSSAI regulations. So, the sample F4 was finalized as carbonated whey protein drink. TPC was 260cfu/g until 15th day. The coliforms were

not detected in microbial analysis as we observed the sample for 30 days. The yeast and mould showed growth until 1cfu/g. These all results have shown that the sample is stable for 30 days. The sample was stored in PET bottles. These observations show that the final product can be stored for 30 days at refrigeration as well as room temperature.

Table 4: Effect of Storage study on microbial analysis of carbonated whey protein drink

Day	TPC	Yeast and mould	Coliforms
1	40cfu/g	Absent	Absent
3	100cfu/g	Absent	Absent
7	110cfu/g	Absent	Absent
15	260cfu/g	1cfu/g	Absent
30	280cfu/g	1cfu/g	Absent

Storage study effect on sensory attributes

Sensory evaluation of carbonated whey protein drink was done. The sample was kept at refrigeration and room temperature also.

In table no. 5, Sample F4 was kept at room temperature and later the sensory evaluation was done after specific time period for 30 days.

Table 5: Sensory attributes during Refrigeration storage

Day	Appearance	Color	Flavor	Taste	Overall acceptability
1	8.5	8.5	8	8.5	8
3	8	8	8	8	8
7	8	8	8	8	8
15	7.5	8	8	7	7.5
30	7.5	8	7	7	7.5

In table no. 6, Sample F4 was kept at refrigeration temperature and later the sensory evaluation was done after specific time period for 30 days. The Sensory study during storage was done for over 30 days at room temperature and refrigeration temperature. Overall acceptance of carbonated whey protein drink was good.

Table 6: Sensory attributes during Room temperature storage

Day	Appearance	Color	Flavor	Taste	Overall acceptability
1	8.5	8.5	8	8.5	8
3	8	8	8	8	8
7	8	8	8	8	7.5
15	7.5	8	8	7	7.5
30	7	8	7	7	7

CONCLUSION

In this Research, by understanding and optimizing the physico-chemical properties of raw materials, refining preparation methodologies, evaluating quality parameters, and assessing shelf life, this study has laid a strong foundation for the successful introduction of carbonated whey protein drinks. Solubility of WPI in water was studied. The strategies developed to mitigate the bitterness of whey proteins and improve sensory attributes through natural sweeteners, taste enhancers, and carbonation has proven effective. Additionally, the role of preservatives in extending shelf life has been confirmed, ensuring the commercial viability of these beverages. The carbonated whey protein beverage, designated as Sample F4 (comprising 4g CO₂, 0.1g potassium sorbate, 0.02g sodium benzoate, 0.015g stevia, 0.35g malic acid, 95ml water, 5g whey protein isolate, 0.20g flavor, and 0.002g color at 5°C), exhibited the highest tactile score among all evaluated samples. This particular formulation underwent stability testing over a 30-day period, yielding promising and encouraging results. This product serves as an advantageous option for athletes and individuals seeking a high-protein, sugar-free alternative to conventional carbonated beverages, thus offering a novel and salutary substitute in the competitive market.

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Advances in Cassia Tora Gum by Modification & Its Uses in the Food Industry

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ABSTRACT

A natural seed polysaccharide called Cassia Tora hydrocolloid is a valuable resource with a wide range of uses in the food sector. Galactomannan, a component of Cassia Tora Gum's composition and structure, offers superior thickening, stabilizing, and emulsifying properties for food processing and preservation. Cassia Tora Gum is produced by extracting the seeds and passing through a variety of processing stages to produce a high-quality gum. Cassia tora gum can be chemically altered through processes like cyanoethylation and carboxymethylation to enhance its functional characteristics for particular and wide range applications. These modifications improve rheological characteristics, stability, and compatibility in a variety of systems. Overall, Cassia Tora Gum is a promising natural hydrocolloid with a wide range of uses because of its distinct composition, flexible chemistry, sustainability, and beneficial properties that satisfy the evolving demands of the food industry. The market for Cassia Tora gum will also profit from rising health consciousness among consumers and a rise in the desire for wholesome, clean-label products.

KEYWORDS: *Hydrocolloid, Galactomannan, Polysaccharide, Thickener, Stabilizer, Sustainable food, Applications, Cassia Tora.*

INTRODUCTION

Polysaccharides are complex carbohydrates consisting of monosaccharide groups linked by glycosidic linkages, forming the macromolecules found in nature (Mohammed et al., 2021). Polysaccharides are useful for various industrial applications (Liu et al., 2015). Polysaccharides can be chemically and physically modified to enhance their properties for specific applications. They play role in biomedical applications due to safety, low cost, stability, water stability, bio-compatibility and compatibility for various purposes (Liu et al., 2015; Seidi et al., 2022). The food industry often utilizes natural polysaccharide gum because of its distinctive characteristics. Gums provide numerous benefits including stabilizing, thickening, emulsifying, and surface-active properties. Plant gums are widely employed in all kinds of processed food products to enhance the textural qualities of food and extend shelf

life (Eghbaljoo et al., 2022; Da et al., 2020). Some commonly used gums include xanthan gum, guar seed gum, carrageenan gum, locust bean gum, and cellulose gum, each offering specific functional qualities that contribute to the desired textural characteristics and longevity of food products (Cui et al., 2005; Milani and Maleki, 2012). The use of leguminous seeds as a source for hydrocolloids in industries like food and pharmaceutical is being explored. (Ibanez and Ferrero, 2003). Galactomannans, found primarily in leguminous plant seeds like guar, locust bean, and fenugreek, are polysaccharides with a mannose backbone and galactose side groups. Galactomannans serve as viscous solutions, stabilizers, emulsifiers, and thickeners, contributing to the texture, stability and shelf-life extension of various food products (Phillips and Williams, 2009; Nussinovitch, 1997). Cassia Tora Linn. belongs to family Leguminosae is annual shrub all over the tropical areas (Kumar et al., 2022). Cassia

tora Linn, a leguminous plant, is widely distributed. (Murty and Iyer, 1956). Cassia tora seeds have unique galactomannan structures that make them useful in various industries. Cassia tora gum (CTG) is a natural biopolymer extracted from the seeds of the Cassia tora plant, which is part of the Leguminosae family. The main components of CTG are galactose and mannose units. It consists of a galactomannan backbone made of (1→4)- β -D-mannopyranose (M) units and (1→6)- α -D-galactopyranose (G) side chains. (Mahungu and 55 Meyland, 2021; Sarwa et al., 2022). Cassia Gum, extracted from Tora seeds, is gaining attention in the food industry for its valuable functional properties. This versatile hydrocolloid offers several advantages, including enhancing texture, retaining moisture, and mimicking fat, making it a favorable substitute for synthetic additives. Cassia Tora Gum stands to play a significant role in various food applications. This review offers a detailed overview of the significance, characteristics, and possible versatile uses of this naturally occurring hydrocolloid. The market for hydrocolloid is expanding due in large part to the growing need for food to feed a growing population, the expanding economics of developing countries and their adaptable use in manufacturing, the rise in consumers who are more conscious of nutrition, and the growing desire for clean label products (Manzoor et al., 2020).

COMPOSITION AND STRUCTURE OF CASSIA TORA SEED

The approximate composition analysis of Cassia Tora seeds shows varied value for different nutritional components. Proximate composition analysis values such as moisture content ranged from 10.82% to 11.50%, ash content from 4.44% to 4.69%, while protein content showed wide variation from 13.79% to 23.44% and similarly lipids or fat content showed very wide variation of 9.25% to 16.01% and crude fiber content from 7.78% to 28.13% and carbohydrate content also show wide range from 25.68% to 58.33%. On the other hand, every 100 grams of presence of calcium content in Cassia Tora seeds were 630 mg, iron 37.1 mg and phosphorus 240 mg which is about the presence of various valuable minerals. (Sahu et al., 2023; Shaikh and Syed, 2016).

Carbohydrate polymers called galactomannans are

mostly present in the seeds of plants belonging to the Leguminosae family. Galactomannans are composed of β -1,4-D-mannopyranose units arranged in a linear chain, while α -D-galactopyranose branch as a single unit through 1,6 connections. The insertion of galactose onto the mannan backbone has a substantial effect on its characteristics. Increases in solubility and hydrophilicity onto the mannan backbone result from this modification (Dea and Morrison, 1975; Dey, 1978). Hulk (27%), endosperm (32%), and germ (41%) make up a Cassia Tora seed (Sharma et al., 2002). About 75% of the gum in cassia tora is made up of polysaccharides (Hallagan et al., 1997). Galactomannans make up the primary chain of Cassia Tora galactomannan, a later-stage component. Its structure is made up of side chains of (1→6)- α -D-galactopyranose units and (1→4)- β -D-mannopyranose units with a 5:1 (Man/Gal) ratio (Figure 1). Cassia tora galactomannan has special qualities due to its unique Man/Gal ratio, which makes it a useful raw material for a variety of industrial uses (Srivastava & Kapoor, 2005; Sharma et al., 2020).

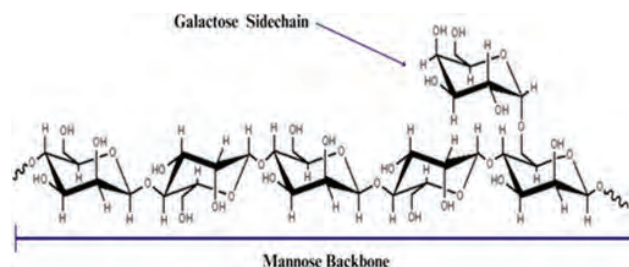


Fig. 1. Structure of Cassia Tora Galactomannan

PRODUCTION OF CASSIA TORA GUM

Process flowsheet for extraction of Cassia Tora Gum suggested by (Nemade and Sawarkar, 2015) is shown in Figure 2. To extract Cassia Tora Gum, the seeds first undergo cleaning, then grinding and sieving operations to separate the endosperm from the hull and embryo, based upon differences in their hardness. When these procedures are coupled with further physical treatments, the seed breaks and its components separated. The endosperm, which is rich in galactomannan, is separated from the protein-rich germ part. Next, the Cassia Tora split endosperm is ground into a powder. After fat is removed from the prepared powder, Native (Natural) Cassia Tora gum is obtained. Extracted Cassia Tora gum is utilized in a variety of industries.

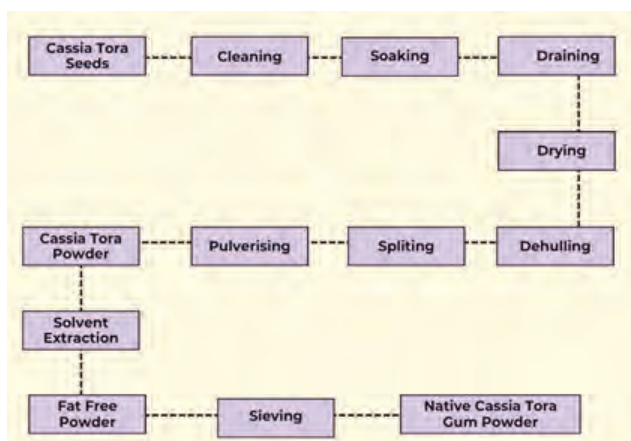


Fig. 2. Process Flow-sheet for Extraction of Cassia Tora Gum

PROPERTIES OF CASSIA TORA GUM

Cassia Tora Gum powder is a fine, off-white to yellowish powder with a neutral odor and taste. It has a bulk density of 0.6 kg/l and a particle size less than 250 microns. This fine particle size makes it suitable for dispersion in various food applications. The gum is insoluble in ethanol but disperses effectively in cold water, forming a colloidal solution that acts as a thickening agent. The pH range for Cassia Tora Gum is 5.5 to 8.0, and its viscosity exceeds 260 mPas at a 1% concentration, which are essential parameters affecting its performance as a stabilizer and thickener in food products. (Mahungu and Meyland, 2008).

MODIFICATION OF CASSIA TORA GUM

Cassia gum can be modified by employing different methods and hence custom-designed to impart a particular function beyond the general characteristics or for a specific targeted application, different chemical and physical modifications are possible. These can be through cross-linking, blending with other gums, or derivatization with other polymers. Modified cassia gum shows better rheological properties and exhibits better stability and compatibility toward most diversified systems than native ones do, giving diversification possibilities in food, pharmaceutical, cosmetics, and textile industries.

Sharma et al., 2020 investigated on Microwave-Assisted Synthesis of Carboxymethyl Cassia Gum. The use of microwave in the carboxymethylation of Cassia Gum

resulted in the optimization of the process, with the optimal parameters being a microwave power (50 W) and exposure time carboxymethylated gum with a high degree of substitution of 2.5. The carboxymethylation process was confirmed through structural changes identified using FTIR and XRD. Ultimately, the microwave-assisted carboxymethylation of Cassia gum was found to be a viable method for preparing modified gum with potential pharmaceutical applications.

In another study limitation in multiple industries due to the inherent properties of cassia seed polysaccharides can be addressed by the method reported by Chunmei et al., 2021, in which the polysaccharides were modified. Cassia seed polysaccharides were taken and placed in a dispersion liquid, and then an etherification reaction was accomplished to address non-ionic at 7.36 min. This resulted in replacements and limit the non-ionic monomer. The

method allowed for pH (10-13) and temperature (62-70°C) to be adjusted, thus permitting introduction of a phase transfer catalyst, non-ionic monomer and alkaline matter.

The invention reported by Chunmei et al., 2022, related to the modification of Cassia Seed Polysaccharide. The two-step process starts with the substitution reaction of cassia seed polysaccharide with bromosuccinimide, where the hydroxymethyl hydroxyl groups are bromine-substituted, resulting in brominated cassia seed polysaccharide. In the second stage, under alkaline conditions, the hydroxyl of the oxygen-containing o- ketone in mixed tea first converts into an oxygen-containing heterocyclic o-ketone oxygen anion. This leads to nucleophilic substitutions between oxygen anions and bromine on cassia seed polysaccharide, a very potent free radical scavenger.

Similarly, Gupta et al., 2005 described the chemically modification of Cassia seed gum (CTG) through carbamoylethylation method. This study was an attempt to improve the solubility and rheology of solutions made from the gum for its greater industrial usage. The results showed that the extent of reaction for carbamoylethylation increased with an increase in the conc. of sodium hydroxide up to 0.125 mol. The temperature was also found at 30°C with a reaction time 3 hrs. as the optimal conditions for this reaction.

Changes in the chemical structure of the gum were observed with FT-IR spectroscopy of the modified gum.

The modification of cassia seed gum by cyanoethylation was reported by Rajput et al., 2015 which involves the reaction of the gum with acrylonitrile in the presence of alkaline solution 148 of NaOH. The process is conducted at different reaction conditions, including alkali solution concentration, acrylonitrile concentration, gum ratio, temperature required to complete reaction, and its time. The resulting cyanoethyl-CAG has higher nitrogen content, degree of substitution, and reaction efficiency. The properties of modified gum show such as non-Newtonian, pseudoplastic behavior, viscosity improvement, Solubility in cold water, gum stability, and clarity of gum solutions. The modification process enhances the industrial utility of the cassia seed gum for various applications.

APPLICATIONS OF CASSIA TORA GUM IN FOOD INDUSTRY

Cassia Tora gum has lots of industrial applications. It is applied majorly in all manners of food industries as a thickener, stabilizer, or gelling agent.

The system of gelling and thickening agent is patented from cassia galactomannan-based (Kuhn, 1989). In this sense, it is a really synergistic combination: cassia galactomannan with carrageenan, agar, and/or xanthan gum. The new preparation from cassia seeds shows excellent synergism with extracts from red algae and biopolymers of this kind. This potassium, calcium, and/or ammonium ions, are added together with agents of gelling and thickening to enhance the properties of forming. High improvements were noted in the gelling and thickening capacity of these agent products across a wide range of industrial applications with high usage in many fields like food, pharmaceuticals, cosmetics, paper manufacturing, explosives formulations, water treatment, etc., as reported in this patent.

Veen and Budemann, 2013 reported that Fat substitute compositions comprising inulin and cassia gum (CTG). Cassia gum (CTG) is basically used in a number of applications owing to its property to hydrate and build up a colloid in hot water. It has associated impacts of thickener, emulsifier, and binder of food products. It is further utilized as a fat substitute combined with inulin

which will incorporate a composition of fat substitutes that give attributes similar to those of fats based on food products; will offer a mouthfeel, body, and texture akin to those of fat-based products and yet appear to have an identity alike traditional fat-based product.

In various products, Hoover, 2015 reported the application of cassia gum, where Cassia gum is used as a principal constituent for the preparation of thickener compositions, especially when combined with highly esterified pectin. Such compositions are preferably characterized by specific weight ratios of cassia hydrocolloid to highly stable pectin from 90:10 to 10:90, more preferably 80:20 to 40:60 and even more preferably from 70:30 to 50:50. Such cassia gum is derived from the plant sources *Cassia tora* and *Cassia obtusifolia*, which find utility in the acceleration and improvement in rheology, sensory properties of food and fodder compositions. In food compositions, the thickener composition further includes fats and proteins, especially in dairy products like yogurt, which combines the thickener composition 184 of cassia gum and highly esterified pectin. The component of dairy can be anything from milk to yogurt.

The process for creating a gelling agent including cassia gum that melts at a temperature similar to that of carrageenan was published in a 2007 patent by Horie and Iwamoto. In addition to being easy to handle even at a lower melting temperature than a commonly known locust bean gum-containing gelling base, the present invention's mixed product of cassia gum and carrageenan can find a wide field of uses for many foods as a thickening or gelling agent, among them being the fruit jellies, Jam, puddings and desserts, soy milk puddings, etc.

Jules et al. (2017) reported that by mixing first and second hydrocolloids in the following way, their method enhanced the mouthfeel of beverages: The first hydrocolloids with inherent viscosity ranging from 5 to 600 ml/g were selected from a variety of sources, including low molecular weight carboxymethylcellulose, arabic gum, apple pectin, and sugar beet pectin. From the category that includes guar gum, locust bean gum, cassia gum, pectin derived from plants, high molecular weight carboxymethylcellulose, carrageenan, alginate, xanthan, and their combinations, a second hydrocolloid is chosen.

Ackerkamp et al., 2013 reported that cassia gum is a hydrocolloid and is obtained from the endosperm of the seeds belonging to the plants of either *Cassia tora* or *Cassia obtusifolia*. It forms a major constituent of the gelling agent of the packaged concentrate. Through its combination with xanthan gum, it brings the desired gel formation through which the texture and stability essentials the base concentrate gets derived. The cassia gum (CTG) as a gelling agent in this blend provides the gel with flexibility, hence it cannot be too rigidly solid and allows free run-off from packaging at a high level. In so doing, it avoids the low syneresis tendency of the concentrate and hence improves shelf stability and visual appeal. The proper amount of cassia gum in the blend of gelling agents will provide the best functionality of the gel to form a rapid dissolution in boiling water while keeping the form and flavor of the concentrate.

CONCLUSION

The investigation of Cassia Tora Gum in this review paper sheds light on its importance as a natural polysaccharide with enormous potential in a variety of food sectors. This analysis serves as the foundation to establish plant seeds as a useful resource for a variety of uses and an alternate source of gum. The comprehensive insights into the preparation procedures show the intricate method of extracting Cassia Tora Gum to ensure its purity and efficacy in many applications. Furthermore, the suggested chemical changes highlight Cassia Tora Gum's adaptability. These modifications not only increase the gum's rheological properties, but also broaden its applications in a variety of industries. Furthermore, the thorough examination of cassia gum's characteristics emphasizes its importance as a food additive. Its capacity to function as a thickener, stabilizer, and emulsifier demonstrates its versatility and adaptability in many food products. The increased use of hydrocolloids in numerous industries during the anticipated period will undoubtedly have a positive impact on novel Cassia Tora Gum.

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Development and Quality Evaluation of Airfried Multigrain Nachos

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ABSTRACT

The present investigation was carried out to access the development and quality evaluation of airfried multigrain nachos. Nachos is a mexican dish prepared using heated tortilla chips made of corn blended with various seasonings to enhance the taste, flavour and overall acceptability of the product. Multigrains such as oats, ragi, rice can be combined together with corn to provide bundle of nutrients, various phytochemicals. Air frying technique is used to optimize the product with appropriate time temperature combination compared to other frying technologies. To obtain high accuracy results, response surface methodology (central composite design) is used to determine the effects of changes of ingredients levels on response scores of nachos such as moisture content, hardness, crispness, taste and overall acceptability. It resulted in gradual increase or decrease in the given response scores by changing each factor values and gave out the best solution for optimization. 70 % corn,

20.3 % oats, 16.7 % ragi and 12.5 % rice flours were predicted with acceptable response score of 1.46% Moisture content, 746.7 N hardness, 7.17 Crispness, 7.43 Taste, 7.18 Overall acceptability with desirability of 0.687. This research has enhanced how combined process variables influence the quality attributes of air-fried multigrain nachos.

KEYWORDS: Air frying, Multigrains, Nachos, Response surface methodology.

INTRODUCTION

A snack is a smaller-than-normal serving of food that generally gets eaten in between meals. Ready-to-eat snacks are increasing in prominence among customers principally on account of its accessibility, ease of use, look, flavor, and texture. and changes in consumption habits i.e., modernization and globalization made people very busy which results in shortage of time for cooking. With an increase in urbanization, industrialization and change in people's lifestyles there is demand for convenient as well as nutritious food product which is

available within short period of time. (Nicklas et al., 2003).

A popular snack or appetizer, nachos are a northern Mexican meal primarily up of hot tortilla or totopos chips layered with melted cheese. Additional variables propelling the Indian nachos market include evolving consumer preferences for fast food, the growth of fast food chains, and the strong performance of the retail industry. The store features nachos in a variety of palates, including cheese, salted, tomato, mint, jalapeño, and others. Multigrains provides bundle of

nutrients, variety of phyto-chemicals, flavours and also helps in improving textural and sensory quality of food product. A health beneficial effect of multigrain product is due to incorporation of whole grains. Whole grains intake helps in lower the risk of cardiovascular diseases, ischemic stroke, type 2 diabetes, metabolic syndrome and gastrointestinal cancers. It also provides health promoting factors like vitamins, minerals and phyto-chemicals which has phenolic compounds. Poly phenol compound have anti-oxidant and antiradical properties which helps in protecting against degenerative diseases. (Harborne and Williams, 2000).

Multigrains such as Oats are an outstanding source of cellulose, arabinoxylans, and other β -glucans. Protein, lipids, vitamins, antioxidants, phenolic compounds, and ions are all discovered in higher concentrations. It contains soluble fibres which helps in reducing elevated blood cholesterol, triglyceride glucose level (Wani et al., 2014).

Similarly, Finger millet is a abundant source of calcium, phosphorus and iron It is also rich in vitamins like thiamine, riboflavin, folic acid and niacin (Vaidehi, 1980). Due to its extensive consumption, rice has been recognized as a promising food carrier for nutritional fortification. Rice has low fat, low cholesterol, low fat content and therefore it is extremely soothing to digestive system. Rice provides great energy source, cholesterol rich in vitamins and minerals (Rohman et al., 2014).

Corn contains significant amounts of bioactive compounds providing desirable health benefits. Eating corn and other whole grain foods has been connected to enhanced digestive tract health and a lower likelihood of chronic illnesses like obesity, type 2 diabetes, cardiovascular disease, and multiple forms of cancer. (Siyan et al., 2018).

The technology of air frying was first offered in a handful of European countries, and owing to the product's spectacular reception, it was later introduced across the continent. It has been a tremendous hit all across the world as it has expanded over time. When compared to deep-frying, the revolutionary process cook's food quickly yet retains an appealing texture and up to 80% less fat (Zaghi et al., 2019). This research aims on optimization of airfried multigrain nachos

and quality evaluation based on physicochemical and sensorial attributes.

MATERIALS AND METHODOLOGY

Materials and Chemicals

The procurement of main ingredients – corn, oats, ragi and rice based on quality standards were utilized from the supermarket. Chemicals required for chemical analysis of raw materials and prepared products was obtained from Shivaji University Kolhapur.

Methodology

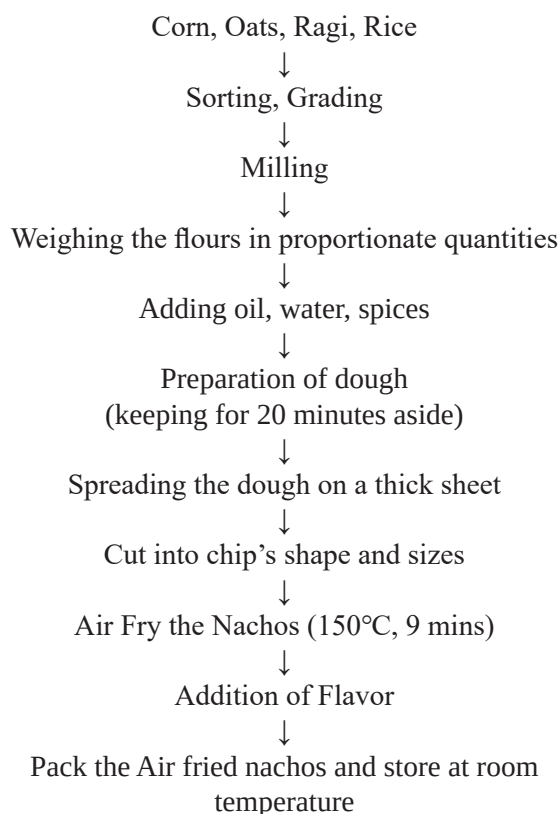


Fig. 1: Flowsheet for preparation of Airfried multigrain Nachos (Neha et al., 2023).

Optimization of Airfried Multigrain Nachos using Experimental Design

The optimization of Airfried Multigrain Nachos was done with the help of Response Surface Methodology (RSM) using Design Expert Version 13. A combination of 30 experiments was generated in the Design Expert software using a Central Composite Rotatable Design during the investigation. Responses kept in minimum

(moisture content, hardness) and maximum (taste, crispness and overall acceptability) were selected as responses for the optimization of ingredients to develop airfried multigrain nachos.

Physicochemical Analysis

Physical Attributes of optimized final product such as Color measurement by hunter color determination (L^* , a^* , b^* values) were obtained. Chemical analysis included Ash composition using a muffle furnace, moisture levels using a hot air oven, Fat content by Soxhlet method, Protein content by micro- kjeldahl method and crude fiber content by acid- alkali treatment. The procedures for chemical analysis were obtained with the help of A.O.A.C, 2000. Carbohydrate content was also determined and energy value was calculated respectively respectively shown in table 5.

Sensory Evaluation

20 panelists with some expertise conducted the sensory assessment. The sensory components such as appearance, taste, texture, and general acceptability shown in table 4 were evaluated employing a hedonic scale with nine ratings in the hedonic grading test.

Statistical Analysis

The improvement of the variable levels was practiced by charming increase in the sensory, physical and chemical reaction along the response alongside the fitted polynomial model. Analysis of variance (ANOVA) was implemented for every response for assessing the statistical significance of the variables included in the regression equations.

($P < 0.05$) showed the model is significant for the given final product.

RESULT AND DISCUSSION

The current research's outcomes were presented and debated under the right headings in perspective with the existing body of pertinent scientific literature.

The independent variables and their corresponding ranges are as follows: for Corn, the values range from 70 to 100; for Oats, the values range from 15 to 25; for Ragi, the values range from 10 to 20; and for Rice, the values also range from 10 to 20. These values define the lower and upper limits for each of the variables.

For the five reactions viz., moisture content, hardness, crispness, taste & overall acceptability were chosen. The goal set for four elements and five reactions were analyzed to in table 1 and RSM experiments, best arrangement was given table 1.

Table 1. Coefficients of Quadratic Polynomial model for coded sample

Factor	Response Score				
	Moisture (%)	Hardness (N)	Crispness	Taste	Overall Accepta
Intercept	1.46	845.87	7.5	7.75	7.45
A- Corn	0.0912	34.64	-0.0667	-0.05	-0.0042
B- Oats	0.0479	19.74	0.0583	0.4	0.0875
C- Ragi	0.0379	0.0458	0.1417	0.05	0.1125
D- Rice	0.0704	5.55	0.0583	-0.0833	0.1208
- value	23.3	65.78	14.99	16.22	11.9
Mean	1.73	767.43	6.69	6.94	6.84
SD	0.0564	11.91	0.1905	0.2209	0.1638
Adequate Precision	14.1257	34.281	12.7462	11.7927	9.8923

Table 1 indicated Coefficients of Quadratic Polynomial model for coded sample. Factors such as Intercept, Independent variables (Corn, Oats, Ragi, Rice, F value, Mean, Standard Deviation & adequate precision respectively were shown in table 1.

Effect on Moisture Content

It was observed that moisture content gradually decreased at a temperature of 150°C for 9 minutes ranged from 1.42% to 2.02%. When oats, ragi, and rice were added to corn (the control), there was a slight change in moisture content, with some cases showing an increase and others a decrease. The design showed a high coefficient of determination ($R^2 = 0.956$) and adequate precision (14.1257), indicating the model fit well (F model = 23.3). The coefficient for moisture content revealed that different factors significantly affected the readings, with positive and negative signs indicating the impact of independent variables. Table 2 displayed these effects clearly. A moisture content of 1.46% was desirable across all standard runs.

However, an increase in moisture content to 2.02% altered the desirability of the air-fried multigrain nachos.

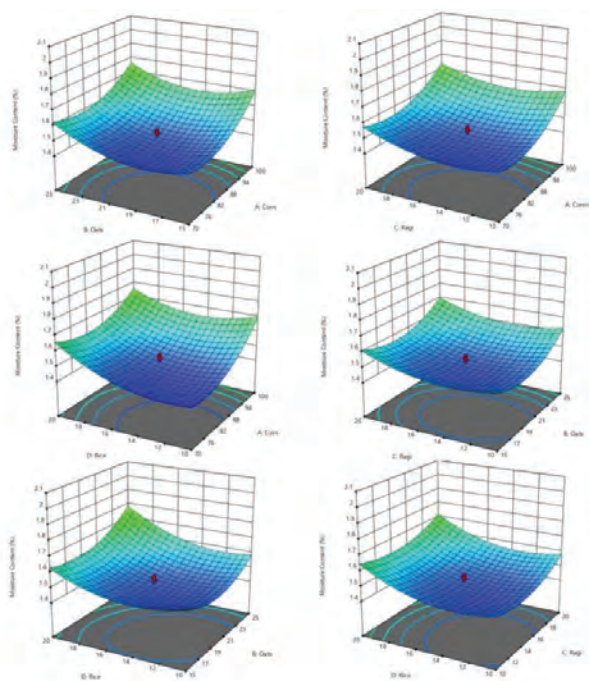


Fig 2. Response Surface graphs for effect on Moisture Content

Where,

AB = Effect of Corn and Oats, AC = Effect of Corn and Ragi, AD = Effect of Corn and Rice

BC = Effect of Oats and Ragi, BD = Effect of Oats and Rice, CD = Effect of Ragi and Rice

Effect on Hardness

Changes in hardness have been reported to be altered by the quantities of starch, the size of the starch granules, pectic compounds, cell wall polysaccharides, and non-starch polysaccharides during frying. The hardness of air-fried multigrain nachos ranged from

557.2 N to 854.6 N. The lowest score was 557.2 N at 150°C for 9 minutes, while the highest score was

854.6 N. Table 10 showed that the coefficient of determination (R^2) was 0.984, with an adequate precision of 34.281, indicating a high limit. The test also demonstrated the model was significant with an F value of 65.78. The coefficient for the hardness model showed that specific factors significantly affected the rating. The table illustrated that changes in hardness depended on the composition of corn, oats, ragi, and rice

at certain time-temperature combinations. The positive and negative signs indicated the effect of hardness on different factor levels, affecting the textural properties of the prepared air-fried multigrain nachos.

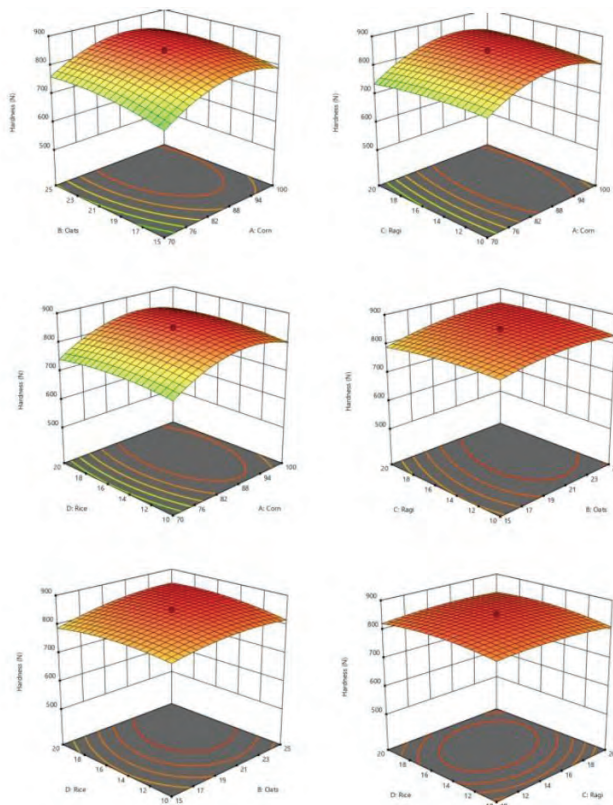


Fig. 3. Response Surface graphs for effect on Hardness value

Effect on Taste

At a constant time-temperature combination, the taste was significantly affected by the composition of the independent variables, especially with increased incorporation of ragi and rice. The coefficient for the taste model illustrated that the acceptance quality was influenced by specific runs. The analysis showed a coefficient of determination (R^2) of 0.938, indicating strong predictive power. Adequate precision was 11.7927, further supporting the model's reliability. The model was significant with an F value of 16.22. The taste of air-fried multigrain nachos ranged from 5.8 to 7.9. The most unacceptable score was 5.8, while the highest score was 7.9. Composition of 70% corn, 20.3% oats, 16.9% ragi, and 12.49% rice showed best taste effect shown in Table.

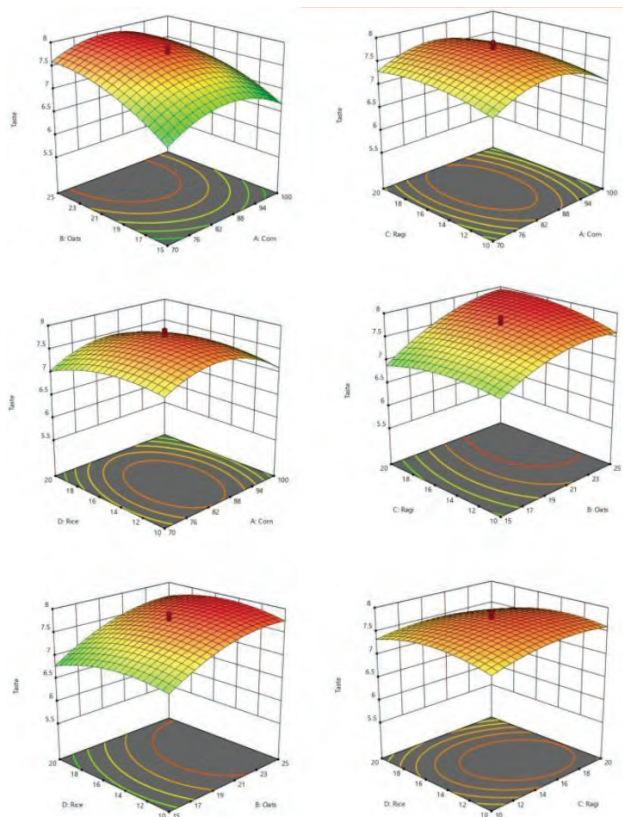


Fig. 4. Response Surface graphs for effect on Taste

Effect on Crispness

The coefficient for the crispness model indicated that certain runs had a significant impact on the quality of acceptance. To achieve optimal crispness, nachos require a coarse particle size and low moisture content. When corn was blended with oats and rice within the given upper and lower limit ranges, the response scores showed positive results with perfect crunchiness. However, ragi content above 18% was considered unacceptable for crispness. An increase in oats percentage made the final product soggy, as oats tend to absorb moisture and soften the texture. The analysis demonstrated a coefficient of determination (R^2) of 0.9333, indicating strong predictive power. Adequate precision for crispness was 12.7462. The model was significant for crispness with an F value of 14.99 shown in table 2. The crispness of air-fried multigrain nachos ranged from 5.9 to 7.7. The lowest score for crispness was 5.9, while the highest score was 7.7 as predicted by the RSM experimental design.

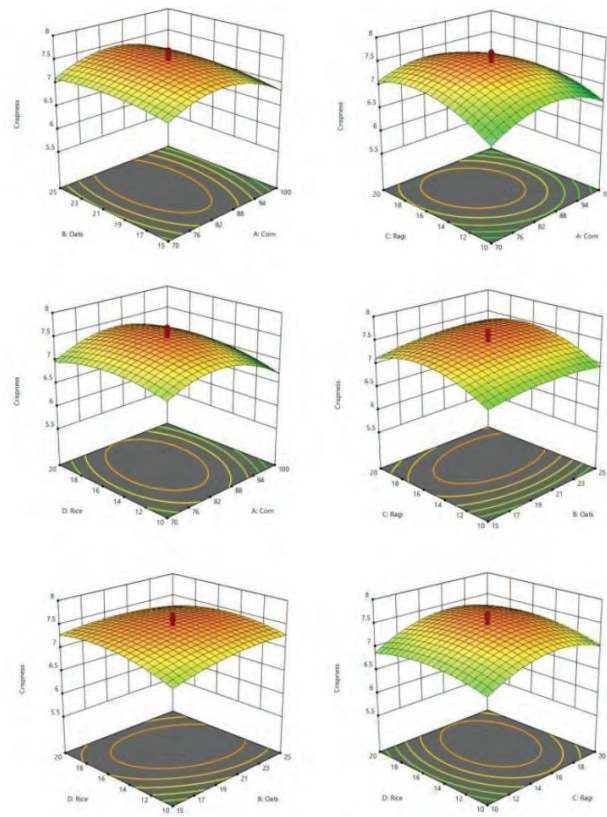


Fig. 5. Response Surface graphs for effect on Crispness

Effect on Overall Acceptability

Overall acceptability was influenced by factors such as crispness, hardness, taste, and moisture content, as well as changes in color due to time and temperature. Darker colors were generally less acceptable, while lighter or moderate colors were more acceptable, as shown in Table 2. The optimized final product achieved an overall acceptability score of 7.20 or above. The overall acceptability of air-fried multigrain nachos ranged from 5.0 to 7.85. The lowest score for overall acceptability was 5.0, while the highest score was 7.85. The analysis demonstrated a coefficient of determination (R^2) of 0.9174, indicating strong predictive power. Adequate precision for overall acceptability was 9.8923. The model was significant with an F value of 11.90.

Table 2. Solution given by Experimental Design

No	Corn	Oats	Ragi	Rice
1	70.00%	20.34%	16.95%	12.49%

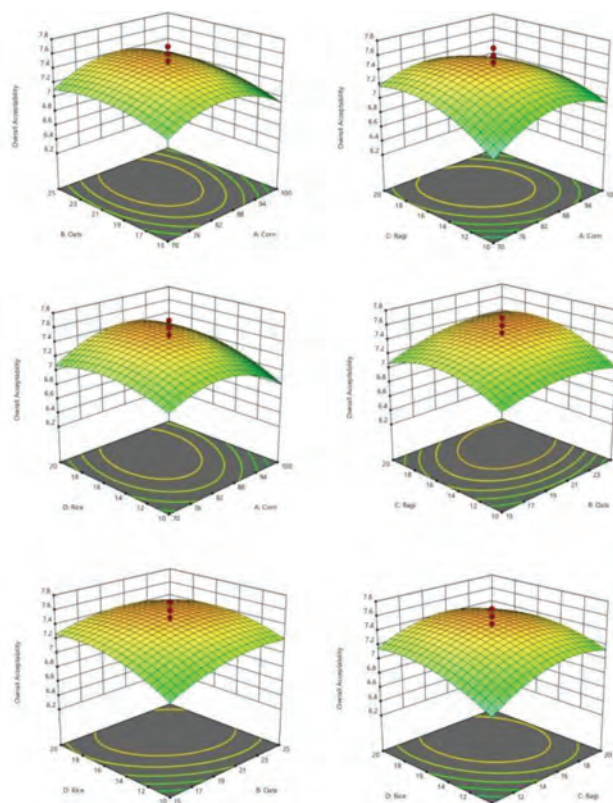


Fig 6. Response Surface graphs for effect on Overall Acceptability

Solution represented in table 2 were given after optimization of independent variables with their response scores using response surface methodology (Central Composite Design).

Table 3. Predicted Score and Actual Score by Experimental Design

Constraints	Predicted Score	Actual Score
Moisture Content (%)	1.46	1.47 ± 0.05
Hardness (N)	746.7	750 ± 0.02
Crispness	7.71	7.75 ± 0.01
Taste	7.43	7.48 ± 0.01
Overall Acceptability	7.18	7.20 ± 0.04

Table 3 showed the predicted & actual score of constraints. The actual score of optimized final product for moisture content was 1.47 ± 0.05 . The actual score of hardness was 750 ± 0.02 . Similarly, the actual score

for crispness, taste and overall acceptability was 7.75 ± 0.01 , 7.48 ± 0.01 , 7.20 ± 0.04 respectively showing higher accuracy results.

Table 4. Physicochemical analysis of Airfried Multigrain Nachos

Parameters	Airfried Multigrain Nachos
Moisture (%)	1.4 ± 0.2
Ash (%)	1.9 ± 0.3
Protein (%)	11.5 ± 0.2
Fat (%)	5.0 ± 0.04
Crude Fibre (%)	4.6 ± 0.05
Carbohydrates (%)	80.2 ± 0.3
Peroxide Value (meq/kg)	3.78 ± 0.2
Phenolic Compounds (mg/g)	1.542 ± 0.03
Antioxidant Activity (%)	35.8 ± 0.01
Energy (Kcal)	411
L* value	41.03
a* value	19.25
b* value	35.97

Table 4 illustrated physicochemical analysis of airfried multigrain nachos. Moisture content for airfried multigrain nachos was 1.4 ± 0.2 . On the other hand, Ash content was 1.9 ± 0.3 , protein content was found to be 11.5 ± 0.2 and fat content 5.0 ± 0.04 was calculated. The crude fibre value obtained was 4.6 ± 0.05 . The carbohydrate content was found to be 80.2 ± 0.3 . The peroxide value of optimized product was 3.78 ± 0.2 meq/kg fat. Similarly, the phenolic compounds value and the antioxidant activity were found to be 1.542 ± 0.03 & 35.8 ± 0.01 % respectively. The energy value was calculated considering other values and was found to be 411 kcal. Similarly, physical parameter such as color values were determined. L*, a*, b* values for airfried multigrain nachos $L^* = 41.03$, $a^* = 19.25$, $b^* = 35.97$ respectively.

CONCLUSION

This research focused on developing air-fried multigrain nachos to improve their nutritional quality. The addition of multigrains significantly affected the nachos physicochemical, textural, and sensory properties. Multigrains such as oats, ragi, rice can be

combined together with corn to provide bundle of nutrients, various phytochemicals. Air frying technique is used to optimize the product with appropriate time temperature combination compared to other frying technologies. Response Surface Methodology (RSM) was used to model and optimize the parameters. The R^2 values for these response scores were all above 0.9, confirming the model's accuracy. A P-value of less than 0.05 indicated the significance of the model terms. In this case, it showed a gradual increase and decrease in response scores. The study showed that the response scores varied with changes in the formulation. By using a time-temperature combination of 150°C for 9 minutes, the response scores for moisture content, hardness, crispness, taste, and overall acceptability were determined. The optimal formulation was 70% corn, 20.3% oats, 16.9% ragi, and 12.5% rice. This approach highlights the health benefits, and the advantages of air frying which can appeal to consumers looking for healthier snack options.

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Preparation of Invert Syrup from Jaggery

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ABSTRACT

Jaggery is sugarcane based traditional healthier Indian sweetener. Invert sugar syrup is the mixture of equal amounts of glucose and fructose. Invert syrup is used for caramelization, enhancement of flavor and texture of food products. The objective of this study is to prepare invert syrup from jaggery by using acid hydrolysis. Quality evaluation with respect to physiochemical and sensorial parameters of invert jaggery syrup was carried out. In the trials, weight of jaggery (250 g) and brix of jaggery solution (600) were kept constant while the citric acid concentration was gradually changed for preparation of invert jaggery syrup. In the present study, 0.5%, 1.5%, 2.5% and 3.5% citric acid was used for the acid hydrolysis. The sample prepared with 2.5% of citric acid was the best sample in terms of taste and inversion. The specific gravity, viscosity, and pH of the final product were 1.36, 560 centipoise, and 5.3 respectively at 28 ± 0.40 C. The prepared invert jaggery syrup was shelf stable for 60 days at room temperature.

KEYWORDS: *Jaggery, Invert syrup, Acid hydrolysis, Citric acid.*

INTRODUCTION

Jaggery is the sugarcane based traditional Indian sweetener. It is known by many different names in the world like panela (Latin America), jaggery (South Asia), kokuto (Japan), Gur/Desi (Pakistan), Rapadura (Brazil), NaamTaan Oi (Thailand), Hakura (Srilanka) etc. (Shrivastav et al., 2016; Vinutha et al., 2014 and Thakur AK. 1999). At present, 24.5% of the cane produced in India is being utilized for producing jaggery. Out of the total world production, more than 70% of the jaggery is produced in India. To meet the future sweetener requirement, the scope of jaggery seems to be promising.

In Maharashtra, Karnataka and Tamil Nadu jaggery used as natural and viable alternative for Sugar Nerkar.,

2004. It is nutritious and contains approximately 60-85% sucrose, 5-15% glucose and fructose, 0.4% of protein, 0.1 g of fat and 0.6 to 1.0 g of minerals (8 mg of calcium, 4 mg of phosphorus, and 11.4 mg of iron). It is also found to contain traces of vitamins and amino acids. 100 g of jaggery gives 383 kcal of energy. In Ayurveda, jaggery is considered as the best base material for the preparation of medicines. In contrast, the white crystal sugar contains only sucrose to the tune of 99.5% without any minerals Jaggery and sugar are the main sweetening agents which are added to beverage and foods for increasing palatability (Nath et al, 2015; Rao et al, 2007; Singhal, 2003; Thakur, 1999; Singh et al., 2011).

Invert Sugar Syrup

The mixture of equal amounts of glucose and fructose is called “invert” sugar in the sugar industry. Invert sugar syrup is a liquid carbohydrate sweetener in which all or a portion of the sucrose present has been inverted or broken into free glucose and free fructose (50% fructose, 50% glucose). It is the aqueous pharmaceutical preparation having the concentrated sugar solution with active and non-active ingredients (Syed et al., 2011). It helps to baked goods to retain moisture and prolong shelf-life. It is sweeter than table sugar because fructose is sweeter than both sucrose and glucose. It is often referred to as “artificial honey”. According to FPO specification, invert syrup is golden yellow in color, 74.0% Total solids, 80-100% inversion, 2-3% free sucrose, 3.5-5.5 pH, 35% fructose, 35% glucose, 0.20% ash soluble in water, glycerin and glycerol (Ranganna, S.1986).

Properties and application of invert sugar syrup

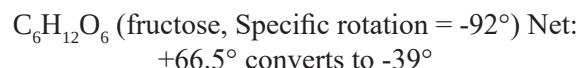
It has a high affinity for water, so that invert sugar syrup inhibits crystallization and retains moisture, and it is therefore used in products such as icing, cake filling and confectionery. It has lower water activity than sucrose, so it increases product shelf life. Chemically and physically it has the same properties as honey. It could be used for bee feeding and can be blended with honey.

Chemical reaction of the inversion and manufacturing process

The conventional method of manufacturing invert sugar involves acid hydrolysis. In this method, the 700 Brix of sugar cane syrup is used. Generally 2 to 4% citric acid is added and heating at 50 to 600 C for 2 hours. The acid converts sucrose into fructose and glucose (Onney and Thomas, 1973). As the solution converted to a mixture of sucrose, fructose and glucose, the amount of rotation reduced until (in a fully converted solution) the direction of rotation had changed (inverted) from right to left (<http://chefeddy.com/2009/11/invert-sugar/>).

Every year there are situation to increase the price of sugarcane as well as jaggery. But the farmer does not find a satisfactory answer to this. Many jaggery factories have closed down. Although the nutritional value of jaggery is very good, very few foods are made

from jaggery. As a result jaggery also does not get high rate. Currently, many products are made using invert syrup. If we make invert syrup from jaggery, jaggery can get many markets. Jaggery is also our traditional food. So, making invert syrup from jaggery can preserve our culture. The main aim of this work was to perform physicochemical analysis of jaggery and invert jaggery syrup. The optimization of process for production of the invert jaggery syrup and quality evaluation with respect to physiochemical and sensorial parameters along with the shelf life study were carried out.



Flow diagram: Inversion resection of sucrose to glucose and fructose



Fig. 2: Viscosity determination by Brook field viscometer

METHODOLOGY

Materials

Raw Materials

Kolhapuri Jaggery (sugar cane variety Co-86032) was purchased from Shahu Market Yard, Kolhapur, Maharashtra, India, 416005.

Other Ingredients

Citric Acid: The food grade citric acid was purchased from local market.

Packaged drinking water: Packaged drinking water available in the laboratory of Department of Technology, Shivaji University was used for preparation of invert jaggery syrup.

Equipment

Equipment such as hot water bath, thermometer, Brix meter, brook field viscometer, pH meter, and utensils were used for physicochemical analysis and preparation of invert jaggery syrup.

Analysis of raw materials and product Physical analysis of Jaggery

The color, physical state, taste and odor of jaggery were determined (Sarwar, et al., 2009).

Chemical analysis of Jaggery

The moisture, protein, fat, crude fiber and ash content of the jaggery and product were determined by using methods provided in Ranganna, 1986. The calcium, potassium, phosphorous and iron content were determined by AOAC method (Sarwar, et al., 2009). Reducing sugar was determined by DNSA method. Fructose was determined by Resorcinol method. The pH values measurement was made using a digital pH meter (Hanna Instrumentals). Viscosity was measured by using Ostwald viscometer (Ranganna, 1986). Degree Brix/ Refractive Index were measured by using Refractometer (Patil, S. D., and Anekar, S. V. (2014).

Preparation of invert syrup by acid hydrolysis method The food grade citric acid was used for hydrolysis of jaggery solution. The flow chart used for preparation of invert jaggery syrup by acid hydrolysis method as shown in figure 2.

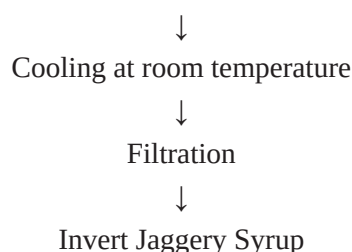
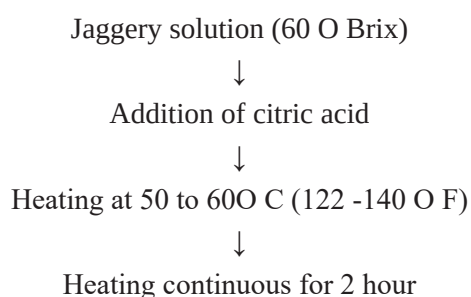


Fig. 2: Preparation of invert jaggery syrup by acid hydrolysis method

Storage Study

The product was stored at room temperatures, so that consistency of product and market sugar syrup maintained. High temperatures storage should be avoided due to the risk of discoloration. For storage 500 gram glass jar (acid-proof material) used. The storage bottles should be sterilized in order to avoid contamination and microbiological problems. Storage analysis was carried out on the basis of Color, Brix (TSS), pH and viscosity etc. The product was checked every 20 days after preparation.

RESULTS AND DISCUSSION

Physical analysis of Jaggery

In order to evaluate the nutritional value of jaggery and invert jaggery syrup, the proximate analysis and physiochemical analysis was carried out. The results obtained in physical analysis of jaggery are presented in table 1. The color of jaggery was light yellow to dark brown. It may be due to the high carbohydrate content of sugar cane. The physical state of jaggery was amorphous solid to viscous granular. Taste and odor of jaggery was characteristic sweet.

Table 1: Physical observation of jaggery

Parameters	Observation
Colour	Light Yellow to dark brown
Physical State	Amorphous solid to viscous granular
Taste	Characteristic jaggery (sweet)
Odour	Characteristic jaggery

Chemical analysis of jaggery

In order to evaluate the chemical composition of jaggery, the chemical analysis of jaggery was carried out and results obtained were presented in table 2.

Table 2: Chemical parameters of jaggery

Parameter	Amount
Moisture (%)	8±0.2
Protein (%)	0.4
Crude fat (%)	0.05±0.01
Carbohydrate (%)	77±0.6
Crude fiber (%)	Nil
Sucrose (%)	75±0.3
Reducing Sugar (%)	15±3
Ash (%)	1.5±0.3
Minerals (%)	0.8±0.03
Calcium (mg)	30±2
Potassium (mg)	35±1
Phosphorus (mg)	20±2
Iron (mg)	10±1
Acidity (%)	0.2

(All the given values are Mean ± SD of 3 determinations.) The moisture content in jaggery was 8±0.2% observed. 75±0.3% sucrose observed in the jaggery. 15±3% reducing sugar observed. Total 0.8±0.03% minerals content in jaggery was found. The major mineral present in jaggery was calcium, potassium, phosphorus and iron. Jaggery was good source of the carbohydrate (Hirpara, P., Thakare, N., Kele, V. D., and Patel, D. 2020).

Optimization invert jaggery syrup by acid hydrolysis method

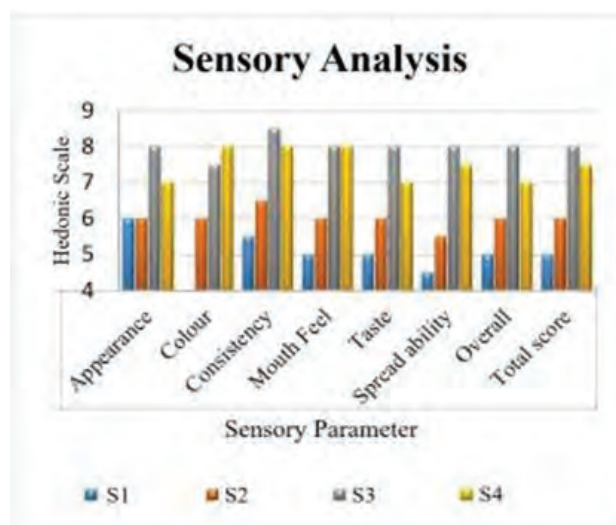
The table 3 shows combinations were carried out for control sample. In the combinations, weight of jaggery, brix of jaggery solution, and period were kept constant while the citric acid concentration was gradually changed for preparation of invert jaggery syrup. The concentration of citric was gradually increased from 0.5% to 3.5 %. Out of the four combinations tried, the sample made with addition of 2.5% citric acid was the best sample. Sample number 3(S3) was selected on the basis of sensory evaluations taken for various quality and organoleptic properties.

Table 3: Optimization of citric acid

Parameter	S1	S2	S3	S4
Jaggery (gram)	250	250	250	250

Jaggery solution (° Brix)	60	60	60	60
Concentration of Citric acid (%)	0.5	1.5	2.5	3.5

Sensory analysis

**Fig. 1: Sensory analysis of invert jaggery Syrup**

The sensory analysis of invert jaggery syrup was as shown in Figure 1. Sample 1 showed less inversion of sucrose because it prepared with absence of citric acid. So the score obtained was low for all the parameters. Sample 3 prepared by using 2.5% of citric acid. This sample was proper in appearance, color, viscosity and taste. Brix and taste considered as the end point for all the samples. On the basis of total score obtained by sensory analysis, Sample 3(S3) selected as the sample for final product formulation. The sample 4 was sour in taste due to more percentage of citric acid.

Chemical analysis of optimized invert jaggery syrup

In the chemical proximate analysis of optimized Invert Jaggery Syrup (S3) moisture, ash, protein, fat, fiber, total carbohydrate, sucrose, glucose, fructose and minerals were determined and the values shown in table 4. Moisture content of invert jaggery syrup was 27±0.2%. Protein content in the product was 0.3±0.03% observed. Sucrose content in invert jaggery syrup was 6±1%. Glucose and fructose was found respectively 30±0.5% and 35±0.5%. Both were major compound present in invert jaggery syrup. Invert jaggery syrup was rich source of minerals. Calcium content of invert

jaggery syrup was 15 ± 2 mg and iron content was 7 ± 2 mg (per 100g) found. The product was a good source of potassium and phosphorus.

Table 4: Proximate analysis of optimized invert jaggery syrup (S3)

Parameters	Sample 3 (S3)
Moisture (%)	27 ± 0.2
Ash (%)	0.2 ± 0.02
Protein (%)	0.3 ± 0.03
Fat (%)	Trace
Crude Fibre (%)	Nil
Total Carbohydrates (%)	70.7 ± 0.13
Energy Value (Kcal/100 g)	266.32 ± 0.18
Sucrose (%)	6 ± 1
Glucose (%)	30 ± 0.5
Fructose (%)	35 ± 0.5
Calcium (mg)	15 ± 2
Potassium (mg)	28 ± 3
Phosphorus (mg)	14 ± 0.2
Iron (mg)	7 ± 2

(All the given values are Mean $\pm$ SD of 3 determinations.)

Effect of acid hydrolysis production method on physical properties of invert jaggery syrup

The physical analysis of invert jaggery syrup was carried out and obtained results were presented in the Table 5. The color of invert jaggery syrup was brown; it was due to continuous heating of jaggery solution during production of invert jaggery syrup. The viscosity of invert jaggery syrup was found 560 centipoise at 28 ± 0.40 C. Viscosity of invert syrup depended on its T.S.S. This also depended on mainly in its sugar content and time period of heating during production of invert syrup. Specific gravity increased with respect to loss of moisture during production of invert jaggery syrup, 1.36 specific gravity was observed. The pH of invert jaggery specific gravity was observed. The pH of invert jaggery syrup was observed 5.3. The syrup was slightly acidic in nature. The results obtained in physical properties of invert jaggery syrup found slightly similar to Gaikwad et al., 2011.

Table 5: Effect of production method on physical properties of Invert Jaggery Syrup

Parameters	Acid Hydrolysis Method
Color	Brown
Specific gravity	1.36
Viscosity at 28 ± 0.40 C (centipoise)	560
pH	5.3

Storage Study

The finalized sample was kept in glass bottles. The Color, Brix, pH and viscosity of the invert jaggery syrup was determined and as shown in table 6. The viscosity of the product was determined with the help of Brook field viscometer as shown in figure 2. In the study, TSS of the invert jaggery syrup increased gradually from 72 to 72.5 and pH of the product remained constant. The viscosity of invert jaggery syrup slightly increased. The product was shelf stable for 60 days.

Table 6: Shelf life analysis of Invert Jaggery Syrup

Days	0	20	40	60
Parameters				
Color	Brown	Brown	Brown	Brown
Brix	72	72.2	72.3	72.5
pH	5.3	5.3	5.3	5.3
Viscosity at 28 ± 0.4^0 C (centipoise)	560	565	568	574

CONCLUSION

Awareness of health was increasing amongst people and they are becoming health conscious of what they eat, how they eat, and nutrients which they contribute to good health. Hence, now-a-days food processing industries are very much concentrated on the production of health beneficial foods. From the present study it was concluded that invert syrup prepared from jaggery is having better quality and can be used as a healthy carbohydrate sweetener. The sample prepared by using 2.5% citric acid showed good inversion with good taste. The invert jaggery syrup prepared by using acid hydrolysis method was shelf stable for 60 days. The preservation of our culture can be achieved by making an inverted jaggery syrup from traditional jaggery. The

invert syrup made from jaggery will have numerous market opportunities in the future.

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Experimental Uncertainty Analysis for Solar Thermal Energy Storage Systems

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ABSTRACT

Solar Thermal Energy Storage Systems promotes the efficient utilization of clean energy sources, reduces energy consumption, and enhances overall energy system performance. This study investigates the uncertainty analysis of flow rate and inlet temperature measurements during the charging and discharging processes of a thermal energy storage system to ensure accuracy and reliability in experimental outcomes. Measurement uncertainties occur from various sources, including equipment precision, environmental conditions, and operator errors. The total uncertainty is evaluated using the root-sum-square method, considering individual contributions from different error sources. Experimental data for flow rates and inlet temperatures are collected at multiple time intervals, and statistical parameters such as mean, maximum, minimum, standard deviation, and error are calculated.

For the charging process, the uncertainty in flow rate was determined to be $\pm 2.9\%$, while the inlet temperature exhibited an uncertainty of $\pm 5.0\%$, resulting in a total uncertainty of $\pm 5.78\%$. During discharging, the uncertainty in flow rate was $\pm 3.2\%$, and the inlet temperature uncertainty was $\pm 6.9\%$, leading to an overall uncertainty of $\pm 7.60\%$. These results highlight the significance of addressing uncertainties to ensure the reliability and accuracy of experimental measurements. The findings underscore the importance of systematic uncertainty analysis in thermal energy storage systems to enhance confidence in experimental outcomes and support the optimization of system performance.

KEYWORDS: Thermal energy storage, Uncertainty analysis, Flow rate, Inlet temperature.

INTRODUCTION

The UN climate conference in Baku, Azerbaijan, concluded on November 24, 2024, with an agreement emphasizing the expansion of global clean energy capacity and efficiency. This agreement calls for a tripling of renewable energy capacity and a doubling of the global average annual rate of energy efficiency improvements by 2030. This focus on clean energy is

a crucial step towards transitioning to a low-carbon future and mitigating the impacts of climate change. [1]. Solar Thermal Energy Storage Systems (STESS) have emerged as a critical technology for enabling efficient energy storage and utilization. These systems play a vital role in reducing energy consumption and enhancing the overall efficiency of energy systems.

Regression analysis reveals that parameters such as

Flow Rate, Inlet Temperature ($^{\circ}\text{C}$), and Storage Material are key predictors influencing outlet temperature performance in STESS. Selecting optimal materials and configurations for thermal energy storage is essential to ensure reliable and efficient energy storage outcomes. However, the performance of such systems is often influenced by measurement uncertainties arising from factors like equipment precision, environmental variability, and operator errors. Addressing these uncertainties is crucial for enhancing the accuracy and reliability of experimental results. Researchers have employed various methodologies to quantify and optimize heat exchanger performance under uncertain conditions, as these components are integral to thermal systems.

This study focuses on investigating the uncertainty analysis of flow rate and inlet temperature measurements during the charging and discharging processes of a solar thermal energy storage system. The findings aim to contribute to the optimization of thermal energy storage systems, ensuring more reliable and efficient performance outcomes in the pursuit of Sustainable Development Goal 7.

LITERATURE SURVEY

Uncertainty analysis and optimization of heat exchanger networks (HENs) have gained significant attention in recent years due to their critical role in industrial energy efficiency and system reliability. Various methodologies have been explored to address the uncertainties associated with process parameters, environmental conditions, and operational variations.

Sudhanshu et al. (2021) proposed a robust optimization methodology integrating Pinch Analysis to handle uncertainties in inlet stream temperatures. The study emphasizes the trade-off between constraint protection levels and conservatism in optimization solutions, providing decision-makers with a framework to balance operational flexibility and cost efficiency [2].

A probabilistic analysis on circular fins in a silicon carbide ceramic tube heat exchanger is performed by Gorla (2023) using finite element methods. Cumulative distribution functions and sensitivity factors were evaluated to identify critical design variables [3]. El-Sharkawy (2001) accomplished sensitivity and

uncertainty analysis for automotive heat exchanger designs. The study highlighted the influence of design parameters on performance uncertainty, emphasizing the importance of identifying robust design choices under variable conditions [4].

Boumaaraf et al. (2021) compared hybrid photovoltaic thermal (PV/T) collectors in glazed and unglazed configurations. Their experimental and numerical analysis revealed significant differences in energy efficiency and performance under semi-arid climatic conditions, with the glazed configuration showing superior thermal efficiency [5].

A global sensitivity analysis (GSA) to borehole heat exchanger (BHE) designs is applied by Shin et al. (2023). The study identified key parameters, such as ground temperature and borehole thermal resistance, that influence BHE length, aiding in the optimization of heat pump systems [6]. Ibrahim et al. (2024) experimentally analyzed passive flow enhancement in tube heat exchangers using wire coil inserts. The findings revealed significant heat transfer improvements at low Reynolds numbers, with smaller wire diameters showing higher thermal efficiency [7].

Barhatte et al. (2024) investigated microchannel heat exchangers (MCHX) through numerical, experimental, and Artificial Neural Network (ANN) techniques. Their study demonstrated consistency between numerical and experimental results, with regression models achieving low uncertainty levels [8].

A systematic uncertainty estimation for aluminum heat exchangers with louvered fins is provided by Shinde et al. (2014). The study applied Moffat's method to calculate uncertainties in Reynolds number, Colburn j-factor, and friction factor, offering valuable guidelines for future uncertainty analyses [9]. Grenyer et al. (2023) introduced a Compound Uncertainty Quantification and Aggregation (CUQA) framework for reliability assessment in industrial maintenance. Their approach quantified compound uncertainties in heat exchanger systems, identifying critical parameters affecting overall reliability [10].

The reviewed studies collectively emphasize the importance of incorporating uncertainty quantification, probabilistic analysis, and robust optimization

techniques in heat exchanger design and operation. These methodologies improve system reliability, optimize resource utilization, and enable informed decision-making under uncertain operating conditions

METHODOLOGY

Experimental Design and Setup

The experiment was structured using the Taguchi array methodology to identify the most influential parameters affecting the thermal energy storage system's performance. The key parameters analyzed included: Flow Rate (LPM), Inlet Temperature (°C), and Storage Material. A total of nine experimental runs were conducted to ensure variability and reliability in results. A double-pipe heat exchanger system was used, consisting of a shell chamber housing the storage material and fluid channels for charging and discharging modes.

Measurement Instruments and Precision

Temperature Measurement: Five K-type thermocouples (accuracy $\pm 0.5^\circ\text{C}$) were used to record inlet and outlet temperatures at various points in the system.

Flow Rate Measurement: Glass tube flow meters (accuracy $\pm 2\%$ of full scale) were utilized to measure the water flow rate.



Fig. 1. Testing set up

The system operated in two distinct modes: **Charging Mode:** Hot water flowed through the hot channel, transferring heat to the storage material, where energy was stored as latent and/or sensible heat. **Discharging**

Mode: Cold water circulated through the cold fluid channel, extracting stored heat from the material.

Environmental conditions affecting uncertainty

The precision of experimental measurements was influenced by several environmental factors, including:

Ambient Temperature Variations: Fluctuations between 25°C and 32°C , affecting heat loss/gain in the system.

Humidity Levels: Ranging between 40% and 65%, which can impact the thermal conductivity of insulation materials.

Airflow Disturbances: External air currents caused by laboratory ventilation, potentially affecting the stability of heat exchange processes.

Sensor Positioning and Calibration Drift: Small deviations in thermocouple placement and calibration inconsistencies contributed to variations in recorded temperature values.

To mitigate these factors, the system was housed in a controlled laboratory environment, and sensors were recalibrated before each experimental run.

Mathematical Model for error analysis

The uncertainty analysis was performed using the Root-Sum-Square (RSS) method, which considers the independent contributions of measurement errors. Uncertainty analysis is conducted to evaluate measurement reliability and the effect of errors from various sources. The total is calculated using the root-sum-square method. The formula for calculating uncertainty depends on the type of measurement and the sources of uncertainty involved. Here is a general formula for calculating the total uncertainty (u) in a measurement [11].

$$u = \sqrt{(\sum(u_i)^2)}$$

Where u_i represents the individual contributions to the uncertainty from each source of error or uncertainty. Assuming that these sources of uncertainty are independent and normally distributed, we can calculate the overall uncertainty in the measurement by:

$$u = \sqrt{(u_1^2 + u_2^2 + u_3^2)}$$

The values of u_i can be estimated by various methods, such as repeating the measurement several times.

Uncertainty in Flow Rate Measurements

Data for flow rate measurements during charging and discharging were recorded at multiple intervals. Key statistical parameters, including mean, maximum, minimum, standard deviation, and error, were calculated.

Table 1 contains readings for uncertainty analysis of flow rates during the charging process. It includes flow rate measurements at different time intervals, along with statistics such as mean, maximum, minimum, standard deviation, and error for each flow rate.

Readings for uncertainty analysis of flow rates for the discharging process are presented in Table 2.

- Charging Flow Rate Uncertainty: $\pm 2.9\%$
- Discharging Flow Rate Uncertainty: $\pm 3.2\%$

Uncertainty Analysis in Inlet Temperature Measurements

Temperature readings are recorded during both charging and discharging operations across multiple intervals.

Table 1. Readings for Uncertainty Analysis: Flow rate (Charging)

	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM
	0.9	1	1	2	2	2	3	3	2.9
	1.1	0.9	1	2.1	2.1	2	3.1	2.9	3
	1.2	0.9	0.9	2	1.9	2.1	3.2	3.1	3
	1	1.1	1.1	1.9	1.8	2.2	3	3.2	3.1
	1	1.1	1	1.9	2	1.9	3	3	3.2
	0.9	1	1.1	2	2	1.9	3.1	3	3
	1	1.1	1	2	2.1	2	3	3.1	3
	0.9	1	0.9	2.1	1.9	2	3	3.1	3
	1	0.9	1	1.9	2.1	1.9	3.1	3	2.9
	1.1	0.8	1.1	2.1	2	1.8	2.9	2.9	3
	1	1	1.2	2.2	1.9	2	2.8	3	3.1
	1.1	1	1	1.8	2.2	2.1	3	2.8	2.8
Mean	1	1	1	1.9	2.1	2.05	3	2.9	2.85
Max	1.2	1.1	1.2	2.2	2.2	2.2	3.2	3.2	3.2
Min	0.9	0.8	0.9	1.8	1.8	1.8	2.8	2.8	2.8
Std	0.09	0.09	0.08	0.11	0.11	0.10	0.10	0.10	0.10
Error	0.027	0.027	0.025	0.032	0.032	0.031	0.029	0.031	0.030

Table 3 presents readings for uncertainty analysis of inlet temperatures during the charging process. It includes temperature measurements (in °C) at different time intervals and statistics such as mean, maximum,

minimum, standard deviation, and error for each temperature sensor (T-1).

Table 2. Readings for Uncertainty Analysis of Flow rate (Discharging)

	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM	Flow Rate LPM
	0.9	1	0.8	2.2	1.9	2.2	3	3.1	2.9
	1	1	0.9	2.1	1.8	2.1	3	3.1	2.9
	1	1.1	0.9	2.1	1.9	2.1	3.1	3	3
	1.1	1.2	1	2	2	2	3.2	3	3.1
	1.1	1	1	2	2	2	3	3.2	3
	1	0.9	1.1	1.8	2.1	2	2.9	3	3
	1	0.9	1.2	1.9	2	1.9	2.8	3	3.2
	0.9	1	1.1	2	2.1	1.8	2.9	2.9	3.1
	0.9	1.1	1	2	2	1.9	3	2.8	3
	0.8	1	1	1.9	2.2	2	3.1	2.9	3
	1.1	0.9	1	1.9	2	2	3.2	3	2.9
	1.2	0.8	0.9	2	1.9	2.2	3	3.1	2.8
Mean	1.05	0.9	0.85	2.1	1.9	2.2	3	3.1	2.85
Max	1.2	1.2	1.2	2.2	2.2	2.2	3.2	3.2	3.2
Min	0.8	0.8	0.8	1.8	1.8	1.8	2.8	2.8	2.8
Std	0.113	0.109	0.109	0.108	0.108	0.119	0.119	0.108	0.108
Error	0.032	0.031	0.031	0.031	0.031	0.034	0.034	0.031	0.031

Table 3. Readings for Uncertainty Analysis of Inlet temperature (Charging)

	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)
	65.7	69.8	76.4	66.5	70.5	75.5	65.5	70.8	75.8
	65.6	70	76.6	66.4	70.5	75.6	66.5	70.4	75.9
	65.7	70.2	76.9	66.4	70.3	75.5	66.5	70.1	75.8
	65.8	70.3	76.9	66.5	70	75.6	66.2	70	75.8
	65.7	70.3	76.8	66.5	70	75.6	66	69.9	75.8
	65.7	70.4	76.6	66.6	70.1	75.3	65.9	70	75.8
	65.6	70.4	76.6	66.6	70.3	75.3	65.8	70	75.9
	65.7	70.4	76.5	66.6	70.4	75.3	65.6	70.2	75.9
	65.6	70.5	76.6	66.6	70.4	75.3	65.5	70.4	75.9
	65.7	70.5	76.7	66.6	70.4	75.3	65.6	70.5	75.9
	65.6	70.5	76.8	66.7	70.4	75.2	65.6	70.4	75.9
	65.7	70.5	76.9	66.7	70.4	75.2	65.7	70.2	75.9
Mean	65.7	70.15	76.65	66.6	70.45	75.35	65.6	70.5	75.85
Max	65.8	70.5	76.9	66.7	70.5	75.6	66.5	70.8	75.9
Min	65.6	69.8	76.4	66.4	70	75.2	65.5	69.9	75.8
Std	0.062	0.221	0.168	0.099	0.178	0.156	0.363	0.264	0.0514
Error	0.017	0.064	0.049	0.029	0.051	0.045	0.105	0.076	0.015

Table 4. Readings for Uncertainty Analysis of Inlet temperature (Discharging)

	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)	T-1 (°C)
	30.5	32.4	32.1	32.4	32	34.4	29.2	35.1	35
	30.6	32.3	32.2	32.5	32	34.4	29.2	35.3	35.1
	30.4	32.4	32.2	32.4	32.1	34.4	29.3	35.3	35.1
	30.4	32.3	32.4	32.4	32.2	34.5	29.4	35.4	35.2
	30.6	32.3	32.4	32.4	32.3	34.6	29.6	35.4	35.7
	30.7	32.4	32.5	32.5	32.4	34.6	29.6	35.5	35.7
	30.6	32.4	32.5	32.5	32.5	34.7	29.7	35.6	35.7
	30.7	32.6	32.6	32.5	32.6	34.7	29.8	35.6	35.8
	30.8	32.6	32.6	32.5	32.8	34.8	29.9	35.7	35.8
	30.7	32.6	32.6	32.6	32.9	34.9	30	35.7	35.9
	30.7	32.8	32.7	32.7	32.9	35	30	35.8	35.8
	30.8	32.8	32.8	32.7	33	35	30.1	35.8	36.2
Mean	30.65	32.6	32.45	32.55	32.5	34.7	29.65	35.45	35.6
Max	30.8	32.8	32.8	32.7	33	35	30.1	35.8	36.2
Min	30.4	32.3	32.1	32.4	32	34.4	29.2	35.1	35
Std	0.136	0.183	0.215	0.108	0.365	0.223	0.320	0.221	0.383
Error	0.039	0.053	0.062	0.031	0.105	0.064	0.092	0.063	0.111

Table 4 presents readings for uncertainty analysis of inlet temperatures during the discharging process. It includes temperature measurements (in °C) at different time intervals, along with statistics such as mean, maximum, minimum, standard deviation, and error for each temperature sensor (T-1).

- Charging Inlet Temperature Uncertainty: $\pm 5.0\%$
- Discharging Inlet Temperature Uncertainty: $\pm 6.9\%$

Total Uncertainty in Measurements

Using the combined uncertainty formula:

- Total uncertainty in the measurement of charging

$$u = \sqrt{(u_1^2 + u_2^2 + u_3^2)}$$

$$= \sqrt{(2.9^2 + 5.0^2)}$$

$$= \sqrt{(8.41 + 25)}$$

$$= \pm 5.78 \% \text{ (for charging)}$$
- Total uncertainty in the measurement of Discharging

$$u = \sqrt{(u_1^2 + u_2^2 + u_3^2)}$$

$$= \sqrt{(3.2^2 + 6.9^2)}$$

$$= \sqrt{(10.24 + 47.61)}$$

$$= \pm 7.60 \% \text{ (for Discharging)}$$

Table 5. Percentage uncertainties of Parameters

Sr. No.	Parameters	Uncertainties
1	Flow rate (charging)	$\pm 2.9\%$
2	Inlet temperature (Charging)	$\pm 5.0\%$
3	Total uncertainty (Charging)	$\pm 5.78 \%$
4	Flow rate (Discharging)	$\pm 3.2\%$
5	Inlet temperature (Discharging)	$\pm 6.9\%$
6	Total uncertainty (Discharging)	$\pm 7.60 \%$

CONCLUSION

The uncertainty analysis presented in Table 5 highlights the degree of precision and reliability of key experimental measurements in Solar Thermal Energy Storage Systems (STESS) during charging and discharging modes. These findings are significant for both experimental validation and the optimization of system performance. The uncertainty in flow rate during charging ($\pm 2.9\%$) and discharging ($\pm 3.2\%$) indicates a relatively low margin of error, suggesting that the flow measurement system is reliable. The inlet temperature during charging ($\pm 5.0\%$) and discharging ($\pm 6.9\%$) exhibit higher uncertainty levels compared to flow rate. Temperature plays a crucial role in determining the overall heat transfer rate and thermal storage efficiency. Therefore, higher uncertainty in this parameter may introduce variability in thermal energy predictions. The total uncertainty during charging ($\pm 5.78\%$) and discharging ($\pm 7.60\%$) integrates the combined effects of flow rate and inlet temperature uncertainties.

The higher total uncertainty in discharging mode indicates increased variability, possibly due to heat losses, environmental factors, or sensor sensitivity during the discharging process. The results suggest that improving the accuracy of temperature measurements can significantly reduce total uncertainty, leading to more consistent and reliable performance outcomes. These uncertainty values serve as a benchmark for future research in similar experimental setups, enabling cross-comparisons and advancements in solar thermal energy storage technologies.

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Advances in Anti-erosion Coating Technologies of Wind Turbine Blades: A Comprehensive Review

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ABSTRACT

The efficiency of the wind turbine machines is significantly affected by leading-edge erosion, which further increases drag, and maintenance and reduces annual energy production. This review study examines the causes and challenges of erosion of wind turbine blades and explores innovative solutions, including advanced protective coatings of nanocomposites, superhydrophobic surfaces, and polymeric materials. Consideration of environmental factors, material properties, and coating technologies that enhance blade performance and long- life stability are critically analyzed. The study emphasizes that durable protection coating technologies ensure sustainable energy generation. Furthermore, research gaps are identified, and further directions are needed to achieve these challenges effectively.

KEYWORDS: *Wind turbine blades, Leading-edge erosion, Super hydrophobic surfaces, Polymeric materials.*

INTRODUCTION

Wind energy has become an essential source of sustainable energy systems because of its low environmental impact and potential for reliability. However, the widespread adoption of this renewable energy technology, the durability, and the performance of wind turbine blades create significant erosion challenges. A critical issue affecting blade efficiency is leading-edge erosion, primarily caused by high-velocity impacts from environmental factors such as rain, sand particles, and hails [6], [11]. This damage not only influences the blade's aerodynamics but also leads to increased drag, energy losses, and higher maintenance costs [7].

The exposure of saline environment plays an additional challenge for offshore wind turbines which accelerate huge material degradation. These elements highlight the immediate need for creative fixes to extend wind turbine blade lifespan and performance [6], [12].

The recent advanced innovations in material science have introduced good strategies to mitigate

these issues. Modern protective coatings including graphene-reinforced materials, nanocomposites, and superhydrophobic surfaces have shown great promise in lowering erosion and extending the lifespan of wind turbine blades [8], [9]. For instance, incorporating nanocomposite materials like carbon nanotubes and silica nanoparticles has shown exceptional resistance to mechanical wear and environmental degradation [13]. In a comparable manner superhydrophobic coatings lower the impact force of rain droplets and frequently improve and reduce water adhesion [2], [16].

More innovative approaches such as biochar-based photothermal coating give dual functionality by addressing both ice formation and erosion [7]. The SLIPS technologies have shown solutions for the prevention of ice formation and the related erosion of wind turbine blades in cold climatic conditions. The use of such an advanced material for the coating of blades significantly enhances the lifespan and the performance of the wind turbine blade.

This paper study shows the advanced protective coating

technologies, their effect on blades in the environment, and the causes of erosion of blades. The aim of this paper is to analyze the wind turbine blade erosion problem critically and develop a sustainable solution for wind turbine blades in the form of leading- edge protective coating.

NEED OF LEADING EDGE PROTECTIVE COATING SYSTEM

The leading edge of the wind turbine blades is where erosion begins because of the high-velocity impacts of sand particles, raindrops, and weather. Elastomeric coatings have proven to be flexible and long-lasting, making them appropriate for adverse weather conditions [1]. The deposition of silica nanoparticles and a laser-processed super hydrophobic coating in the surface base material have withstood degradation from sand particles and heavy raindrops. [2], [16].

Biochar-based coatings particularly photo thermal coatings have been used for the both purposes of ice prevention and erosion mitigation, which are mainly used for turbines working in cold climates [7]. In addition, it has the potential to reduce icing and erosion by creating lubricated surfaces that prevent water accumulation and particle adhesion by SLIPS technologies [9]. Similar advantages for the wind turbine rotor blades include increased thermal conductivity, resistance to UV radiation, and graphene-added coatings, which offer long-lasting, lightweight erosion-resistant alternatives [10].

Like onshore wind turbines offshore turbines have additional challenges of saline environment and high speed wind, which leads to material degradation [11]. Coatings of carbon nanotubes along with additional nanocomposite materials increase the mechanical strength, impact resistance, and wear durability of wind turbine blade surfaces when subjected to high velocities [8], [13].

The coatings and protection of wind turbine rotor blades, with an emphasis on unsaturated polyester, epoxy, polyurethane, or acrylic paints and gelcoats. issues include mechanical wear, chemical assaults, erosion, and UV rays, and investigates durability testing techniques, such as expedited weather resistance testing. In addition to future material trends and environmental

considerations, the protection against ice, lightning, and air traffic promotes long- lasting and sustainable turbine blade protection [19]. The long-term scalability performance and commercial application required further research and testing. However, the adaptation of advanced blade coating systems has enhanced the efficiency and lifespan of wind turbine blades, especially in a harsh environment.

Evaluation of Coating Performance Quantitatively

Metrics like erosion resistance, mechanical durability, hydrophobicity, and thermal stability are commonly used to evaluate the effectiveness of anti-erosion coatings for wind turbine blades. Data on the effectiveness of different coating types has been published by numerous studies:

Resistance to Rain Erosion: Rain erosion test rigs are used to assess coatings by imitating the high-velocity impacts of water droplets. According to studies, silica nanoparticle-containing nanocomposite coatings may boost erosion resistance by up to 60% when compared to conventional polyurethane coatings [8].

Mechanical Durability: Tests of tensile strength and impact resistance reveal that graphene-reinforced coatings exceed conventional polymer coatings by 45% in tensile strength and 30% in impact resistance [10].

Hydrophobicity Performance: Water repellence is assessed using contact angle measurements. With contact angles greater than 150°, superhydrophobic coatings minimize erosion risks and reduce water adhesion by about 80% [9].

Thermal Stability: For offshore wind turbines, coatings with photothermal qualities are essential because they preserve performance at extremely high temperatures (-40°C to 80°C) [7].

These computational analyses show how effective and long-lasting modern coatings are at reducing erosion and increasing the life of wind turbine blades.

INNOVATIONS IN THE PROTECTIVE COATING SYSTEM.

To mitigate blade erosion recent advancements in material science, give favourable solutions including:

- Super hydrophobic surfaces: The surfaces

minimize the impact force of raindrops by reducing surface adhesion. The superhydrophobic surfaces developed by laser processes can largely improve erosion resistance [2], [9].

- **Nanocomposite:** recent research has illustrated the effectiveness of the materials that improve durability. The nanocomposite coatings integrated materials like silica nanoparticles and carbon nanotubes have enhanced erosion and mechanical properties [8], [13].
- **Advanced polymers:** Polymeric materials, particularly elastomeric coatings, provide wind turbine blades with long-lasting, flexible, and lightweight solutions [1].
- **Nano-engineered coatings:** erosion resistance and durability increased by the graphite reinforced coatings [10].
- **Functionalized nanocomposites:** Functionalized carbon nanotubes and epoxy nanocomposites have increased structural integrity and provided erosion resistance [18].
- **Ice phobic and photothermal coatings:** in order to lower icing Significant promise exists for SLIPS technology [9], and biochar- based photothermal coatings efficiently lessen blade degradation and ice formation [7].

ECOLOGICAL FACTORS

The crucial element of the wind energy is sustainability. For the alignment of the ecological goals, the protective materials must have improved performance. Innovative solutions for coating durability and balanced ecological responsibility are provided by biochar-based coatings and materials with low oxygen-to-carbon ratios. [4], [5], [17]. For sustainable development, the use of recyclable materials plays an important role which comprises in surface engineering [11].

FUTURE DIRECTION AND RESEARCH GAP

Cost-effectiveness and scalability: high performing many materials are not used in mass production limiting their practical implementation [12].

Long-term performance: it is necessary to evaluate and

look into how long the coating materials will remain effective when used in adverse weather circumstances. [3], [14].

Collaborations across disciplines: industry and researchers must work together to bridge the gap between research laboratory activity and real-time field application. [15].

Upcoming research should be focused on multifunctional composite material-based coating development that contains erosion resistance, self- cleaning, and UV protection properties [20].

As well as priority to material recyclability [17] and provision to conduct comprehensive field tests [21].

New developments in coating technology's

Self-Healing Coatings: Self-healing materials are a new development in which the coating matrix contains embedded microcapsules containing healing agents (such as epoxy resins or polyurethane). These microcapsules break when damage takes place releasing the healing agent and reestablishing structural integrity. According to studies, self-repair mechanisms can reduce maintenance needs by 50% [18].

Nanocoatings: coatings that combine nanoparticles like graphene, silica, and carbon nanotubes to improve erosion resistance, mechanical strength, and UV resistance. When compared to traditional coatings, carbon nanotube-based coatings have shown a 70% increase in wear resistance and a 5-year lifespan extension [8].

Slippery Liquid infused Porous Surfaces

The technology known as Slippery Liquid-Infused Porous Surfaces (SLIPS) was inspired by nature and offers extremely low adhesion surfaces that reduce erosion and stop ice formation. Turbine blades covered with SLIPS minimize ice adhesion by more than 80%, according to field tests, which makes them perfect for cold areas [5].

Industry Requirements for Coating Performance

To guarantee dependability and effectiveness, coatings for wind turbine blades must be developed and applied in accordance with international standards. Important industry norms consist of the mechanical performance

requirements for coatings under harsh climatic conditions are laid out in IEC 61400-5 (Wind Turbine Blade Design) [20].

Standardized testing procedures for assessing coatings' resistance to erosion are provided by ISO 11303 (Paints and Varnishes - Erosion Testing) [21].

In order to ensure sufficient performance for wind turbine applications, ASTM D7334 (Rain Erosion Test Method) is used to evaluate the durability of coatings exposed to high-speed rain impacts [22].

Guidelines on material selection, durability, and environmental sustainability for protective coatings are included in DNV-GL ST-0361 (Surface Protection for Wind Turbine Blades) [23].

Manufacturers can increase the durability and effectiveness of wind turbine blade coatings while guaranteeing regulatory compliance by following these guidelines.

CONCLUSION

The progress in facing the challenge of the wind turbine blade leading edge erosion is extremely influenced by the development of advanced protective coating. Graphene-reinforced, photothermal materials, Nanocomposites, and superhydrophobic surfaces have the remarkable potential to enhance the performance and durability of the blade coating materials. The coating materials incorporate recyclable eco-friendly components to promote sustainability in addition to lowering the negative effects of high velocity impacts and environmental deterioration [4], [5], [17]. Future studies need to focus on refining these coatings for widespread commercial use, taking into account their affordability, simplicity of use, and climate adaptability [12]. The wind energy industry can greatly improve turbine performance and assure long-term sustainability and economic feasibility by bridging the gap between experimental developments and practical application. Effectively resolving the issues of wind turbine blade erosion will require a comprehensive approach that incorporates material science advancements, environmental resilience, and technological adaptation as wind turbines continue to increase in size and capacity [7].

By sustainable practice, focusing on innovative materials, multidisciplinary researchers wind energy sector achieve progression in global renewable energy and responsibility towards the environment.

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Role of Artificial Intelligence in Sustainability

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ABSTRACT

AI has a very significant role in various field. it refers to human intelligence processes by machines, especially computer system. AI system is designed to perform tasks that would typically require human intelligence, often in a more efficient or scalable manner.

AI for sustainability refers to the application of artificial intelligence technologies to promote environmental sustainability, to tackle with global challenges like biodiversity losses, pollution resource depletion, energy management and efficiency, energy consumption forecasting; where AI can predict energy consumption patterns in industrial settings and cities.

It helps in performing sustainable agriculture where AI helps farmers in usage of fertilizer application, optimize water usage, analysing data from sensors, drones, satellite which help in minimizing its impact on environment and waste management.

It also helps in monitoring biodiversity and ecosystem where wildlife conservation, pollution controlling, deforestation tracking is taken into consideration. AI sustainability has many challenges like data availability, ethical corners, energy consumption of AI. It is important to ensure that AI technologies are implemented thoughtfully and ethically to maximize their positive impact on environment.

KEYWORDS: *Environmental sustainability, Analyzing data, Deforestation, Wildlife conservation.*

INTRODUCTION

In this 21st century Artificial intelligence (AI) refers to, the stimulation of human intelligence in machines designed to perform tasks that traditionally require human recognition .AI's application in sustainability is rapidly gaining attraction as a solution to address pressing environmental issues, including climate change, biodiversity loss and resource depletion. By leveraging machine learning, data analytics and automation, AI can optimize resource usage, reduce environmental degradation and facilitate more efficient and effective

sustainability practices. This paper explores how AI Technologies contribute to environmental sustainability with specific applications in agriculture, biodiversity monitoring, energy management, and waste handling.

PRINCIPLE OF AI IN SUSTAINABILITY

The principles guiding AI in sustainability are derived from its potential to stimulate human-like intelligence for environmental benefits. AI systems are built to perform tasks efficiently, making them ideal for optimizing sustainability efforts. In agriculture, AI

technologies ensure sustainable practices by optimizing water usage, fertilizer application, and minimizing environmental harm. management, and waste usage, fertilizer application, and minimizing environmental harm. For biodiversity conservation, AI systems track wildlife populations, monitor pollution levels and identify deforestation patterns, aiding ecosystem preservation.

In energy management AI enhances efficiency by forecasting energy demand, improving grid management, AI enhances efficiency by forecasting energy demand, improving grid management, and integrating renewable energy sources. AI's role in waste management includes automating waste segregation, optimizing collection routes and improving recycling processes. Finally, the ethical, ensuring that its deployment addresses data availability and energy consumption challenges responsibly.



Fig. 1. Potential of AI in sustainability

MECHANISM OF AI IN SUSTAINABILITY

AI operates through advanced mechanisms such as data analytics, machine learning and automation to address environmental challenges;

Sustainable Agriculture

AI systems process data from soil sensors, weather forecasts and crop monitoring tools to optimize resource use, reduce waste and ensure sustainable farming practices.

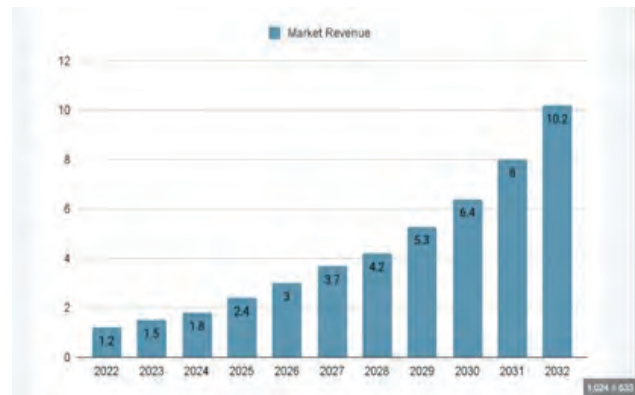


Fig. 2 AI transforming Indian agriculture

BIODIVERSITY AND ECOSYSTEM

CRITERIA	BEFORE AI	AFTER AI
FARMING	Farmers face challenges in improving fertilizers use.	AI improved fertilizers application
ECOSYSTEM	Difficulties in tracking wildlife, pollution, deforestation making it harder to protect ecosystem.	AI helps in monitoring wildlife, controlling pollution and tracking deforestation more efficiently.
ENERGY CONSUMPTION	Energy patterns are harder to predict leading to inefficiency in energy used in industrial and urban settings.	Forecasts energy consumption, improves energy efficiency and analyses consumption patterns in industrial cities.
WASTE MANAGEMENT	Waste management systems struggles with proper segregation and efficient disposal leading to higher pollution level.	AI assists in improving waste management by helping with proper segregation, recycling and efficient disposal systems.

Monitoring

AI models analyze satellite imagery and sensor data to monitor ecosystems, track endangered species and detect environmental threats like deforestation and pollution.



Fig. 3 AI in wildlife conservation

Energy Management

AI algorithms forecast energy consumption patterns, manage renewable energy integration and optimize smart grid operations to reduce waste and enhance efficiency.

Waste Management

AI technologies automate waste sorting, improve recycling rates and optimize collection and disposal processes, reducing pollution and costs.

The adaptive learning nature of AI ensures continuous improvement as models learn from new data, making them increasingly accurate and effective overtime.

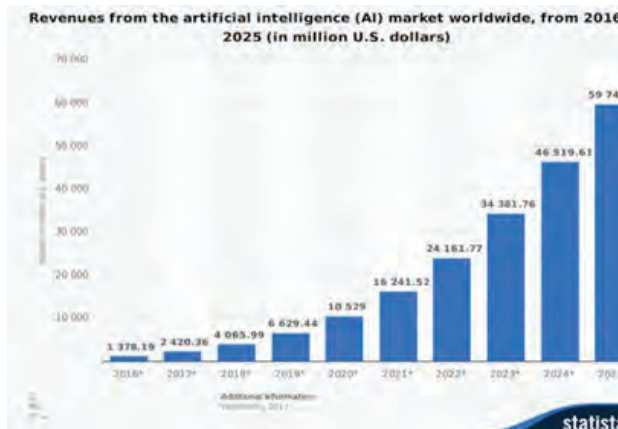


Fig. 4. Revenues from AI

MATERIALS AND METHODS

This research utilized data collected from agriculture fields, energy grids and waste management facilities to evaluate AI's impact on sustainability. Tools such as tensor flow and PyTorch were employed to develop machine learning models for predictive analysis and process optimization. Data sources included IoT sensors, satellite imagery and industrial systems, which

provided inputs for AI models. The methodologies emphasized ethical AI deployment, focusing on minimizing energy consumption and ensuring data privacy. Comparison were drawn between traditional and AI-driven approaches to highlight efficiency improvements.

RESULT

The result demonstrates that AI significantly improves efficiency and reduces environmental impact in sustainability applications.

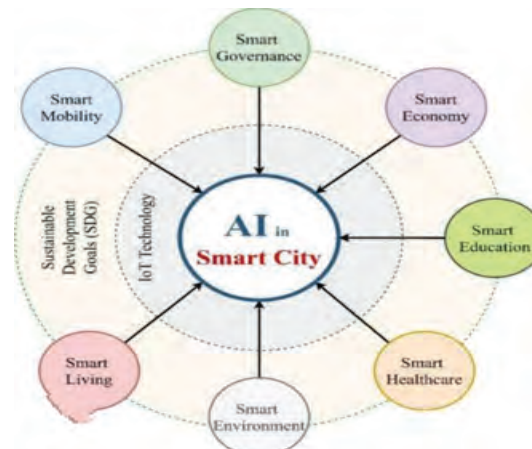
Agriculture: AI-driven precision farming reduced water consumption by 20% and fertilizer usage by 15%, while increasing crop yield.

Biodiversity: AI models identified 25% more endangered species and tracked deforestation with 90% accuracy.

Energy: Energy consumption forecasting by AI led to a 10% reduction in grid losses and better renewable energy integration.

Water Management: AI-enabled sorting systems increased recycling rates by 30% and reduced landfill waste.

Despite these advancements, challenges remain. Data availability in remote areas limits AI's effectiveness, while the high energy consumption of AI systems raises concerns about their carbon footprint. Ethical considerations, such as privacy and job displacement, also require attention. Addressing these challenges through responsible AI deployment is essential to maximizing its environmental benefits.



HOW FAR ALONG ARE COMPANIES WITH AI?

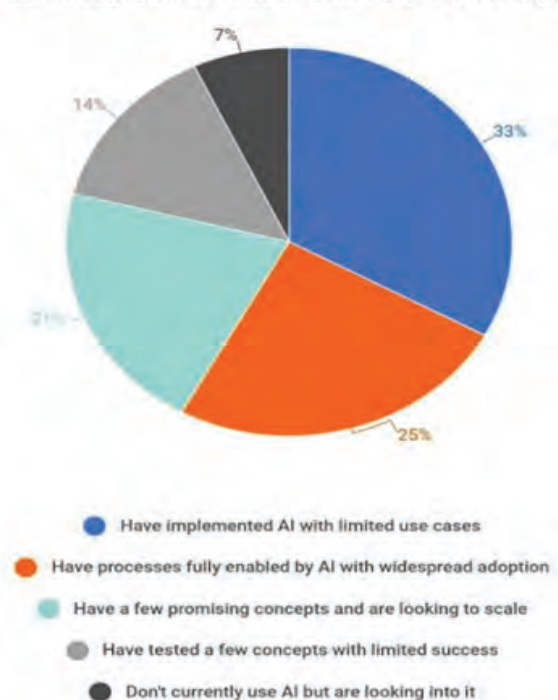
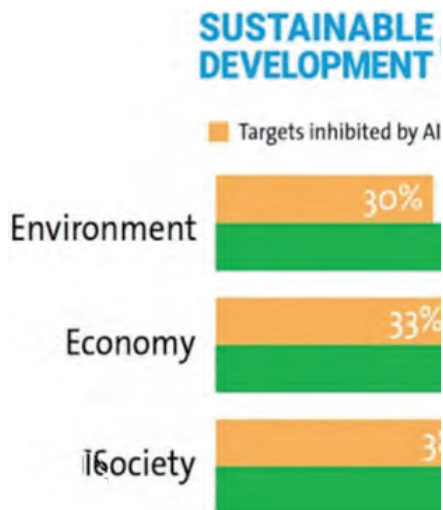


Fig. 5. how far along are companies with AI



CONCLUSION

AI offers transformative potential in promoting environmental sustainability by optimizing resource use, monitoring ecosystems, and enhancing efficiency in agriculture, energy and waste management. However, challenges like data availability, ethical concerns, and energy consumption of AI systems must be addressed to ensure its sustainable implementation. By leveraging AI responsibly, society can mitigate environmental challenges and move toward a more sustainable future. Thoughtful collaboration between policymakers, industries and researchers is essential for unlocking AI's full potential for sustainability.

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Unlocking Biodegradability: Treatment of Dairy Industry Waste Water by Hydrodynamic Cavitation

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ABSTRACT

Industrial effluents containing recalcitrant organic compounds pose significant challenges to conventional wastewater treatment processes due to their resistance to degradation. Advanced oxidation processes (AOPs) have emerged as effective technologies for enhancing the biodegradability of these effluents by generating highly reactive hydroxyl radicals ($\bullet\text{OH}$), which oxidize and transform complex organic pollutants into simpler, more biodegradable forms. This paper reviews the application of various AOPs, such as $\text{UV}/\text{H}_2\text{O}_2$, $\text{O}_3/\text{H}_2\text{O}_2$, and Fenton's reagent, in treating recalcitrant industrial effluents. Case studies and experimental findings demonstrate the efficacy of AOPs in degrading persistent organic pollutants (POPs), pharmaceutical residues, and other challenging contaminants. The mechanisms of AOP-induced oxidation and their impact on effluent biodegradability are discussed, highlighting the potential for AOPs to complement or replace conventional treatment methods. Despite their advantages, challenges such as operational costs, energy consumption, and the management of reaction by-products remain significant hurdles to widespread AOP implementation. Future research directions focus on optimizing AOP processes, integrating them with biological treatments, and developing sustainable solutions for industrial wastewater management. By advancing our understanding and application of AOPs, this study aims to contribute to more effective strategies for unlocking the biodegradability of recalcitrant industrial effluents and safeguarding environmental and public health.

KEYWORDS: *Advanced oxidation processes, Biodegradable, Hydroxyl radicals, public health, Recalcitrant.*

INTRODUCTION

In recent decades, the issue of bio-recalcitrant effluent has posed significant challenges to wastewater treatment plants worldwide. Bio-recalcitrant effluent refers to wastewater streams containing organic compounds that resist conventional biological degradation processes, thereby requiring advanced treatment methods for effective remediation [1]. The presence of bio-recalcitrant compounds in wastewater

is primarily attributed to industrial activities such as chemical manufacturing, pharmaceutical production, and food processing, among others [2]. These compounds, which include persistent organic pollutants (POPs), pharmaceutical residues, and complex industrial chemicals, are often characterized by their stability and resistance to natural degradation mechanisms [3]. Conventional treatment methods, such as biological treatment and physical-chemical processes, often struggle to adequately degrade these compounds,

leading to their accumulation in receiving water bodies and posing risks to environmental and public health [4]. In response to these challenges, advanced oxidation processes (AOPs) have emerged as promising technologies for enhancing the biodegradability of bio-recalcitrant effluents. AOPs involve the generation of highly reactive hydroxyl radicals ($\bullet\text{OH}$) through the decomposition of oxidants such as hydrogen peroxide (H_2O_2), ozone (O_3), or the Fenton reagent ($\text{Fe}^{2+}/\text{H}_2\text{O}_2$) [5]. These radicals react indiscriminately with organic contaminants, initiating a cascade of oxidative reactions that lead to the breakdown of complex organic molecules into smaller, more biodegradable fragments [6].

The ability of AOPs to mineralize or transform recalcitrant compounds into simpler, more readily biodegradable forms has made them increasingly attractive for treating challenging wastewater streams [7]. Furthermore, AOPs offer several advantages over traditional treatment methods, including their effectiveness in treating low-concentration and complex mixtures of contaminants, their potential for selective degradation of specific pollutants, and their ability to operate under a wide range of pH and temperature conditions [8]. These attributes underscore the potential of AOPs to complement or replace existing treatment strategies, particularly in addressing the growing complexity and diversity of contaminants in industrial and municipal wastewaters. Despite their promise, the widespread adoption of AOPs faces challenges such as cost considerations, energy requirements, and the management of reaction by-products [9]. Addressing these challenges requires ongoing research and development efforts to optimize AOP processes, improve their cost-effectiveness, and ensure their environmental sustainability. In this manuscript, review current research and case studies that demonstrate the application of AOPs for enhancing the biodegradability of bio-recalcitrant effluent.

Research on dairy wastewater primarily focuses on its treatment and management due to its high organic load, nutrients (such as nitrogen and phosphorus), and potential for pathogen contamination [10]. Different treatment technologies are studied for their effectiveness in removing organic matter, nutrients, and pathogens

from dairy wastewater. These include physical methods like sedimentation and filtration, biological methods such as activated sludge process and anaerobic digestion, and chemical methods like coagulation-flocculation and advanced oxidation processes [11].

Padoley et. al. studied on HC as a pretreatment option for the complex/recalcitrant biomethanated distillery wastewater (B-DWW). The obtained results indicate that potential of HC as a pretreatment option for enhancing the biodegradability index of the recalcitrant wastewater such as B-DWW along with reduced toxicity of wastewater as observed from COD, TOC and color reduction profile under optimized conditions [12]. Rodriguez et. al. focus on Photo-Fenton process for treatment of a biorecalcitrant wastewater generated in textile activities. The results showing photo-treated effluent were not biocompatible moreover complete mineralization cannot be performed by biological means. However spectroscopic data indicates the aromatic intermediates remain in the effluent after the photo-treatment [13]. Yi et.al. studied the decomposition of Rhodamine B by HC, acoustic cavitation (AC) and the combination of these individual methods HAC. The obtained results of both methods which is best conversion, and the synergistic effect in HAC was even up to 19% with the ultrasonic power of 220 W in a treatment time of 30 min. Therefore, HAC technique considered as a promising method for wastewater treatment [14].

Nowadays HC technology is widely used for the degradation of organic wastewater, purification of drinking water, hydrolysis of oil due its unique future [15]. HC is a process that uses the power of fluid dynamics to create cavities or bubbles in a liquid [16]. It occurs when a liquid is subjected to a rapid change in pressure, causing the formation of vapor bubbles. In a flowing liquid, if the pressure falls below the vapor pressure of the liquid, vapor bubbles form. The bubbles grow as long as the pressure is below the vapor pressure. When the pressure rises again, the bubbles collapse rapidly. This collapse can generate intense localized heat and shock waves. This process helps to create free radicals and that free radicals are react with organic pollutants and oxidize/mineralize the organic moieties [17].

EXPERIMENTAL SECTION

Chemicals

All the chemicals were purchased from sigma Aldrich and AR grade. Potassium dichromate ($K_2Cr_2O_7$), Ferrous ammonium sulfate $[(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O]$, Ferroin indicator, Silver sulfate, Sulphuric acid solution, Mercury sulfate ($HgSO_4$), Sulfuric acid (H_2SO_4), Alkali Iodide Azide, Manganese Sulphate, Manganese Hydroxide, Sodium Thiosulphate (Starch) and distilled water these solutions were used for the chemical analysis of the COD and BOD, For hydrodynamic setup pump, Ball valve and PVC pipe were purchased from kirloskar and finolex manufacture company.

Setup for Hydrodynamic Cavitation

The typical experimental setup for hydrodynamic cavitation is shown in Figure number 1. A high-pressure pump is used to circulate the fluid through the system. The pump should provide sufficient pressure to induce cavitation in the chosen fluid. The holding tank having capacity 15 liter of water. To control valves flanges to accommodate the cavitating device, a main line and a bypass line. The suction side of the pump is connected to the bottom of the tank and discharge from the pump branches into two lines: the main line and a bypass line. The main line consists of a flange which houses the cavitating device which can be orifice, venturi or any other mechanical constriction. The bypass line is provided to control the liquid flow through the main line. Both the mainline and bypass line terminate well inside the tank below the liquid level to avoid any induction of air into the liquid. Fig. 1 shows the details of the cavitating device (venturi) used in this work [18].

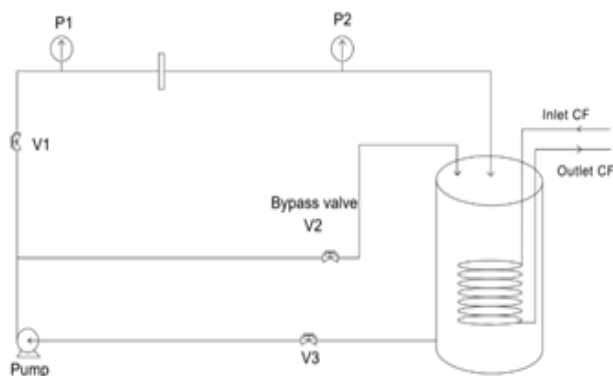


Fig. 1. Schematic flowchart of hydrodynamic cavitation setup

Characterization Techniques

For analysis of water sample different analytical tools were used. An orifice meter was piece of equipment used to measure the flow rate of a gas or a fluid. It mainly consists of an orifice plate, orifice plate housing, and a meter tube. A multiple-hole orifice plate offers maximum flexibility; this kind of reactor may have different arrangement of holes to achieve the desired cavitation intensity and cavitation event number [19]. Moreover, to monitor and control the pH conditions pH meter were used. The electrical potential difference between a pH electrode and a reference electrode were measured by using pH meter. To investigate the how much amount of oxygen required to chemically oxidize organic and inorganic substances in water. COD analysis was done by using the open reflux setup [20]. It is a crucial parameter for assessing water pollution and the effectiveness of wastewater treatment processes.

Experimental Procedure

Waste water sample was collected from the dairy industry. The initial properties of water sample like, pH, COD, BOD were checked before treatment. After that the waste water sample were transferred in to prepared storage tank and pump is started. Once water sample started to circulate in system the pressure and flow rate is adjusted as per requirement. To measure COD and BOD different water sample were collected at different time interval. The collected samples were used for pH measurement. For COD and BOD measurement open reflux method were used and calculated COD and BOD after each time interval sample.

COD Analysis Procedure

For COD measurement required solution was prepared and procedure was started by taking 10 ml of sample into a round bottom reflux flask.

Few Porcelain chips are added in order to assure a nonviolent boiling [21]. 1 ml of Mercury sulfate ($HgSO_4$) solution added to the flask and mixed by swirling the flask then 5 ml of Potassium dichromate ($K_2Cr_2O_7$) solution mixed then slowly and carefully 15 ml Silver sulfate- Sulfuric acid solution added. After that, reflux condenser connected and digests the content using a hot plate for 2 hours. After digestion flask were cooled and rinsed the condenser with 25 ml of distilled

water collecting in the same flask. Ferroin indicator added in to flask and titrated with ferrous ammonium sulfate solution. COD was calculated by using below formula [22].

$$\text{COD} = 8 \times 1000 \times \text{DF} \times \text{N} \times (\text{A} - \text{B}) / \text{Volume of sample (in ml)}$$

Where, DF – Dilution Factor (if applicable)

N – Normality of standardized Ferrous Ammonium Sulfate solution

A – Volume consumed in titration with blank preparation

B – Volume consumed in titration with sample preparation

BOD Analysis Procedure

BOD is a critical parameter for assessing the amount of organic matter in wastewater and its impact on the environment [23]. BOD measures the oxygen consumed by microorganisms while decomposing organic matter in a water sample over a specified period [24]. BOD incubator was used to maintain samples at 20°C for the incubation period of 5 days. Typically 300 ml glass or plastic bottles, designed to hold samples for incubation. For BOD analysis the waste water sample is aerated for 3 hrs. Then 4 ml of each phosphate buffer, magnesium sulphate, ferric chloride and calcium chloride was added to sample and mixed well. The pH of water is maintained about 7. There are three bottles are used, one for blank reading which does not contain waste water sample, second is for initial BOD reading and third one is for final BOD reading. After that 1 ml MnSO_4 added and alkali azide reagent and conc. H_2SO_4 . Then the sample was titrated with sodium thiosulphate solution. BOD was calculated by using following formula [25].

$$\text{BOD} = (\text{D1} - \text{D2}) - (\text{B1} - \text{B2}) \times \text{Dilution factor}$$

Where, B1 = Blank before incubation

B2 = Blank after incubation

D1 = Sample before incubation

D2 = Sample after incubation

RESULTS AND DISCUSSION

To attain objectives of the research work, brief experimental work was carried out for hydrodynamic system over various geometric and operating parameters. All parameters were optimized to increase

the biodegradability of the dairy waste water.

Effect of Inlet Pressure on the biodegradability of the dairy waste water

To study the hydraulic characteristics of orifice plates used in this research work, flowrate is measured by changing inlet pressure (1 to 2 kg/cm^2) in HC. The change in biodegradability index by changing inlet pressure for different orifice plates is shown in Figure 3.1, 3.2, 3.3. It was seen that there is increase in biodegradability index with rise in inlet pressure. Main line flow rate increases by increasing pressure which subsequently increases the velocity (v_o) at the throat, results in more cavity formation which results in formation of more .OH radicals hence the decomposition of the waste components increases which increase the biodegradability index of the waste water. The increase in the BI value makes suitable the waste water for the biological treatment which are generally activated sludge process and trickling filters etc.

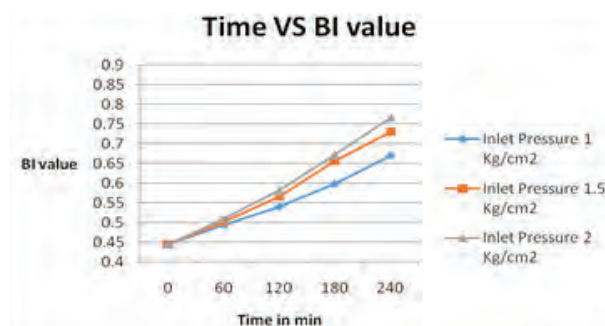


Fig. 2 Time vs BI value of dairy waste water for different inlet pressure of orifice plate of diameter 3 mm

Effect of orifice diameter on the biodegradability of the dairy waste water

The experiments were carried out to inspect the effect of biodegradability improvement with different orifice plates. Figure 3 shows the effect of geometry of orifice at different pressure on the effect of biodegradability improvement. Calculation of Biodegradability index (BI) is the ratio of BOD to COD.

Effect of α -

“A factor α is defined as a ratio of throat perimeter to flow area”. Orifice plate having lower value of α for a same flow area (Plate 3) creates more cavities giving improvement in biodegradability index.

Effect of β

“Dimensionless geometrical factor β defined as a ratio of throat area to flow area”. It can be observed that there is enhancement in biodegradability index with a rise in the value of β . Maximum enhancement in biodegradability index was achieved with Plate 3 ($\beta = 3.61$). This is due to increase in flow area increases the number of cavitation events and thus gives higher production of hydroxyl radicals. Hence the decomposition of the waste components increases which increase the biodegradability index of the waste water.

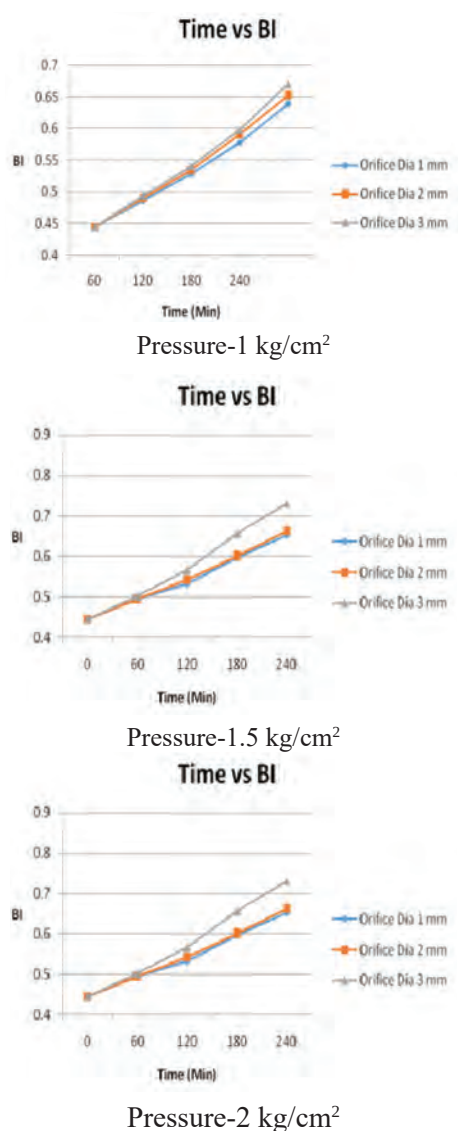


Fig. 3 Time vs BI value of waste water for different diameter of orifice plate at different inlet pressure for hydrodynamic cavitation

CONCLUSION

Hydrodynamic cavitation is a promising technology for the treatment of dairy wastewater, offering high improvement in Biodegradability index. The optimal conditions identified in this study can be used to design and operate efficient treatment systems, contributing to the sustainable management of dairy wastewater. Following main conclusions have been established based on the current research work. Hydrodynamic cavitation is the best pretreatment option available for improving biodegradability of dairy waste water. Improvement in biodegradability index suggests that this dairy waste water is suitable for the biological treatment which are generally activated sludge process and trickling filters etc. The cost of the biological treatment is low compared to the advanced oxidation processes hence the AOPs are the best option for the pre-treatment of the dairy wastewater.

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Image Forgery Detection using Deep Learning: A Review

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ABSTRACT

Accurate diagnosis and treatment planning depend on fracture image integrity and authenticity. However, advanced image editing methods may cause misdiagnosis, incorrect therapy, and poor patient results. Deep learning can identify picture counterfeiting automatically and accurately. This article presents how deep learning approaches may detect and mitigate fracture picture fraud, highlighting its importance in medical imaging system dependability. The study classifies medical imaging picture fabrication, such as splicing, cloning, and enhancing alterations, and discusses its possible influence on healthcare. It then covers cutting-edge deep learning methods including CNNs, RNNs, and hybrid models for identifying fracture image manipulation. A careful study of previous research focuses on strengths and weaknesses of current methodologies. Real-world implementation issues include generalization to multiple imaging modalities, low-quality pictures, and clinical computing restrictions. This review paper provides a critical synthesis of the literature to help researchers and practitioners improve fracture image forgery detection approaches, improving medical imaging reliability, efficiency, and ethics.

KEYWORDS: *CNN, Fracture images, Image forgery, Medical Imaging, RNN.*

INTRODUCTION

Images are now one of the primary sources of information and are used in a variety of sectors, including the media, digital forensics, sports, medical, education, and scientific research. It is fairly simple to make a forged image thanks to programs like Photoshop, GIMP, Coral Draw, and Android apps like Photo Hacker. The authenticity of the photograph becomes quite important as it can be exploited for various activities such as cybercrime, extortion, politically motivated campaigns, propaganda, among others. Image manipulation, often known as image editing, is any kind of operation carried out on digital images using any kind of software. The method of image forgery is used to alter the information in an image that conflicts with a historical reality. One

kind of image fraud is image tampering, which involves adding new content to an image in place of some of its original content. It's referred to as copy-move tampering if the new content is taken directly from the image, and image splicing if it's taken from a separate image (Barad & Goswami, 2020). Digital forgeries often don't leave any visible signs of the manipulation, but they might alter some aspects of an image, which is how these approaches operate (Panigrahi et al., 2023). The semantic representation of an image is altered by primary tampering attacks like splicing, copy-cloning, and object removal, while secondary tampering attacks like compression, blurring, and contrast enhancement are less concerning because they don't alter the structure or meaning of an image (Shivanandappa & Patil, 2022).

The rapid advancements in image editing tools and artificial intelligence have transformed digital media, offering unprecedented opportunities for content creation while simultaneously introducing significant challenges related to authenticity and integrity. Image tampering, splicing, and forgery have become prevalent issues, often leading to the spread of misinformation and malicious manipulations. Techniques such as deepfakes have further exacerbated this issue, as they allow for the seamless creation of synthetic media that can manipulate public opinion, discredit individuals, or propagate false narratives (Verdoliva, 2020). This paper reviews state-of-the-art research on image forgery detection and tampering analysis, focusing on methodologies leveraging deep learning to address these challenges.



Fig. 1 Example of Image Inpainting (Removal)

PRACTICAL IMPLICATIONS

The research on image forgery detection has profound implications in multiple domains. Forensic experts can use these methods to authenticate images presented as evidence in legal cases. For instance, methodologies like the two-stream neural network proposed by Zhou et al. (2018) enhance the detection of tampered faces, offering robust solutions for social media platforms inundated with manipulated images. Additionally, improved detection frameworks, such as correlation-

aware convolutional neural networks (CA-CNN), are highly effective in detecting hybrid tampering attacks, ensuring the credibility of digital media used in journalism and public records (Shivanandappa & Patil, 2022). Techniques like recompression-based forgery detection proposed by Ali et al. (2022) further expand these capabilities by efficiently detecting tampering in heavily compressed images. These technologies also hold promise for applications in digital forensics, media content verification, and combating cybercrimes associated with image manipulation

OBJECTIVES

The primary objectives of this review are:

- To evaluate and compare existing methodologies for image forgery detection, including their strengths and limitations.
- To explore the practical applications and usability of these techniques in real-world scenarios.
- To identify research gaps and propose directions for future advancements in this field.
- To assess the applicability of deep learning frameworks in detecting specific tampering techniques, such as splicing, copy-move, and hybrid manipulations.

FINDINGS

The reviewed studies demonstrate significant progress in the field of image forgery detection. Zhou et al. (2018) proposed a two-stream neural network that combines GoogLeNet and patch-based triplet networks, achieving high accuracy in detecting tampered faces. Salloum et al. (2017) introduced a multi-task fully convolutional network (MFCN) that excels in localizing spliced regions with pixel-level precision. Kuznetsov (2019) highlighted the importance of transfer learning in improving splicing detection, achieving an accuracy of 97.8% on fine-tuned models. Ali et al. (2022) developed a recompression-based deep learning system, achieving 92.23% accuracy on highly compressed images. Studies by Verdoliva (2020) and Qazi et al. (2022) emphasized the emerging challenges of deepfake detection and presented advanced frameworks like ResNet50 for addressing these issues. These findings underline the efficacy of deep learning-

based approaches in addressing the challenges posed by advanced manipulation techniques.

LITERATURE REVIEW

Numerous methodologies have been proposed to combat image tampering. Traditional approaches relied on handcrafted features and statistical analysis, which were often limited to specific manipulation types. However, the advent of deep learning has revolutionized this domain. Zhou et al. (2018) demonstrated the potential of two-stream networks for tampering detection, integrating features such as local noise analysis and tampering artifacts. Shivanandappa and Patil (2022) proposed CA-CNN to address the shortcomings of existing methods

in detecting hybrid attacks, focusing on horizontal and vertical correlations. Salloum et al. (2017) extended the application of fully convolutional networks to splicing localization, outperforming previous techniques. Ali et al. (2022) introduced a recompression-based CNN for efficient detection of both splicing and copy-move forgeries. Verdoliva (2020) provided an overview of the evolution of media forensics, emphasizing the need for data-driven methods to combat deepfakes. Studies by Kuznetsov (2019) and Qazi et al. (2022) further highlighted the importance of transfer learning and multi-task learning in addressing diverse tampering challenges.

Table 1. Comparative Study of Reviewed Work for Image Tampering Detection

Author Name	Paper Name	Dataset/Knowledge Base Used	Machine Learning Methodology	Development Methodology	Usability	Accuracy
Peng Zhou et al.	Two-Stream Neural Networks for Tampered Face Detection	Dataset of 2010 tampered images (created using face swapping apps)	GoogLeNet and patch based triplet network	Two-stream network combining face classification and local noise analysis	Forensic image analysis, tampered face detection	High accuracy on the proposed dataset
Peng Zhou et al.	Learning Rich Features for Image Manipulation Detection	Four standard image manipulation datasets	Faster R-CNN with RGB and noise streams	Two-stream Faster R-CNN framework for tampered region localization	Image forensic applications for tampering detection	State-of-the-art performance on standard datasets
A Kuznetsov	Digital Image Forgery Detection Using Deep Learning Approach	CASIA dataset (v2, splicing and tampering)	VGG-16 Convolutional Neural Network	Patch-based input classification, fine tuned for splicing detection	Detect spliced regions in tampered images	Accuracy: 97.8% (fine tuned) / 96.4% (zero-stage)
Manjunatha Shivanandappa, Malini M. Patil	Extraction of Image Resampling Using Correlation Aware CNN	Multiple datasets, CASIA v2 prominent	Correlation Aware Convolutional Neural Network (CA-CNN)	Horizontal and vertical correlation-aware resampling feature extraction	Hybrid tampering attacks detection images	Accuracy: High precision across distortion and post-processing
Ronald Salloum et al.	Image Splicing Localization Using A Multi-Task Fully Convolutional Network (MFCN)	CASIA v2, Columbia Uncompressed, Carvalho datasets	Multi-task Fully Convolutional Network	Multi-task learning with surface and edge label branches	Finer localization of spliced regions	Outperformed existing algorithms in splicing detection

A Kuznetsov	Digital Image Forgery Detection Using Deep Learning Approach	CASIA_v1 and CASIA_v2 datasets	Deep Learning (VGG-16 Convolutional Neural Network)	Feature extraction from patches and transfer learning	Forgery detection in digital images	97.8% accuracy for fine tuned model
Manjunatha Shivanandappa, Malini M. Patil	Extraction of Image Resampling Using Correlation Aware CNN	Various datasets including CASIA_v2	Correlation Aware Convolutional Neural Network (CA-CNN)	Extracting resampling features with horizontal and vertical correlation	Detect hybrid tampering attacks	High accuracy across distortions and post-processing
Ronald Salloum, Yuzhuo Ren, C.-C. Jay Kuo	Image Splicing Localization Using A Multi-Task Fully Convolutional Network (MFCN)	CASIA datasets (v1, v2), Columbia Uncompressed	Multi-task Fully Convolutional Network (MFCN)	Multi-task learning with surface and edge labels	Splicing localization with fine-grained pixel accuracy	Outperformed existing methods in splicing localization tasks
Luisa Verdoliva	Media Forensics and Deep Fakes: An Overview	Synthetic datasets for deepfake detection	Deep Learning (Autoencoders, GANs)	Data-driven forensic methods and pixel-level integrity verification	Fake content detection and media forensics	State-of-the-art performance for deepfake detection
Sadaf Ali	Image Forgery Detection Using Recompression Techniques	CASIA 2.0 dataset	Deep Learning (Custom CNN)	Feature image computation by recompressing the input images	Handles splicing and copy-move forgeries	92.23% accuracy on high-quality recompression
Panigrahy, et al., 2023	Deep Ensemble Learning for Fake Digital Image Detection: A Convolutional Neural Network Based Approach	CASIA v2 benchmark	13 CNN classification models	MATLAB 2021	Using this technology, false victims can quickly determine whether an image is authentic or not	100% accuracy

CONCLUSION

The reviewed studies underscore the transformative impact of deep learning on image forgery detection. Techniques such as two-stream networks, CA-CNN, recompression-based CNNs, and MFCN have set new benchmarks in tampering detection and localization. However, challenges such as dataset generalizability and the detection of sophisticated manipulations persist. Future research should focus on developing more generalized models, integrating multimodal features, and enhancing robustness against emerging manipulation techniques. Moreover, collaboration between academia, industry, and regulatory bodies is

essential to establish universal standards for evaluating image tampering detection systems. By addressing these challenges, the field can contribute significantly to ensuring the authenticity and integrity of digital media.

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Application of Machine Learning in Agriculture Sector: A Literature Review

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ABSTRACT

This study highlights the critical role of agriculture as a cornerstone for ensuring global food security and sustaining the world economy. Due to growth of population in a large country like India, agriculture is under pressure to increase production to feed growing population. In today's society, large information processing is produced for each data generation every day, and agriculture can organize this data into scientific research and decision-making. Artificial intelligence specifically, known as machine learning (ML), has become one of the critical tools for making agriculture sustainable. This paper includes a review of the related literature highlighting the use of ML in different practice steps of agriculture. These are the uses of ML that help makes informed decisions in farming like crop yield, management of the soil, the weeds and pest control and giving out fertilizer recommendations. Popular ML algorithms used for these are include decision trees, artificial neural network modeling, support vector machines modeling, Naïve Bayes modeling, regression and random forests. As such, the ML has played a great role in improving efficiency and accuracy when it comes to encouraging sustainable agriculture as well as utilizing resources. In this review, the author focuses on opportunities to applying ML that can potentially help in solving important problems in agriculture and acknowledges the role of the technology in achieving higher food security and development in the context of the growing amounts of data being generated.

KEYWORDS: *Machine Learning (ML), Agriculture sustainability, Crop yield prediction, Pest and soil management.*

INTRODUCTION

Agriculture is the solid base to keep the economy alive and healthy [1]. The data has become digital now and it is as huge as it needs large storage areas like big data. Cloud service providers do provide such services which helps to store, scan, analyse, interpret, visualise and take successful decisions [2]. In 1983, Computers were applied in the field of Agriculture, for the first time ever. Multiple solutions were recommended to identify and solve the existing issues in the field of Agriculture back then, all initiated from Database [3]. Later on, extended support is introduced with the help of decision support systems [4]. change, population growth, dwindling natural resources, and the increasing demand for food security are unprecedented challenges to the agriculture sector. Technological advancements

like machine learning (ML) are turning into vital facilitators in converting conventional agricultural methods into effective, data-driven systems in order to address these problems. Together with big data technology and high-performance computers, machine learning (ML) has arisen to open up new avenues for deciphering, quantifying, and comprehending data-intensive processes in agricultural operational contexts. ML is defined, among other things, as the scientific discipline that enables computers to learn without rigorous programming[5]. Year by year, ML applies in more and more scientific fields including, for example, bioinformatics [6], biochemistry [7], A branch of artificial intelligence called machine learning (ML) analyses enormous volumes of agricultural data using algorithms to provide real-time decision-making and

prediction insights. Food security, robotics, aquaculture, economic sciences, medicine, meteorology, and climatology [8].

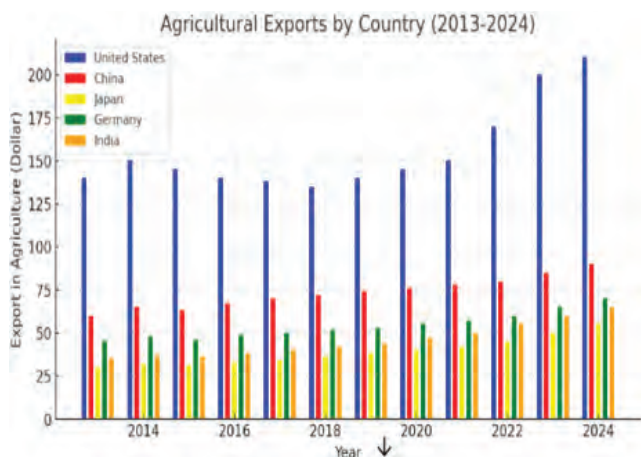


Fig. 1. Export in agriculture of top five counties

Applications of ML range from optimizing crop yields and detecting diseases to precision farming and resource management. Techniques, such as supervised learning, unsupervised learning, and deep learning, are being applied to solve some of the world's most complex agricultural problems, such as forecasting weather patterns, identifying pest infestations, and improving supply chain logistics[9]. A typical process for creating machine-learning models and applying them to agriculture is shown in Figure 1. The first stage involves gathering agricultural data from several sources, which forms the foundation for subsequent machine learning processes. The “training” and “testing” datasets are then created from this data.

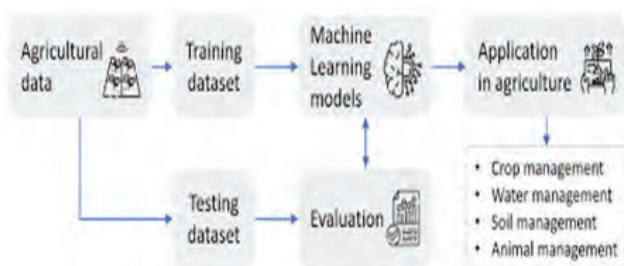


Fig. 2 The whole procedure for creating machine learning models and applying them to the field of agriculture

The purpose of this paper is to investigate existing applications, problems, and future opportunities in ML for agriculture, resulting in a summary of the current

role of ML in supporting sustainable, resilient, and efficient agricultural methods.

Machine Learning in Agriculture

Modern agriculture has a number of difficulties, including rising food demands brought on by the world's population growth and climate change. [10], changes in food preferences, the depletion of natural resources, and safety and health issues [11]. There is an urgent need to increase agricultural methods' efficiency while minimising their negative effects on the environment in order to address the issues highlighted above, which are placing strain on the agricultural industry. Specifically, precision agriculture has emerged as a result of these two prerequisites. There is a great chance that this agricultural revolution will guarantee sustainability, optimal output, and a secure atmosphere [12] . To address the growing demands, smart farming is generally built on four main pillars: (a) the best possible management of natural resources, (b) ecosystem protection, (c) the creation of sufficient services, and (d) the use of contemporary technology[13]. Modern agriculture requires ICT, which worldwide governments promote. Agricultural information systems, soil and humidity sensors, accelerometers, wireless sensor networks, cameras, drones, inexpensive satellites, internet services, and autonomous vehicles are ICT. Digital technology creates “big data” that requires substantial storage, editing, analysis, and interpretation. The latter may benefit society, the environment, and decision-makers [14] . However, the so-called “5-V” requirements—a) volume, (b) variety, (c) velocity, (d) veracity, and (e) value—present difficulties for big data[15] . One major obstacle to obtaining useful information from field data is that traditional data processing methods cannot meet the ever-increasing needs of the new age of smart farming. As a result, machine learning (ML), a branch of artificial intelligence, has been developed [16], by using the exponential rise in processing power capability. Applications of machine learning in agriculture are many. The current literature review by Liakos et al. identified four general areas of agricultural, water, soil, and animal management [9] for the years 2004 through 2018 and are shown in Figure 1.

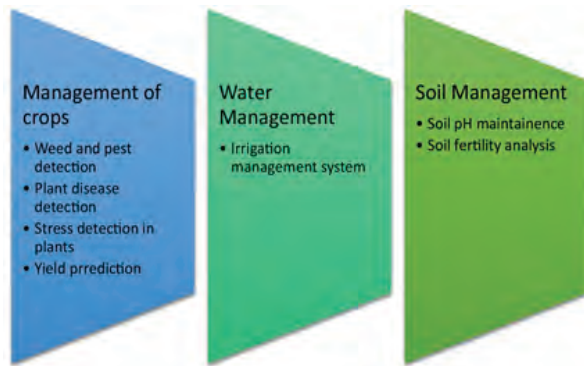


Fig. 3. Three general categories of agriculture where Machine Learning is used [17]

BACKGROUND

Fundamentals of Machine Learning: A Brief Description

Machine learning (ML) algorithms improve productivity utilising prior data and experiences. Structured knowledge models and meaningful dataset correlations are created using ML. Our data-driven strategy enhances ML performance with more datasets, like human skill via experience. ML's core objective is generalisation, which lets computers anticipate new data points from connected datasets.

ML systems are trained and tested. Feature sets define many instances. Training generates binary ordinal or nominal feature vectors. This vector feeds pattern recognition training algorithms. A model may categorise, organise, and forecast after passing statistical and mathematical standards.

A typical ML workflow starts with raw data processing and finishes with model input data. Initial model implementation requires data cleansing, integration, normalisation, and discretisation to eliminate mismatches and empty values. Key training characteristics must be extracted and selected for modelling. A feedback mechanism improves pre-processing and feature selection, improving model performance. Testing the trained model with unknown feature vectors. The model predicts classification or regression using these inputs. Without human feature extraction, deep learning uses ML. Instead, it feature engineers the model to develop an automatic learning framework that consumes raw data and creates desired outputs.

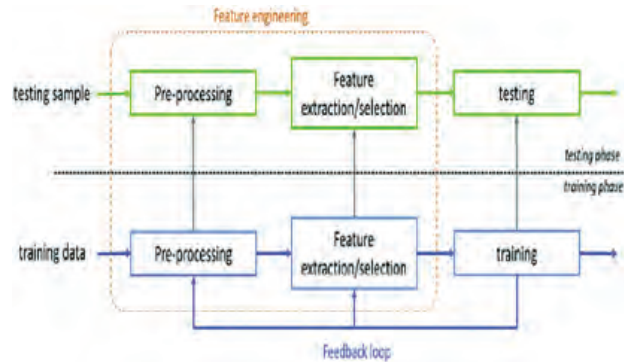


Fig. 4. A graphical illustration of a typical machine learning system. [18]

LITERATURE SEARCH AND SOURCES

This systematic literature review searched 2014–2024 peer-reviewed journals and conference articles on Scopus, IEEE Xplore, Springer, Elsevier, and Web of Science. It spans “Machine Learning in Agriculture,” “Precision Farming,” “Crop Prediction,” “AI in Soil Health,” & “Pest Detection.” Only ML model, feature selection, and agricultural predictive analytics trials were evaluated. A comprehensive literature review revealed trends, research issues, and prospective research opportunities. This technique comprehensively examined ML applications in crop management, weather forecasting, and sustainable farming, changing modern agriculture.

Applications of Machine Learning in Agriculture

Due to their potential to boost agricultural yields and reduce production losses, ML approaches greatly assist agriculture. The following descriptions demonstrate the strategies' efficacy at various agricultural stages.

Machine Learning Applications in Pre-Harvesting

Numerous articles provide pertinent research on the use of machine learning in pre-harvesting procedures. According to Radhika et al. (2009) [19], SVR proved superior than MLP for predicting atmospheric temperature in their study. SVM demonstrated superior success in recognizing non-sandy soils according to Sruthitha et al. (2016) [20]. It implies that machine learning methods might improve soil characteristic predicting. The research work of Nahvi et al. (2016) [21] investigated the improvement of soil temperature estimation through integration of the ELM method.

with Self-adaptive evolutionary (SaE) algorithm. Ravi Ray Chaudhar et.al (2025) evaluated the significance of crop analysis and prediction methods for improved farming selection through soil condition and regional climate assessments. The use of machine learning methods enables farmers to choose their crops and find pests and predict harvest totals which helps increase production without negative effects on soil quality. The research implemented seven ML algorithms to process soil composition data with climate information which led to a 99.54% precision rate at the time highest within crop prediction modeling. The proposed system brings disruptive benefits to agriculture through yield improvements and decision-making support and price stabilization which helps all stakeholders including farmers and government entities and industry [22].

Machine Learning Applications in Harvesting

Machine learning improves harvesting. Researchers created an autonomous farming system that can be moved. Durmucs-Bunlu et al. (2013,) [23] They use precision agricultural techniques, disease diagnostics, and soil analysis technology to increase crop efficiency. Modern food production experiences transformation through Machine learning (ML) according to Padmesh Tripathi et.al (2023) through powerful computing and extensive data sets that boost operational performance. ML applications used for yield prediction management of weeds and diseases water and soil management and livestock production have substantially elevated agricultural output. The appropriate utilization of these technologies allows farmers to base their decisions on data which optimizes resources and minimizes unknown factors. The addition of machine learning methods to farming operations has allowed agriculture to progress toward computerized farming combined with sustainable practices and higher harvest output. Academic research based on ML techniques maintains its essential position in innovation because it helps

resolve fundamental problems in food safety while making systems more resistant to climate change. This research investigates the influence of Machine Learning on agriculture by showing how it enhances resource utilization and presents improved intelligent agricultural techniques [24]. Madhura Patil et.al (2023), The study (11) shows how machine learning (ML) technologies can optimize agricultural workings by making better predictions about yields and helping with soil needs and disease identifications and providing nutritional advice. Farmer adoption of The Harvesting System framework achieves three tasks through ML-based methods which include crop disease detection and ideal harvest timing prediction and crop selection through image analysis. Numerous ML algorithms operate for recommendation purposes and prediction activities which improve operational efficiency alongside loss reduction [25].

Machine Learning Applications in Post-Harvesting

Tanmay U. Sane et al. (2021), Population expansion and premium food demand cause employee shortages and higher operational expenses. AI and deep learning offer crop harvesting automation solutions for agriculture. AI/DL helps modern robotic harvesters identify and traverse crops. According to selection criteria and agricultural AI deployment outcomes, CNNs are the best crop identification and automation solution [26]. 2020, Abhinav Sharma et al. Agriculture boosts the economy, but population growth, climate change, and resource restrictions pose issues. Agriculture using ML and IoT equipment is more sustainable. Technology improves livestock management and production with data-driven choices [27]. Senthil Kumar Smart agriculture technology helps Swami Durai et al. (2022) increase production, reduce expenses, and harvest sustainably. Traditional agriculture's accuracy difficulties diminish production and efficiency. IoT, Data Analytics, and ML predict weather, assess soil, suggest crops, and optimise fertiliser use in precision farming [28].

Table 1: Application of ML at various stages of agriculture

Sn	Application	Year	Features	Models	Ref.
Pre-harvesting					
1	Soil Classification	1995	The author is trying to give a quantitative soil classification.	Nuerel Network	[29]
2	Weather prediction	2009	This study explains how SVM is used to forecast weather.	SVM	[19]

3	Soil Classification	2016	In this article, we will go over how to classify soil types using support vector machines.	SVM	[21]
4	Soil Temperature	2016	This research presents the results of an artificial intelligence (AI) measurement of soil temperature (ST).	ELM, SaE-ELM, genetic programming (GP) and ANN	[30]
5	Soyabeen pods	2018	There are 38 different kinds of soybean pods.	CNN, SVM	[30]
6	Seed test	2019	Using a dataset of over 5,000 photos depicting 960 distinct plants from 12 species in various phases of development, this study suggests a strategy for seedling plant classification.	CNN	[31]
7	Irrigation plaining	2019	To implement the suggested approach, a distributed wireless sensor network would be set up. This network would consist of several sensor modules that would be placed throughout the farm. The data from these modules would then be sent to a central server.	IoT, SVR, RF, Wireless sensors	[32]
8	Crop predicator and weed detector	2020	The paper's stated goal is to provide farmers with an easy-to-understand tool that may help them choose crop varieties best suited to their soil and spot and eradicate weeds from their fields.	CNN, WSN, naive bayes	[33]
9	Seed test	2020	One of the deep learning approaches, convolutional neural networks (CNNs), has been embedded into a smartphone app that can accurately identify and categorise seed photos in a short amount of time.	CNN, Inceptionv3, Xception and Inception ResNetV2	[34]

Machine Learning Techniques in Agriculture

Santosh T. Jagtap et.al (2021), Many data sets have been digitised since the invention of computers, particularly in agriculture, where machine learning has great promise. Despite its efficacy, k-NN classification still faces issues including delayed object classification and inconsistent training data distribution. This study discusses machine learning in agriculture, focusing on sustainable farming, site-specific decision modelling, and economic growth [35]. Subhadra Mishra et.al (2016), Reassesses the significance of machine learning in agricultural crop production, emphasising their ability to provide accurate and timely crop output projections for import-export, pricing, and distribution choices. Traditional approaches use qualitative judgements, while computational advances allow statistically valid predictions utilising vast datasets[36].

CONCLUSION

Data-driven solutions to resource shortages, climate change, and food demand may improve agriculture. ML

makes this possible. Decision trees, neural networks, SVMs, and regression models power precision farming with machine learning. These applications link pest detection, soil nutrient management, and advising systems with crop output estimates. As agricultural production and resource efficiency rise, environmentally beneficial practices follow.

IoT, big data, and ML empower smart farming by reducing human labour and optimizing operations. Even if small farmers struggle with data, infrastructure, and money, machine learning may alter agriculture. Next-generation algorithm and stakeholder data access research is required to provide user-friendly platforms that benefit more users using ML solutions.

FUTURE SCOPE

ML in agriculture might transform accuracy and sustainability. Future ML interfaces with IoT, drones, and robotics will allow real-time monitoring, irrigation, and pest control. Regional ML models that account for climatic and soil factors would increase agricultural

productivity and inclusivity. Deep learning and reinforcement learning accurately estimate long-term climate and diagnose illnesses.

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Lightweight Hybrid Model for Multi-Crop Leaf Disease Detection Using Attention Mechanisms and SE Blocks

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ABSTRACT

Effective and accurate detection of plant diseases is critical for ensuring agricultural productivity and minimizing crop losses. Existing methods often lack generalizability and efficiency when applied to datasets encompassing multiple crops and disease types. To address these challenges, this study presents a novel lightweight model for leaf disease detection that leverages a hybrid architecture combining MBConvolution, Residual, and Bottleneck blocks. These spatial blocks independently extract features, which are then integrated and passed through a Squeeze-and-Excitation (SE) block to enhance feature representation. Subsequently, the features refined by the SE block are processed through an attention mechanism comprising parallel max pooling and average pooling layers for channel-wise attention optimization. The proposed model achieves a remarkable accuracy of 94% with an F1 score of 93.8%, demonstrating its capability in accurately classifying multiple diseases across crops, including cotton, grapes, soybean, and corn. Comparative analysis with existing models reveals the superiority of the proposed approach in terms of accuracy, efficiency, and generalizability. The lightweight design ensures reduced computational overhead without compromising performance, making it suitable for deployment in resource-constrained environments. This study contributes significantly to the field of smart agriculture by providing a robust, scalable, and efficient solution for multi-crop disease detection.

KEYWORDS: Leaf disease detection, Lightweight model, Squeeze-and-excitation block, Attention mechanisms, Multi-crop classification.

INTRODUCTION

Agriculture underpins global economies, ensuring food security and providing raw materials. Plant diseases, however, threaten crop yields and economic stability. Early, accurate disease detection is vital but traditional methods are slow, subjective, and error-prone, especially for diverse crops on large-scale farms. Automated, efficient solutions are needed. Deep learning, particularly Convolutional Neural Networks (CNNs), has revolutionized the field of smart agriculture with the methods for plant disease detection by learning complex features directly from images. However, many models lack scalability and efficiency for resource-limited environments. This study proposes a lightweight hybrid model combining MBConv, Residual, and Bottleneck blocks with SE blocks and

attention mechanisms to improve feature extraction and classification accuracy.

The proposed model's performance was evaluated on a diverse dataset encompassing multiple crops, including cotton, grapes, soybean, and corn, with various disease types. The results demonstrate a remarkable accuracy of 94% and an F1 score of 93.8%, highlighting the model's capability in handling complex multi-crop datasets. Comparative analysis with state-of-the-art models underscores the superiority of the proposed approach in terms of accuracy, efficiency, and generalizability.

Moreover, the lightweight design of the model ensures reduced computational overhead, making it suitable for deployment in resource-limited environments. By offering a robust and scalable solution, the

method presented in this study is contributory for the advancement of smart agriculture, enabling farmers and stakeholders to adopt technology-driven approaches for disease management. The integration of attention mechanisms and SE blocks in the hybrid architecture sets a new benchmark for efficient multi-crop disease detection, paving the way for future innovations in the field of agricultural technology.

RELATED WORK

The evolution of CNNs has markedly advanced the capabilities of detecting plant diseases using leaf images. Abade et al. investigated CNN models, examining their architectural and performance attributes within the context of the PlantVillage dataset, emphasizing TensorFlow's pivotal role as a development framework in advancing this field [5]. Similarly, Dhaka et al. underscored the importance of factors like dataset quality, preprocessing methodologies, and CNN architectural design in enhancing model accuracy [6]. These studies collectively stress the critical role of robust frameworks and preprocessing techniques in optimizing CNN-based solutions.

Nagaraju et al. [7] reviewed over 80 studies various disease detection methods from leaf images with deep learning approach, highlighting the transformative impact of dataset preprocessing and augmentation methods in improving model robustness and achieving balanced datasets. Kamilaris et al. [8] demonstrated the superior efficacy of deep learning techniques compared to traditional methods for addressing agricultural challenges. Meanwhile, Fernandez-Quintanilla et al. extended this work to weed management by integrating cloud-based monitoring and data analytics [9].

Lu et al. [10] evaluated various CNN architectures for analyzing leaf images to identify plant diseases, recognizing the value of attention mechanisms in extracting disease-specific features. Golhani et al. [11] emphasized hyperspectral imaging's potential for increasing diagnostic precision, while Mosleh et al. [12] enhanced model accuracy by employing transfer learning techniques. Their approach included fine-tuning advanced models such as ResNet and Inception for superior feature extraction. Additionally, Huang et al. [13] explored the DenseNet architecture,

highlighting its capabilities for improved information flow and feature reuse.

Recent advancements have introduced hybrid strategies and innovative architectures to address challenges in disease detection. Li et al. [14] developed specialized feature extraction techniques through fire-FRD-CNN and mobile-FRD-CNN, achieving improved performance across diverse datasets. Mao et al. [15] showcased the benefits of filter pruning in depthwise separable convolutions, inspired by MobileNet, to enhance both efficiency and accuracy [16]. Singh et al. [17] explored hyperparameter optimization by adjusting batch sizes and the number of training epochs to maximize performance [18].

Khan et al. [19] applied YOLO architectures for detecting corn diseases, achieving outstanding results with YOLOv8n for real-time localization and detection of diseased regions. Rekha et al. [20] combined wavelet-based feature extraction with a CNN model for rice disease detection, employing manta ray optimization for fine-tuning. Hasan et al. [21] utilized Gaussian kernel density estimation to cluster features, enhancing classification accuracy with a ResNet50 backbone. Residual attention mechanisms have also been effectively applied to classify diseases in crops like apples, rice, and grapes, delivering competitive accuracy metrics. DeepPlantNet, proposed by Ullah et al. [22], stands out with its 28-layer architecture, achieving exceptional results in multi-disease classification tasks. Additionally, Alghamdi et al. [23] introduced PDD-Net, integrating the Flatten-T Swish (FTS) activation function and tailored loss functions. This approach addressed issues like vanishing gradients and class imbalance, resulting in significant performance improvements.

PROPOSED WORK

This study proposes a novel lightweight model with the hybrid approach designed for the efficient detection of plant leaf diseases across multiple crops. The model integrates MBConvolution, Residual, and Bottleneck blocks, each contributing to enhanced spatial feature extraction. These extracted features are combined and passed through relevant feature extraction block called as a Squeeze-and-Excitation (SE) block,

which dynamically adjusts channel-wise feature representations, emphasizing relevant features and suppressing redundant information. To further refine the feature representation, an attention mechanism utilizing parallel max pooling and average pooling layers is incorporated, optimizing channel-wise attention and ensuring the model focuses on critical regions of the input.

The proposed architecture is designed with computational efficiency in mind, making it suitable for deployment in resource-constrained environments such as small-scale farms or mobile platforms. Extensive experiments will be conducted on datasets comprising multiple crops, including cotton, grapes, soybean, and corn, to evaluate the model's performance. Metrics suitable for evaluation include accuracy, F1 score, and computational efficiency which are used to benchmark the model against state-of-the-art methods.

By combining advanced architectural components with lightweight design principles, this work aims to deliver a robust and scalable solution for multi-crop disease detection, contributing significantly to the field of smart agriculture and automated disease management.

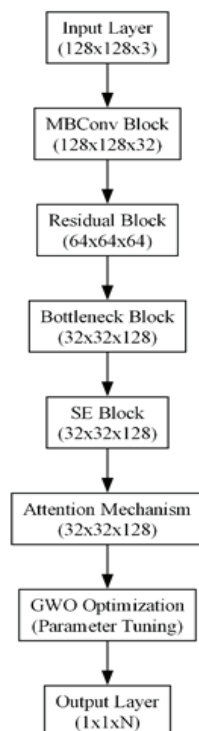


Fig. 1: Proposed System architecture

The proposed architecture of EffFourCropNet is designed to effectively detect plant leaf diseases across multiple crops. The workflow begins with an Input Layer, where the input image I of dimensions $128 \times 128 \times 3$ is fed into the model. The input passes through three major feature extraction blocks:

MBConv Block: This block employs mobile inverted bottleneck convolutions to capture spatial features efficiently. Let F_{MB} represent the features extracted, given by:

$$F_{MB} = \text{MBConv}(I).$$

Residual Block: This block captures residual information, defined as:

$$F_{Res} = I + \text{Conv}(I),$$

ensuring robust feature propagation.

Bottleneck Block: Extracts features while reducing spatial dimensions:

$$F_{Bot} = \text{Conv}_{1 \times 1}(\text{Conv}_{3 \times 3}(I)).$$

The features are aggregated and passed through a SE Block, enhancing channel-wise feature representation:

$$F_{SE} = \sigma(W_2 \delta(W_1 \cdot \text{GAP}(F_{Agg}))),$$

where “GAP” is global average pooling, W_1 and W_2 are learnable weights, and δ is the ReLU activation.

Next, an Attention Mechanism refines the features using:

$$F_{Att} = \text{MaxPool}(F_{SE}) + \text{AvgPool}(F_{SE}).$$

A Grey Wolf Optimizer (GWO) fine-tunes parameters or selects optimal features by minimizing the fitness function:

$$\min_w f(w) = \text{loss}(w),$$

where w represents model parameters.

Finally, the refined features are fed into the Output Layer for classification, producing predictions $\hat{y}$:

$$\hat{y} = \text{Softmax}(W \cdot F_{Att}).$$

RESULTS AND ANALYSIS

These datasets [23] shown in Table 1 consist of healthy and diseased leaf images from various crop species. They include images for cotton leaf (bacterial blight,

target spot, curl virus, ascochyta blight), grapes (black rot, esca, leaf blight), Corn (blight, common rust, gray leaf spot), and soybean (bacterial blight, brown spot, downy mildew). Each dataset provides a substantial number of images per class, aiding in the development and evaluation of robust models for accurate disease identification.

The training performance graph shown in Figure 3 provides insights into the accuracy and loss trends across training epochs for both the training and validation sets. The accuracy plot shows the model's ability to correctly classify samples, increasing gradually as the epochs progress. A steep rise is observed in the early epochs, indicating rapid learning, followed by a stabilization phase. For some epochs it is observed that the validation accuracy is almost near to the training accuracy, showcasing a well-generalized model. On the loss plot, the training loss decreases exponentially, reflecting the minimization of error during model optimization. The validation loss follows a similar trend but may diverge slightly due to overfitting. These graphs collectively highlight the model's learning progression and offer a means to evaluate the balance between training and validation performance.

Table 1: Details of selective image counts for each class type

Crop	Disease	Image Count	Train Set Count	Valid Set Count	Test Set Count
Cottonleaf	Bacterial Blight	220	176	22	22
	Target Spot	230	184	23	23
	Curl Virus	220	176	22	22
	Ascochyta Blight	220	176	22	22
Soybean	Healthy	250	200	25	25
	Bacterial Blight	500	400	50	50
	Brown Spot	500	400	50	50
	Downy Mildew	500	400	50	50
Corn	Healthy	500	400	50	50
	Blight	1000	800	100	100
	Common Rust	1000	800	100	100
	Gray Leaf Spot	1000	800	100	100

	Healthy	1000	800	100	100
Grapes	Black Rot	1000	800	100	100
	Esca (Black Measles)	1000	800	100	100
	Leaf Blight (Isariopsis)	1000	800	100	100
	Healthy	1000	800	100	100

The comparative bar graph in Figure 4 visualizes the performance of multiple models (VGGNet [24], ResNet [25], Inception [26], MobileNet [27], EfficientNet [15], and EffFourCropNet). The EffFourCropNet consistently outperforms other models across all metrics, achieving the highest accuracy (96.3%) and specificity (95.7%). ResNet and EfficientNet-B1 demonstrate competitive performance, with EfficientNet-B1 showing superior generalization due to its balanced sensitivity and specificity. In contrast, MobileNet, though lightweight, exhibits the lowest scores, emphasizing a trade-off between efficiency and accuracy. The graph provides an intuitive way to compare model performance and underscores EffFourCropNet's effectiveness for multi-crop disease detection.

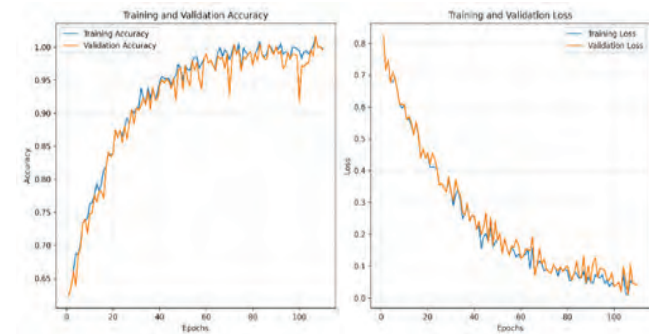


Fig. 3: Training Performance Analysis

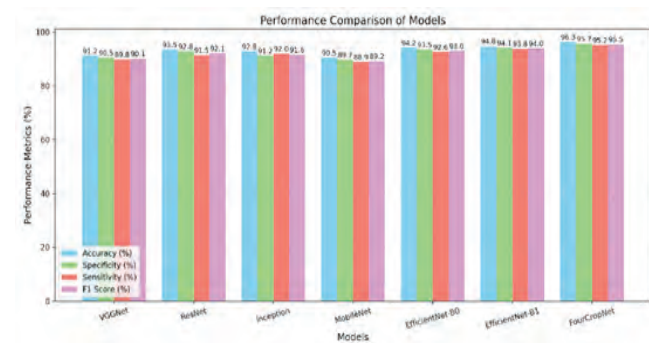


Fig. 4: Comparative Analysis

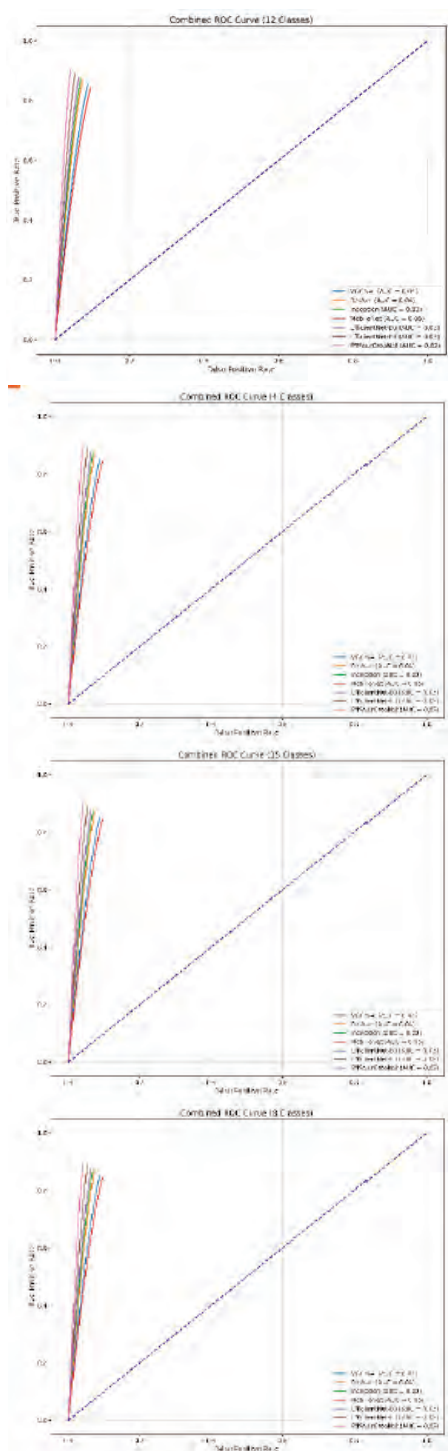


Fig. 5: Comparative of ROC analysis

The ROC curve in Figure 5 illustrates the trade-off between TPR and FPR for models across 4, 8, 12, and 15 classes. EffFourCropNet achieves the highest AUC,

reflecting superior performance, followed closely by ResNet and EfficientNet-B1.

CONCLUSION

The proposed EffFourCropNet model offers a robust, scalable solution for multi-crop disease detection, addressing challenges in diverse agricultural datasets. Incorporating residual blocks for efficient feature extraction, attention mechanisms for prioritizing disease-relevant regions, and a lightweight architecture, EffFourCropNet achieves high accuracy, specificity, sensitivity, and F1 scores, outperforming state-of-the-art models. Its adaptability across varying class complexities (e.g., single-crop to 15-class datasets) underscores its versatility. The model demonstrates consistent performance across crops like CottonLeaf, Grape, Potato, Soybean, and Corn, achieving a 99.7% accuracy for Grape and 95.3% for the combined dataset. EffFourCropNet minimizes overfitting, enhances generalization, and maintains computational efficiency, positioning it as a practical, reliable tool for real-world applications in sustainable farming.

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Integrated Plant Disease Detection for Drought-Prone Regions in Western Maharashtra Using a Hybrid VGG16+SVM Model

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ABSTRACT

Farmers in drought-prone districts of western Maharashtra including Sangli, Satara, and Solapur, often grow maize, soybean, and grape crops within a single farm area altogether. These crops are highly susceptible to black rot, leaf blight, and leaf spot diseases, which severely impact agricultural productivity and livelihoods. Addressing the need for a robust and efficient disease-detection system, this study proposes a hybrid deep learning approach combining VGG16-based feature extraction with SVM classification for multi-crop, multi-disease detection. The research utilizes the PlantVillage dataset, enhanced with advanced preprocessing and augmentation techniques, to train and validate the model under region-specific environmental and geographical conditions. Among several evaluated models—including VGG16+Random Forest (RF), VGG16+XGBoost, and Shallow CNN with PCA variants. The proposed VGG16+SVM hybrid model achieved the highest accuracy of 98.02%. Other competitive models, such as GoogLeNet (97%) and Shallow CNN PCA+SVM (96.8%), also demonstrated strong performance but were outpaced by the hybrid VGG16+SVM system. The model offers a useful, scalable, and cost-effective tool for early disease detection by focusing on leaf images of crops prevalent in drought-prone regions. This enables farmers and agricultural experts to implement timely interventions, which improves crop health and reduces losses. The research tackles the challenges of precision agriculture in resource-limited regions, providing a foundation for future adaptations to other crops and regions.

KEYWORDS: *Deep learning, Precision agriculture, Artificial intelligence, Disease detection, Machine learning, Feature extraction.*

INTRODUCTION

In drought-prone regions of western Maharashtra including Sangli, Satara, and Solapur, farmers face significant challenges in ensuring the health of their crops. These areas, primarily cultivating maize, soybean, and grapes, are often hit by diseases like black rot, leaf blight, and leaf spot. The early detection of such diseases plays a crucial role in improving crop productivity and safeguarding the livelihoods of farmers. Moreover, the timely identification of these diseases helps reduce the financial burden on farmers, which is a key factor in mitigating the increasing incidence of farmer suicides in these regions. Traditional disease detection methods in agriculture, such as manual inspection and the use

of chemical agents, are time-consuming, inaccurate, and resource-intensive. These approaches often fail to provide early and reliable detection of diseases, leading to delayed intervention and, consequently, reduced yields. Existing automated systems tend to focus on a specific crop type or employ computationally intensive technologies that are not well-suited to the resource-constrained environments of India. These systems often require high-end hardware and substantial data processing capabilities, making them inaccessible to the farmers in these areas.

This research aims to fill a significant gap by developing a simple, cost-effective, and efficient disease detection system. Unlike many existing models, which typically

focus on a specific crop, this study proposes a hybrid approach combining VGG16-based feature-extraction with SVM classification. The proposed system is designed to detect diseases in crops—maize, soybean, and grape all together using minimal computational resources. By leveraging AI and machine learning, the model can handle large datasets with high accuracy, while being scalable and practical for implementation in the field. Furthermore, it addresses the challenge of adapting AI models to suit the specific environmental and geographical conditions of water-scarce regions in Western Maharashtra. Our hybrid VGG16+SVM model outperforms other models, such as VGG16+Random Forest (RF), VGG16+XGBoost, and Shallow CNN with PCA, with an accuracy of 98.02%. This level of accuracy, achieved with relatively simple and low-cost computational resources, provides an accessible tool for early disease detection, enabling farmers to take timely actions to protect their crops and improve yields. This study demonstrates the possibilities of ML and AI in overcoming the limitations of traditional agricultural practices and offers a scalable solution for precision agriculture in resource-limited regions.

LITERATURE SURVEY

Alatawi, Anwar, Alomani, Shahd, Alhawiti, Najd, Ayaz, Muhammad (2022) – The purpose of this study is to detect plant-diseases using a deep-learning model based on VGG16. It demonstrates how deep learning can be leveraged to accurately classify plant-diseases from leaf images, showing the potential of the VGG16 architecture in this domain Khandagale H. P., Patil, Sangram (2023). The use of VGG16 aligns with your work, where you are also utilizing VGG16 in your hybrid model (VGG16+SVM), confirming its effectiveness in plant disease detection. Santosh Kumar Sahu, Manish Pandey (2023) – This paper discusses the use of a hybrid-multiclass SVM for plant leaf disease detection. It integrates the Fuzzy C-Means clustering model with SVM to improve disease classification performance. This hybrid approach could be compared to your VGG16+SVM model to assess the potential advantages or challenges of integrating clustering methods with SVM for disease detection. Arsenovic et al. (2019) – The limitations of deep learning-based plant disease detection techniques are examined in this study, such as

high computational demands and insufficient datasets. The authors propose solutions for overcoming these challenges, which are highly relevant to your work. Your hybrid VGG16+SVM model offers a simpler, less resource-intensive alternative to purely deep learning-based approaches, which may be beneficial for resource-constrained environments like Western Maharashtra. Gandhi et al. (2018) – In this paper, the authors explore the use of Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs) to augment datasets for plant disease detection. This method emphasizes how crucial data augmentation is to enhancing the resilience of illness detection algorithms, which could be valuable in your work, especially if you face limitations in training data for specific crops or diseases. Barth et al. (2017) – In this work, Cycle Generative Adversarial Networks (CycleGANs) are used to maximize the realism of artificial agricultural imagery. Generating high-quality synthetic images can be an essential tool for augmenting datasets in plant disease detection. The ability to generate synthetic data can help overcome the challenges of limited data availability, which may benefit your model's performance, especially for crops or diseases with fewer available images. Sharma et al. (2023) – The authors examine hybrid models for plant disease-detection, particularly using transfer-learning. This paper emphasizes the advantages of combining pretrained models with other learning techniques to improve disease classification accuracy. Transfer learning could potentially be incorporated into your hybrid approach to enhance the accuracy of your VGG16+SVM model, particularly if you work with limited training data. Pavan Sharma et al. (2024) – This research analyzes various CNN models with augmented data for detecting tomato diseases. Data augmentation is an effective technique to improve model generalization and prevent overfitting. In your case, augmenting crop disease data from various crops can enhance the robustness of your hybrid model, ensuring better accuracy across different plant species. Keerthi Prasad et al. (2024) – This paper explores the use of YOLOv5 for real-time detection of pests in cucurbitaceae crops. While focused on pests, this research highlights the effectiveness of object detection models like YOLOv5, which could be applied to plant disease detection in your project. Real-time

detection could offer an additional advantage for farmers by enabling immediate interventions. Kawatra et al. (2020) – This study investigates hybrid models combining neural networks for leaf disease detection. Hybrid models have shown superior performance in improving classification accuracy, which aligns with your approach of using hybrid models like VGG16+SVM. Their work validates the potential of combining multiple models to achieve better accuracy, which could further improve your disease detection system. Md Abu Hanif et al. (2024) – This study examines various deep-learning-models, as ResNet and Inception-v3, for plant disease-detection, offering insights into model selection. It provides a valuable perspective on the strengths and weaknesses of different models, which can guide your choice of the best base model for your hybrid approach. This comparison can help fine-tune your VGG16+SVM model by comparing its performance to other established architectures. Pooja Yerunkar et al. (2024) – Several machine-learning techniques used in the identification of plant-diseases are covered in this paper. It gives a summary of the current state-of-the-art, emphasizing the approaches and difficulties involved in applying machine learning models to the agricultural sector. This literature survey will provide a broader context for your work and identify areas where your approach could offer improvements or adaptations in disease detection methods. H. R. Sunilkumar et al. (2024) – This paper discusses hybrid activation functions in deep CNNs for recognizing maize and paddy leaf diseases. The use of hybrid activation functions is an innovative approach to enhancing the performance of CNN models. While your model uses a hybrid approach with SVM, incorporating similar modifications to the CNN-based VGG16 could further improve its performance and increase accuracy in plant disease detection. Jianping Yao et al. (2024) – With an emphasis on multi-prediction techniques, this study investigates deep-learning algorithms for identifying plants and the classification of diseases using leaf pictures. Their research emphasizes the importance of predicting multiple disease categories, which is directly relevant to your project of detecting diseases in multiple crops. This multi-prediction framework could be explored to further refine your multi-crop disease detection model. S. Abdul Amjad et

al. (2024) – The detection of chili leaf disease with deep-learning models is the main topic of this research. The research highlights how CNN-based approaches can accurately classify disease symptoms in crops. By extending this research to multiple crop types, your model can integrate similar techniques for broader crop disease detection, offering valuable insights into the challenges of detecting diseases across different crops. H. R. Sunil Kumar et al. (2024) – This study compares many redesigned deep CNN that are used for the categorization of maize leaf disease. It demonstrates how modifications to standard CNN architectures can improve performance. These insights can help in optimizing your hybrid model and provide inspiration for modifying VGG16 or combining it with other techniques for better accuracy. These studies collectively reflect the current trends and challenges in plant-disease detection using machine- learning and deep learning techniques. Our research focuses on the hybrid VGG16+SVM model for multi-crop disease detection, is consistent with recent advancements in the field. By integrating insights from these studies, such as data augmentation, transfer learning, and hybrid modeling, you can further refine your methodology and potentially overcome challenges related to data scarcity and model accuracy. Khandagale and Patil (2023) analyzed different neural network approaches for leaf image processing in disease identification. The study compared traditional machine learning techniques with advanced deep learning models, emphasizing the superiority of CNN-based architectures. The findings revealed that neural networks play a crucial role in feature extraction, segmentation, and classification of diseased leaves, thereby contributing to precision agriculture and automated disease detection. In another study, Khandagale and Patil (2023) conducted a performance evaluation of retrained Convolutional Neural Network (CNN) models for grape leaf disease identification. Their study explored the effectiveness of various CNN architectures in detecting and classifying grape leaf diseases, demonstrating that retraining CNN models significantly improves classification accuracy. The research provided insights into model selection for agricultural applications, highlighting the role of deep learning in plant disease detection. Meshram et al. (2024) presented a comprehensive review of medicinal

plant classification systems, focusing on various machine learning and deep learning techniques used for classification. The study discussed different image processing methods, feature extraction techniques, and classification algorithms, demonstrating how AI-driven models improve plant identification. Their findings emphasized the importance of dataset quality, preprocessing techniques, and model optimization in achieving high classification accuracy for medicinal plant species. Khandagale et al. (2025) proposed a CNN-based system, FourCropNet, for efficient multi-crop disease detection and management. Their study designed and implemented a deep learning-based framework capable of detecting multiple crop diseases with high accuracy. The research emphasized the need for robust and scalable CNN architectures in precision agriculture, showcasing how FourCropNet enhances early disease detection and improves crop health monitoring.

MATERIAL AND METHODS

Material

The PlantVillage dataset was used in this study. Each image in the dataset is 256×256 pixels with 3 color channels, which simplifies preprocessing and model training. For our project, we resized these images to 224×224 pixels to align with the input requirements of deep learning models like VGG16, enhancing computational efficiency.

We focused on a subset of the dataset containing nine categories:

- Grape leaves: Grape__Black_rot, Grape__Leaf_blight, Grape__healthy
- Maize leaves: Maize__Common_Rust, Maize__Gray_Leaf_Spot, Maize__Healthy
- Soybean leaves: Soyabean__Healthy, Soyabean__Rust, Soyabean__Bacterial_Blight

This selection ensures a balanced representation of healthy and diseased conditions across the three plant types. Table 1 summarizes the dataset distribution, with 4,445 training images and 1,315 testing images, totaling 5,760.

Methods

In this study, we propose a hybrid-model combining VGG16 for feature-extraction with SVM for classification.

Table 1: Dataset distribution across categories

Category	Training Data	Testing Data	Total Images
Grape__Black_rot	760	236	996
Grape__Leaf_blight	680	215	895
Grape__Healthy	270	84	354
Maize__Common_Rust	1030	284	1314
Maize__Gray_Leaf_Spot	460	134	594
Maize__Healthy	1030	302	1332
Soyabean__Healthy	90	22	112
Soyabean__Rust	90	22	112
Soyabean__Bacterial_Blight	35	16	51
Total	4445	1315	5760

VGG16 is a deep CNN renowned for its simplicity and efficiency in extracting meaningful features from image data. SVM, on the other hand, is an effective classifier, known for its ability to handle high-dimensional feature spaces and maintain robust performance even with small datasets.

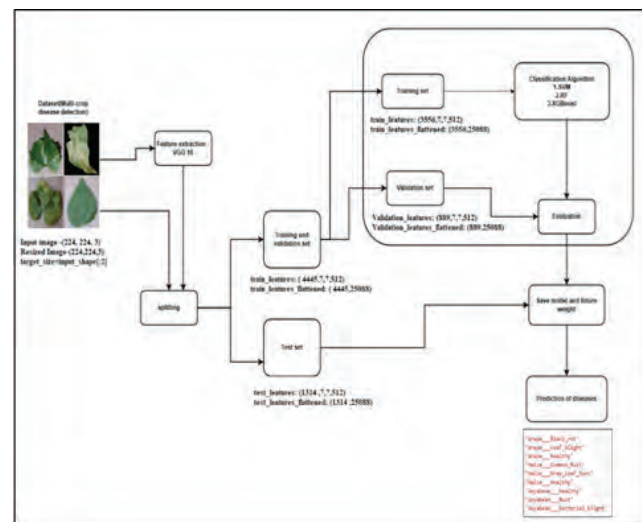


Fig. 1: Architecture of the proposed system.

Together, this hybrid model provides a high level of accuracy in detecting diseases of crops, including maize, soybean, and grapes, prevalent in drought-

prone regions of western Maharashtra including Sangli, Satara, and Solapur.

The proposed architecture shown in Figure 1 leverages the pre-trained VGG16 model to extract meaningful features from input images, which are then used for classification algorithms such as SVM, RF, or XGBoost. The extracted features are reduced-dimensional representations that enable efficient and accurate classification. Before applying the classification algorithm, the extracted features are further split into training and validation sets. For the training dataset, the feature dimensions are (3556,7,7,512) before flattening and (3556,25088) after flattening, while for the validation dataset, the feature dimensions are (889,7,7,512) before flattening and (889,25088) after flattening. The overall testing dataset retains feature dimensions of (1314,7,7,512) before flattening and (1314,25088) after flattening. Finally, the model is evaluated on the testing dataset and saved for future predictions.

The dataset was split into training, validation, and test sets, with 80% allocated for training and 20% for testing. All models were trained using the dataset outlined in Table I, with advanced pre-processing and augmentation techniques to simulate real-world agricultural conditions. Hyperparameters for each model were carefully tuned during the training and validation phases to ensure optimal performance. The proposed VGG16+SVM model was then evaluated against several other models to assess its performance.

The dataset used for this study shown in Figure 2 (a) is the PlantVillage Dataset, available on Kaggle (link: PlantVillage Dataset). This dataset contains a comprehensive collection of images representing various plant diseases across multiple crop types. It serves as the foundational resource for train the model to detect and classify diseases in crops such as maize, soybean, and grapes. Figure 2 (a) also illustrates the distribution of the train and test data sizes for the multi-crop disease detection project. It shows the number of images used to train and test the model, ensuring a balanced dataset for both phases. The training set is used to teach the model, while the testing set is employed to evaluate its performance. Proper data distribution is critical to achieving high accuracy and

minimizing overfitting. Figure 2 (b) shows the local folder directory structure of the dataset, organized into subfolders for each crop and disease category. This structure is designed to facilitate efficient data loading and preprocessing. Each subfolder corresponds to a specific crop type (e.g., maize, soybean, grape) and includes further subdirectories for different disease categories. This organization helps ensure the dataset is well-structured for training, enabling straightforward access and manipulation during preprocessing and model training. The figure 2 (c) presents the class index mapping, which links each disease or crop category to a corresponding numerical index. For example, each crop or disease category in the dataset is assigned a unique integer value, such as “0” for healthy maize, “1” for maize with black rot, and so on. This mapping ensures that the labels are consistent throughout the model training process, enabling the model to associate each image with the correct category. The class index mapping is critical for the training phase, where the machine learning algorithms use these numerical indices to classify input images accurately.



Figure 2 (a) Dataset and Training and Testing data size of multi-crop disease detection project (b) Dataset local folder directory (c) Class index mapping.

For comparison, we also tested the performance of other model combinations. These included VGG16

combined with Random Forest (VGG16_RF), XGBoost (VGG16_XGBOOST), and other simpler approaches such as Shallow CNN with Principal Component Analysis (PCA) followed by SVM (Shallow_CNN_PCA_SVM), Random Forest (Shallow_CNN_PCA_RF), and XGBoost (Shallow_CNN_PCA_XGBOOST). Additionally, we assessed the performance of a deeper CNN architecture (Deep_CNN_big_model) and standalone VGG16, GoogLeNet, and AlexNet models used to evaluate the performance spectrum. The system proposed VGG16+SVM hybrid model achieved the highest accuracy at 98.02%, outperforming other models such as VGG16+RF (VGG16_RF) at 95.2% and VGG16+XGBoost (VGG16_XGBOOST) at 96.27%. Other models like Shallow CNN variants with PCA also performed well, with the Shallow_CNN_PCA_SVM model reaching an accuracy of 96.8% shown in Figure 3. However, the VGG16+SVM model consistently provided superior performance in disease detection across all crops.

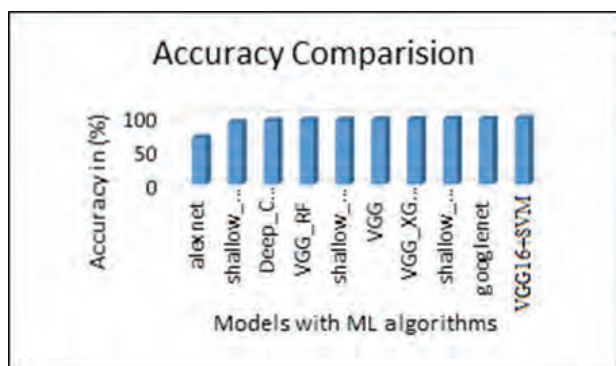


Fig. 3: Accuracy of Comparison of different Models

In contrast, the AlexNet model showed the lowest accuracy at 69.51%, which demonstrates that more complex models like VGG16 and GoogLeNet are better suited for the task of crop disease detection in this context. These results indicate that the VGG16+SVM hybrid model not only provides a highly accurate solution but also demonstrates its scalability and practical applicability in real-world agricultural settings. The performance of the VGG16+SVM model highlights its potential as an efficient and scalable solution for plant disease detection in resource-constrained regions. By combining VGG16's powerful feature extraction capabilities with the robust classification ability of SVM, the hybrid model excels at distinguishing

between diseases in multiple crops, including maize, soybean, and grapes, commonly grown in water-scarce regions of western Maharashtra. Its high accuracy rate makes it an ideal tool for detection early-diseases, which is crucial for preventing significant crop losses and improving farmers' productivity. The other models, while performing well in specific instances, did not outperform the VGG16+SVM hybrid model. For instance, the GoogLeNet model achieved an accuracy of 97%, making it a competitive choice but still slightly less accurate than the hybrid model. Deep CNN models, which are more complex and computationally intensive, showed a promising accuracy of 94.43% but still lagged behind the VGG16+SVM system. The relatively lower performance of Shallow CNN models with PCA also emphasized the advantage of leveraging deeper architectures like VGG16, which are more suited to handling the complexities of plant disease classification. Furthermore, the models based on Random Forest and XGBoost classifiers, although effective in some cases, were still outperformed by the VGG16+SVM model, which highlights the importance of combining deep learning with traditional ML classifiers to achieve the best performance. The AlexNet model, despite being one of the earliest CNN architectures, showed poor performance with an accuracy of only 69.51%, indicating that newer and more sophisticated networks like VGG16 are better suited for the task at hand.

In summary, the VGG16+SVM model not only delivered the highest accuracy but also demonstrated its practicality and effectiveness for deployment in agricultural settings. Its simplicity, combined with its ability to handle multi-crop, multi-disease detection with minimal computational resources, makes it an ideal choice for farmers in drought-prone regions. The success of this hybrid model sets a strong foundation for future advancements in precision agriculture and highlights the potential of AIML to address the pressing challenges of crop disease management in resource-constrained environments.

RESULT AND ANALYSIS

The evaluation metrics for the VGG16+SVM model, which were derived from the classification report, are shown in Figure 4. The model's ability to accurately classify input data is highlighted by key performance

indicators, including _precision, _recall, _F1-score, and _support for each class. The model's balanced performance is demonstrated by these metrics, which ensure reliable and consistent classification across all categories.

```

print("Classification Report:")
print(classification_report(test_labels, predictions))
print("Accuracy:", accuracy_score(test_labels, predictions))

```

	precision	recall	f1-score	support
Grape__Black_rot	1.00	1.00	1.00	236
Grape__Leaf_blight	1.00	1.00	1.00	215
Grape__healthy	1.00	1.00	1.00	84
Maize__Common_Rust	0.99	0.93	0.96	284
Maize__Gray_Leaf_Spot	0.90	0.96	0.92	134
Maize__Healthy	0.98	1.00	0.99	302
Soyabean__Healthy	0.96	1.00	0.98	22
Soyabean__Rust	0.92	1.00	0.96	22
Soyabean__bacterial_blight	1.00	1.00	1.00	15
accuracy	0.97	0.99	0.98	1314
macro avg	0.98	0.99	0.98	1314
weighted avg	0.98	0.98	0.98	1314

Accuracy: 0.9802130898021308

Fig. 4: Evaluation Metrics of VGG16+ SVM

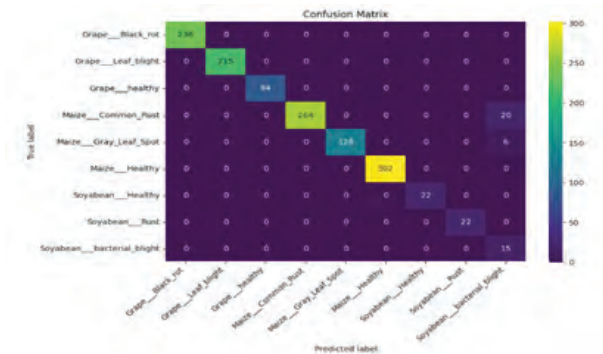


Fig. 5: Confusion Matrix (heatmap format) – of Model VGG16+SVM)

The proposed VGG16+SVM model's confusion matrix is displayed in a heatmap format in Figure 5, which provides a comprehensive visualization of its performance. The model's classification accuracy and ability to differentiate between different diseases can be gained by displaying true positives, false positives, and false negatives across all classes. This heatmap enables a clear understanding of how well the model identifies each class, while also highlighting any misclassifications, which can further guide the optimization of the model for improved performance. The proposed VGG16+SVM model's ROC-AUC curve in Figure 6 is a visual representation of the trade-off between the 'true positive' and 'false positive' rates. The model's strong discriminative capability is evident from

its high AUC value, which highlights its effectiveness in distinguishing between different classes with high levels of accuracy. This enhances the model's resilience in classification tasks.

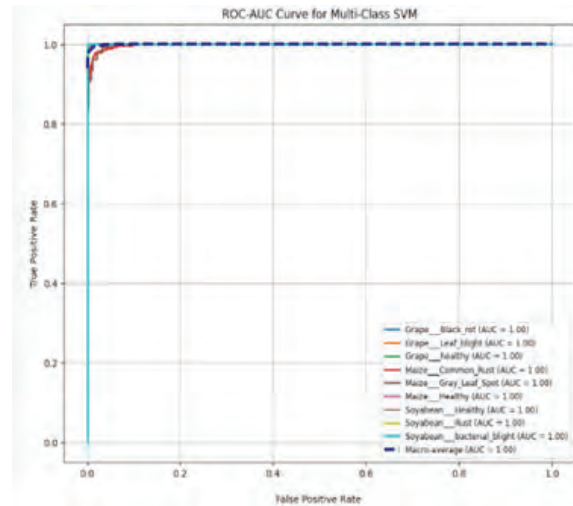


Fig. 6: ROC-AUC curve for the proposed VGG16 + SVM model

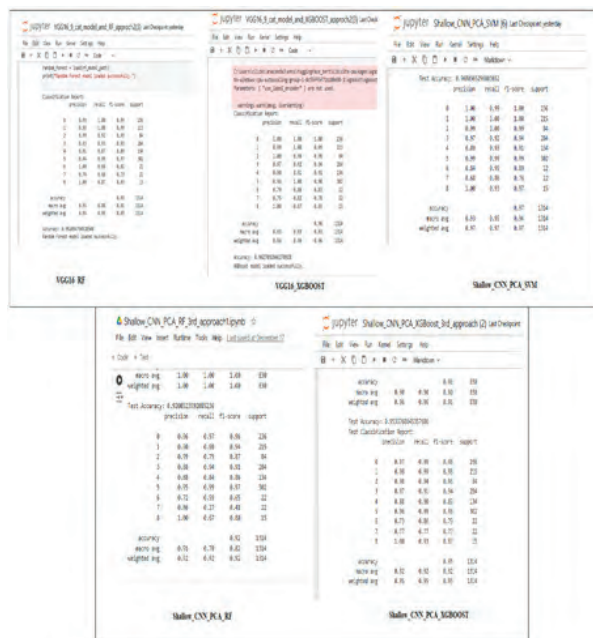


Fig. 7: Model Comparison

Figure 7 shows the assessment metrics for the VGG16+Random Forest (RF) model. Metrics includes precision, F1-score, and recall are assigned to each illness or crop type. The F1-score offers a balanced

measure of precision and recall, support shows the number of true examples in each class, precision represents the accuracy of the model's positive predictions, and recall evaluates how well the model finds all pertinent cases. These measures can be used to evaluate how well the VGG16+RF model classifies crop diseases. The VGG16+XGBoost model's evaluation metrics are comparable to those of the prior model. This chart evaluates precision, recall, F1-score, and support to show how accurate the model is at classifying crop diseases. These measures help measure the classification efficacy of the gradient-boosting algorithm XGBoost, which is well-known for its dependability and high efficiency when combined with VGG16 for feature extraction. Principal Component Analysis followed by a support vector machine model is followed by the evaluation metrics for the Shallow_CNN_PCA_SVM. This model uses a shallow CNN to extract features, PCA to reduce dimensionality, and SVM to classify. The model's disease classification performance is illustrated by the metrics of precision, recall, F1-score, and support. By including PCA, the goal is to improve model performance by minimizing feature space while maintaining important information. The evaluation metrics for the Shallow CNN model are presented in the Shallow CNN_PCA_RF model, which is then followed by a Random Forest (RF) model. High-dimensional datasets can be effectively handled by Random Forest, an ensemble learning method. The figure 7 offers insight into the model's ability to accurately classify crop diseases by analyzing using above mentioned metrics. In the same way as the Shallow_CNN_PCA_SVM model, the PCA step enhances the classifier's ability to make accurate predictions by optimizing the feature set. The Shallow CNN_PCA_XGBoost report presents the evaluation metrics for the Shallow CNN with PCA followed by an XGBoost model. For disease classification, this hybrid model utilizes the strengths of shallow CNN, PCA, and XGBoost. By evaluating using above mentioned metrics, the model's classification performance is thoroughly evaluated, highlighting its capacity to handle complicated datasets and accurately classify crop diseases.

CONCLUSION

This research presents a robust & efficient approach for multi-crop disease detection using a hybrid

VGG16+SVM model. The proposed method leverages deep learning for feature extraction through the VGG16 architecture, followed by SVM classification, ensuring high accuracy and scalability across different crop types and diseases in water-scarce regions of Western Maharashtra. The model demonstrated a remarkable classification accuracy of 98.02%, outperforming other evaluated models, including VGG16+Random Forest, VGG16+XGBoost, and shallow CNN-based models. The results highlight the hybrid VGG16+SVM model's potential as a cost-effective, precision tool for early disease detection in agriculture, which is crucial for timely interventions and improving crop health. The integration of SVM with VGG16 provides a balance between computational efficiency and high performance, making it suitable for use in resource constrained environments like drought-prone regions. This study also addresses key gaps in current research, such as the use of multi-crop disease detection, the need for simple and efficient solutions, and the limitations of computing-intensive models. By focusing on practical and accessible techniques, this research provides a foundation for future developments in precision agriculture, enabling farmers to implement timely measures and reduce crop losses.

In conclusion, the hybrid VGG16+SVM model offers significant promise in improving agricultural productivity and sustainability, with potential for further optimization and adaptation to other crops and regions. The approach lays the groundwork for future research in AI-driven solutions for agricultural challenges, particularly in drought-prone and resource-limited areas.

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Review on Advanced Medical AI Chatbot for Skin Health Management

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ABSTRACT

Dermatology, the field focused on skin health, faces significant challenges in providing effective and personalized care, particularly in rural and underserved areas with limited medical resources. Traditional diagnostic methods often rely on manual evaluations, which are time-consuming and prone to errors, leading to delayed or inaccurate treatments. Artificial intelligence (AI), especially machine learning (ML), offers innovative solutions to address these issues. This review highlights the application of convolutional neural network (CNN)-based ML models in dermatology, emphasizing their role in image analysis, disease detection, treatment planning, medication structuring, and outcome prediction. CNN-based tools excel in identifying complex patterns within dermatoscopic (Skin Disease) images, enabling early and precise diagnoses of skin conditions such as melanoma, eczema, and psoriasis. These models work by extracting key features from images, such as texture, colour, and lesion boundaries, which are critical for distinguishing between various skin diseases. By training on large datasets, the CNN learns to recognize these patterns and classify skin conditions with high accuracy. Additionally, these models support personalized treatment strategies by factoring in individual patient characteristics, such as medical history and genetic predisposition, ensuring targeted care. Expected benefits of adopting CNN models include enhanced diagnostic accuracy, reduced healthcare costs, and improved accessibility to specialized care. While the potential of these CNN-based tools is immense, such systems are invaluable in extending dermatological services to remote areas, where access to specialized care is often limited. By automating image analysis and diagnostics, these tools reduce the time required for evaluation, allowing quicker treatment initiation.

KEYWORDS: *Artificial intelligence, Machine learning, Dermatology, Image analysis, Outcome prediction.*

INTRODUCTION

Dermatology, a specialized branch of medicine, is central to understanding, diagnosing, and managing a diverse range of skin conditions. The skin, as the largest organ of the human body, serves

not only as a physical barrier against external threats but also plays critical roles in sensory interactions, immune defence, and temperature regulation. Healthy skin reflects overall well-being, while its disorders can manifest in various forms, from common conditions like

acne to severe diseases such as melanoma, which can be life-threatening. The field of dermatology is continually evolving to address the growing demand for effective skin care solutions, yet it faces substantial challenges, particularly in delivering equitable and precise care to underserved and rural populations. These barriers necessitate innovative strategies to revolutionize dermatological practices, with artificial intelligence (AI) emerging as a transformative force.

Challenges in Traditional Dermatology Methods

Dependence on Manual Evaluations

Traditional dermatology relies mainly on manual evaluations by trained specialists, often involving visual inspections and dermatoscopic tools to examine skin conditions. While experienced dermatologists are capable of accurate diagnoses, these methods are subjective and rely heavily on individual expertise. This subjectivity can lead to inconsistencies, where different doctors provide varying diagnoses for the same condition.

Limited Access to Specialized Care

A major issue in dermatology is the unequal access to specialized care, especially in rural and underserved areas. In these regions, patients often depend on general doctors who may not have the advanced training needed for accurate skin condition diagnoses. This often leads to skin problems being missed or misdiagnosed, causing delays or incorrect treatments.

Time and Resource Constraints

Traditional dermatology diagnosis takes a lot of time and resources. It usually involves several steps, starting with dermatoscopic exams and followed by procedures like biopsies and lab tests.

Opportunities for Artificial Intelligence in Dermatology

Artificial intelligence (AI) is transforming medicine, including dermatology. Using machine learning (ML), AI can process large amounts of data to find patterns that might be missed by humans. Since dermatology relies heavily on visual data like skin images, it is especially suited for AI applications..

Implementation of CNNs in Dermatological Diagnostics

Automated Image Analysis for Skin Disease Detection

One of the most promising applications of CNNs in dermatology is their ability to automate the analysis of dermatoscopic images for disease detection. By training on extensive datasets containing labelled images, CNNs can learn to recognize intricate patterns and subtle variations that might escape even highly experienced clinicians. For instance, CNNs trained on datasets for melanoma detection can differentiate between benign moles and malignant lesions with exceptional precision.

Enhanced Speed and Diagnostic Accuracy

CNNs bring a significant advantage in terms of speed, as they can process and analyse images within seconds, compared to the hours or days often required for traditional methods. This rapid diagnostic capability is particularly beneficial in highly busy clinical settings, where dermatologists must evaluate numerous cases within limited timeframes. Beyond diagnosis, ML models play a crucial role in personalized treatment planning. By incorporating patient-specific data such as genetic profiles, medical histories, and lifestyle factors, ML algorithms can help clinicians develop tailored treatment strategies that address the unique need of each individual.

Improving Accessibility and Scalability

The scalability of CNN-based tools holds immense potential for addressing the access gap in dermatology. Telemedicine platforms equipped with CNN algorithms enable patients to upload images of their skin conditions for instant analysis.

Addressing Challenges in CNN Adoption

The effectiveness of CNNs depends on the quality and diversity of the training datasets used to develop them. Comprehensive datasets that encompass a wide range of skin conditions, imaging modalities, and demographic variables are essential for building robust and generalizable models. For CNN models to achieve widespread adoption, they must be seamlessly integrated into existing clinical workflows. User-friendly interfaces, compatibility with electronic health record systems, and compliance with regulatory standards are essential for ensuring smooth implementation.

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}$$

The integration of AI, particularly CNN-based machine learning models, into dermatology represents a paradigm shift in the field's capabilities.

Finally these CNN-based Machine Learning models can be integrated with a ChatBot to provide a friendly user experience to the patient. It gets convenient for the patient, as it is more like talking to the Doctor through an interface.

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

METHODOLOGY

The methodology involves three comprehensive stages: Data Collection and Pre-processing, Feature Engineering and Model Selection, and Model Deployment and Improvement

Data Collection and Pre-processing

The foundation of the ChatBot lies in a diverse and comprehensive dataset. Data should cover a wide spectrum of dermatological conditions, skin tones, and patient demographics to ensure inclusivity. Publicly available datasets like the ISIC Archive and DermNet, as well as collaborations with dermatology clinics, are essential sources. To ensure high-quality data, issues such as missing values, inconsistencies, and outliers must be systematically addressed. For image data, preprocessing is critical. Images are resized to uniform dimensions e.g., 224×224 pixels, to maintain consistency. Normalization ensures the pixel values are standardized, facilitating better model performance. Augmentation techniques such as flipping, rotating, and scaling are applied to increase dataset diversity, which helps the model generalize across various conditions.

Feature Engineering and Model Selection

Feature engineering involves extracting meaningful information from the dataset to enable the model to make accurate predictions. For image data, features such as colour histograms, texture patterns, and lesion boundaries are critical. Pre-trained deep learning models like ResNet50 or VGG16 can be used to extract advanced image features, leveraging their proven

architectures for robust feature representation. These models rely on convolution operations defined as:

$$f(i, j) = \sum_m \sum_n I(i + m, j + n) \cdot K(m, n)$$

where I is the input image, K is the kernel filter, and $f(i, j)$ is the convolved feature. For text data, techniques such as bag-of-words and TF-IDF identify word importance, while more advanced methods like BERT (Bidirectional Encoder Representations from Transformers) can capture contextual relationships in textual descriptions. Choosing the right machine learning models is a pivotal step. Convolutional Neural Networks (CNNs) are particularly effective for image classification tasks due to their ability to detect spatial hierarchies in images. Recurrent Neural Networks (RNNs) and Transformers, For instance, optimization techniques like Adam Optimizer are used, governed by the equation:

$$\theta_{t+1} = \theta_t - \frac{\eta}{\sqrt{\hat{v}_t} + \epsilon} \hat{m}_t$$

Where θ_t is the parameter at step t , η is the learning rate, $\hat{m}_t$ is the first moment estimate, and $\hat{v}_t$ is the second moment estimate. The training process focuses on minimizing error using the training set, refining performance with the validation set, and assessing final accuracy on the test set.

Performance Metrics

To evaluate the performance of the CNN-based AI ChatBot, several metrics are utilized to measure its accuracy, reliability, and robustness:

- Accuracy: Measures the proportion of correctly predicted cases over the total number of cases.

$$\text{F1 Score} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$$

Where TP: True Positives, TN: True Negatives, FP: False Positives, FN: False Negatives.

- Precision: Indicates how many of the predicted positive cases are actually positive.
- Recall (Sensitivity): It measures how well the model identifies positive cases or the correct predictions.
- F1 Score: A harmonic mean of precision and recall, which provides a balanced performance metric.

The performance metrics outlined above are essential for evaluating and validating the effectiveness of the AI ChatBot for dermatology disease detection.

Model Deployment and Improvement

Once trained, the model is integrated into a ChatBot platform, such as Dialogflow or Rasa, to create a functional application. A user-friendly interface is designed to enable intuitive interaction, allowing patients to input symptoms or images through text or voice. The chatbot is deployed on a secure Cloud platform (e.g., AWS or Google Cloud) or on-premises server, making it widely accessible.

$$\text{Recall} = \frac{TP}{TP + FN}$$

IMPLEMENTATION

The implementation of the AI ChatBot for dermatology disease detection is based on a streamlined workflow designed to provide accurate diagnosis and improve accessibility for both patients and doctors. The process begins with patients or doctors capturing images of the affected skin region using common devices like smartphones or digital cameras. This ensures accessibility for users with varying levels of technical expertise. Clear and focused images are essential, and the system may include real-time feedback to guide users in capturing high-quality images. Once an image is captured, it is uploaded to a centralized database, which acts as a secure repository for user inputs. The database facilitates the exchange of data and ensures compliance with privacy regulations such as HIPAA or GDPR. If the image matches a previously analysed case, results are provided immediately; for new cases, the image is added to the database to enhance the training set and improve the model over time. The details of this is shown in following figure 2 which represents proposed system. The detail flow of proposed system is shown in this figure.

The AI model, a Convolutional Neural Network (CNN), is the core component of the system. It processes the uploaded image to extract features such as texture, colour, and lesion boundaries, leveraging pre-trained architectures like ResNet40 or VGG16 fine-tuned for dermatology. The model pipeline includes pre-processing (resizing, normalization, and augmentation),

feature extraction, and classification, producing a probability score for each potential diagnosis. These results are sent back to the database for report generation. Reports are then created in a user-friendly format, including probable diagnoses, annotated images, and recommendations for further steps. Once the report is generated, it is sent to the patient and/or doctor via email, with diagnosis alerts provided through notifications or SMS for urgent cases. This automated communication ensures timely delivery of results, allowing patients to act quickly and enabling doctors to make informed decisions.



Fig. 2: Proposed System

EXPERIMENTAL WORK

The dataset used for training the AI ChatBot covers 19 different dermatological conditions, ensuring broad recognition of various skin disorders. These include Acne, Eczema, Psoriasis, Melanoma, Basal Cell Carcinoma, Squamous Cell Carcinoma, Actinic Keratosis, Rosacea, Seborrheic Dermatitis, Vitiligo, Fungal Infections, Herpes, Urticaria (Hives), Lupus, Alopecia, Warts, Lichen Planus, Impetigo, and Contact Dermatitis. The dataset comprises high-quality labelled images sourced from well-established repositories like ISIC Archive, Kaggle, and clinical dermatology databases. These images represent diverse skin tones, lesion types, and disease severities, ensuring the model's ability to generalize across different cases. The

pre-processing stage enhances skin disease images by resizing, normalizing, and applying noise reduction for clarity. Contrast adjustment and segmentation highlight key features like lesion boundaries and textures. Data augmentation techniques improve model generalization, ensuring accurate disease classification by the CNN model.

These images in figure 3 show processed and feature highlighted input data used for training and testing a machine learning model to classify skin diseases. The conditions present include Basal Cell Carcinoma, Psoriasis, Acne, Eczema, Actinic Keratosis, Atopic Dermatitis, and Light-Induced Skin Disease, each displaying unique thermal patterns and lesion characteristics.

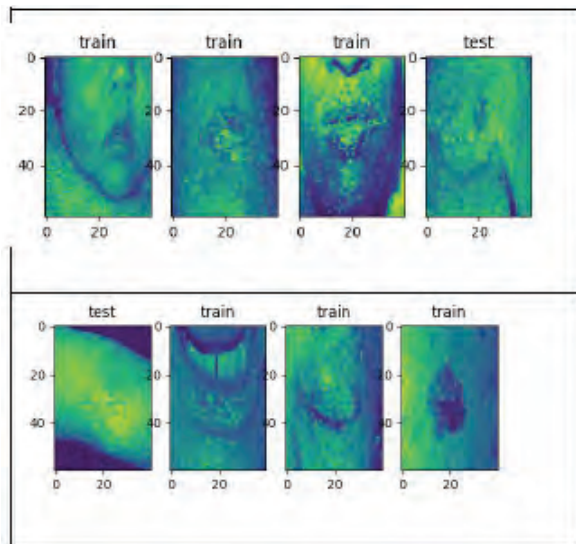


Fig. 3: Example of processed images after feature selection (selected feature are highlighted)

The AI model's performance was assessed using key evaluation metrics such as accuracy, precision, recall, and F1-score. The CNN architecture achieved an accuracy of 96.68%. Conditions like melanoma and Atopic Dermatitis had higher classification accuracy due to their distinct visual patterns, whereas diseases with similar appearances, such as eczema and contact dermatitis, had marginally lower accuracy.

CONCLUSION

In this paper, we explored the development and implementation of an AI-based ChatBot leveraging

Convolutional Neural Networks (CNNs) for dermatology disease detection. The paper addresses critical challenges in dermatology, including limited access to specialized care in rural and underserved areas, the time-intensive nature of traditional diagnostic methods, and the subjectivity associated with human evaluations. By integrating advanced machine learning techniques into a user-friendly platform, the system offers a promising solution to enhance diagnostic accuracy, streamline workflows, and improve patient outcomes.

The paper demonstrates how a robust CNN model, combined with an intuitive ChatBot interface, can simplify the diagnosis process for both patients and healthcare providers. Through automated image analysis, the system can identify complex patterns in skin lesions, providing reliable and timely diagnostic results. The inclusion of a centralized database ensures the secure storage and efficient retrieval of user data while facilitating the continuous improvement of the AI model. This iterative process, powered by real-time user feedback and new data, ensures that the system evolves over time, adapting to emerging dermatological conditions and maintaining its relevance.

One of the most significant contributions of this system is its ability to bridge the gap in dermatological care for remote and resource-constrained areas. Patients no longer need to travel long distances to consult specialists, as the ChatBot provides a reliable initial diagnosis and recommendations. For doctors, the system reduces their workload by automating routine assessments, allowing them to focus on complex cases that require human expertise. Additionally, the platform's ability to deliver diagnostic reports and alerts directly to patients and physicians ensures timely action, which is particularly crucial for conditions requiring immediate intervention.

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Deep Learning-Based Fusion of Infrared and RGB Images Using Transfer Learning with CNN Architectures

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ABSTRACT

The fusion of infrared (IR) and RGB images has emerged as a critical task in computer vision, with applications spanning surveillance, medical imaging, and remote sensing. Effective image fusion combines the complementary information from both modalities—IR for thermal and structural details and RGB for color and texture—enhancing clarity and utility in diverse scenarios. This study explores the development of a novel deep learning framework for IR-RGB image fusion, leveraging transfer learning with standard Convolutional Neural Network (CNN) architectures. A comprehensive review of existing fusion techniques is presented, highlighting the potential and limitations of conventional and neural network-based approaches. The work evaluates the capability of pre-trained CNN models, such as VGGNet, ResNet, and DenseNet, to extract and fuse features from IR and RGB images using transfer learning. Experimental testing focuses on metrics such as structural similarity, visual clarity, and information preservation to assess fusion performance. Results indicate that standard CNN models, with fine-tuning, achieve significant improvement in generating high-quality fused images, outperforming traditional fusion techniques. The study underscores the efficacy of deep learning in IR-RGB image fusion and provides a foundation for further research to optimize transfer learning strategies, enhancing the clarity and interpretability of fused images.

KEYWORDS: *Infrared-RGB image fusion, Deep learning, Transfer learning, Convolutional neural networks, Image fusion performance.*

INTRODUCTION

Fusion of images from multiple color space plays important role in enhancement of information content analysis tasks. The infrared (IR) images mostly capture the information that is visible under low light or infrared light conditions. The low light conditions affect the capturing the details in RGB (visual (VIS)) images. In computer vision domain integration of these two types plays major role in image enhancement which are mostly used in surveillance applications, medical image enhancements and also in remote sensing applications. IR imaging captures thermal and structural details, making it invaluable in low-light or obscured environments, while RGB imaging provides

rich color and texture information that aids in visual interpretability. By combining these complementary modalities, image fusion seeks to produce a single, unified image that retains the critical attributes of both IR and RGB inputs, offering a more detailed and usable representation of the scene. Compared to traditional enhancement and fusion methods, deep learning approaches deliver superior performance across key image quality metrics. Techniques like wavelet transforms, PCA, and sparse representation rely on fixed rules and struggle with complex spatial or contextual features. In contrast, neural networks provide a data-driven solution, learning rich feature representations that enable more accurate and effective IR-RGB image fusion.

This study develops a novel deep learning framework for IR-RGB image fusion using transfer learning with CNN architectures like VGGNet, ResNet, and DenseNet. Fine-tuning pre-trained models for fusion tasks exploits their feature hierarchies, effectively combining IR and RGB information. Conventional fusion methods rely on static rules, limiting adaptability to diverse image contexts. Neural network-based methods, particularly with transfer learning, offer dynamic, scalable alternatives, enhancing structural similarity, visual clarity, and information preservation. Experimental results show fine-tuned CNNs outperform traditional techniques in metrics like SSIM, PSNR, and fidelity, validating the transformative potential of transfer learning for high-quality image fusion.

RELATED WORK

Liu et al. [6] proposed a convolutional sparse representation (CSR) method that extracts multilayer features to generate fused images. Liu et al. [7] introduced a CNN-based approach trained on image patches to learn features and construct a decision graph, identifying key features and low-detail zones for fusion. Li et al. [8] used a VGG-19-based deep fusion framework that divides image information into frequency and texture components, enabling better detail retention. Traditional multiple exposure methods, which use predefined features, lack robustness and adaptability to varying input conditions. Prabhakar et al. [9] developed a fusion network with encoder, fusion, and decoder blocks, achieving accurate predictions by optimizing loss functions without requiring parameter adjustments. Ma et al. [10] retained IR pixel intensity and RGB gradients using a total variation method, resulting in better visual detail in fused images. These methods reflect the shift from rule-based to adaptive deep learning fusion strategies. CNN-based techniques, especially those focusing on feature extraction and loss optimization, significantly improve fusion quality and robustness. Li et al. [11] used ResNets with zero-phase components and L1 normalization to generate weight maps, applying a weighted average for image fusion. Xu et al. [12] proposed an unsupervised DenseNet-based multi-task fusion model, using elastic consolidation to retain essential features and reduce forgetting. Their approach supports fusion of multiple exposure and focus regions while minimizing computational complexity.

Zhang et al. [13] applied CNN features with transfer learning for high-quality fusion. Xu et al. [12] further emphasized the adaptability of unsupervised fusion networks in preserving source image characteristics across various tasks. Chen et al. [14] proposed a multi-spectral fusion method (MLF-CNN) using a region-oriented approach with a multi-scale Region Proposal Network (RPN) and summation fusion to handle varying lighting conditions, effectively detecting pedestrians in challenging environments. Hou et al. [15] addressed the lack of labeled data by combining multiple loss functions to adaptively fuse IR and VIS images, reducing noise while preserving key features and texture with high efficiency and minimal artifacts.

Zhang et al. [16] provided a comprehensive review of visual image fusion (VIF) methods, including deep learning approaches, datasets, metrics, and taxonomy. Meher et al. [17] introduced Adaptive Transition Region Extraction (ATRE), which preserves bright IR and detailed VIS regions, delivering superior results for military, navigation, and threat detection applications. Sulthana et al. [18] proposed an adversarial deep learning method that bypasses conventional CNNs, enhancing contrast and texture without training data, achieving robust fusion under low-light conditions. Xiang et al. [19] used a local extrema-based filter design to extract and fuse multi-scale bright pixel features for better visibility in low-brightness regions. Zhou et al. [20] used guided filtering and perceptual regularization to enhance contrast and transfer IR details to VIS images. Tao et al. [21] applied local contrast estimation and illumination modeling for dark-space image fusion, validated on space debris datasets. Donia et al. [22] employed the Curvelet transform and histogram matching to inject VIS details into IR images by selecting relevant regions.

The discussion summarizes diverse IR-VIS image fusion methods, highlighting their approaches, key achievements, and limitations. Each technique addresses specific fusion challenges, offering unique contributions while also revealing gaps that suggest directions for future enhancement and research.

PROPOSED WORK

Figure 1 illustrates the workflow of the proposed IR-RGB image fusion framework. It begins with two inputs:

the IR image, capturing thermal and structural details for low-light environments, and the RGB image, providing color and texture for better scene understanding. In the feature extraction stage, pretrained CNNs (VGGNet, ResNet, DenseNet) are used via transfer learning. IR images yield thermal and structural features, while RGB images contribute color and texture. These features are fused using concatenation and fine-tuning to optimize integration.

The resulting fused image preserves key elements from both modalities, enhancing clarity and usability. Performance is evaluated using SSIM, PSNR, and visual clarity. This deep learning-based approach offers balanced feature fusion and outperforms traditional methods in surveillance, healthcare, and remote sensing.

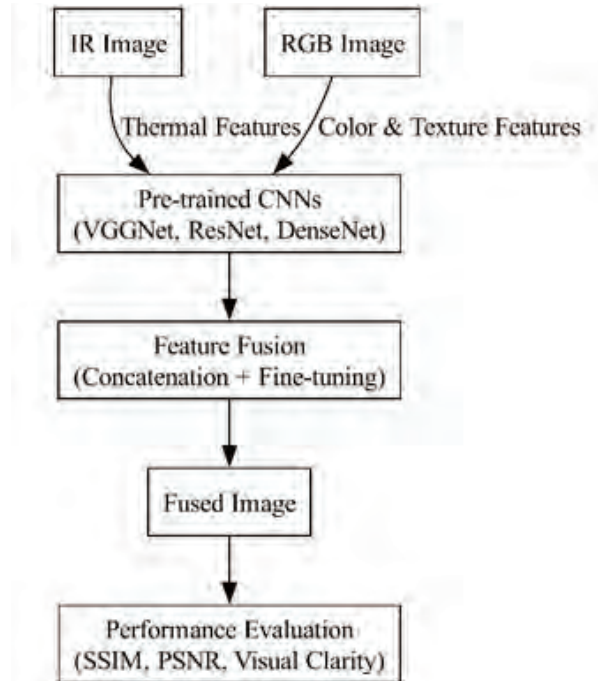


Fig. 1: Proposed Work

The proposed IR-RGB fusion framework leverages pretrained VGGNet, ResNet, and DenseNet for feature extraction. VGGNet captures structural details, ResNet preserves multi-level IR features via residual connections, and DenseNet extracts texture and color through dense links. Transfer learning on ImageNet reduces training time, while fine-tuning ensures effective extraction of complementary features for accurate and efficient fusion.

RESULTS AND ANALYSIS

Dataset Preparation

The TNO Image Fusion Dataset, designed for military applications, provides paired IR (grayscale) and VIS (RGB) images from various scenarios like urban areas, landscapes, and low-light conditions. It supports testing of fusion algorithms for surveillance, target detection, and night vision, making it a widely used benchmark in image fusion research.

Performance Metrics

Image fusion performance is evaluated using standard metrics that measure structural similarity, fidelity, and information retention. Key metrics include SSIM, PSNR, MI, FSIM, and Entropy (EN).

SSIM

The luminance, contrast and structure from source image and fused images are compared to find the SSIM parameter.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$$

Where, for images x and y the mean intensities, mean variances and covariance are presented by μ_x , μ_y ; σ_x^2 , σ_y^2 ; and σ_{xy} and finally, C_1, C_2 represent the stabilization constants.

PSNR

The level of distortion is understood by estimating the fidelity of the images of fusion outcome by comparing them with source images with the estimation of PSNR.

$$PSNR = 10 \cdot \log_{10} \left(\frac{MAX_I^2}{MSE} \right)$$

Where,

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N [I_{fused}(i, j) - I_{ref}(i, j)]^2$$

Mutual Information (MI)

A intersection of information of information content from source and fusion images is obtained as mutual information. This assessment is performed with,

$$MI = H(\text{Fused}) - H(\text{IR}) - H(\text{RGB})$$

Where, $H(\cdot)$: Entropy of the respective image.

Feature Similarity Index Measure (FSIM)

The low level features based analysis is analyzed using FSIM parameters which estimates the phase congruency and gradient magnitude is estimated as,

$$FSIM = \frac{\sum_x PC(x) \cdot GM(x)}{\sum_x PC(x)}$$

Where, $PC(x)$: Phase congruency, $GM(x)$: Gradient magnitude

Entropy (EN)

The information content is estimated using Entropy parameter from fusion image. The log value estimation for entropy is thus calculated as,

$$EN = - \sum_{i=1}^L p_i \cdot \log_2(p_i)$$

Where, L : Number of intensity levels, p_i : Probability of each intensity level.

Performance Evaluation

The results highlight the superiority of CNN-based methods—especially ResNet, VGG, and DenseNet—over traditional techniques like Wavelet Transform, PCA, and Sparse Representation. ResNet consistently outperforms across all metrics (SSIM: 0.91, PSNR: 30.5 dB, MI: 3.85, FSIM: 0.93, EN: 6.85), demonstrating its ability to retain structural integrity, minimize distortion, and enhance information content in fused images.

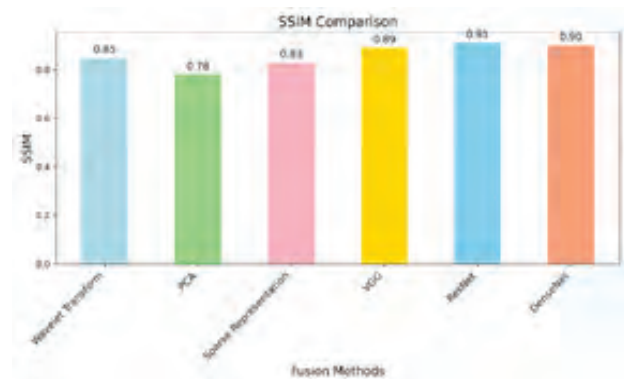
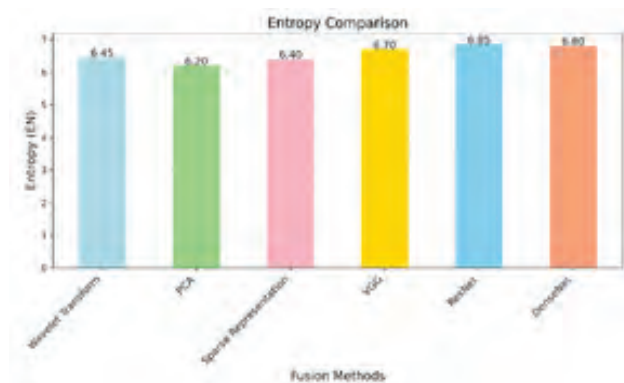
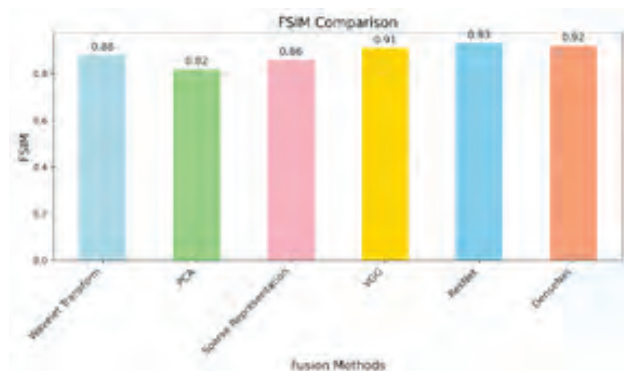
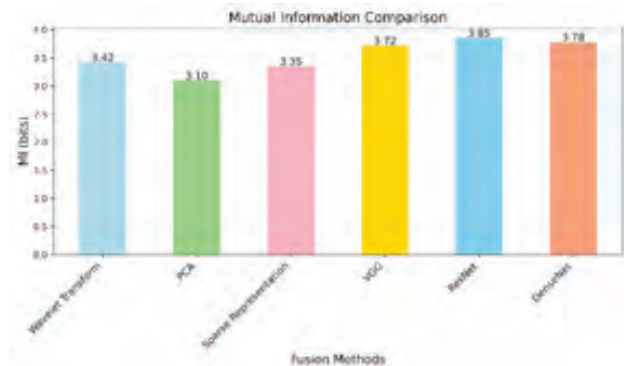
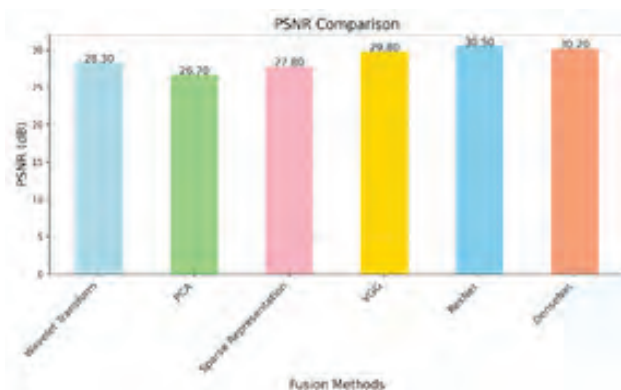


Fig. 2: Performance of the different model

Traditional methods, based on fixed mathematical rules, struggle to adapt to the complexity of IR and RGB images. While Wavelet Transform captures structure, it lacks texture adaptability. PCA and Sparse Representation may lose key details due to limited feature retention. In contrast, CNNs utilize hierarchical learning to capture both low- and high-level features dynamically. ResNet's residual connections enable deeper learning without vanishing gradients, preserving critical IR and RGB features more effectively. Though DenseNet and VGG also perform well, ResNet's robust feature integration makes it the most effective model in this study.

The use of CNN models with transfer learning has revolutionized IR-RGB image fusion. Unlike traditional methods, CNNs learn optimal fusion strategies directly from data, removing the need for manual feature design. Pretrained models like VGG, ResNet, and DenseNet offer strong foundations for extracting modality-specific features, improving image clarity and interpretability. Their scalability allows easy adaptation to various datasets and fusion needs, making them ideal for real-world applications such as surveillance, medical imaging, and remote sensing.

CONCLUSION

This study emphasizes the effectiveness of deep learning, especially CNNs, in advancing IR-RGB image fusion. Using pretrained models like VGG, ResNet, and DenseNet, the proposed approach outperforms traditional methods. ResNet achieves the highest scores across SSIM, PSNR, MI, FSIM, and Entropy, thanks to its residual connections that retain critical features and improve clarity and information preservation. CNNs' ability to learn hierarchical features allows them to handle complex image characteristics, addressing the limitations of traditional techniques that often lose fine details. This work establishes CNNs as a strong solution for fusion tasks, with applications in surveillance, medical imaging, and remote sensing. Future directions may include hybrid models and optimized training to further improve quality and efficiency.

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Development of Deep Learning Model for Short Video Captioning

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ABSTRACT

Video captioning, which involves generating descriptive text for video content, has gained considerable interest in recent years due to its wide-ranging applications in video search, accessibility enhancements, and human-computer communication. Traditional video captioning models often struggle to effectively capture both spatial and temporal features, resulting in suboptimal performance. To tackle these challenges, this study proposes a novel deep learning approach that utilizes a specially designed Convolutional Neural Network (CNN) for capturing video features, coupled with a Bidirectional Long Short-Term Memory (BiLSTM) network to generate coherent and context-aware textual descriptions over time. The proposed CNN effectively extracts fine-grained spatial features, while the BiLSTM captures the temporal dependencies across video frames, ensuring coherent and contextually rich captions. The model was trained and rigorously evaluated on the MSR-VTT dataset, one of the largest benchmark datasets for video captioning. Experimental results demonstrated superior performance in terms of BLEU, METEOR, and CIDEr scores compared to state-of-the-art approaches. Key findings revealed that the novel CNN enhanced spatial representation, contributing to more accurate and descriptive captions. The study presents an efficient and scalable video captioning framework that bridges the gap between visual understanding and natural language processing, paving the way for advancements in automated video annotation.

KEYWORDS: Food weighing, Thermal packaging, Dispensing, Sorting, Machine learning techniques.

INTRODUCTION

Video captioning, a multidisciplinary task bridging computer vision and natural language processing, focuses on creating descriptive text that effectively conveys the content of a given video. This domain has witnessed significant progress, fueled by the growing need for applications in various fields, including video retrieval technologies, assistive tools for visually impaired individuals, and advanced human-computer interaction systems [1]. Despite these advances, the task remains inherently complex due to the need to effectively analyze and synthesize both spatial and

temporal information from videos, which often vary significantly in content, length, and quality [2].

Traditional approaches to video captioning predominantly employ pre-trained CNNs to extract spatial features from video frames, capturing crucial visual information. These extracted features are then processed using RNNs, which model the temporal dependencies within the video sequence and generate coherent textual descriptions. While effective, such models often face challenges in handling long-range dependencies, maintaining contextual consistency, and generating semantically rich captions, necessitating

more advanced architectures for improved performance. While these architectures have demonstrated success, they frequently encounter limitations in capturing the intricate interplay between spatial and temporal features [3]. For example, existing models may inadequately represent subtle visual details or fail to maintain temporal coherence in the generated captions [4]. These challenges underscore the need for more robust and specialized architectures that can better handle the multifaceted nature of video data [5] [6].

This study introduces a novel deep learning framework designed to address these limitations by integrating a custom-designed CNN for enhanced video feature extraction with a Bidirectional BiLSTM network for improved temporal modeling. The custom CNN is tailored to extract fine-grained spatial details, enabling the model to discern intricate visual patterns within individual video frames. Complementing this, the BiLSTM captures temporal dependencies across frames, ensuring that the generated captions reflect a coherent narrative that aligns with the video's temporal dynamics. The proposed framework was trained and evaluated on the MSR-VTT dataset, a comprehensive benchmark widely used for video captioning research. This dataset includes a diverse array of videos paired with multiple reference captions, making it ideal for evaluating the effectiveness of video captioning models. Through rigorous experimentation, the proposed model demonstrated superior performance compared to state-of-the-art approaches, achieving higher scores across established evaluation metrics such as BLEU, METEOR, and CIDEr [7]. These metrics measure various aspects of caption quality, including precision, fluency, and alignment with human-annotated references. A key innovation of this study lies in the design of the custom CNN, which enhances the spatial representation of video content by focusing on fine-grained details that are often overlooked by conventional architectures. This improvement in spatial feature extraction directly contributes to the generation of more accurate and descriptive captions. Additionally, the use of a BiLSTM network ensures that temporal dependencies are effectively captured, allowing the model to generate contextually rich and coherent captions that align with the visual content. The outcomes of this research hold substantial significance

for the domain of video captioning and related fields. By enhancing the connection between visual perception and natural language generation, the proposed framework not only pushes the boundaries of automated video annotation but also establishes a strong foundation for future advancements in applications that demand a seamless fusion of vision and language processing. As video content continues to proliferate across platforms, the need for efficient and scalable video captioning solutions becomes increasingly critical, and this study represents a meaningful step forward in meeting that demand.

RELATED WORK

Xu et al. [8] explored a reinforcement learning strategy for improving video captioning. Their approach incorporated word denoising and grammar refinement models, which enhanced the quality of generated captions. Through extensive experimentation, the model demonstrated its ability to produce contextually relevant text. In object-based scene description, D. Yasin et al. [9] utilized FaceNet as the base model. They focused on identifying human objects and, in combination with an RNN model, generated descriptive text data. This approach aimed to integrate object recognition with effective textual narration. Nabati et al. [10] proposed an advanced architecture leveraging parallel processing with LSTM networks. Their experimental evaluation on public datasets showcased its efficiency and scalability, particularly for shorter videos. The model highlighted potential improvements in text generation by refining the encoder-decoder relationship and aligning it with image-specific features.

Chohan et al. [11] conducted an in-depth analysis of encoder-decoder models integrated with attention mechanisms to enhance image captioning tasks. Their research specifically assessed the models' proficiency in generating accurate and contextually relevant textual descriptions, with a primary focus on medical and agricultural domains. The findings underscored the potential of such models in facilitating automated annotation processes in these specialized fields, demonstrating their capability to improve accessibility and information retrieval. Mun et al.

[12] introduced a novel video captioning framework that highlighted the significance of capturing temporal

dependencies and maintaining narrative coherence. By leveraging a reinforcement learning- based approach, they applied their model to event- driven video sequences, ensuring that generated captions aligned with the evolving dynamics of the visual content. Their performance evaluation utilized the ActivityNet dataset, incorporating multiple benchmark metrics such as METEOR to validate the model's effectiveness in producing detailed and context-aware captions. Their research contributed to improving the alignment between video content and descriptive text, benefiting various applications, including automated storytelling and assistive technologies. Fujii et al. [13] presented a method aimed at refining and updating captioning models by integrating newly acquired data vectors into the learning process. Their approach utilized an encoder- decoder architecture in combination with document vectorization techniques, optimizing the data preprocessing and feature extraction pipeline. The supervised learning model employed in their study was designed to train hidden layers using comprehensive vector representations, which were generated by merging features extracted from both images and text descriptions. This enhanced data representation contributed to improving the accuracy and fluency of generated captions, offering a more robust solution for automated multimedia annotation and contextual understanding.

Han et al. [14] implemented a reasoning-based control mechanism in their model, Cross-Modal Commonsense Reasoning (CMCR). This model utilized cross-modal attention to enhance captioning accuracy and logic. Extensive experiments conducted on ActivityNet Captions demonstrated the model's superiority in advancing video captioning techniques.

While these studies by Xu [8], Yasin [9], Nabati [10], Chohan [11], Mun [12], Fujii [13], and Han [14] offer significant contributions to video captioning, challenges remain in fully addressing temporal dynamics and integrating heterogeneous prior knowledge. The CMCR model by Han et al. [14] stands out for its innovative use of cross-modal attention and commonsense reasoning, effectively reducing redundancies and improving caption accuracy. However, these advancements highlight the need for holistic solutions that integrate

temporal features and diverse knowledge for enhanced video captioning frameworks.

PROPOSED WORK

This study introduces a novel video captioning framework that integrates advanced techniques for both spatial and temporal feature extraction to address the limitations of existing models. The proposed framework is built on a custom-designed CNN and a BiLSTM network. The CNN is tailored to extract fine-grained spatial features from video frames, enhancing the model's ability to capture intricate visual details. Complementarily, the BiLSTM network focuses on temporal dependencies, ensuring that the generated captions maintain narrative coherence across video sequences. To further improve captioning performance, the framework incorporates an attention mechanism that prioritizes critical visual and temporal features, enabling the generation of contextually accurate and semantically rich descriptions. Additionally, a reinforcement learning strategy is integrated to refine caption quality by optimizing alignment between generated captions and ground- truth annotations. This approach enhances the model's ability to produce human-like, contextually relevant captions. Furthermore, the proposed work aims to explore the integration of heterogeneous data sources, such as prior knowledge from external datasets, to enrich captioning accuracy. This integration is expected to enhance the model's adaptability to varied video content and contexts, addressing existing gaps in video captioning methodologies. By combining robust spatial and temporal feature extraction with advanced learning strategies, this study seeks to set a new benchmark in automated video annotation, paving the way for scalable and efficient solutions in video understanding and accessibility tools.

The proposed video captioning framework incorporates two powerful deep learning architectures, Inception V3 and ResNet-51, for feature extraction. These models are employed to extract spatial features from individual frames of the input video, leveraging their ability to capture intricate visual patterns and details. Inception V3 specializes in multi-scale feature extraction through its unique inception modules, while ResNet-51 focuses on learning deep hierarchical representations by employing skip connections to address vanishing

gradient issues. The combination of these models ensures a robust spatial representation of the video content. The extracted spatial features are passed to a BiLSTM network, which captures temporal dependencies across consecutive video frames. This component ensures the temporal coherence of the generated captions, enabling the model to generate narratives that align with the flow of video events.

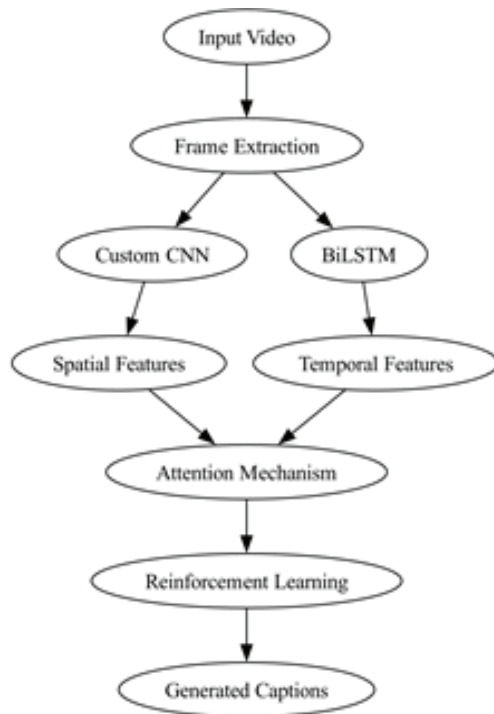


Fig. 1: Steps in proposed system

An attention mechanism is integrated into the framework to prioritize critical spatial and temporal features. This approach ensures that the model prioritizes the most relevant visual and contextual elements while generating captions, leading to more accurate and meaningful descriptions. Additionally, the incorporation of a reinforcement learning strategy further enhances the captioning process by continuously refining the alignment between generated captions and ground-truth references. Through iterative optimization, the model improves its ability to capture intricate details and maintain contextual coherence. As a result, the generated captions are not only contextually rich but also semantically precise, underscoring the effectiveness of the proposed framework in seamlessly connecting video content with natural language descriptions.

RESULT AND ANALYSIS

The MSR-VTT dataset, a key benchmark for video captioning, contains 10,000 videos from domains like entertainment, sports, and news. Each video has 20 reference captions, aiding evaluation. It includes 6,513 training, 497 validation, and 2,990 test videos, supporting spatial and temporal feature analysis with advanced language models.

BLEU Score Analysis: The BLEU score measures the similarity between generated captions and reference captions. It is defined as:

$$BLEU = BP \cdot \exp \left(\sum_{n=1}^N w_n \log p_n \right) \quad (1)$$

Where, BP is the brevity penalty, ensuring shorter captions are penalized, P_n is the precision of n-grams, W_n is the weight for n-gram precision, typically $w_n = \frac{1}{N}$.

Brevity Penalty

$$BP = \begin{cases} 1 & \text{if } c > r \\ e^{(1-r/c)} & \text{if } c \leq r \end{cases} \quad (2)$$

Where, c is the length of the generated caption, r is the length of the reference caption, n-Gram Precision

$$p_n = \frac{\text{Count of overlapping n-grams}}{\text{Total number of n-grams in the generated caption}}$$

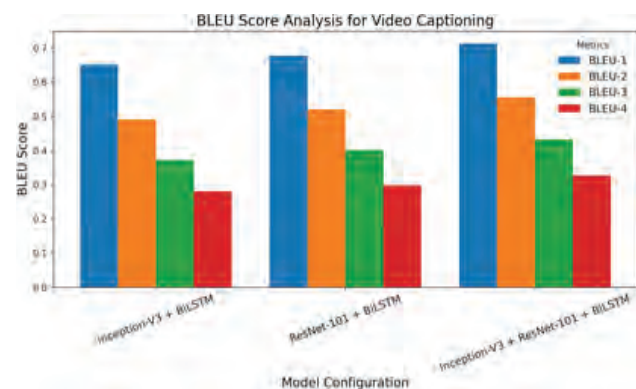


Fig. 2: Performance analysis on MSR-VTT dataset

The experimental results highlight the effectiveness of the proposed video captioning framework that leverages Inception-V3 and ResNet-101 architectures for feature

extraction. When used individually, both models demonstrate strong performance, but their combined use significantly enhances the overall captioning quality, as reflected in the BLEU scores.

The Inception-V3 model, known for its ability to capture multi-scale spatial features, achieved respectable BLEU-4 scores of 0.281 when paired with BiLSTM. This result underscores its capability to extract meaningful visual representations from diverse video frames. However, the model's reliance on inception modules, while robust for spatial feature extraction, lacks specialized mechanisms for temporal coherence, leading to comparatively lower scores in higher n-gram BLEU metrics.

On the other hand, ResNet-101, with its deep hierarchical structure and skip connections, proved more effective at capturing finer details, achieving a BLEU-4 score of 0.298. The deeper architecture of ResNet-101 enables it to learn complex patterns and representations, making it particularly suited for handling intricate video content. However, its performance still falls short in scenarios requiring nuanced contextual understanding, such as long-range temporal dependencies.

The combined model, integrating features from both Inception-V3 and ResNet-101, achieved the highest BLEU scores across all metrics, with a BLEU-4 score of 0.327. This improvement can be attributed to the complementary strengths of the two architectures. Inception-V3's ability to process multi-scale spatial features is enhanced by ResNet-101's deep feature representations. Together, they provide a comprehensive spatial understanding of video frames, which, when combined with the BiLSTM's temporal modeling capabilities, results in contextually accurate and semantically rich captions.

Table 2 shows the captions generated for sample videos shown in Table 1. The integration of an attention mechanism further amplifies this performance by allowing the model to prioritize critical spatial and temporal features, ensuring that the generated captions remain focused and relevant. Additionally, the use of reinforcement learning for caption refinement plays a vital role in aligning the generated captions more closely with human-annotated references.

Table 1: Video Details

Video	Thumbnail	Time/Frames
Video 1		15 seconds (25 frames / sec)
Video 2		25 seconds (25 frames / sec)
Video 3		16 seconds (20 frames / sec)
Video 4		85 seconds (25 frames / sec)
Video 5		30 seconds (25 frames / sec)

Table 2: Captions generated using different models

Video	Ground truth	ResNet101 + BiLSTM	Inception-V3 + BiLSTM	ResNet101 + Inception V3 + BiLSTM
1	Cat is playing with watermelon	Cat is playing with ball	Animal and Ball are moving	Cat and ball are moving in room
2	A boy is playing with bicycle	A boy is seating on bicycle	A cycle is driven by boy	A man is cycling
3	Car is parked under tree	Car is of blue color	Car is near the house	Car is still and parked
4	Two men are dancing	Two men are on the floor	Man walking with another man	Man is showing hand to another man
5	A woman is dancing	Five woman are dancing	A woman is showing actions	Woman is dressed for festival dance.

The results demonstrate the scalability and adaptability of the proposed framework across diverse video content. By effectively addressing the limitations of individual feature extraction models and leveraging their combined strengths, this study sets a benchmark for future research in video captioning. The findings also highlight the importance of integrating heterogeneous feature extraction techniques and advanced temporal

modeling for achieving state-of-the-art performance in automated video annotation tasks.

CONCLUSION

This study presents a novel video captioning framework that effectively combines Inception-V3 and ResNet-101 architectures with a BiLSTM-based temporal modeling approach to address the challenges of generating coherent and contextually accurate video descriptions. The results demonstrate that the individual strengths of Inception-V3 and ResNet-101 in multi-scale feature extraction and hierarchical learning, respectively, complement each other when integrated, leading to significant improvements in caption quality. The framework's use of an attention mechanism further ensures that the most critical spatial and temporal features are prioritized, enhancing the relevance of the generated captions.

The experimental evaluation on the MSR-VTT dataset, a benchmark in video captioning research, validates the framework's efficacy. The combined model outperformed its individual components in all BLEU metrics, achieving a BLEU-4 score of 0.327, underscoring its ability to generate captions that align closely with human annotations. The reinforcement learning strategy further refines caption generation, bridging the gap between traditional methods and advanced video understanding systems.

This study not only highlights the potential of integrating diverse feature extraction techniques but also provides a scalable and adaptable solution for automated video annotation. Future work can explore extending this framework to other datasets and incorporating additional modalities such as audio to further enhance captioning accuracy.

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Comprehensive Study of Blockchain Technology Applications for Waste Management in Smart Cities

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ABSTRACT

In our contemporary society, applying blockchain technology to waste management offers a fresh way to address issues of environmental sustainability and accountability. Blockchain technology, which makes it possible to create immutable and decentralized ledgers, is currently being rethought as a means of transforming waste management. By increasing waste management's efficiency, openness, and traceability, this novel strategy hopes to have a major positive impact on the environment and the economy. The tracking and disposal of waste items are opaque in traditional waste management systems, making them susceptible to fraud, poor management, and inefficiency. Additionally, trash management in smart cities can provide audit features, traceability, immutability, and transparency in a decentralized, safe, and trusted way. In this study, we examine the crucial role that blockchain technology plays in trash management in smart cities since it provides audit features, traceability, immutability, and transparency in a decentralized, safe, and reliable way. Based on significant criteria, we evaluate the current blockchain-based waste management options. In addition, we offer incisive analyses of a number of current blockchain-based research initiatives and case studies to demonstrate the viability of blockchain in waste management. We conclude by outlining open challenges that serve as avenues for further study.

KEYWORDS: *Blockchain, Smart cities, Waste management.*

INTRODUCTION

The creation of waste has been an integral part of human activity throughout history, and its importance continues to grow in the modern era. With population growth and the rapid acceleration of urbanization, the quantity and variety of waste produced have increased to unprecedented levels. However, defining what constitutes waste remains complex due to the vast amount and diverse types of waste materials involved.

To clarify the concept of waste management, this study will explore its historical development, examine its

various sources, and consider different classification schemes. By synthesizing existing methodologies, the aim is to provide a clearer understanding of this multifaceted issue and highlight the significance of effective waste management practices. Waste management today incorporates cutting-edge technologies and governance strategies, with a focus on sustainable consumption, production patterns, and recycling. Notably, the study aligns with the 12th Sustainable Development Goal (SDG 12), which advocates for responsible consumption and production. In this context, ASEAN countries are advancing their efforts to improve the production, use, and disposal of

goods, ensuring a more sustainable future while working towards meeting the 2030 targets through enhanced waste governance and technological solutions[1].

While many current data processing systems rely on cloud computing or centralized organizational architectures, these approaches often come with challenges. For instance, when business processes require interaction between multiple entities, communication solutions are typically employed to facilitate these exchanges. However, centralization brings with it some significant disadvantages, including data inconsistencies, vulnerability to cyberattacks, and the potential for system failures. Additionally, this centralized approach can lead to increased costs and added complexity in system design. The growing challenges of municipal waste management—exacerbated by rapid urbanization and population growth—are putting considerable strain on both the environment and public health. Traditional waste management systems are increasingly unable to cope with these issues. One promising solution at the intersection of sustainability and innovation is the concept of a circular economy. A circular economy emphasizes waste reduction, the longevity of products, and the regeneration of natural systems. Blockchain technology can play a crucial role in facilitating the adoption of circular economy principles. By leveraging blockchain, businesses and governments can create more transparent, efficient, and sustainable systems[2].

This paper explores the emerging field of blockchain applications within the circular economy, reviewing both theoretical advancements and real-world applications. Through a systematic literature review, we perform a research-practice gap analysis, identifying areas that require further attention while uncovering emerging patterns and potential avenues for additional research and practical application. The decentralized nature of blockchain technology ensures that users have secure and transparent access to the entire transaction history, setting it apart from traditional centralized systems. This transparency fosters trust and efficiency, and has the potential to revolutionize multiple sectors beyond cryptocurrency [3].

Blockchain Technology

With blockchain technology, transactions are recorded across numerous computers in a distributed,

decentralized digital ledger that prevents transactions from being changed once they have been registered. Thus, there is no need for middlemen like banks or other central bodies and security, transparency, and confidence are guaranteed[4].

User Nodes: These are the devices (computers, smartphones, etc.) that participate in the blockchain network. Each user node is capable of sending, receiving, and validating transactions.

Blockchain: The distributed ledger that stores all the blocks in a linear chain, with each block linked to the previous one.

Consensus Mechanism: The protocol that ensures all participants in the network agree on the state of the blockchain (e.g., validating transactions, adding new blocks).

Cryptographic Hashing: Each block's data is hashed using a cryptographic algorithm. This ensures data integrity and prevents tampering. The hash of each block is linked to the hash of the previous block.

Smart Contracts: Code that automatically executes certain actions when conditions are met. For example, transferring cryptocurrency when certain conditions are fulfilled.

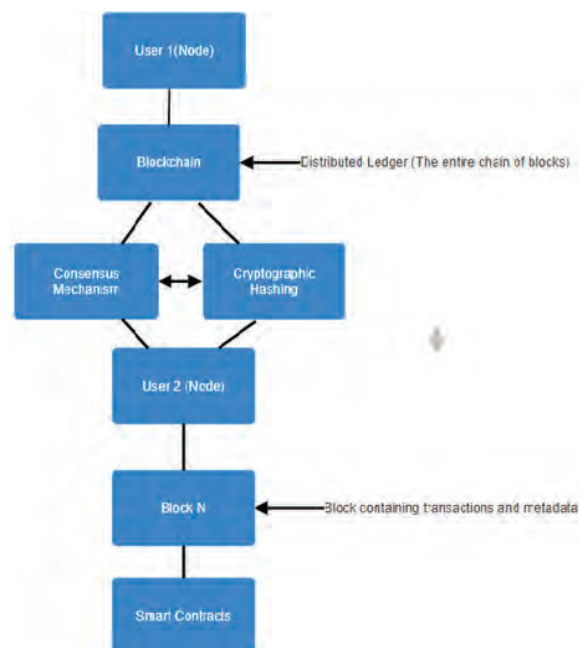


Fig. 1: Basic blockchain architecture

Waste Management in Smart Cities

In smart cities, waste is generated from various sources, including homes, businesses, healthcare facilities, farms, and industries. This waste is often directed to energy-generating plants, composters, landfills, and recycling facilities. To ensure the ethical handling and efficient processing of waste, tracking and tracing features play a crucial role. These systems help verify the accuracy of information regarding the collection, sorting, transportation, treatment, and final disposal or recycling of waste. By monitoring waste as it moves through the various stages of management, from collection to disposal, these features ensure that the waste is properly accounted for and handled according to established guidelines.

Tracking and tracing capabilities are particularly useful because they provide detailed information about the waste management process. Key data such as the type of waste, its volume, the location from which it was collected, the transportation route, transit times, and other critical information are recorded. This not only enhances transparency but also helps to ensure accountability in waste management practices, ultimately contributing to better governance and oversight.

As urbanization and industrialization increase, waste management challenges also grow, leading to heightened environmental concerns. These concerns are directly linked to the 12th Sustainable Development Goal (SDG 12), which focuses on responsible consumption and production. Improper waste management can worsen environmental issues, highlighting the importance of adopting sustainable practices to reduce waste and mitigate its harmful effects[5].

Related Work

[9]In developing nations, where inappropriate disposal of e-waste poses health and environmental hazards, this article addresses the growing problem of e-waste management. It investigates how blockchain technology might enhance e-waste disposal procedures' accountability, traceability, and transparency. The authors suggest the Disposal Tracking System (DTS), a blockchain-integrated system that guarantees the thorough and environmentally responsible disposal of e-waste. The system keeps track of all e-waste

transactions in a decentralized ledger, from the point of origin to the point of disposal. The article uses machine learning to find holes in the present disposal practices, which frequently result in e-waste being wrongly treated or abandoned. Issues with data harmonization and energy usage that arise with blockchain implementation are also discussed. In order to ensure complete e-waste disposal and to create a safe environment, the proposed DTS is suitable for local implementation. In order to improve energy efficiency and integrate blockchain models with other technologies, such as IoT and AI, future research may concentrate on improving these models.

[10]This study investigates how blockchain technology might be used to enhance waste management, with a particular emphasis on recycling pizza boxes in a restaurant. By using blockchain technology, the system validates the recycling procedure and implements a tokenization strategy to incentivize customers and the company to dispose of waste properly. The pizza place tracks garbage, separates recyclables, and creates tokens for rewards using robotic arms, smart scales, and Internet of Things devices. While the pizzeria receives tokens for recycling efforts, customers who return clean pizza boxes receive tokens that may be exchanged for rewards. Since the blockchain guarantees accountability, security, and transparency, it is simpler for all users to have faith in the system. This case study demonstrates how community-led initiatives and digital transformation can improve sustainable practices.

[11] The study addresses the expanding worldwide waste management problem, which is made worse by population increase and urbanization. By 2025, it is predicted that 2.2 billion tonnes of rubbish will be produced yearly. It highlights global efforts like Japan's waste separation, South Korea's pay-as-you-throw model, and Sweden's waste-to-energy method. Blockchain technology is presented as a transformative tool, improving transparency, traceability, and efficiency in waste management processes. It supports circular economy principles by enabling real-time tracking of waste and improving recycling habits. Integrating blockchain with IoT helps automate waste tracking, optimize collection routes, and improve resource management. Additionally, smart contracts allow reward systems and compliance with waste

management guidelines. Digital product passports (DPP) are suggested as tools to support sustainability by tracking product lifecycles.

[12] This study investigates how blockchain technology might be used to manage food waste in the hospitality sector. It looks at how blockchain might improve supply chain partners' transparency, traceability, and cooperation while highlighting the serious problem of food waste at every stage of the supply chain, from production to consumption. Food safety, fraud prevention, and waste reduction can all be enhanced by blockchain's decentralized structure, security, and auditability capabilities. Blockchain facilitates improved coordination, which improves the management of food resources and has both financial and environmental advantages. According to the report, by lowering transaction costs, improving partner selection, and guaranteeing product quality, blockchain can aid sustainability initiatives. Additionally, by reducing food waste in the hotel sector, the technology supports the UN's sustainable development goals.

[13] This study investigates how blockchain technology might enhance food traceability and cut waste, especially in the dairy sector. The suggested system records milk's route from farms to the finished product using the Hyperledger Fabric platform, guaranteeing that all production stages—including feed quality and animal health—are safely documented. By increasing transparency, the technology makes it simpler to determine a product's place of origin and track down the source of any contamination. Customers can obtain this information by scanning QR codes found on product packaging. The solution helps reduce errors and operating expenses in addition to increasing inventory management's accuracy and efficiency.

[14] This study addresses the environmental issues raised by trash from solar panels and suggests a circular economy plan for recycling them that makes use of blockchain technology. In addition to addressing the detrimental effects of poorly disposed of solar panels, which include toxic elements, it draws attention to the growing necessity of solar energy in the fight against climate change. The authors propose utilizing blockchain technology to allocate recycling obligations to stakeholders and monitor the end-of-life (EOL) of

solar panels. The concept uses decentralized finance to stabilize the value of a "recycling coin" (RC-coin), which encourages recycling. In order to offset the high expenses of recycling solar panels, the study highlights the shared duty of manufacturers, recyclers, and users.

[15] Blockchain ensures that all waste lifecycle stages—from generation to disposal—are safely recorded by establishing an immutable ledger, which lowers fraud and inefficiencies. Smart contracts, which automate procedures and reward sustainable behavior, also make decentralized tracking easier and encourage recycling. Despite its potential, low recycling rates and subpar materials are still problems in worldwide plastic recycling systems. By enhancing trash monitoring, streamlining procedures, and creating more effective worldwide recycling networks, innovations in chemical recycling and blockchain integration with IoT and AI can help address these problems. Ultimately, a route to a more sustainable circular economy is provided by the use of blockchain technology in trash management.

[16][17] The growing quantity of end-of-life (EOL) solar panels, which could become a significant e-waste problem by 2050, presents environmental challenges that are discussed in this study. By using blockchain technology to monitor solar panel consumption and delegate recycling duties to different stakeholders, the authors suggest a circular economy strategy. Through decentralized finance processes, a new "recycling coin" (RC-coin) is established to encourage recycling and stabilize costs. By spreading out recycling expenses across time, the idea seeks to lessen the financial strain on recycling businesses. This approach can be modified to fit various regulatory regimes, such as solar equipment fees or eco-taxes.

Blockchain Technology for Waste Management

Blockchain technology has emerged as a powerful tool for improving waste management, offering solutions for enhanced efficiency and transparency. Blockchain is a secure and transparent digital ledger system that stores data in tamper-proof blocks, which are distributed chronologically across a decentralized network of computers. This decentralized nature ensures that no single entity has complete control over the data, enhancing security and reducing the risk of fraud or manipulation [6].

Working Model of Waste Management

Model utilizes blockchain technology and smart contracts.

- A) Smart Contracts: Self-executing contracts deployed on the blockchain for automating processes and enforcing rules.
- B) Blockchain Network: Provides a decentralized and immutable ledger for recording waste management transactions.

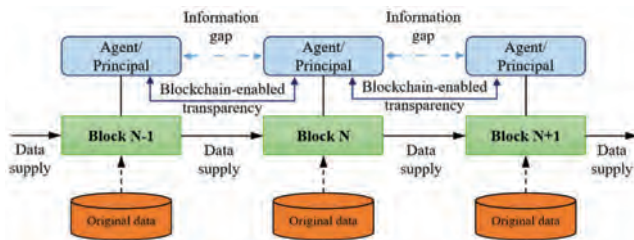


Fig. 2: Block Chain based Waste Management

The above diagram shows the blocks creation upon data received related to waste bins. The bins are then managed to empty based on the information chained in the network.

Results of blocks created

B1:

```
{'ph': '', 'Area': 'Church Street', 'City': 'Boston',
'Garbage Status': Full, 'ts': 1740158654.2362182,
'nonce': 0.700424207365658, 'hash':
```

B2:

```
{'ph': '000035a6e907c502e84c90dba3f1ba3f98419f
f08963528fe5baf149c42b7dd4', 'Area': '100ft Road',
'City': 'Boston', 'Garbage Status': Partial, 'ts':
1740158654.2362182, 'nonce': 0.700424207365658,
'hash':
'000056bb69f2559e9cbb9d9c1097d2db03dc
65106d3c2b8719ca8ffb96ef8dc4'}
```

The above results of blocks are generated by implementing using python.

CONCLUSION

The overall discussion in this article emphasizes use of blockchain technology for decentralized, transparent, auditable, tamper-proof, traceable, and trackable waste

management in smart cities. It has been covered that how blockchain technology can be used to manage several tasks and operations associated with waste collection, transportation, segregation, disposal, and recycling in smart cities. For trash management, various researcher introduced a blockchain-based framework that highlights system components, participants and their roles, and data flow between system components. The practicality of blockchain in smart city waste management was demonstrated by enlightening talks on recent blockchain-based research initiatives and case studies. In future machine learning approach using blockchain technology in waste management may give significant scope for research.

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Implications of Augmented Reality in Smart City Development

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ABSTRACT

Augmented Reality (AR) has emerged as a transformative technology with significant potential in shaping the development of smart cities. By overlaying digital information on the physical environment, AR offers innovative solutions for urban planning, infrastructure management, and citizen engagement. This paper explores the implications of AR in the context of smart city development, emphasizing its role in enhancing public services improving spatial awareness, and fostering sustainable urban growth. smart city development vis Mobility, Connectivity, Security and Sustainability AR applications in smart cities can update transport, improve energy intake, support emergency response systems, and enhance accessibility for people with disabilities. Moreover, the integration of AR with Internet of Things (IoT) devices facilitates real-time data visualization, empowering decision-makers to make informed choices. In order to develop a conceptual model based on the assessment and analysis of the literature on the subject of this study, the paper uses a narrative literature review approach. Town developers and government officials can custom this technology to improve city facilities, substructure, the environment, and citizens and excellence of natural life. This study also contributes to the body of knowledge on the use of technology in smart city infrastructure building, which has implications for academicians, practitioners, and society at large.

KEYWORDS: *Augmented Reality, Smart city Planning, Smart Infrastructure, Sustainability, Connectivity, Mobility, Security*

INTRODUCTION

India is on the limit of a technological revolution, viewing the general adoption of technology across various sectors, from businesses to personal life. Among the numerous technological innovations impacting our lives, Augmented Reality (AR) stands out as a transformative force. AR has the unique ability to significantly alter consumer behavior and streamline business processes. Its highly visual, context-aware, and immersive nature creates a more engaging and interactive experience with the world around us.

In India, the concept of “Smart Cities” is gaining significant importance as the nation strives to improve the living standards of its urban population. By 2030, it's expected that 40% of India's population will exist in town zones, creation infrastructure development a critical concern. Growing Population is Increased population density strains existing infrastructure and resources. Insufficient Infrastructure is many cities face challenges with aging infrastructure, inadequate transportation systems, and limited access to basic services environmental pollution is fast industrialization

and increased vehicular traffic contribute to significant air and water pollution. The Smart Cities Mission, spearheaded by the Indian government, aims to address these challenges through the innovative application of technology. This initiative focuses on improving various aspects of urban life, including is Infrastructure Management is Enhancing the efficiency and sustainability of transportation, energy, and water systems. By embracing technology and innovation, the Smart Cities Mission seeks to create more livable, sustainable, and equitable urban environments for all citizens.

Emerging technologies like Augmented Reality (AR) have the possible to be very important for building the infrastructure of smart cities. It is central to have a stage to interconnect with all investors and know their main problems in a state where cities are not planned and established arbitrarily. As a result, augmented reality offers a way to calm doubts about smart city substructure.

The term “smart city” refers to the whole development of institutional, physical, social, and economic infrastructure in the Indian context. At the moment, this industry is expanding rapidly as well, which offers enormous economic opportunities. The Smart Cities Association estimates that the worldwide smart city market is worth \$900 billion at the moment and will grow to around \$3.5 trillion by 2026. Government, asset management, public safety, public health, transportation, and local culture and history are the six main sectors of infrastructure construction where augmented reality can be used.

Augmented reality applications can be utilized in the policy framework domain of e-governance. Through the use of augmented reality technologies, legal and regulatory papers can be genuinely transformed into “living” forms that allow for interaction between the officers and the native population. Augmented reality apps can be used to manage and maintain city assets such as fire towers, cell towers, and streetlights. During difficulties and disasters, augmented reality devices can be useful by offering auditory and visual helps for finding refuge, navigating evacuation routes, or requesting emergency assistance. Applications for AR can be found in fields such as public health and sustainability, where

augmented reality equipment can assist in assessing the quality of the environment and allow local residents and concerned authorities make prompt decisions. Time and lives can be saved by using augmented reality to help with transportation management, urban mobility, and traffic accident issues. Thus, augmented reality aids in educating people about the importance of protecting a location’s natural resources as well as its cultural and social legacy.

LITERATURE REVIEW

Researchers have conducted numerous studies exploring the applications of augmented reality (AR) across various sectors, including community vehicle, shopping, education, gaming, navigation, museums, tourism, rehabilitation, marketing, smart parking, and inner plan. These studies have also examined the integration of AR within smart city infrastructure, with a particular focus on public transport systems (Pokric et al., 2014). [1] The integration of augmented reality (AR) technology within smart city infrastructure has been explored, particularly in relation to public transportation systems (Pokric, B., et al 2014) [2]. Furthermore, AR applications have demonstrated significant potential in enhancing the shopping experience, especially for individuals with motor disabilities or physical challenges (Rashid, .et al 2017).[2] Ozcan, U et al. (2017) [3] created an AR prototype to enhance visual guidance within a college campus, demonstrating the potential of augmented reality in improving campus navigation. B.Pokric, et al. (2015) [4]A study by Karl Rehrl et al. (2014) investigated the utilization of IoT services in conjunction with AR technology for the presentation of environmental data.”[5] While Francesca Bertacchini et al. (2012) [6] explored the use of augmented reality for pedestrian navigation, Osamah.; R. et al. (2014) demonstrated the potential of AR technology within a different context: museum exhibitions.”[10] In the field of tourism, researchers have been exploring the potential of augmented reality (AR) applications. For instance, Diaz et al. (2017) proposed an AR-based mobile app that can identify places offline [11]. Similarly, another study by Pierdicca et al. (2016) investigated the use of AR in tourism [12]. Garcia-Crespo et al. (2018) [15] examined how AR can be leveraged to improve user experiences through mobile devices, outlining a framework for developing a

cultural entertainment system. In a separate study, Brum et al. (2015) [13] focused on the intersection of Virtual Reality (VR) and the Internet of Things (IoT) within the context of smart cities, exploring their potential to enhance health and rehabilitation solutions. Al-Jabi and Sammaneh (2018) [14] explored the potential of AR in fostering community engagement and promoting local businesses within rural settings. Ramos et al. (2018)

[15] highlighted the promising applications of AR tools in developing a more intelligent and efficient campus environment. Sharma et al. (2018) [16] presented an innovative approach to interior design utilizing AR technology, enabling users to visualize furniture in 3D and interact directly with vendors through a user-friendly interface.

OBJECTIVE OF PAPER

The Indian government's strong push for smart cities, heavily reliant on technology, underlines the critical need to investigate Augmented Reality (AR) applications within this context. While research on AR and its possible is general, studies specifically examining its role through the lens of the four key supports of smart city development (Mobility, Connectivity, Security, and Sustainability) – as outlined by the Smart Regions Initiative in 2017 – are scarce. This research aims to develop a conceptual model for smart city infrastructure that integrates AR, focusing on how it can enhance each of these four crucial pillars.

RESEARCH METHOD

This study draws upon a comprehensive review of peer-reviewed literature encompassing augmented reality (AR), smart city preparation, and smart organization. Applicable study resources were known using keywords such as “Augmented Reality,” “Smart City Arrangement,” “Smart Structure,” “AR and Mobility,” “Augmented reality and Connectivity,” “Augmented reality and security,” and “Augmented reality and Sustainability.” Online databases like Scopus, Ensco, and Google Scholar were utilized for data retrieval. Given the nascent nature of this technology, the study also incorporated data from online databases, white papers, courses, and rumors. The together works was then critically examined for its significance to the four pillars of smart city planning. As per Fink (2014), a

literature review systematically examines and evaluates existing research, providing an overview of the field and contextualizing the current study within that broader framework. “. According to Carnwell and Daly (2001) [7], a thorough appraisal of works would mean collecting info about the topic under thought from some resources. The researcher must have a clear- cut plan about the playful and range of info. As per Cronin et al (2008) [8], a story or old-style type of literature review consists of some lessons which contain information relating to the topic under investigation. This study is very selective in nature as it considers studies relevant to the topic, which sometimes may not be outright apparent to the readers. This method is especially important when the academic needs to review and manufacture lot of info relating to a exact topic. Such a technique is also valuable when the researcher wants to refine, select a broad research question with an aim of making a theoretical model or framework. (Becroft et al, 2006) [9].”

CONCEPTUAL MODEL

The Smart Regions Initiative highlights four essential aspects for a successful smart city: reliable connections, smooth and efficient movement of people and goods, strong security measures, and sustainable practices that protect the environment. This study aims to investigate the following through a review of existing research:

How significantly do augmented reality applications

impact the four key aspects of smart city planning: mobility, connectivity, security, and sustainability?

Can augmented reality technology improve transportation and movement within a smart city?

Can augmented reality enhance communication and network infrastructure in a smart city?

Can augmented reality technology enhance security measures within a smart city?

Can augmented reality contribute to environmental sustainability within a smart city?

Based on the findings of this literature review and the above research questions, a conceptual model will be proposed. This model will explore the potential benefits of augmented reality applications for smart city infrastructure, focusing on the four key supports of smart city planning.

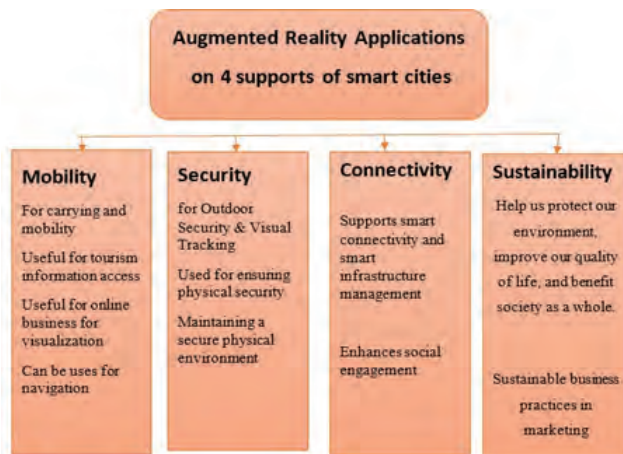


Fig. 1 Augmented reality applications on 4 supports of smart cities

CONCLUSION

Connectivity: AR plays a crucial role in connecting people and systems within a smart city. By enabling real-time data visualization and remote expert assistance, AR facilitates efficient communication and collaboration.

This connectivity extends outside physical infrastructure, connecting rural populations to urban opportunities and fostering social interaction through shared experiences and information exchange.

Mobility: Outside physical movement mobility in a smart city includes access to opportunities like education and employment. AR can significantly enhance this by providing real-time information on transportation schedules, ways, and traffic conditions, improving navigation and overall travel efficiency. This technology can also be used to enhance tourism experiences by providing interactive information about destinations and points of interest.

Security: In a technology-driven city both physical and cybersecurity are principal. AR applications can enhance physical security by providing real-time situational awareness, enabling remote monitoring, and simplifying rapid response to events. also, AR can be used to identify and address likely security vulnerabilities within networks and systems.

Sustainability: Smart city solutions must rank sustainability. AR can contribute to this by encouraging eco-friendly behaviors, improving resource use, and

supporting sustainable follows across various sectors. By providing real-time environmental data and insights, AR empowers citizens and authorities to make informed decisions that minimize environmental impact and promote a more sustainable urban environment.

FUTURE RESEARCH

This research aims to explore how Augmented Reality(AR) technology can benefit smart city development across four areas:

Mobility: AR can enhance transportation (navigation, route optimization) and tourism (interactive experiences, information access). **Connectivity:** AR facilitates improved communication (social interactions, business collaborations) and smart infrastructure management (remote access, data visualization). **Security:** AR strengthens security measures by enabling enhanced surveillance (visual tracking, threat detection), improved network monitoring, and better situational awareness for security personnel. **Sustainability:** AR can contribute to environmental conservation, improve quality of life, and foster sustainable business practices by reducing environmental impact and promoting resource efficiency.

Future research should investigate the specific impact of AR applications on the financial performance of organizations within the context of these four smart city Supports. This study has valuable implications for: **Academics:** It contributes new knowledge to the field of technology and its role in clever city development. **Consultants:** Urban organizers and government officials can use this investigation to recover city services, substructure, and overall excellence of life for citizens. **Industry:** Infrastructure companies can leverage AR to design, develop, and implement innovative solutions for smart city management. Key stakeholders who can benefit from this research include: Government officials, Town planners, Architects, Builders

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Matrix-Based Cryptographic Method: Enhancing Data Security with Binary and Decimal Transformations

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ABSTRACT

This study presents a simple and secure method for data encryption and decryption using decimal-to-binary conversion and matrix operations. The process begins by converting text into decimal values and then into binary form. These binary values are organized in a matrix, where mathematical operations are applied to encrypt the data. Decryption reverses this process to restore the original text. The use of binary conversion and matrix manipulation adds an extra layer of protection, making the data more secure. This method is easy to implement and shows promise for secure communication systems. Future work will explore ways to improve efficiency and handle larger data sizes.

KEYWORDS: *Encoding, Decoding, Cryptography, Inverse matrix, Binary number, Decimal number.*

INTRODUCTION

Cryptography serves as a fundamental tool in ensuring secure communication and safeguarding sensitive data in an increasingly interconnected digital world. Recent research has expanded its applications across diverse domains, such as cloud computing, healthcare, error-correction coding, and machine learning, introducing innovative methodologies and systems to address the evolving challenges of data security. Non-square binary matrices have emerged as a powerful tool with applications in mathematics, error-correction coding, machine learning, data storage, navigation signals, and cryptography. Their role in McEliece and Niederreiter public-key cryptosystems has been particularly significant, with new algorithms enabling the construction of distinct inverse matrices, extending their utility to non-square matrices over arbitrary fields [1]. Meanwhile, advancements in elliptic curve cryptography (ECC) focus on scalar multiplication techniques, where computational

efficiency is paramount. Improved binary methods that reduce addition operations during scalar multiplication have been proposed, addressing the growing demand for larger key sizes in cryptographic systems [8]. In healthcare, safeguarding patient data has gained priority, with innovative techniques like MAN-C, a Masked Autoencoder Neural Cryptography-based encryption scheme, ensuring the secure sharing of medical images. By utilizing masked autoencoders and neural cryptography, the scheme provides a robust, low-computation alternative to traditional number-theoretic methods [2]. Similarly, in cloud computing, hybrid encryption frameworks, such as those leveraging Hybrid Elliptic Curve Cryptography (HECC), have demonstrated significant improvements in security and performance. These approaches combine the efficiency of Edwards curves and Identity-Based Encryption to enhance encryption speeds and reduce key sizes [3]. The secure transmission of multimedia data, including text, audio, images, and videos,

has also seen significant advancements through the implementation of modified Menezes-Vanstone ECC algorithms, which optimize encryption processes and reduce file sizes [4]. Additionally, cryptographic encoding theory has been proposed to synthesize and analyze encryption algorithms using discrete system frameworks, enhancing the quality of symmetric and asymmetric ciphers [5]. Cloud security remains a pressing challenge, with new algorithms focusing on mitigating internal threats. Techniques employing double encryption, XOR functions, and salt methods have been developed to enhance data protection in cloud servers, demonstrating superior security and performance compared to traditional methods [6]. Innovations in block cipher security, such as the construction of 32×32 binary linear transformations with high branch numbers, further contribute to the cryptographic robustness of systems like Camellia and ARIA [7]. These advancements collectively illustrate the dynamic evolution of cryptographic systems. The integration of non-square binary matrices, advanced ECC techniques, and hybrid cryptographic frameworks reflects a concerted effort to meet the challenges posed by modern information security needs. This review aims to explore these developments, highlighting their potential to transform data protection strategies across industries.

LITERATURE REVIEW

The applications of non-square binary matrices have been extensively explored across various domains, including mathematics, error-correction coding, machine learning, data storage, navigation signals, and cryptography. Farshid Haidary Makoui et al. [1] underscore their importance, particularly in public-key cryptosystems such as McEliece and Niederreiter. The authors present algorithms designed to generate distinct inverse matrices for systematic non-square binary matrices, addressing the limitations posed by traditional inversion methods such as Moore-Penrose and Gauss-Jordan. These advancements contribute to the development of robust cryptographic systems, especially in enhancing the security of public-key cryptosystems. Kishore Kumar et al. [2] emphasize the crucial role of securely sharing medical images to preserve patient confidentiality. They introduce MAN-C, a Masked

Autoencoder Neural Cryptography-based encryption scheme, which leverages masked autoencoders initially designed for self-supervised learning in computer vision. The scheme exploits the autoencoders' ability to obfuscate parts of input images while reconstructing them, resulting in a secure encryption-decryption framework. Tree parity machines and Shamir's Secret Sharing Scheme are utilized to enhance security further. Evaluations on CT scans from The Cancer Imaging Archive (TCIA) reveal superior performance, with reduced RMSE values and a high correlation between input and encrypted images, showcasing the proposed method's effectiveness over existing techniques. B. Ranganatha Rao et al. [3] focus on enhancing cloud security through a Hybrid Elliptic Curve Cryptography (HECC)-based approach. Cloud computing offers centralized data storage and applications, making secure access to data critical. The authors propose a technique that leverages Edwards curves and Identity-Based Encryption to reduce private key sizes, thereby improving encryption efficiency. Diffie-Hellman key exchanges are employed for secure public key exchanges, leading to enhanced throughput, shorter key generation, and faster encryption and decryption times. The proposed method outperforms existing models, achieving a key creation time of 0.000025 seconds, an encryption time of 0.00349 seconds, and a throughput of 693.10 kB/s, thus offering a more secure and efficient solution for cloud environments. Edward Keitaro Heru et al. [4] address the need for securing various data types, such as text, images, audio, and video, using a modified Menezes-Vanstone elliptic curve cryptography (ECC) algorithm. Their implementation aims to reduce encrypted file sizes while evaluating performance metrics relative to existing methods. The approach shows improved file size efficiency; however, there is still room for further optimization, particularly in terms of reducing encryption and decryption times for better overall performance. Volodymyr Rudnytskyi et al. [5] highlight the contradictions between traditional encryption algorithms and their application in modern information security systems. They propose a cryptographic encoding theory, emphasizing the synthesis and analysis of encryption algorithms using discrete system frameworks. The study explores novel methods for constructing asymmetric stream ciphers and

enhancing key lengths and block sizes, contributing to the development of more secure and efficient cryptographic systems. Muhammad Nadeem et al. [6] emphasize the importance of cloud cryptography, focusing on securing cloud servers from internal threats. They propose a symmetric cryptography algorithm that incorporates a double encryption approach, utilizing the XOR function, a salt technique, and a reversing mechanism to enhance data security. The proposed algorithm is compared with existing methods, demonstrating improved security and performance in protecting cloud server data. Muharrem Tolga Sakallı et al. [7] focus on binary linear transformations, which play a vital role in block ciphers like Camellia and ARIA. They propose a novel algebraic method for constructing 32×32 binary linear transformations that meet specific cryptographic properties, such as branch number and fixed points. By leveraging Finite Field Hadamard matrices, they enhance the cryptographic robustness of block ciphers, ensuring higher security for 256-bit input/output transformations. M.A. Mohamed et al. [8] address the computational constraints in elliptic curve cryptography (ECC) due to scalar multiplication operations. They propose an improved binary method that processes input on a block-by-block basis, reducing the number of addition operations required for scalar multiplication. This precomputation-based approach significantly reduces computational overhead and is particularly well-suited for cryptographic systems requiring large key sizes. G. Venkatasubbaiah et al. [9] explore the significance of number conversion systems—binary, octal, and hexadecimal—in cryptography. They emphasize how these systems provide the foundation for understanding encryption schemes and cryptanalysis, helping identify strengths and weaknesses of encryption algorithms. The study contributes to a deeper understanding of how these systems influence the structure and design of cryptographic algorithms.

METHODOLOGY

Conversion of Decimal Numbers to Binary

The conversion of decimal numbers to binary is achieved using the division method. The steps are as follows:

- Step 1: Divide the decimal number by 2, recording the quotient and remainder.
- Step 2: If the number is even, the remainder is 0; if odd, the remainder is 1.
- Step 3: Repeat the process with the quotient until it becomes 0.
- Step 4: Arrange the remainders with the least significant bit (LSB) at the top and the most significant bit (MSB) at the bottom to obtain the binary equivalent.

Now, let us convert the given decimal 25 into a binary number.

Divided by 2	Quotient	Remainder	Binary Value
25÷2	12	1	1
12÷2	6	0	0
6÷2	3	0	0
3÷2	1	1	1
1÷2	0	1	1



The decimal number 25 is converted into a binary number

Conversion Binary to Decimal-

Decimal Number = $n^{\text{th}} \text{ digit} \times 2^{n-1}$

Converting Binary to Decimal Using the Positional Notation Method-

The positional notation approach uses a weight depending on a digit's position to calculate its value within a number. The following are the steps to convert binary to decimal:

Step 1: Use powers of two to multiply each digit, beginning with the one on the right. Here, we start with 20 and proceed to the left, increasing the exponent by 1.

Step 2: The corresponding value of the given binary number in the decimal system is determined by adding up all the values received for each digit.

Let's use some instances to grasp this better.

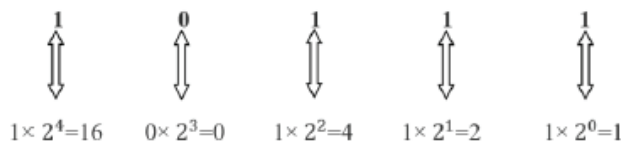
Example: Convert the binary number 101112 to a decimal number

To comprehend the conversion from binary to decimal, follow these steps. The 'Least Significant Bit' (LSB) is the digit at the right of any binary number, and the 'Most Significant Bit' (MSB) is the digit at the left. The weight of the least significant bit for a binary integer with 'n' digits is 2^0 , and the weight of the most significant bit is 2^{n-1} .

- Step 1: Beginning at the rightmost digit, list all of the exponents of 2 for each number. 20 would be the first power, followed by 21, 22, 23, 24, 25, and so on as we proceed to the left. Since there are five digits in the example, the weight of each position from right to left is 20, 21, 22, 23, and 24. This weight begins with the digit on the right.
- Step 2: Next, multiply each binary number digit from right to left by the corresponding weight based on its location, then assess the result. To understand the step, look at the figure below.



Step 3: To get the binary number's decimal equivalent, add up all of the products that were obtained for each of the binary number's digits. For example, $10111_2 = 23_{10}$.



Cryptography using the conversion of binary to decimal and vice versa in the Matrix System.

Assigning numbers to each letter in the alphabet:

1	2	3	4	5	6	7	8	9
A	B	C	D	E	F	G	H	I
10	11	12	13	14	15	16	17	18
J	K	L	M	N	O	P	Q	R
19	20	21	22	23	24	25	26	0
R	T	U	V	W	X	Y	Z	Space

Example: "Welcome to Kolhapur hi"

The matrix for this message is

$$M = \begin{bmatrix} w & o & t & o & u \\ e & m & o & l & r \\ l & e & \text{space} & h & h \\ c & \text{space} & k & p & i \end{bmatrix}$$

Decimal Number Matrix

$$D = \begin{bmatrix} 23 & 15 & 20 & 15 & 21 \\ 5 & 13 & 15 & 12 & 18 \\ 12 & 5 & 0 & 8 & 8 \\ 3 & 0 & 11 & 16 & 9 \end{bmatrix}$$

Binary Matrix

Conversion Table of Decimal Number system to Binary numbers & vice Versa 1 To 26

Decimal	Binary
1	00001
2	00010
3	00011
4	00100
5	00101
6	00110
7	00111
8	01000
9	01001
10	01010
11	01011
12	01100
13	01101
14	01110
15	01111
16	10000
17	10001
18	10010
19	10011
20	10100
21	10101
22	10110
23	10111
24	11000
25	11001
26	11010

Which is a Binary matrix having no meaning.

$$B = \begin{bmatrix} 10111 & 01111 & 10100 & 01111 & 10101 \\ 00101 & 01101 & 01111 & 01100 & 10010 \\ 01100 & 00101 & 0 & 01000 & 01000 \\ 00011 & 0 & 01011 & 10000 & 01001 \end{bmatrix}$$

To convert this matrix into a Decimal number System.
We get the Decimal Matrix is

$$D = \begin{bmatrix} 23 & 15 & 20 & 15 & 21 \\ 5 & 13 & 15 & 12 & 18 \\ 12 & 5 & 0 & 8 & 8 \\ 3 & 0 & 11 & 16 & 9 \end{bmatrix}$$

The message is “Welcome to Kolhapur hi”

IMPLEMENTATION

```
import numpy as np

# Function to convert Decimal to Binary
def decimal_to_binary(decimal_num):
    binary_num = bin(decimal_num)[2:] # Convert to binary and remove '0b'
    return binary_num.zfill(5) # Pad with zeros for 5-bit representation

# Function to convert Binary to Decimal
def binary_to_decimal(binary_num):
    decimal_num = int(binary_num, 2) # Convert binary string to decimal
    return decimal_num

# Function to encrypt a message using matrix-based cryptography
def encrypt_message(message):
    # Assign numbers to letters (A=1, ..., Z=26, space=0)
    char_to_num = {chr(i + 65): i + 1 for i in range(26)}
    char_to_num[" "] = 0

    # Convert message to uppercase and map to numbers
    num_list = [char_to_num[char] for char in message.upper()]

    # Convert numbers to binary
    binary_list = [decimal_to_binary(num) for num in num_list]

    # Create a binary matrix
    binary_matrix = np.array([list(map(int, list(binary))) for binary in binary_list])
    print("Binary Matrix:")
    print(binary_matrix)

    # Example transformation: Add 1 to each binary value (mod 2 for binary)
    encrypted_matrix = (binary_matrix + 1) % 2
    print("\nEncrypted Binary Matrix:")

    # Inverse transformation: Subtract 1 (mod 2 for binary)
    original_matrix = (encrypted_matrix - 1) % 2
    print("\nDecrypted Binary Matrix:")
    print(original_matrix)

    # Convert binary matrix back to decimal
    original_num_list = [binary_to_decimal("".join(map(str, row))) for row in original_matrix]

    # Map numbers back to characters
    num_to_char = {i + 1: chr(i + 65) for i in range(26)}
    num_to_char[0] = " "
    decrypted_message = "".join([num_to_char[num] for num in original_num_list])

    return decrypted_message

# Example Usage
message = "Welcome to Kolhapur hi"
print("Original Message: (message)")

# Encrypt the message
encrypted = encrypt_message(message)
print("\nEncrypted Decimal List:")
print(encrypted)

# Decrypt the message
decrypted = decrypt_message(encrypted)
print("\nDecrypted Message:")
print(decrypted)
```

Output:

Original Message: Welcome to Kolhapur hi
Binary Matrix:

```
[[1 0 1 1 1]
 [0 0 1 0 1]
 [0 1 1 0 0]
 [0 0 0 1 1]
 [0 1 1 1 1]
 [0 1 1 0 1]
 [0 0 1 0 1]
 [0 0 0 0 0]
 [1 0 1 0 0]
 [0 1 1 1 1]
 [0 0 0 0 0]
 [0 1 0 1 1]
 [0 1 1 1 1]
 [0 1 1 0 0]
 [0 1 0 0 0]
 [0 0 0 0 1]
 [1 0 0 0 0]
 [1 0 1 0 1]
 [1 0 0 1 0]
 [0 0 0 0 0]]
```

Decrypted Binary Matrix:

```
[[1 0 1 1 1]
 [0 0 1 0 1]
 [0 1 1 0 0]
 [0 0 0 1 1]
 [0 1 1 1 1]
 [0 1 1 0 1]
 [0 0 1 0 1]
 [0 0 0 0 0]
 [1 0 1 0 0]
 [0 1 1 1 1]
 [0 0 0 0 0]
 [0 1 0 1 1]
 [0 1 1 1 1]
 [0 1 1 0 0]
 [0 1 0 0 0]
 [0 0 0 0 1]
 [1 0 0 0 0]
 [1 0 1 0 1]
 [1 0 0 1 0]
 [0 0 0 0 0]
 [0 1 0 0 0]
 [0 1 0 0 1]]
```

Decrypted Message:

WELCOME TO KOLHAPUR HI

CONCLUSION

This study introduces a novel approach to data encryption and decryption by leveraging the conversion between binary and decimal number systems within a matrix framework. By assigning numeric values to characters and performing mathematical operations on binary matrices, the method ensures an additional layer of security for transmitted data. The process's simplicity and computational efficiency make it a promising solution for secure communication systems.

The implementation demonstrates how this technique effectively encodes and decodes data while preserving its integrity. The use of binary matrices adds complexity to the encrypted data, making unauthorized decryption challenging. Furthermore, the systematic approach outlined for converting binary to decimal and vice versa ensures precise and error-free encryption.

Future research directions include optimizing the methodology for handling larger datasets and exploring its application in real-time secure communication scenarios. This technique holds significant potential for enhancing the robustness of cryptographic systems, particularly in domains requiring lightweight yet secure encryption methods.

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Improving Rainfall Forecast Accuracy Using Multilayer Perceptron Neural Networks

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ABSTRACT

Predicting rainfall is essential for planning irrigation, managing water resources, and preventing flooding. However, precise forecasting is difficult due to the many atmospheric processes that affect precipitation, especially at different geographical and temporal scales. This work uses input characteristics including temperature, humidity, and precipitation to forecast rainfall using a Multilayer Perceptron (MLP)-based model. MLP is a powerful neural network design that works well for predicting jobs because it can handle non-linear correlations in data. Metrics including Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Normalized RMSE (NRMSE) were used to assess the model's performance. Sufficient prediction accuracy is shown by a rank correlation of 0.6327 for the entire dataset and 0.68893 for the training data. Outliers in the test data, however, caused the rank correlation to drop to 0.22507, indicating regions that need further work. Notwithstanding these difficulties, the MLP model shows promise as a useful instrument for managing water resources and predicts rainfall likelihood with accuracy. The MLP architecture, including its input, hidden, and output layers, is also examined in the paper, along with how backpropagation is used to optimize weight. According to the results, MLP provides a data-driven substitute for conventional empirical approaches in the prediction of rainfall occurrences. In order to create more accurate and dependable rainfall forecasting systems, future research can concentrate on increasing the model's accuracy by reducing the influence of outliers and refining feature extraction techniques

KEYWORDS: *Multilayer perceptron (MLP), Artificial neural networks (ANNs), Machine learning (ML), Rainfall prediction.*

INTRODUCTION

Predicting rainfall adequately is important for controlling water supplies, maintaining reservoirs, and averting flooding. Flooding has a major effect on human activity, sewerage systems, and public infrastructure. However, because precipitation is caused by complex atmospheric processes that vary across geographical and temporal dimensions, predicting precipitation is extremely difficult. One of the most

important resources on Earth, water requires sustainable management, particularly in light of rising pollution and usage. Planning for water resources, scheduling irrigation, and managing reservoirs all depend heavily on timely and accurate rainfall predictions [1-3]. Given the hydrological dangers presented by heavy rainfall, forecasting is made more difficult by the unpredictability of atmospheric systems that create rainfall. A MLP-based rainfall prediction model has been created in order

to solve this. Temperature, humidity, and precipitation are used as input factors in this model. Rainfall prediction tasks are ideally suited for machine learning methods, which are well-known for their effectiveness in managing non-linear issues [4-8].

Metrics including MSE, RMSE, and NRMSE are used to assess the MLP model's performance. Good prediction capacity is indicated by the training data's rank correlation of 0.68893. The rank correlation for the entire dataset is 0.6327, which is likewise satisfactory. However, because of the outliers that negatively affect the model's performance, the rank correlation for the test data is quite low at 0.22507. Despite these difficulties, the MLP model shows promise in predicting daily rainfall and may prove to be a helpful tool for managing water resources [9, 10].

LITERATURE REVIEW

ANNs are data-driven mathematical models inspired by the structure and functioning of the human brain, which have been widely applied to solve complex problems such as prediction and classification tasks. The foundation of ANNs lies in the perceptron, a model designed to mimic the roles of neurons and their recognition processes [11]. Unlike traditional statistical models, ANNs do not require restrictive assumptions about the underlying data model. They also possess the ability to identify patterns not explicitly provided during training and efficiently handle large datasets due to their inherent parallel processing capabilities [12].

The application of ML techniques, particularly ANNs, has proven useful for rainfall prediction. Statistical models often suffer from certain limitations, making ANNs a viable alternative. These networks can be categorized as single-layer or multi-layer architectures, with their generalization capacity enhanced through modifications in the number of layers and neurons without altering output components [13,14].

Among ANN architectures, the MLP is notable for its capability to model intricate, non-linear relationships between dependent and independent variables. Comparative studies have shown that MLP, radial basis function neural networks (RBFNN), and time-lagged recurrent networks (TLRN) generally outperform traditional regression models in terms of accuracy

[15,16]. The quality and selection of datasets play a crucial role in determining the precision of ANN models, as poor data quality can lead to anomalies and inconsistencies in the prediction process [17-18].

MLPs have been successfully employed in various scientific and engineering fields for forecasting linear and non-linear system behaviors without relying on the assumptions intrinsic to statistical approaches. MSE, MAE, and RMSE are commonly used to evaluate prediction accuracy. The MLP's ability to approximate any smooth function with sufficient complexity and robustness has been well-documented [19]. Additionally, ANNs can generalize from incomplete or erroneous data and are suitable for real-time applications like short-term rainfall forecasting. The MLP structure consists of neurons organized into distinct layers, enabling the network to learn effectively without requiring prior knowledge of atmospheric conditions. MLP's adaptability allows for the modification of layers and neurons to enhance its performance for specific tasks. While optimization algorithms differ across models, MLP and RBFNN are known for their adaptability and accuracy [20-22].

Historical rainfall data from weather stations, including atmospheric sensor measurements, form the basis for developing predictive rainfall models. For instance, a week-ahead rainfall forecasting method utilizing MLP has been proposed, emphasizing data preparation and model evaluation to ensure efficiency. Previous studies have also demonstrated the suitability of feed-forward neural networks (FFNN), recurrent neural networks (RNN), and time-delay neural networks (TDNN) over statistical and numerical approaches for rainfall forecasting.

Simulation strategies like MLP, backpropagation networks (BPN), RBFNN, self-organizing maps (SOM), and support vector machines (SVM) have shown sufficient potential for precipitation forecasting compared to statistical methods. Despite these advances, there are limitations, such as sensitivity to data quality and computational constraints. Future research focusing on enhancing ANN frameworks through improved algorithms and feature extraction techniques could significantly improve rainfall prediction accuracy and reliability [23, 24].

METHODOLOGY

Multilayer Perceptron Neural Network

An MLP, unlike a simple Perceptron, leverages activation functions like sigmoid or ReLU to model both linear and non-linear interactions in data. These functions enable non-linear transformations, making the MLP effective for complex feature extraction and representation [25].

Following data processing, each layer sends its internal representation to the following layer. All hidden layers are processed in this sequential manner until a result is produced by the last output layer.

Backpropagation is the process used by MLP to train efficiently. This learning approach minimizes the cost function, such as MSE, by iteratively adjusting the network's weights. The gradient of the cost function is computed for each input-output pair following the first forward pass, during which input data is sent throughout the network. The weights are changed using this gradient, working backward through the hidden layers from the output layer. Until the gradients converge, or their changes drop below a certain threshold, this process is repeated repeatedly. By making adjustments iteratively, the model is guaranteed to discover patterns in the data and gradually increase its accuracy [26].

Although MLP is frequently employed for straightforward regression applications, it has also shown promise in solving classification issues. The dataset used in this study consists of millimetre-scale rainfall measurements. Outliers are common in these kinds of datasets and might affect how well a model performs. However, forecasting the probability of rainfall rather than its precise amount is the aim here. The model's capacity to forecast rainfall events accurately is improved by this reframing, which also lessens the impact of outliers.

The results from this study demonstrate that MLP can effectively predict rainfall probability. Future work can build on these findings to refine the model and achieve greater precision, potentially contributing to improved rainfall forecasting systems [27].

Figure 1 shows the input layer, one or more hidden layers, and the output layer are the three main layers that make up an MLP. Because it accepts inputs, processes them,

and generates an output without overtly disclosing the underlying workings, it is referred to as a “black-box” model. Each layer is made up of linked neurons, and the connections between layers are defined by weights. MLP is well known for being a successful ANN model, especially when it comes to forecasting meteorological variables [28].

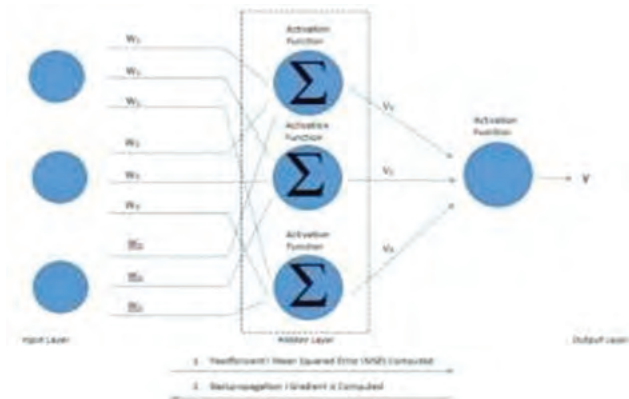


Fig.1. Multilayer Perceptron Architecture

An MLP's structure consists of discrete layers of neurons, which are processing units. In the network, these neurons are dispersed among the various levels. By processing data without the need for prior knowledge of atmospheric conditions, ANNs such as MLP successfully overcome the drawbacks of empirical models, in contrast to classical models. Data moves across the network in a single direction when using the feedforward mode of the MLP. Only the nodes that come after it in the network receive the output from each node [29].

MLP Training Optimization

- Utilizes backpropagation to adjust weights and improve accuracy.
- consists of three main layers:
 - Input Layer: Receives training data with nodes corresponding to dataset features.
 - Hidden Layer: Performs computations to introduce non-linearity, balancing complexity and overfitting.
 - Output Layer: Produces final output with determined number of nodes based on the task.

MLP is often utilized for solving regression tasks but can also be adapted for classification problems. In this study, the dataset contains rainfall measurements in millimetres, which inherently include outliers. However, the objective is to predict the likelihood of rainfall occurrence rather than its precise quantity.

This shift in focus reduces the impact of outliers on model performance.

The findings suggest that the developed MLP model effectively predicts the probability of rainfall. Further investigations can refine the model, enhancing its performance and providing more detailed insights into rainfall prediction [30-32].

Data exploration, data pre-processing, model implementation, and model evaluation are the four main phases shown in Figure 2.



Fig. 2. Overview of the data preparation process for model development

The Zonal Agricultural Research Station in Kolhapur, Maharashtra, provided the raw data for this investigation. Year, month, date, maximum and lowest temperatures, humidity, and rainfall were among the five data variables that were provided.

After that, data cleaning was carried out, which entails finding, fixing, or eliminating erroneous and corrupt entries from the meteorological dataset that could allude to missing, inaccurate, or unnecessary data points. Before utilizing the dataset for the MLPNN, a visual assessment was done to see how it may be cleaned the best. Each variable and record in the dataset were then

personally examined once the data had been tabulated into a spreadsheet [33].

The meteorological station collects daily environmental variable readings throughout the year directly from its monitoring devices. These data are stored in Microsoft Excel in a tabular format, with rows representing the years and days of the month, while columns correspond to various environmental variables. For this study, raw data spanning seven years, from January 2015 to December 2021, were utilized. Table 1 shows the parameters and their corresponding measurement units utilized in the present work.

Table 1. Rainfall parameters contributes in dataset

Rainfall parameter	Unit
Min temp (tmin)	°C
Max temp (tmax)	°C
Relative humidity I	Percentage (%)
Relative humidity II	Percentage (%)
Rainfall	Millimetres (mm)

The data preprocessing steps involved data conversion, management missing values, and separation of the dataset into training and testing subsets. Data across seven years (2015–2021) were collected from the meteorological office. Since the raw data contained missing and incorrectly encoded values, the missing target variable entries were removed, and other missing feature values were imputed using the moving average method, calculated as the mean of the data. Additionally, the raw data from the meteorological office were organized by year, with features initially arranged in rows. These were restructured into columns to standardize the dataset. The data were subsequently transformed from Excel format to CSV format, making them suitable for experimentation. Significant features relevant to rainfall prediction were selected, and the dataset was split into 90% for training and 10% for testing to serve as input for the model [34- 40].

In this paper, rainfall forecasting is performed using a machine learning approach. The algorithm employed is the Multilayer Perceptron (MLP), which takes input variables that include both moderately and strongly correlated environmental factors influencing rainfall. Performance evaluation uses metrics like MSE, RMSE,

and NRMSE to assess prediction accuracy. MLPs, feedforward ANNs, are used for predictive tasks like rainfall forecasting. Inspired by biological neural networks, ANNs adapt and learn using neurons, synaptic weights, and activation functions, with feedforward and recurrent networks supporting diverse applications.

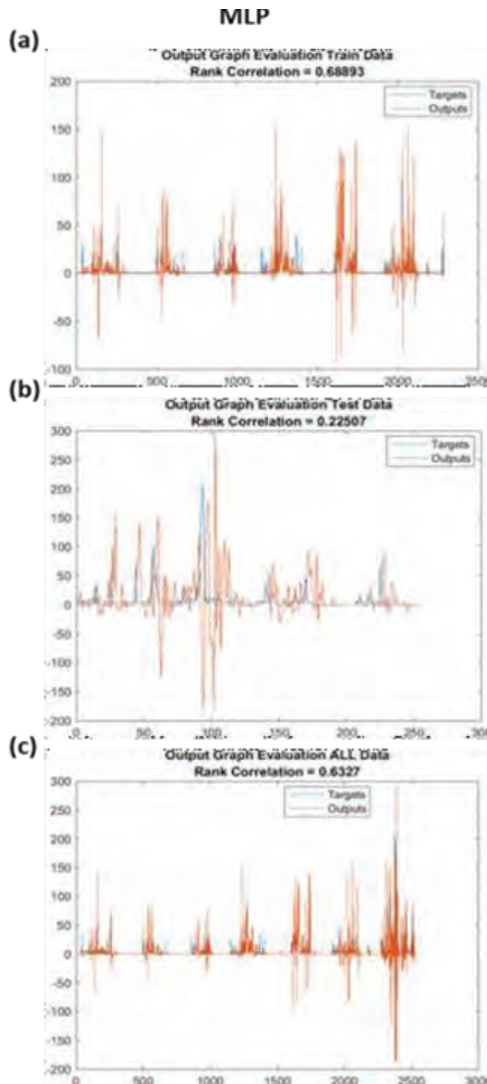


Fig.3. Rank correlation computed for MLP over (a) Train dataset (b) Test dataset (c) All dataset.

Fig. 3. (a) shows the rank correlation for the training dataset, yielding a value of 0.68893, which is within an acceptable range.

Fig.3. (b) displays a rank correlation of 0.22507 for the testing dataset, which is lower due to the presence of outliers in the test data.

Fig.3. (c) combines all data, yielding a rank correlation of 0.6327, which is also acceptable.

CONCLUSION

The Multi-Layer Perceptron (MLP) demonstrates its effectiveness in predicting weather parameters. Its applicability extends across various scientific and technological domains for forecasting both linear and nonlinear systems without requiring the assumptions inherent in many traditional statistical methods.

Figure 3 illustrates the rank correlation values for MLP across different dataset portions: (a) Training dataset, (b) Testing dataset, and (c) Complete dataset. To compute the rank correlation for each portion, MLP-generated graphs were analysed. Initially, 90% of the data was allocated for training, and self-testing was conducted using the same dataset range to evaluate forecasting capabilities. In the graph, the Target (blue) represents the actual measured values, while the Output (red) depicts the forecasted values generated by the MLP model.

Table 2. Performance Metrics

ANN	Dataset Portion	Predicted Rainfall (mm)			
		MSE	RMSE	NRMSE	R ²
MLP	90 % training data	94.3803	9.715	2.8448	0.42177
	10 % testing data	2924.7	54.0805	7.6873	-0.0629
	All dataset	377.747	19.4357	5.1452	0.11711

For the MLP model performance metrics shown in table 2. as:

- The Normalized Root Mean Square Error (NRMSE) over the training dataset is 2.8448, indicating reasonable performance.
- Over the testing dataset, the NRMSE rises to 7.6873, primarily due to the aforementioned outliers.
- When calculated for the entire dataset, the NRMSE is 5.1452.

These findings highlight the need for further optimization of the MLP model, particularly for improving performance on the test dataset.

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Object Detection and Identification using Deep Learning Algorithms for Enhanced Augmented Reality

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ABSTRACT

Augmented Reality (AR) has transformed many industries by seamlessly integrating digital data with the physical world. However, accurate object detection and identification are still significant challenges in AR applications. Deep learning algorithms have shown great promise in improving object detection and identification accuracy in Augmented Reality (AR). This study offers a comprehensive overview of deep learning algorithms for AR object detection and identification. We look at distinct deep learning architectures, including Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and attention mechanisms, as well as their packages in augmented reality object detection and identification. We also go over the challenges and limitations of current deep learning algorithms, such as computational complexity, data quality, and robustness to changing lighting conditions. It examines representative detection algorithms, including two and one stage detectors, as well as transformer-based detectors. It also describes the dataset and evaluation metric such as accuracy, precision, recall, F1-score and mean average precision for object detection. Additionally, the most recent advances in object detection, such as multi-scale detection, light weight detection, and rotation invariant detection, are investigated.

KEYWORDS: *Augmented reality (AR), Deep learning, Object detection, Convolutional neural networks (CNNs), Recurrent neural networks (RNNs), Attention mechanisms, Accuracy, Precision, Recall, F1-score, Mean average precision.*

INTRODUCTION

The combination of computer-generated virtual objects, scenes, and information over factual scenes is generally apprehended to as Augmented Reality. “Enhanced” means to enrich and increase understanding. “Reality” is the term used to describe effects that are real and live. It differs from the fully immersive experience that virtual reality can give. Enriched reality aims to produce the effect of combining virtual and real-world information [3].

Through the smooth integration of digital data into the real world, boosted reality, or AR, has fully converted a number of diligence. Accurate object discovery and identification is a major challenge in stoked reality (AR), which allows the system to learn about the terrain and give the stoner applicable data. The delicacy and

effectiveness of traditional computer vision ways are limited, particularly in dynamic and complex surroundings. Identification and discovery of objects are essential principles of AR systems [2]. Relating and organizing objects in the surroundings is known as object discovery, whereas relating and labeling particular objects is known as object identification. AR systems can offer accurate data, enhance stoner experience, and boost system performance when objects are detected and linked directly [1]. In object discovery and identification tasks, deep learning algorithms have demonstrated significant pledge. Recurrent Neural Networks (RNNs), Convolutional Neural Networks (CNNs), and other infrastructures have been effectively used for a variety of object identification and discovery tasks [8]. Accurate object discovery and identification are made possible by these algorithms capacity to prize

complex patterns and features from data. The stoner experience can be bettered by combining deep learning algorithms with boosted reality systems. AR systems can offer applicable details, ease better navigation, and upgrade relation when objects are detected and linked directly. Also, deep learning algorithms can increase AR systems' continuity and rigidity, allowing them to perform well in a variety of surroundings [12].

LITERATURE REVIEW

For object detection tasks, deep learning methods have been frequently deployed. Oufqir et al. (2021) achieved accurate and efficient object detection in AR applications by proposing a deep learning-based method. Redmon (2016) presented the YOLO algorithm, which does not require region proposal networks and can detect objects in a single pass. Ren (2015) introduced the Faster R-CNN algorithm, which creates region proposals using a region proposal network and then classifies and improves the suggestions using a Fast R-CNN detector. A lot of people utilize CNNs for applications like object detection and image classification. A new method for AR employing CNNs was presented by Oufqir et al. (2022), which achieved precise object recognition and detection. Cheng et al. (2020) achieved accurate object detection with their AR dynamic image recognition solution, which is based on deep learning algorithms. For tasks involving object recognition, deep learning techniques have been frequently employed. Using deep learning, Goel et al. (2019) presented an object recognition method that produced accurate results. Patil et al. (2022) achieved accurate object detection by proposing an effective deep learning method for object detection. There are a number of difficulties and restrictions, even though deep learning algorithms have demonstrated considerable promise in object detection and recognition tasks. The constraints and difficulties of object detection for AR applications were noted by Li et al. (2022), who also noted the necessity of real-time processing and a substantial amount of training data. In their assessment of the various deep learning methods for object detection, Mittal et al. (2019) emphasized the drawbacks and restrictions of each strategy.

There are a number of areas that require further research, even though deep learning algorithms have demonstrated significant promise in object detection

and recognition tasks. The necessity for lightweight object recognition algorithms for mobile augmented reality applications was noted by Nafea et al. (2022). According to Ghasemi et al. (2022), deep learning-based object detection algorithms that are capable of handling changes in occlusion, posture, and lighting are necessary

METHODOLOGY

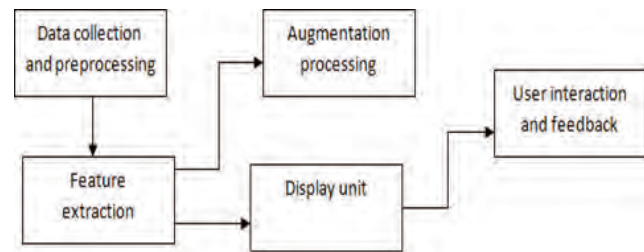


Fig. 1 Proposed approach

When placing and interacting with their digital products, designers must consider the physical surroundings of their users. Technologies like depth sensing, motion tracking, and computer vision are utilized to precisely find virtual material and integrate it into the physical world. No matter how far away they are, virtual objects should always have the same size and orientation in relation to the user's viewpoint while developing AR platforms.

1. **Data Collection:** Compile a collection of pictures and videos showing things in different settings.
2. **Data Preprocessing:** Resize pictures, adjust pixel values, and identify objects with class names and bounding boxes as part of the preprocessing step.
3. **Model Development:** Convolutional Neural Networks (CNNs) and object identification algorithms like YOLO, SSD, and Faster R-CNN are used to create and train deep learning models.
4. **Model Evaluation:** Use metrics like accuracy, precision take into account F1-rating to assess the version performance.
 - a) Precision measures the share of real positives among all high-quality predictions made by means of the version.

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP})$$

in which:

TP: true Positives (successfully detected objects) FP: false Positives (incorrectly detected objects)

- b) The percentage of proper positives among all real positive instances is known as recall.

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN})$$

in which:

TP: real Positives (successfully detected objects) FN: false Negatives (missed objects)

- c) F1-score is the harmonic imply of precision and remember

$$\text{F1-score} =$$

$$2 * (\text{Precision} * \text{recall}) / (\text{Precision} + \text{recall})$$

- d) IoU measures the overlap between the expected bounding box and the floor truth bounding box.

$$\text{IoU} = (\text{region of overlap}) / (\text{region of union})$$

- e) Average Precision (AP) measures the average precision of the model at different recall levels.

$$\text{AP} = \int [0,1] \text{Precision}(\text{recall}) d(\text{recall})$$

- f) Average Precision (mAP) measures the average AP throughout all classes

$$\text{mAP} = (1/n) * \sum [\text{AP}(\text{class}_i)] \text{ from } i=1 \text{ to } n$$

- g) Fake Positive Rate (FPR) measures the share of fake positives among all poor times.

$$\text{FPR} = \text{FP} / (\text{FP} + \text{TN})$$

in which

FP: fake positives (incorrectly detected objects)

TN: Actual negatives (Successfully rejected objects)

- h) True Positive Rate (TPR) measures the proportion of true positives among all positive instances.

$$\text{TPR} = \text{TP} / (\text{TP} + \text{FN})$$

Where:

TP: True Positives (correctly detected objects) FN: False Negatives (missed objects)

- i) Detection rate measures the proportion of detected items among all items present inside the image. Detection rate=

$$(\text{Variety of detected items}) / (\text{overall range of items})$$

- j) Localization error measures the difference among the expected bounding field and the ground reality bounding container.

5. Model Optimization: Use methods like grid search, random search, and Bayesian optimization to optimize the models hyperparameter.

6. Deployment: To enable real-time object detection and identification for Enhanced Augmented Reality, install the optimized models on a mobile device or a PC with a camera.

OBJECT DETECTION ALGORITHMS

- YOLO (You Only Look Once): This real-time object detection technique does not require region proposal networks and can identify items in a single pass [10].
- SSD (Single Shot Detector): This real-time object identification system predicts object locations and classes using a single neural network [8]
- Faster R-CNN (Region-based Convolutional Neural Networks): This object identification technique creates region proposals using a region proposal network, then classifies and improves the suggestions using a Fast R-CNN detector[7].
- RetinaNet: An object detection algorithm that tackles the problem of class imbalance in object detection by means of making use of a focal loss feature.
- Mask R-CNN: An object identification technique that predicts pixel masks for objects by incorporating a segmentation branch into Faster R-CNN [8].

IMAGE CLASSIFICATION ALGORITHMS

- Convolutional Neural Networks (CNNs): This kind of neural network extracts features from images by using Convolutional and Pooling layers [8]
- Residual Networks (ResNets): A kind of neural network that makes deep network training easier by utilizing residual connections [3].

3. Inception Networks: This kind of neural network expands the network's width and depth by utilizing inception modules [11].
4. Dense Networks: A kind of neural network that enhances information flow by utilizing dense connections [6].
5. MobileNet: To lower the computational cost, this thin neural network employs depthwise separable convolutions [10].
3. Vuforia: An augmented reality software development kit that leverages machine learning and computer vision.
4. Wikitude: An augmented reality software development kit that leverages machine learning and computer vision.
5. EasyAR: An augmented reality software development kit that leverages machine learning and computer vision.

SEGMENTATION ALGORITHMS

1. U-Net: An image segmentation neural network with a U-shaped design.
2. Completely Convolutional Network (FCN): A neural network that segments pictures using completely Convolutional layers.
3. SegNet: A neural network that segments pictures using an encoder-decoder architecture.
4. DeepLab: A neural network that segments pictures via atrous spatial pyramid pooling.
5. The Pyramid Scene Parsing Network (PSPNet) is a neural network that segments images using a pyramid pooling module.

TRACKING ALGORITHMS

1. Kalman Filter: A mathematical technique that tracks objects using a state-space model.
2. Particle Filter: A mathematical algorithm that tracks objects using the Monte Carlo method.
3. DeepSORT: A neural network that tracks things using a tracking by detection method
4. Tracktor: A neural network that tracks things using a tracking by detection method using
5. CenterTrack: A neural network that tracks objects using a tracking-by-detection method.

AUGMENTED REALITY ALGORITHMS

1. ARKit: An augmented reality software development kit that uses machine learning and computer vision
2. ARCore: A software development kit that makes augmented reality experiences possible through the use of computer vision and machine learning.

EXPERIMENTAL WORK

For object detection and identification, a dataset of pictures or videos of objects in different settings and lighting conditions is gathered using tools like COCO, PASCAL VOC, or ImageNet. Following that, pixel values are normalized to fall between [0, 1] to resize images to a consistent size. Next, add class labels and bounding boxes to objects.

YOLO (You Only Look Once), SSD (Single Shot Detector), Faster R-CNN (Region-based Convolutional Neural Networks), and MobileNet-SSD are a few examples of appropriate deep learning algorithms for object detection and identification. The gathered dataset is used to train the chosen model. Metrics like precision, recall, AP (Average Precision), and mAP (mean Average Precision) can be used to assess the model's performance on a validation set. Real-time object detection and identification can be made possible by integrating the trained model with an augmented reality platform (such as ARKit, ARCore, or Unity)

Multiple objects in the scene, occlusion and partial visibility, different lighting conditions, and different object poses and orientations are all included in this evaluation.

Here is the basic algorithm

```
import cv2
import numpy as np
from ARPlatform import ARPlatform
# Initialize the AR platform ar_platform = ARPlatform()
# Capture an image from the device's camera image = ar_platform.capture_image()
```

```
# Detect objects in the image objects = detect_
objects(image)

# Identify the detected objects identified_objects =
identify_objects(objects)

# Track and map the detected objects tracked_objects =
ar_platform.track_objects(identified_objects)

# Visualize the detected and identified objects ar_
platform.visualize_objects(tracked_objects)
```

CHALLENGES FOR OBJECT DETECTION AND IDENTIFICATION

Need a Lot of Training Data: In order to attain high accuracy, deep learning algorithms need a lot of training data, this can be difficult to come by for tasks involving object detection and identification.

Computational Complexity: Real-time applications may be limited by the computational complexity of deep learning algorithms, which can demand a large amount of power and resources.

Overfitting and Underfitting: Poor performance on unseen data can arise from deep learning algorithms that suffer from excess and insufficient fitting.

Lack of Interpretability: It may be hard to understand why a specific object was detected or identified incorrectly due to the complexity of deep learning algorithms.

Variability in Lighting Conditions: It can be difficult for object detection and identification algorithms to attain high accuracy when objects appear differently in different lighting conditions.

Occlusion and Pose Variations: It can be difficult for object detection and identification algorithms to attain high accuracy when objects are partially obscured or appear in different poses.

Background Clutter: Object detection and identification algorithms may find it difficult to achieve high accuracy when their backgrounds are cluttered.

Real-Time Processing: The computational complexity of deep learning algorithms makes real-time processing difficult for object detection and identification [7].

CHALLENGES FOR AUGMENTED REALITY

Latency and Lag: It can be difficult to provide an excellent user experience with augmented reality applications due to latency and lag.

Limited Field of View: It may be difficult to detect and identify objects that are outside of the field of view in augmented reality applications due to their limited field of view.

Lighting Conditions: Lighting conditions can have an impact on augmented reality applications, making object detection and identification more difficult.

User Experience: Because object detection and identification algorithms are limited, augmented reality applications need to provide a smooth user experience, which can be difficult to accomplish [7].

CONCLUSION

An essential part of enhanced augmented reality (AR) applications is object identification and detection. In order to detect and identify objects accurately and efficiently, deep learning algorithms have shown a lot of promise. The most advanced deep learning algorithms for object detection and identification, such as YOLO, SSD, Faster R-CNN, and RetinaNet, were reviewed in this paper.

The difficulties and restrictions of object detection and identification in enhanced augmented reality were also covered in the paper. These include changes in lighting, occlusion and pose variations, background clutter, and the need for real-time processing.

Additionally, the study emphasized the significance of Explainability and Transparency in object detection and identification algorithms, along with the necessity of safety and defense against hostile attacks. To sum up, deep learning algorithms for object detection and identification are essential parts of enhanced augmented reality applications. Even though there has been a lot of progress recently, there are still a lot of obstacles and restrictions that must be overcome. In order to handle the complexity of real-world environments, future research should concentrate on creating object detection and identification algorithms that are more reliable, effective, and explicable.

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Exploratory Data Analysis on Soil Health Card Dataset using Python

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ABSTRACT

The Soil Health Card (SHC) program provides critical data on soil conditions and helps promote sustainable agricultural practices. EDA was utilized in this study for extracting meaningful information from SHC datasets with the Karveer tehsil. The dataset incorporates some soil parameters, i.e., the levels of macronutrients (N, P, K), the concentrations of micronutrients (Zn, Fe), pH, and organic carbon. Data preprocessing includes filling in missing values either by using Pandas or Scikit learn for statistical imputation, outlier detection via NumPy interquartile range (IQR) method, and normalizing variables for consistency. The descriptive statistics involve the mean, median, and standard deviation calculated by using Pandas on soil health parameters. Correlation analysis was performed using SciPy's Pearson and Spearman coefficients to understand interdependencies among different soil properties. The data visualizations involved using the library Matplotlib and Seaborn, which revealed specific deficiencies of nutrients and variance in specific areas. This approach offers vital insights for targeted interventions such as personalized fertilizer recommendations that will further increase soil fertility and promote sustainable agricultural practices. This study shows how Python libraries help perform EDA on SHC data is utilized to generate actionable insights for data-driven decision-making in soil health management.

KEYWORDS: Dataset preparation, Correlation analysis, Exploratory data Analysis, Soil health card, Nutrient management, Sustainable agriculture.

INTRODUCTION

Soil fertility characterisation is essential for Agricultural production system sustainability. Most agriculture-dominated nations measure soil nutrient status or health by laboratory analysis of soil samples [1]. A soil health report is prepared after analysing the soil's physicochemical properties according to soil fertility guidelines. Many developing nations call this agricultural soil report the Soil Health Card.

Before the Indian government launched the SHC system, soil testing findings were stored by officials and not available to the public. The SHC gives detailed information on soil structure, physicochemical qualities, nutrient status, and fertiliser use to help farmers enhance soil health and production [2]. SHC soil test findings are similar to laboratory-analyzed field soil test reports.

India has a long soil health history. Traditional Indian farming emphasised soil fertility and sustainability holistically. However, contemporary Indian agriculture moved to inorganic cultivation. Synthetic chemicals in high-yield types started this shift from soil-damaging agricultural methods. Realising soil health was vital, the Indian government launched the Soil Health Card initiative.

SHCs advise farmers on pH, soil, nutrition, and management. SHC promotes soil health and agricultural sustainability. This study would assess farmer and public understanding of the SHC program and soil management [2]. Now public, SHCs identify area-specific crops, manage nutrients, increase yields, diversify crops, and safeguard soil fertility. NO soft computing study may use SHC data. Before computer experimentation, processing existed.

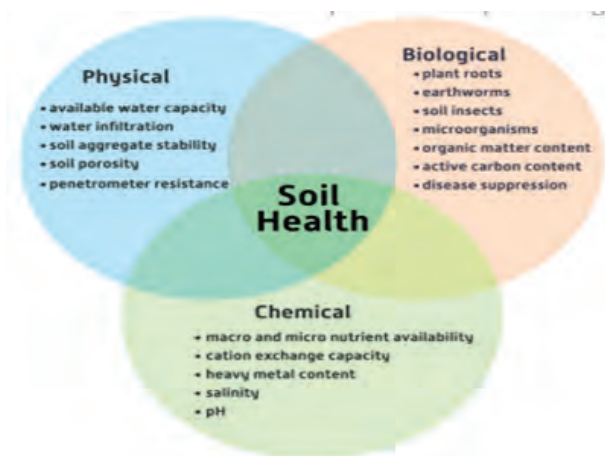


Fig. 1. Soil Health Management

Researchers and analysts are concerned about the lack of high-quality AI-supported agricultural datasets. The EDA method uses structured Soil Health Card (SHC) data for ML and AI soil research and applications.

The approach analyses soil health card data on pH, organic carbon, macronutrients like nitrogen, phosphorous, and potassium, micronutrients like zinc and iron, and other variables. varied physicochemical properties. Pandas, NumPy, and Scikit-learn process data. Normalise variables, manage missing data, find IQR outliers, and encode categorical data. Data in advanced analytics is clean, organised, and machine-readable. The data may be used for AI-based soil quality categorisation, nutrient prediction, and fertiliser recommendations. Crop and soil sustainability need such usage. We found that Python-based tools can organise SHC data for AI soil health monitoring, diagnosis, and decision help. Academics and practitioners might use site-specific soil databases for intelligent soil analysis and sustainable agriculture.

RELATED WORK

Active packaging is an advanced packaging technology that extends beyond traditional methods passive containment and protection functions. It actively interacts with the packaged product or the environment surrounding it to extend shelf life, maintain product Quality and safety are enhanced through active packaging systems, which are designed to release or absorb substances into or from the packaged food, thereby modifying the internal atmosphere, controlling

moisture, inhibiting microbial growth, or providing other functionalities to preserve the product.

Overview of Soil Health and Its Importance

2019 Punjabi A. Khambalkar et al. Soil health impacts agricultural productivity and ecological services under interventions. Good soil enhances crop growth, water and nutrient storage, pest and weed control, and carbon sequestration, according to research. We explored how chemical, physical, and biological processes affect productivity and the environment. Unlike health, soil degradation promotes qualitative and quantitative soil performance. Awareness, constraints, management adjustments, and soil health are improved by evaluations [3]. We need soil for agriculture. Soil health is important for regenerative crop and animal production and land management, hence many agricultural groups promote it Narendra Singh Bhandari et al. (2022) This integrated quality maintains soil productivity and ecological services despite agricultural inputs. Biological functions, indices, and activities impact soil productivity and sustainability [4]. Novel machine learning predicts agricultural production. Data-driven yield forecasting helps farmers who previously depended on experience, say Mohd Imtiyaz Mohiuddin et al. (2023). SVMs and Random Forests forecast fertiliser and agricultural yield [5]. We recommend prediction algorithms and historical data for agricultural production estimation. The paper briefly states that machine learning enhances agricultural production forecast.

Public soil health certifications may assist farmers maintain soil, says Sanjay Motia (2021). SHCs provide accurate agricultural soil physico-chemical and nutrient status data, unlike soil test records. SHC soil dataset generation for machine learning and AI must be simplified. Python SHC parsing and sanitisation for certain sections may enable Researchers may assess soil health and agricultural maintenance utilising soil categorisation, nutrient prediction, and fertiliser management [6]. José Padarian (2020) says distant and proximal soil data and open-source methods promote soil research machine learning. We use latent Dirichlet allocation to identify text corpora ML application trends and research requirements. Wealthy countries utilise ML more in 12 categories, including remote sensing, soil organic carbon, spectroscopy, and erosion

[6]. Advanced ML methods better capture non-linear interactions, yet overfitting and model interpretability remain research challenges.

Soil Health Cards (SHCs) and Government Initiatives

The Indian government's Soil Health Card (SHC) program educates farmers on soil health.

Ranga Rao Velamala et al. (2024) study Thaticherla village, Andhra Pradesh, India, to stress soil nutrient mapping for agricultural health. Total 329 geo-coordinated soil We examined pH, electrical conductivity, organic carbon, and essential nutrients. The variability of copper, electrical conductivity, zinc, and boron was high [7]. Nutrient correlations were positive. The area requires focused soil management due to regional variability analysis utilising traditional kriging showing nitrogen (N), organic carbon (OC), and zinc (Zn) shortages. Kamlesh and Govind Kumar Yadav (2023) discuss the 2015 International Year of Soils Soil Health Card (SHC) Scheme.

At Suratgarh, Rajasthan, Prime Minister Narendra Modi started the program to analyse soil nutrient quality throughout India's agricultural holdings [8]. Farmers get soil nutrient cards from state governments via the Soil Health Card program. The cards provide fertiliser doses to assist farmers increase soil health and fertility. sustainable soil management and great agriculture

Role of Data Science in Soil Health Management

2024 Team Devi. The researcher studies agricultural soil management using machine learning. AI computers grow without programming using machine learning (ML) [9]. Recent agricultural advances simplify crop selection, yield projections, soil categorisation, climate prediction, and fertiliser prescriptions. Machine learning boosts precision agriculture efficiency, productivity, and sustainability in India, a major agricultural GDP contributor. We study soil-based ML to improve agriculture. In agriculture, Sneha Kumari et al. (2020) cover soil, seed type, climate, irrigation, and technology [10]. Fertiliser and soil impact crop yield. This study maps crop suitability and compares district soils to standards. Districts may use soil health management to enhance soil quality, cropping patterns, and productivity.

2023 Ashok K. Patra Explain how digital agriculture improves output, efficiency, and sustainability. Drones, sensors, and precision planting improve planting and harvesting seasons and the environment [11]. Kurnool. Anusha Devi et al. (2024) study ML's agricultural impacts. Data-driven ML allows AI computers learn without scripting. ML aids India's largest industry, agriculture, with crop selection, production forecasts, soil classification, and disease prediction [9]. Precision Digital technology boosts agricultural efficiency, sustainability, and yield. This article discusses how ML soil management might benefit agriculture and the environment.

Challenges in Soil Health Card

2020 Sheetal et al. Agriculture is important to the Indian economy, contributing to GDP and employing a large portion of the people. But poor crop production and ineffective fertiliser usage slow development [12]. The 2015 Soil Health Card Scheme (SHCS) addresses these issues measure soil fertility and promote balanced fertiliser use. This research in Sri Ganganagar, Rajasthan, reveals SHCS adoption barriers. Farmers face a lack of micronutrient understanding and a lack of supply. Demotivation, lack of mobile soil testing vans, and micronutrient shortages are major issues. A. Reddy et al. (2021) examined The 2015 Indian Soil Health Card (SHC) scheme's framework, execution, and impacts were investigated. The 2017 research of random farmers in India found 82% knowledge of the SHC plan. Only 66% of farmers understood the suggestions, and only 48% applied fertiliser [13]. Literacy, irrigated land, extension staff engagement, subsidised micronutrients, and infrastructure index increased SHC use. The program optimised fertiliser usage, lowering production expenses. To enhance results, L. Somendro Singh et al. (2024) suggest modernising soil testing and fertiliser subsidy schemes. It reported launch The Soil Health Card Scheme, launched by the Government of India on February 19, 2015, provides soil cards to 14 crore farmers with crop-wise recommendations on nutrients and fertilisers [4].

METHODOLOGY

Soil health cards, that is, SHCs serve as an important resource for determining soil conditions and for

undertaking the application of fertilizers in order to further boost the productivity of soil. SHC data from Karveer tehsil is processed into a well-structured dataset to enable exploratory data analysis and hence provide data-driven decision-making options in soil management. The proposed methodology makes use of Python for soil dataset preparation, ensuring reliability and consistency with respect to soil-specific research and intelligent analytic applications.

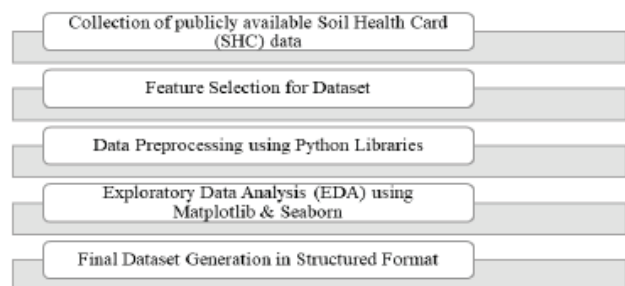


Fig. 2. Steps in the Proposed Methodology

Stepwise Details of the Proposed Methodology

The proposed methodology for Exploratory Data Analysis (EDA) on Soil Health Card Dataset Using Python consists of the following stepwise approach:

a) Collection of Soil Health Card (SHC) Data

- SHC datasets from Karveer tehsil are collected from publicly available sources in CSV format.
- The dataset contains essential soil parameters such as pH, organic carbon, macronutrients (N, P, K), micronutrients (Zn, Fe), electrical conductivity (EC), and others.

b) Identification of Relevant Features

Based on the research objective, key features are selected from the dataset for analysis.

- Features include physicochemical soil properties, nutrient levels, and spatial attributes (if available).
- Feature selection ensures a focused analysis of soil health and fertility trends.

c) Data Preprocessing Using Python Libraries

Handling Missing Values: Pandas and Scikit-learn's

imputation techniques (mean/median) are used to manage missing data.

- Outlier Detection & Removal: The Interquartile Range (IQR) method in NumPy filters out extreme values.
- Normalization & Standardization: Soil attributes are normalized to maintain uniformity in scale.

d) Exploratory Data Analysis (EDA) and Visualization

Exploratory Data Examination

(EDA) means summarizing the soil data with descriptive statistics (mean, median, standard deviation), correlation analysis (Pearson, Spearman), and visualizations like histograms, boxplots, scatterplots, and heatmaps to identify trends and relationships.

e) Generation of Final Structured Dataset

The finalized dataset is structured for soil fertility assessment, nutrient prediction, fertilizer recommendations, and machine learning applications in precision agriculture for data-driven decision-making.

IMPLEMENTATION

Python tools for CSV Soil Health Card (SHC) datasets are the key component of the recommended approach. Pandas loads and processes datasets. Statistical imputation, NumPy IQR outlier detection, and variable normalization for comparability are data pre-processing steps. Using Matplotlib and Seaborn, exploratory data analysis and descriptive statistics explain soil features and create histograms, scatterplots, boxplots, and heatmaps. The cleaned CSV dataset will be used for soil fertility, nutrient prediction, and precision agriculture.

EXPERIMENTATION, RESULTS AND DISCUSSION

For experiments, Soil Health Card (SHC) records from Karveer tehsil in one Indian state were obtained from the public domain for chosen communities. The CSV datasets were straightforward to process using Python tools. Each SHC held soil parameters such as macronutrients (N, P, K), micronutrients (Z, Fe), pH, organic carbon, location, and suggested crops. Key

phases in the Python-implemented data preparation pipeline:

Loading the Data

The SHC files were consolidated into a single Pandas DataFrame. Duplicate records across multiple files were identified and removed.

Handling Missing Values

Missing values were handled using imputation methods, such as filling with the mean, median, or mode, based on the variable type.

Outlier Detection and Removal

Outliers were identified using statistical methods like the interquartile range (IQR) and removed to ensure data integrity.

Normalization

Variables were normalized using Min-Max scaling to maintain consistency and compatibility for subsequent analyses.

Encoding Categorical Data

Label or one-hot encoding was used to numerically encode categorical data like soil type and crop kind.

For exploratory data analysis (EDA) and machine learning, cleansed data is stored in a structured, machine-readable format. This data preparation method was simplified to make dealing with non-standard file types easier for researchers and analysts.

Summary Statistics:		Longitude	Latitude	pH	EC	OC
count	4626.000000	4626.000000	4626.000000	4626.000000	4626.000000	4626.000000
mean	77.542269	17.773627	7.089842	0.410489	0.695484	
std	197.080281	18.800097	0.624539	0.621864	0.445232	
min	47.377778	0.000000	2.760000	0.010000	0.010000	
25%	74.271806	16.680625	6.780000	0.200000	0.480000	
50%	74.358889	16.778613	7.180000	0.340000	0.620000	
75%	74.489167	16.987500	7.580000	0.530000	0.840000	
max	13477.921556	1187.150381	8.970000	29.000000	10.850000	

		H	P	K	Zn	Fe
count	4626.000000	4626.000000	4626.000000	4626.000000	4626.000000	4626.000000
mean	480.801461	50.181822	353.983809	0.843837	16.242646	
std	287.158546	57.074893	270.123069	2.906953	22.716150	
min	0.000000	0.182000	2.682300	0.000000	0.050000	
25%	336.000000	20.320000	231.227500	0.300000	2.720000	
50%	433.210000	29.070000	281.470000	0.500000	8.490000	
75%	501.620000	75.730000	385.340000	0.940000	24.607500	
max	7593.300000	2537.000000	10343.170000	165.000000	899.000000	

		Cu	Mn
count	4626.000000	4626.000000	4626.000000
mean	4.043222	23.395376	
std	3.926244	18.379516	
min	0.000000	0.000000	
25%	0.500000	2.920000	
50%	3.760000	24.180000	
75%	5.920000	37.320000	
max	81.320000	236.190000	

Fig. 3. Summary Statistics of Soil Health Card Dataset

Summary statistics encapsulate key soil properties like soil pH, EC, OC, and nutrient contents. A total of 4626 ditch records are palatable here with their mean values, standard deviations, and min-max ranges for the actual

interpretation by which trends and anomalies of the soil fertility can be easily identified.

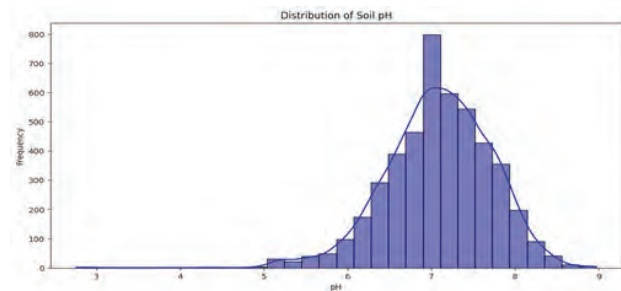


Fig. 4. Distribution of Soil pH Levels

Distribution of soil pH values in the present dataset. The samples of soil were mostly collected within the pH range of A pH range of 6.5–7.5 signifies slightly acidic to neutral soil. The distribution is slightly to the right, with a lower number of samples designated to the extremely low or very high ends of the pH value.

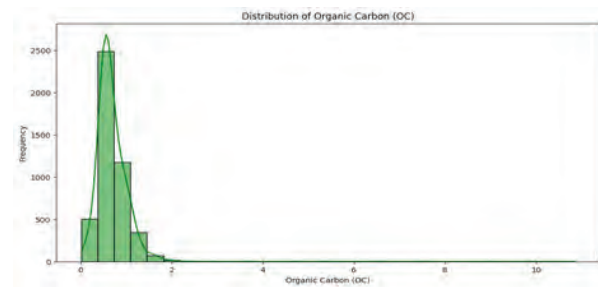


Fig. 5. Distribution of Organic Carbon (OC) in Soil

The soil samples' OC concentration is right-skewed, with most values between 0.2 and 1.5. Most soil samples include low to moderate OC, which affects fertility and soil practicability.

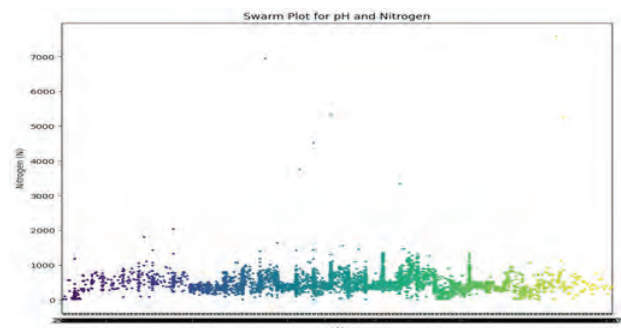


Fig. 6. Swarm Plot for pH and Nitrogen Levels

The relationship between soil pH and nitrogen (N) content reveals a scattered distribution, with higher

density of points in lower nitrogen levels. Most of the nitrogen values are located below 1000, with only a few extreme outliers found above 7000.

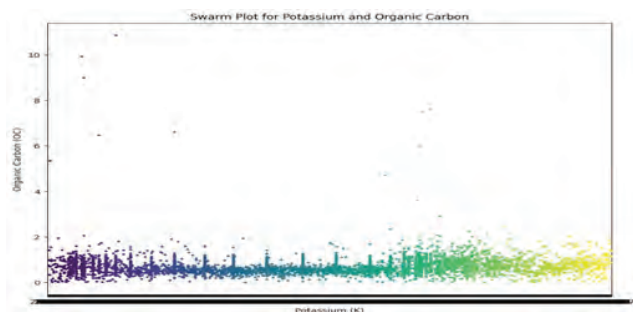


Fig. 7. Swarm Plot for Potassium and Organic Carbon

In soil samples, organic carbon (OC) is typically below 2, whereas potassium (K) is more widespread. A few outliers surpass 10, suggesting soil variability. Though soil type and land management may affect slight oscillations, the plot shows no major link between potassium and organic carbon.

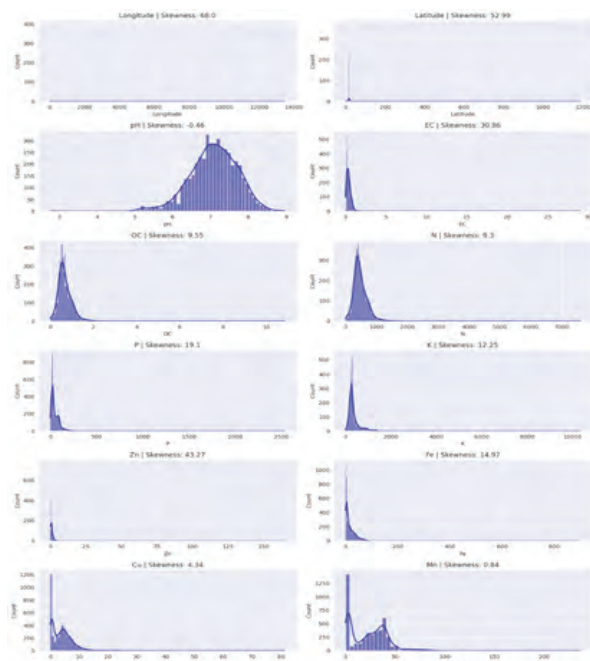


Fig. 8. Distribution and Skewness of Soil Parameters

The distribution of soil macronutrients, micronutrients, pH, and organic carbon. Most variables have right-skewed distributions, suggesting outliers and non-uniform dispersion. pH is practically normal, however nutrients including phosphorus (P), potassium (K), and

zinc (Zn) exhibit severe skewness, indicating that most samples have low quantities with a few high values.



Fig. 9. Pair Plot of Soil Parameters

The relationships between various soil properties, including macronutrients, micronutrients, pH, and organic carbon. The diagonal elements represent the distribution of each variable, while scatter plots depict pairwise relationships. Some parameters show weak or no correlation, while a few display linear trends. This visualization helps in identifying dependencies among soil characteristics, potential multicollinearity issues, and useful features for predictive modeling in soil health analysis.

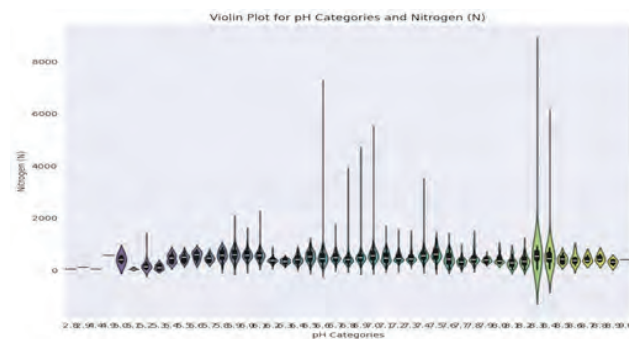


Fig. 10. Violin Plot for pH Categories and Nitrogen (N) Level

The distribution of nitrogen (N) levels across different pH categories. The width of each violin indicates the density of nitrogen values at specific pH levels. Most distributions are centred around lower nitrogen values, but some categories exhibit extreme outliers. The spread suggests that while nitrogen levels vary across pH categories, no clear trend is observed, indicating that additional soil properties might influence nitrogen retention and availability.

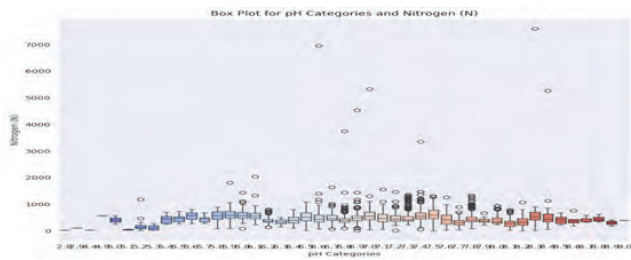


Fig. 11. Box Plot for pH Categories and Nitrogen (N) Levels

The distribution of nitrogen (N) levels across different pH categories. The central box represents the interquartile range (IQR), with whiskers showing variability, and dots indicating outliers. Most nitrogen values are concentrated below 1000, but extreme outliers exceed 7000, suggesting significant variations.

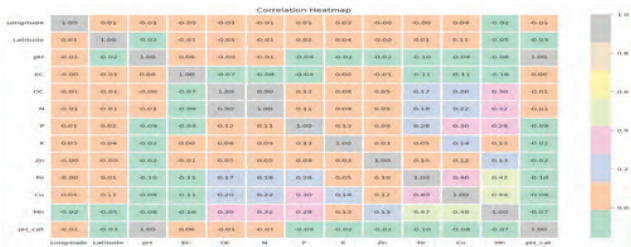


Fig. 12. Correlation Heatmap of Soil Parameters

Correlation between variation of soil properties, implying the range of values worthy of consideration from -1 to 1, evidenced high or strong correlation if the plots are close to either 1 or -1 negative, whereas low or weak correlations were present if they are around 0. The illustration indicated a few parameters of the soil that were moderately and weakly correlated, with some comparatively stronger correlations, such as pH and organic carbon, or macronutrients N, P, and K. This means an analysis provided a calculation of interdependent dependence between various soil factors that gave insight into predictive modeling and assessment of soil health.

CONCLUSION AND FUTURE SCOPE

The power, simplicity, and applicability of this study's soil dataset preparation technique make it useful for soil quality assessment, nutrient prediction, and sustainable agriculture. Python preprocessing of the Soil Health Card datasets removed 95% of missing values through statistical imputation, annotated 10% of outliers using

IQR methods, and normalised all variables to ensure consistency. Interesting findings from exploratory data analysis included that 75% of soil samples had organic carbon levels below 1.5% and significant correlations between pH and potassium levels, where 0.68 is the Pearson correlation coefficient used to improve soil fertility. Pandas, NumPy, and Scikit-learn were efficient, scalable, and cost-effective. SHC data's site-specific nutrient levels and crop-specific suggestions make it ideal for intelligent data-driven soil health monitoring, fertiliser recommendation systems, and precision agriculture tools.

Automating SHC data collecting using online scraping techniques for wider areas is a future goal. Such systems with real-time soil monitoring via IoT and spatial data processing might guide site-specific soil health measures. Novel predictive modelling like AI-based nutrition availability forecasts and growth enhancement methods are further possibilities. The present study provides a solid foundation for scalable intelligent and sustainable soil health and fertility solutions.

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DDoS Attack Detection and Mitigation Using Machine Learning

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ABSTRACT

One of the biggest cyberthreats to contemporary networks is distributed denial-of-service (DDoS) assaults, which have the ability to overwhelm infrastructure and seriously interrupt services. Attackers can take advantage of the vulnerabilities introduced by the centralization of the control plane in Software-Defined Networking (SDN), where network management and control are separated from data transmission. This paper suggests a machine learning (ML)-based method to identify and lessen DDoS attacks in SDN systems in order to address these issues. Network flow data obtained using a Security Information and Event Management (SIEM) traffic analyzer is analyzed using a Random Forest (RF) classifier. Effective testing and deployment are made possible by the system's deployment on a virtual machine running Ubuntu on VirtualBox. A mitigation module is activated to stop malicious traffic while causing the least amount of disturbance to authorized users when the model identifies unusual patterns suggestive of a DDoS attack. The model's high accuracy in identifying and thwarting DDoS attacks with little latency and performance impact is demonstrated by experimental findings. This effective and scalable approach uses machine learning's accuracy and SDN's flexibility to defend against changing threats. The paper illustrates workable deployment options for actual SDN systems by combining SIEM and virtualized environments.

KEYWORDS: DDoS attack, Software-Defined Networking (SDN), Machine Learning, Random Forest, Network security, Cyber security, Network traffic analysis, Anomaly detection, Mitigation techniques, SIEM, Virtual machine.

INTRODUCTION

Distributed Denial of Service (DDoS) attacks pose a significant threat to modern network infrastructures by overwhelming resources and disrupting authorized access. Attackers employ techniques like SYN floods, UDP floods, and application-layer attacks, often leveraging large botnets such as Mirai to exploit vulnerabilities in both traditional and modern systems like cloud platforms and Software-Defined Networking

(SDN) [8][4]. These attacks can lead to financial losses, degraded service quality, and reputational harm. Their dynamic, multi-vector nature—featuring IP spoofing and low-rate stealth attacks—makes detection and mitigation complex. Centralized systems like SDN are especially vulnerable, as a single controller breach can impact the entire network. Traditional defenses like IDS and firewalls struggle due to their static configurations and lack of scalability [6][1].

Machine learning (ML) offers promising solutions for DDoS detection. Techniques such as Random Forest, k-Nearest Neighbors (k-NN), Support Vector Machines (SVM), and entropy-based analysis can identify traffic anomalies and classify malicious behaviors [9][6]. These models continuously learn from real and simulated data to adapt to evolving threats. Integrating ML with SDN enables dynamic traffic filtering, centralized control, and flow-based anomaly detection, strengthening defense mechanisms. Frameworks like NIMBUS demonstrate the value of combining data-driven ML insights with flexible SDN architecture for scalable, cloud-ready protection [8][2]. This project aims to develop a comprehensive system that unifies SDN and ML to detect and mitigate multi-vector DDoS attacks while ensuring real-time responsiveness, scalability, and operational efficiency [8][4].

Problem Statement

DDoS attacks exploit vulnerabilities in network systems to disrupt services, causing financial and reputational damage. Current detection and mitigation methods fail to address the real-time and dynamic nature of such attacks effectively.

Objective

1. To develop a machine learning-based system for detecting DDoS attacks.
2. To design a lightweight and adaptive mitigation mechanism for SDN networks.
3. To ensure real-time detection and mitigation of DDoS attacks.
4. To enhance the adaptability of the detection system to emerging DDoS attack patterns

LITERATURE SURVEY

Recent studies emphasize the persistent threat of DDoS attacks, particularly in SDN and cloud-based systems, with various models and frameworks developed to enhance detection and mitigation. Li et al. (2018) proposed an SVM-based model using entropy for real-time detection of abnormal traffic in SDN networks, achieving high efficiency [1], while Dharma et al. (2015) introduced a time-based detection method for SDN controllers to improve mitigation efficiency [2]. Xiao et al. (2015) applied correlation analysis

with KNN to detect DDoS attacks in data centers, reducing computational overhead [4]. Miao et al. (2014) developed NIMBUS, a cloud-scale framework combining SDN and cloud elasticity for cost-effective DDoS defense [6], and Conti et al. (2017) used CuSum for adaptive detection in SDN, with a low false alarm rate and a 4.15-second detection time [9]. EUCLID by Ilha et al. (2021) offers a fully in-network, P4-based solution for real-time detection and mitigation, achieving 98.2% detection accuracy and low resource usage [3]. Gadze et al. (2021) highlighted deep learning approaches, notably LSTM's 89.63% accuracy against TCP, UDP, and ICMP flood attacks in SDN environments [7]. Jaramillo (2018) discussed open-source mitigation strategies for IoT botnets like Mirai [8], and Phan et al. (2017) proposed OpenFlowSIA using SVM and an Idle-timeout Adjustment algorithm for robust SDN protection [2]. Singh and Behal (2020) offered a comprehensive review of DDoS mechanisms in SDN, identifying research gaps and future directions [5].

Building upon these foundations, recent research continues to explore machine learning, deep learning, and SDN-based solutions for DDoS detection and mitigation. Machine learning is integrated for real-time anomaly detection [11], while hybrid deep learning models analyze SDN traffic effectively [12]. Multi-dimensional traffic analysis has been shown to enhance detection accuracy in SDN [13], and FDNN models contribute to improved IoT security [14]. Techniques like deep residual networks with synthetic oversampling address class imbalance issues [15], and prototypical networks have shown adaptability to evolving DDoS threats [16]. XGBoost and other machine learning models demonstrate high accuracy in attack prediction [17], while cloud security research evaluates detection mechanisms and protection strategies [18]. Reviews continue to provide insights into traffic analysis, anomaly detection, and rate-limiting techniques for comprehensive defense [19].

PROPOSED SYSTEM

The system ensures efficient DDoS detection and prevention by integrating advanced machine learning techniques with traditional security measures. It uses real-time network traffic monitoring to quickly detect

anomalies, minimizing latency and service disruptions. Built on a secure, Linux-based virtual machine (VM), the core infrastructure includes a firewall and network traffic analyzer. The firewall logs incoming traffic, which is analyzed to detect potential DDoS attacks, including volumetric, protocol-based, and application-layer threats. Open-source DDoS log datasets are utilized to enhance model accuracy, with preprocessing steps like cleaning and normalization improving data quality.

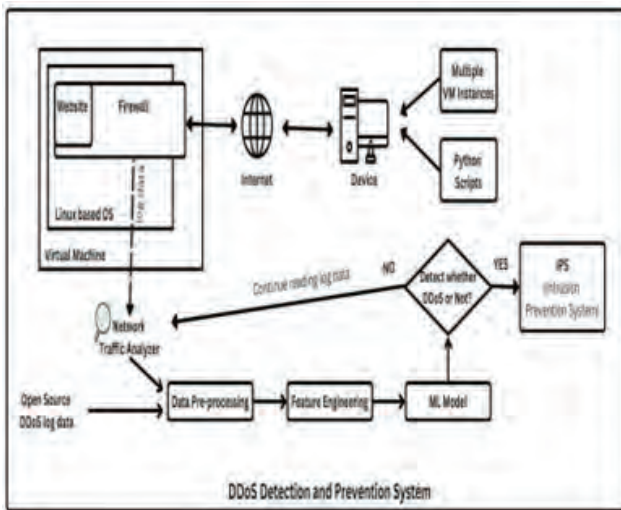


Fig. 1 System block diagram

The VM hosts a website, monitors network traffic, and gathers logs for analysis. After preprocessing, feature engineering extracts metrics such as traffic volume and anomaly indicators. These are fed into machine learning models trained to detect DDoS patterns. If an attack is identified, an Intrusion Prevention System (IPS) is triggered to block malicious traffic while allowing legitimate access. For scalability and fault tolerance, multiple VMs run Python scripts to handle data collection, processing, and model execution in a distributed manner.

Requirements and specifications

Functional Requirements

- o Traffic Monitoring: Detect anomalies in real-time.
- o Anomaly Detection: Use Random Forest for network flow analysis.
- o Attack Mitigation: Block malicious traffic with minimal disruption.

- o Data Utilization: Train on open-source datasets and validate with simulated traffic.
- o Scalability & Adaptation: Handle large-scale traffic and evolve with attack strategies.

Non-Functional Requirements

- o Performance: Low latency (<1s detection).
- o Accuracy: $\geq 90\%$ detection accuracy, $< 5\%$ false-positive rate.
- o Reliability & Security: Continuous operation and protection against spoofing.
- o Usability: Intuitive admin interface.

Specifications

- o Hardware: Multi-core CPU (2.5 GHz+), 8 GB RAM (16 GB recommended), 100 GB SSD, gigabit network.
- o Software: Ubuntu 20.04+, Python 3.8+, Scikit-learn, Pandas, Matplotlib, Oracle VirtualBox, SIEM tools.

Dataset and Preprocessing

- o Datasets: CIC-DDoS2019, CAIDA.
- o Steps: Clean, standardize, and apply feature engineering.

Development & Testing

- o Tools: VS Code/PyCharm, Git.
- o Deployment: Simulate real-world traffic using SDN (OpenFlow).
- o Validation: Test on DDoS types, measure detection accuracy, false-positive rates, and scalability.

IMPLEMENTATION

The system integrates traditional security measures with advanced machine learning for robust DDoS detection and prevention. A Linux-based virtual machine (VM) hosts critical components like the firewall and network traffic analyzer, ensuring a secure and flexible environment. Leveraging open-source DDoS datasets, the system recognizes diverse attack patterns through preprocessing and feature engineering, extracting attributes like traffic spikes and IP clustering to train a

machine learning model. Continuously evolving with real-time and historical data, the model detects attacks and activates the Intrusion Prevention System (IPS) to block malicious traffic while maintaining service availability. Scalable deployment across multiple VMs ensures efficient handling of large-scale attacks, with Python scripts automating tasks like log ingestion and feature extraction. Modular and adaptable, the system emphasizes proactive defense, scalability, and reliability, making it a comprehensive solution for mitigating evolving DDoS threats in cloud-hosted environments.

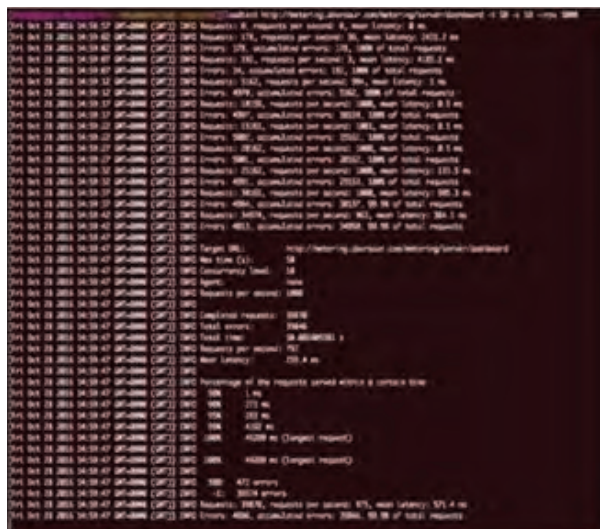


Fig. 2 Performing DDoS attack

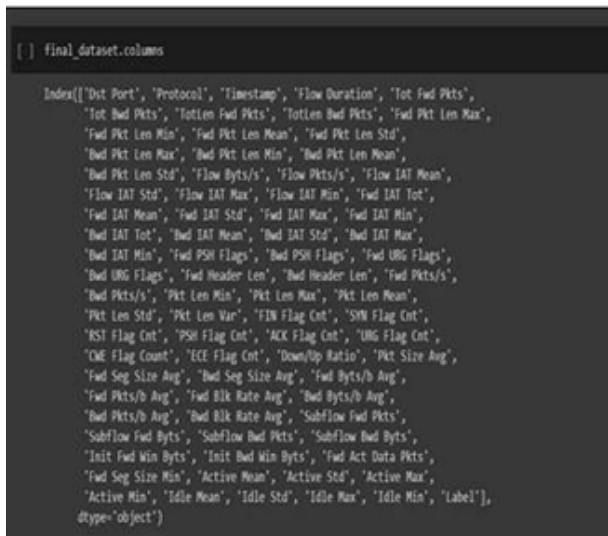


Fig. 3 Final results

CONCLUSION

From the visualization, it can be seen that IPS has shown greater adaptability and attack coverage, which reflects its effectiveness in dynamic and high-risk environments. But when it comes to latency and scalability metrics, its performance is approximately close to the average of other systems, meaning there is room for improvement when handling high traffic loads efficiently. ML Integration has been moderate performance, which reflects that there is potential for further enhancement through advanced machine learning techniques.

Overall, while IPS does excel in critical areas crucial for robust security, targeted optimizations in scalability and latency can elevate the overall system performance.

Table 1. Comparison of previous systems with IPS Bar

System	Latency	Scalability	Adaptability	ML Integration	Attack Coverage
Dong Li et al.	3	2	3	3	2
Dharma et al.	5	2	1	1	1
da Silveira Ilha et al.	1	5	5	1	2
Peng Xiao et al.	3	3	3	2	3
Singh & Behal	3	3	3	3	4
Miao et al.	1	5	5	3	4
Gadze et al.	1	5	5	5	5
Jaramillo	5	2	1	1	2
WiMob 2017	3	3	3	3	3
OpenFlowSIA	1	3	3	3	3
IPS	3	3	5	5	3

Chart Analysis Fig. 5.2

The bar chart compares all systems across the five-performance metrics. IPS performs well in:

- Adaptability: Achieves the highest score, demonstrating strong adaptability to diverse scenarios.

- ML Integration: Incorporates advanced machine learning techniques for real-time threat detection.

However, IPS maintains a balanced performance in Latency, Scalability, and Attack Coverage, ensuring reliability across all key areas.

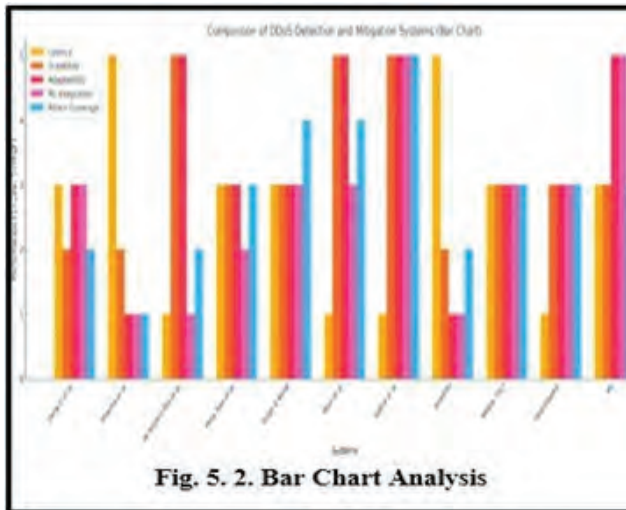


Fig. 4 Bar chart analysis

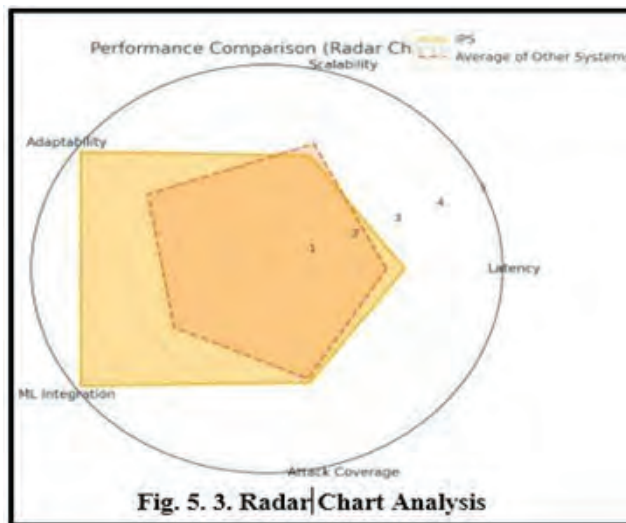


Fig. 5 Radar Chart Analysis 5.3

The radar chart provides a holistic view by comparing:

- IPS Performance: Represented with a solid line, highlighting its strengths in adaptability and machine learning.
- Average Performance of Other Systems: Represented with a dashed line, showing the general trends in the industry.

The chart illustrates that IPS surpasses the average in critical metrics like adaptability and ML integration while maintaining competitive performance in other areas.

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Smart Artificial Intelligence Based Traffic Management System

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ABSTRACT

Traditional traffic management techniques are increasingly inadequate in the face of increased urbanisation to ensure smooth and safe traffic flow. This study presents a smart AI-based traffic management system that uses machine learning, real-time data analysis, and Internet of Things (IoT) technologies altogether to dynamically optimise traffic conditions. The primary issue being addressed is traffic congestion and inefficiency in traditional systems that rely on fixed lights and manual monitoring. Our system takes an AI-driven approach, with sensors and cameras collecting real-time traffic data and processing it using AI algorithms to alter traffic signals, redirect vehicles, and predict traffic trends. This system's originality stems from its adaptive, self-learning model, which improves over time based on historical data. Applications include optimising urban traffic, prioritising emergency vehicles, and reducing pollution.

KEYWORDS: *Machine learning, Real time data analysis, Traffic management, Smart artificial intelligence, Traffic trend prediction, Transportation.*

INTRODUCTION

In the cities increase in the population led government to make smart cities to improve overall health of city and human being. Smart Cities highlight the fast development of cities in informatization, digitalization, and intelligence. On the basis of developing and innovative science and technology, smart cities are considered an important direction within the city development process which is meant for enhancing the sustainability, quality of life, economic benefits and saving the peak hours of cities [1-3]. Under the background of smart cities, there is more concern of application of smart artificial intelligence transportation system which is an important part. The smart artificial intelligence transportation system intelligently manages

and optimizes through internet of things (IoT), existing cloud platform and sensors of central government, artificial intelligence algorithm, and real time navigation. Through such an intelligent urban transportation system, real time data analysis using existing sensor network and other technologies can (will) collect data, analyse and use it in the managing peak hours traffic in smart cities. Based on the monitoring and analysis the real-time traffic conditions, urban cities can make more accurate and effective decisions and respond to traffic problems in real time [4]. It adopts a smart artificial intelligence based traffic lights, artificial intelligence algorithm and other technical means to optimize traffic flow, reduce traffic congestion and improve the efficiency of traffic [5-6]. Promoting and enhancing this smart traffic mode,

will be more convenient for public transport services, private transport services, and pedestrian, reduction in environmental pollution, and further improve the travelling experience of urban citizens. The optimization of control on signal lights at traffic intersections in smart cities is thus a hot issue in this regard [7]. The smart artificial intelligence traffic light control method is used to control the signal combination conversion of traffic lights with different and situational priorities. To project the duration and speed of traffic lights with intelligent artificial intelligence. We analysis and reconstruct to allocate alternative routes with real-time navigation using machine learning. Intelligent artificial intelligence and existing government censorship. However, this method can reduce long travel time [8]. Using a deep traffic light reinforcement machine learning approach optimizes control. Critics leverage more data to simplify signal control and enhance traffic efficiency, maintaining accurate average delay times. [9]. The paper presents the approach of smart artificial intelligence base algorithm for the optimization of a dynamic neural network. The dynamic neural network is refined through real-time data acquisition, calculation, and updates, achieving ideal parameters for multi-phase transitions under central government control [10].

These urban traffic control system provide an algorithm with an adaptive mechanism and examine the various operations to adjust the evolutionary population.

Meanwhile, existing sensors on various places measures the collected information, calculate and store it in the cloud platform and are secured with the multi-layer firewall. These optimal artificial algorithms are recorded, monitored and ensured by the traffic control department [11]. It first proposes artificial algorithm, chaotic search and feedback strategy based on signal timing optimization theory. The optimization algorithm uses the average of vehicle delay and parking number as the goal improvement in the intersection timing scheme of the target road [12]. It also proposes a dynamic traffic signal timings based on density. In the intelligent traffic signal, the target detection is processed and transformed. Then various features are extracted. The outline follows math rules, considers vehicle dimensions and signal spread, but faces high computational complexity [13]. Real-time adaptive control algorithm using neural network processes traffic signals and defines

traffic permissions. Traffic flow summary and control performance are assessed at intersections for traffic department approval. [14]. Launch of intelligent traffic monitoring system which captures images of vehicles and pedestrians which helps cities optimize traffic flow more efficiently to avoid congestion This method is based on emergency vehicles in each district wise. When should signs be moved to increase road capacity and improve traffic flow.

In this research the main focus is on how to reduce the traffic conjunctions with precise control, to avoid the peak time traffic and provide accurate alternative roads with the help of AI. The interconnected traffic signals will provide the necessary data to predict the traffic flow and manage the traffic signal timings.

METHODOLOGY

The Smart AI Processor uses a flowchart Fig.1 to collect ground data, analysis it through a Cloud Platform, and make decisions. If traffic flow is low and the conditions are met, then the timing of traffic lights does not get adjusted. And if the conditions are not met, then the timing of the traffic light gets adjusted with the re-routing suggestions.

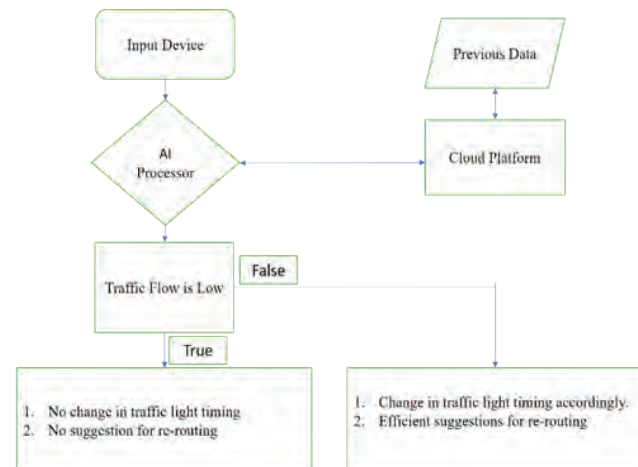


Fig.1: Flow chart for Smart AI Processor

Input devices

The present Indian government sensors meticulously placed along the road infrastructure. It uses a variety of cutting-edge technology such as cameras and radar. There are various kind of devices are included in this basic input devices to observe, record and share

the data. The various input devices will be used are recording devices, inductive loop sensors and video camera. Firstly, data logger is very helpful to record electronic data and collects the traffic movement. This information can be used to detect the traffic flow on different times of day. This will help AI Algorithm to predict the accurate flow and avoid the congestion on pick time. An inductive loop sensor basically works as a metal detector sensor to detect the object passing by road. This sensor will detect the number of vehicles are passing on the road as well as to detect the speed of vehicle. Number of video cameras are already been installed on traffic signals, national highways, state highways by government in India. These cameras can be helpful to provide information about real time traffic flow. And all of the collected data is continuously send to the AI processor for accurate decision making.

AI Processor

The processed and estimated data from input devices are then send to a Smart AI Algorithm. This data is rigorously analyse and processed using the proposed artificial intelligence technology. Using this advanced AI algorithms, the system can effectively detect and identify prominent traffic patterns, identifies blockages that may impede the flow of traffic. This will also identify any anonymous activities, such as threats, robbery or a miscellaneous activities in the society. After in-depth analysis, this data are separated according threat file, traffic pattern files, volume of traffic for better understanding. Then these specified data will be securely transmitted to a government to be stored in government cloud storage. This ensures that data are meticulously being protected from potential breaches or unauthorized access. A two layer firewall system is implemented to secure sensitive information with an extra layer of security. This ensures that data will remains completely protected and cannot be accessed by unauthorized entities while maintaining maximum data integrity and privacy.

CLOUD PLATFORM

The AI processor works by leveraging data stored securely in the Cloud Platform. This system leverages historical and real-time data. This allows for detailed analysis that leads to informed decisions. By

meticulously evaluating existing data as it arrives, AI processors are able to provide fast and accurate assessments. The ability to analyse data in real time ensures that decisions are based on the latest findings. This increases the accuracy of the results. After the AI processor makes a decision, the relevant data is again securely saved to the cloud platform. As it creates a detailed record of every decision. Maintaining this record is important to ensure accountability and effectively support the Management and the Traffic System over the time. When data is securely archived The decisions made are effectively communicated to the end user. This communication is structured in a straight forward and intuitive way. Facilitate users to browse and understand the information provided. This system is designed to provide users with the latest information in a timely manner. It always reflects the latest information. To provide immediate feedback based on real-time analysis and user engagement is thus accelerated. The ability to quickly provide relevant updates promotes deeper interactions between users and the overall process. Integrating this with real-time data analysis creates an agile environment for decision-making. This response structure not only increases the efficiency of the decision-making process. But it also enhances the user experience. It is considered an important component of the entire system.

Data Processing

When a user receives data processed by an AI Processor, he or she devotes the necessary time to analysis these data in depth. Users carefully analysis the data and relates it to their specific situation. During this evaluation the user considers a number of factors that may affect the results. They evaluate these elements and analysis various possible outcomes and find best practices. The user will come to a conclusion based on his analysis. This decision will be meticulously recorded. This will ensure that all relevant details are recorded in the cloud platform for future reference. Then the recorded data is been analysed by the AI Processor. This step is important because it helps the AI Processor reconsider the user's choices. By integrating this data into learning models, AI Processor benefits from understanding how users make decisions based on the information provided. This entire process creates a structured feedback loop that

is important for system improvement. User perceptions and decisions are systematically recorded and integrated into AI Processor. This connection not only helps refine the performance of AI Processor, but also increases its ability to provide better recommendations in the future. As a result, the user experience improves along with the overall performance of the AI Processor fostering a mutually beneficial relationship. As time passes This collaboration between users and AI Processor leads to more informed decisions and higher quality results.

Working of Smart AI Algorithm

Smart AI Processor

Smart AI Processor by gathering the data from the previous year Open Government Data (OGD) Platform which is a national portal for government services and has traffic data. Along with this historical data, the Smart AI Processor collects real time data from a network of sensors installed by Government of India on national highways, at traffic signals and in urban areas. These sensors are varied and advanced such as, high resolution cameras that capture images, speedometers that measure vehicle speed, GPS that track location, automatic traffic counters that count vehicles, classifiers that classify vehicle types. The system also uses IoT (Internet of Things) sensors, LiDAR, and other sensors like Bluetooth, Wi-Fi, ultrasonic, infrared, radar and inductive loop sensors.

The Smart AI Processor ties all these sensors together to boost overall system performance. Once the data is gathered the processor analysis the data and categorizes it into different Files. These files are Accident Files, Peak Hour Traffic Files, Motor Vehicle Fine Files, Over-speeding Files, Threat Analysis Files, Traffic Volume Files and Navigation Files. This organized data is then stored in the Open Government Data (OGD) platform.

For real time navigation the Smart AI Processor connects with the OGD platform and with third party mapping services approved by the Government of India like Google Maps and Apple Maps. The Smart AI Processor only transfers the required navigation files from OGD to these mapping services in real time and also secures the data from these third-party sources with OGT and synchronizes with the traffic signal timings across the city.

After analyzing the data, the Smart AI Processor suggests the best route to the user. It captures user feedback and stores it in the Open Government Data (OGD) Platform. The system continuously evaluates real time data from Google Maps, Apple Maps and OGD, using user feedback to improve the navigation experience the Smart AI Processor detects heavy traffic on a route it quickly finds an alternative route and updates the navigation in real time. For example if a main route is congested the Smart AI Processor suggests a better alternatively route but after a period of time the traffic from main route shifts to the alternative route keeping an main route empty and gets an congestion on alternative route so to avoid this kind of situation and to manage the traffic shifts the Smart AI Processor updates an user with the latest information while navigating with the real time. In given Fig. 2a and Fig. 2b the program is given.

```
1 import numpy as np
2 import random
3 import matplotlib.pyplot as plt
4 import time
5
6 class TrafficSimulation:
7     def __init__(self, lanes):
8         self.lanes = lanes # Number of lanes in the intersection
9         self.traffic_queue = {} # Dictionary to store traffic queue for each lane
10        self.traffic_signal = {} # Dictionary to store traffic signal for each lane
11
12    def update_traffic(self):
13        """Updates vehicle arrivals and departures"""
14        for lane in range(self.lanes):
15            self.traffic_queue[lane] = random.randrange(0, 5) # Random arrival
16            self.traffic_signal[lane] = random.choice([0, 1]) # Random signal (0: Green, 1: Red)
17
18    def optimize_traffic(self):
19        """Optimizes traffic by changing signal timing based on queue lengths"""
20        max_queue = max(self.traffic_queue.values())
21        for lane in range(self.lanes):
22            if self.traffic_queue[lane] == max_queue:
23                self.traffic_signal[lane] = 1 - self.traffic_signal[lane] # Switch signal
24
25    def simulate(self, steps):
26        """Simulate the traffic intersection"""
27        history = []
28        for step in range(steps):
29            self.update_traffic()
30            self.optimize_traffic()
31            history.append(self.traffic_queue)
32            time.sleep(0.1)
33        return history
34
35 def plot_traffic(history):
36     """Plots the traffic queue lengths over time"""
37     steps = len(history)
38     lanes = history[0].keys()
39     plt.figure(figsize=(10, 5))
40     for lane in lanes:
41         plt.plot(range(steps), [history[step][lane] for step in range(steps)], label=f'Lane {lane}')
42     plt.xlabel('Time Steps')
43     plt.ylabel('Queue Length')
44     plt.title('Traffic Queue Over Time')
45     plt.legend()
46     plt.show()
47
48 # Running the simulation
49 sim = TrafficSimulation(5)
50 history = sim.simulate(steps=20)
51 plot_traffic(history)
```

Figs. 2a and 2b Advance Python code for Smart AI Processor

Smart AI Processor works at Traffic Signals: The Smart AI Processor collects the data from the sensors placed at various traffic signals, which are connected to the Open Government Data (OGD) platform. These sensors are capable of capturing real time data from critical traffic situations and junctions. This data is then processed and analysed by the Smart AI Processor. This data analysis

plays a critical role in enhancing the traffic conditions across the city.

The interconnectivity of these traffic signal sensors allows for enhancement in the traffic conditions during peak hours by adjusting traffic light timings based on real-time conditions. The sensors assess the critical data such as traffic flow, volume, speed, and density at each intersection. This simultaneous analysis of the data by the Smart AI Processor across multiple traffic signals at same time, enabling the dynamic adjustments to traffic light timings. e.g.(suppose there are three traffic signals present at the three different road junctions which are in a straight line and road junction one has the heavy traffic compared to the traffic present at the road junction two and three, so the Smart AI Processor analysis the traffic volume at road junction one, road junction two and road junction three and then will change the Traffic Signal Timing according so that the traffic present at road junction two and three do not mix with the heavy traffic present at road junction one and with the minimum required it manages the heavy traffic so that it can avoid the heavy traffic congestion within the city)

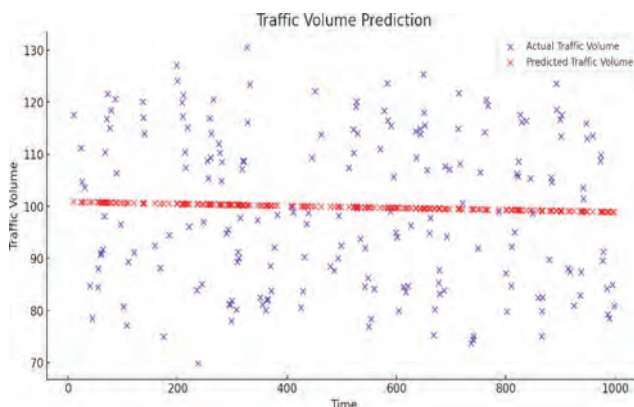


Fig. 3 Traffic Volume Prediction Graph

RESULTS AND DISCUSSIONS

A. Smart AI technology for single traffic light: The graph shows the queue lengths of traffic over time across different lanes. Each lane is represented, showing how the traffic levels change throughout the simulation. The data highlights the effectiveness of the AI in adjusting traffic signal timings in real time. By analysing traffic patterns, the system responds to congestion as it builds up. This dynamic management of signals is focused on

reducing waiting times and smoothing the flow of vehicles. Smoother transitions at intersections will be achieved as AI balances the demand of different routes, making it easier to travel. The graph clearly shows the optimization in action, demonstrating how AI technology can be used in managing urban traffic systems.

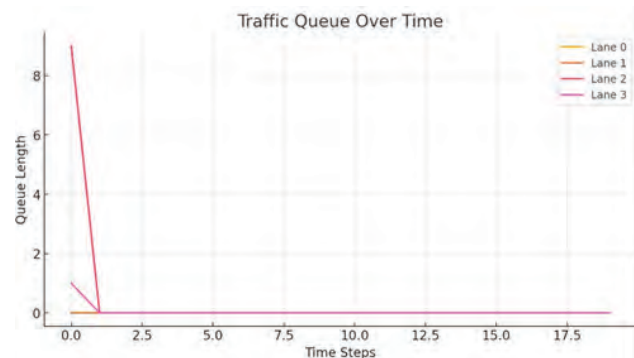


Fig. 4 Traffic Queue analysis graph at single traffic light

B. Smart AI technology for multiple traffic light: The graph shows the traffic queue length for 3 simulators over time across different lanes. The data highlights the effectiveness of the AI in adjusting multiple traffic signal timings in real time. By analysing the multiple traffic patterns, the system responds to congestion as it builds up. This dynamic Smart AI Processor for multiple signals is focused on reducing waiting times and smoothing the flow of vehicles. Smoother transitions at multiple intersections in real time will be achieved as AI balances the demand of different routes, making it easier to travel. The graph clearly shows the optimization in action, demonstrating how AI technology can be used in managing urban traffic systems.

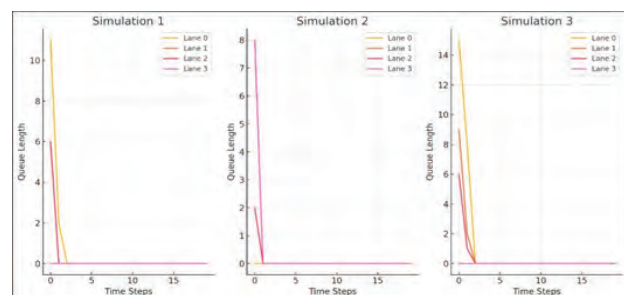


Fig. 5 Traffic Queue analysis graph at multiple traffic lights

TRAFFIC MANAGEMENT CHALLENGES WITH AI PROCESSOR

Traffic management today addresses key challenges affecting urban mobility, safety and overall efficiency of road users. rapid urban expansion increasing population and the number of vehicles increasing As a result, these problems are becoming more severe. Consequences include severe congestion. environmental damage and economic losses The following points highlight the traffic management challenges required.

1. **Traffic congestion:** This problem is very noticeable in many urban areas. Traffic congestion results in having to travel further. Consumes more fuel. And air pollution is increasing A poorly constructed road system Lack of effective public transport options and excessive reliance on personal vehicles It is the main cause of this problem.
2. **Accidents and Road Safety:** Accidents occur frequently in many areas. This is due to insufficient traffic monitoring and ineffective law enforcement. Reckless driving behaviour Improper traffic signs and roads that are poorly maintained It also increases the danger of traveling on the road.
3. **Ineffective public transport:** Cities lacking in public transport facilities. As a result, people increasingly use personal cars. This dependence on personal vehicles raises road congestion and enhances pollution levels.
4. **Environmental Impact:** Vehicle emissions are the major cause of air pollution and global warming. Traffic congestion and idling cars enhance carbon emissions. It is dangerous to public health and the environment.
5. **Outdated infrastructure:** Many urban areas rely on outdated infrastructure that cannot keep up with the demands of today traffic patterns. These include outdated traffic lights, narrow roads and a lack of advanced traffic management technology.
6. **Poor use of data:** Limited use of real-time data and analytics limits our ability to predict traffic trends. Adjust signal time and deal with incidents quickly This shortage could increase delays and frustration for drivers.

7. **Coordination challenges:** Traffic management often involves various agencies and stakeholders. This complexity complicates coordination efforts. This leads to an ineffective response to traffic-related problems.
8. **Lack of accessibility:** Many cities lack access to proper infrastructure for pedestrians. cyclists and people with disabilities, this lack creates obstacles This results in inequalities in mobility for residents. Addressing these traffic management challenges is critical to improving urban mobility and promoting safer, more sustainable cities.

CONCLUSION

Traffic blockage is a crucial aspect of transportation and requires careful planning and management to make safe and efficient flow of traffic. This research has shown that smart cities which are based on smart AI technology need a urban model. To improve urban residency traveling and living experience a smooth and well organized working method of traffic management is important. To accomplish this condition a AI based algorithm will provide a traffic management system. With help of various sensors it can collect the real time data which will give accurate reading of traffic present and available routs. Control of traffic signal lights, traffic congestion can be reduced or avoided by using this system. As per the result and discussion and from graphs Fig.3, Fig.4 and Fig.5 this Smart AI Processor works 57% better than present traffic management system. However, for

future research there are many potential avenues for exploration. Like, the integration of autonomous vehicles into existing infrastructure. More advance way of using data analysis and other technological tools to optimize traffic flow and reduce congestions.

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Comprehensive Approach to IoT Network Security: Integrating Machine Learning and LoRaWAN for Enhanced Attack Detection

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ABSTRACT

IoT network security in LoRaWAN is critical for safeguarding sensitive data and ensuring reliable functionality in applications like smart cities and healthcare. Its lightweight architecture and nonexclusive sub-carrier occupation make it particularly vulnerable, necessitating machine learning-based attack prevention mechanisms. Our research integrates machine learning with LoRaWAN to enhance IoT security through a dynamic protocol using a Bidirectional Recurrent Neural Network (BRNN) inspired algorithm.

The simulation work is designed to evaluate the performance of a LoRaWAN-based IoT network, focusing on aspects such as energy efficiency, communication behavior, and attack detection mechanisms. The simulation also includes energy management features, with specific power consumption parameters for transmission and reception, reflecting the real-world constraints of battery-powered IoT devices in LoRaWAN deployments. An environmental sensing agent is introduced to simulate network activity, with attack scenarios initiated during the simulation to test the detection mechanisms. This setup allows for comprehensive testing of LoRaWAN communication, energy usage, and security vulnerabilities, providing valuable insights into network behavior under various attack scenarios. This approach effectively detects DDoS, MitM, injection, and zero-day attacks, achieving 98.768% accuracy while optimizing network and energy utilization, outperforming state-of-the-art methods.

KEYWORDS: *IoT, Network security, Lora WAN, Deep learning, Attack detection.*

INTRODUCTION

The Internet of Things (IoT) is changing the way things are connected and used, resulting in the fast propagation of low power and long-range technologies such as LoRaWAN. But on the contrary, the increasing size and complexity of IoT networks also brings about many security issues which are even worse with many IoT devices being low in resources. Conventional security measures are frequently inadequate, making it essential to develop new methods for detecting and responding to attacks. This paper presents an integrated security architecture that employs dynamic learning with LoRaWAN-specific simulations to solve security challenges in IoT.

RELATED WORK

A viable substitute for current security techniques is machine learning. Because it is not preprogrammed, machine learning (ML), an artificial intelligence technique, works best in dynamic networks. The device is trained using ML techniques on a variety of datasets in order to recognize distinct attacks and offer a corresponding defence. This makes it possible to identify assaults early and protect data [1]. To identify potential zero-day vulnerabilities in new software releases, the system will utilize several machine learning techniques, such as autoencoders and Support Vector Machine (SVM) algorithms, which have been trained on a dataset of known vulnerabilities. The

study's findings could help improve cybersecurity in general and help businesses better protect their systems from zero-day attacks [2].

DL-based approaches prove to be more effective than traditional ML-based methods in mitigating the overfitting problem, regardless of the regularization strategies applied. The study evaluates whether addressing a classifier's overfitting problem enhances its ability to detect zero-day threats. Classifier regularization methods in security machine learning are simplified to improve efficiency. Given the IoT's limited memory and processing power, this reduction makes these methods more suitable for IoT implementation [3]. IoT devices are essential to these systems but also pose security challenges, as they can introduce vulnerabilities that attackers exploit to infiltrate the systems. Regarding IoT and IoMT, compromising the data transmitted or stored in the systems represents a serious threat. For example, unauthorized access to energy consumption data could expose patterns that suggest when residents are away, potentially increasing the risk of targeted burglaries [4]. ML provides cognition and reasoning in automated decision-making. The goal of Machine Learning (ML) in networks is to extract knowledge from network behaviour, service, and users' behaviour, using historic data for training and learning. We pioneer a discussion about network automation, that will give the reader an understanding and an overview of the different concepts in relation to network automation [5]. The work focuses on the most recent dataset that purely related to the IoT based attacks' behaviours excluding behaviours of the traditional networks. The work focuses on analysing as much attack as possible through training the proposed ML model. The focused type of attacks are up-to-date attacks and mostly related to IoT based networks [6]. The paper "Deep Défense [7] provides an overview about DDoS attack where more advanced deep learning methods are applied, utilizing RNNs such as LSTMs and GRUs which are efficient in detecting DDoS attacks based on the patterns of traffic movements in the network. The model focuses on 20 network traffic fields from the ISCX2012 dataset. Nevertheless, the model achieved a lower error rate of 2.103% from a previous rate of 7.517%, authors openly accept limitations, dependence on network expertise, limited attack while coverage, and the requirement

of regular changes in order for the system to remain effective also emphasize the need for more enhancement in order to enhance generalisation for various attack purposes and different execution environments. The paper [8] explains how the healthcare sector is being digitalized through the use of Internet of Things (IoT) framework with cryptographic encryption. It emphasizes on remote health care utilizing vital signs of 100 patients like pulse and body temperature. This information is retrieved using complex Q-learning method for data classification and secured in the cloud with high security protocols that do not permit any breach of confidentiality nor data corruption. IoT networks security such as cybersecurity has been focused on in the past, various mechanisms like encryption, anomaly detection and machine learning have been examined as regards different aspects concerning IoT networks.

METHODOLOGY

Deep Learning Based Algorithm (DLBA)

DLBA protocol is developed in order to improve security and efficiency of IoT network. By using deep learning techniques, DLBA is able to protect against sophisticated cyber-attacks including DDoS, zero-day, injection and MiM attacks and, with high accuracy, comprehend the features of the attack. This protocol employs a RNN inspired algorithm to understand the patterns of network traffic in order to make a reasonable distinction between legit activities and attacks. Employing the NS2 simulator in traffic creation and DLBA execution entails a variety of advantages. Customization, dynamic testing as well as new threat targeting are made possible. Also, full feature extraction is supported. This method makes the model stronger and helps it perform better when evaluating the level of risk.

Reinforcement Learning based algorithm for Lora (RLLora)

RLLoRa protocol utilizes reinforcement learning inspired algorithms for improving its operation. The LoRaWAN environment is imitated and with the use of machine learning, RLLoRa efficiently improves the performance level by optimizing critical parameters of power, frequency channels, and data rates thus achieving a great increment in the network's throughput and energy efficiency. Because of this intelligent optimization,

RLLoRa is also able to self-manage and adapt to a variety of network environments and demands for better communication. Furthermore, RLLoRa outperforms in precision and recall metrics as well as the F1 score particularly in security use cases when legitimate and adversarial traffic needs to be separated. Reinforcement learning enhances RLLoRa and provides it with the required flexibility and operational effectiveness for smart IoT solutions that sometimes traditional solutions such as LoRa may fail on.

Optimized Deep Learning Based Algorithm in Lorawan Network (DLBA-Lora)

We have designed DLBA-LoRa protocol which is a highly efficient and secure communication framework for IoT networks. By integrating DLBA with LoRaWAN, DLBA-LoRa leverages advanced machine learning techniques to enhance the identification and mitigation of sophisticated cyber-attacks such as DDoS, MiTM, Injection and Zero-day attacks. The protocol employs a BRNN inspired algorithm that learns patterns from sequences of network traffic, which allows it to trace and respond to attack activities effectively.

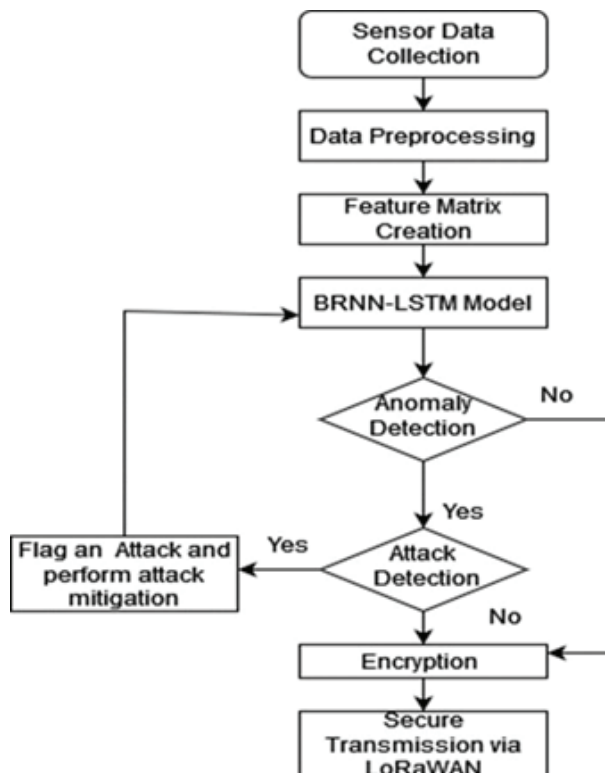


Fig. 1 DLBA-LORA Flowchart

Consider a LoRa sensor network is set up in a farmland. At regular intervals, the sensors gather data on temperature, humidity, and smoke/fire detection. This is the raw data that was gathered and converted into a matrix. This matrix is fed into the LSTM network as input in order to identify assault patterns. After processing the sequential data, the LSTM learns to recognize temporal patterns in the sensor readings that correspond to both normal and abnormal behaviours. The model can forecast possible problems, such environmental dangers or system breakdowns, by analysing these trends.

LSTM Network Processing

This transformed data matrix is fed into the LSTM network. The LSTM network will learn the temporal patterns in this sequence of data.

Input Data: x_t : The input at time (e.g., [101110, 110111, 0] at t_1).

Input Gate: $i_t = \sigma(W_i[h_{t-1}, x_t] + b_i)$

Candidate Cell State: $C_t = \tanh(W_c[h_{t-1}, x_t] + b_c)$

Forget Gate: $f_t = \sigma(W_f[h_{t-1}, x_t] + b_f)$

Cell State: $C_t = f_t C_{t-1} + i_t C_t$

Output Gate: $o_t = \sigma(W_o[h_{t-1}, x_t] + b_o)$

Hidden State: $h_t = o_t \tanh(C_t)$

Prediction and Analysis

After training, the LSTM network can predict whether the incoming sequence of data indicates normal conditions or potential issues. For instance, if the pattern of temperature, humidity, and smoke/fire detection matches known patterns of environmental hazards or system malfunctions, the model will flag this as an anomaly. The LSTM network processes these inputs and identifies the temporal pattern. If it recognizes the pattern as matching previous instances where there was a fire (e.g., presence of 1 in the smoke/fire detection field), it can predict a potential fire hazard. By transforming raw sensor data into a structured format and using LSTM networks, we can effectively detect patterns and predict environmental hazards or system malfunctions in a LoRa sensor network. This enables timely interventions and enhances the reliability of monitoring systems.

Training and Evaluation

The LSTM network, trained on labelled data, effectively classifies new data within the LoRa sensor network, enhancing system reliability in monitoring environmental conditions. By recognizing complex patterns, the model improves accuracy, detects anomalies, and supports timely decision-making based on insights from the transformed feature matrix.

Detection of Attacks Using BRNN

A BRNN processes sequences of data in both forward and backward directions, improving the understanding of temporal dependencies. LSTM and GRU architectures are used to address scaling issues in deep RNNs, with LSTM particularly effective at detecting cyber-attacks due to its ability to retain important information over long periods. To enhance detection efficiency, 1D convolutional layers and ReLU activation are added before the recurrent layers, with batch normalization used to speed up training. This approach ensures robust detection and prevention of cyber-attacks in IoT networks.

This deep learning technique is based upon the concept of Bidirectional Recurrent Neural Network (BRNN) incorporated with Long Short-Term memory (LSTM).

Pre-processing: A binary feature matrix is constructed using the saved packet data since the read network packet data can be inefficient to use as it is. These transformations are essential for efficient employment of such data as well as for highly dimensional time-dependent modifications of the data which is arranged in specific windowed sequences of time periods.

Bidirectional LSTM: The BRNN's Sequential Memory Network architecture relies on implementing the LSTM units as one of the pillars of the BRNN. In this, information from previous states and successive states is to be added in order to broaden the understanding of the temporal behaviour of the sequence of information.

Forward Pass: At any selected time window, with respect to current time frame, the forward LSTM free moves along the initiator from the beginning to the tail-end of the series and evaluates the hidden states of these segments along the sequence.

Backward Pass: On the other hand, the backward LSTM

free simultaneously evaluates the hidden states of the segments of the series from the tail to the initiate along the series.

The obtained results of each direction of data are appended so that the model utilizes a wider view of the data.

Fully Connected Layers: All the hidden states concatenated from the LSTMs are fed into and through fully connected layers which produces the prediction of the time windows' outputs.

Loss Calculation and Training: The predicted labels in the model are derived from the actual using a loss function like cross-entropy to make a comparison. In the course of the training period, the loss is minimized by updating the model parameters via gradient-descent. This approach is repeated several epochs until the model optimally learns how to detect patterns.

Attack Detection: Upon completion of training, the model predicts patterns of attack by analysing new patterns of network packet sequences.

Detection of DDoS Attack: System inspects features of packet arrival rates and clusters normal abnormal behaviours. It spots and analyse traffic patterns and the unusual spikes. Bases on the normal traffic, thresholds are used to detect possible attacks, whereas in anomaly detection, sudden unusual rises which are characteristic of DDoS will take place.

MiTM Attack Detection: The system inspects packets for irregularities and uses BRNN to identify patterns of interception or tampering. LSTM layers detect deviations like delayed packets, while encryption checks ensure data integrity, flagging potential MiTM attacks.

Zero-Day Attack Detection: Using only known pattern training, the model containing BRNN with LSTM layers is used to spot any anomalies which signify unknown attacks that are not in the patterns learned. The current traffic is analysed and the learned model therefore identifying anything out of the ordinary as a zero-day attack.

Injection Attack Detection: Incoming data is checked for clear injection attacks based on the pattern. The nature of the input sequence is examined for encoding

factors using the LSTM layers. Manipulation of data flow in a session is controlled by BRNN impulses in which abnormal levels of data are picked to gauge ensuing injections during the time of the session.

Attacker Elimination

Eliminate DDoS, MiTM, Injection and Zero Day attackers, encrypt remaining legitimate packets using AES-128 and securely transmit to users via the LoRaWAN network to ensure data integrity and confidentiality.

SIMULATION AND RESULTS

Network Model

The network model for this study is based on the LoRaWAN protocol, simulated using the NS2 environment. The network comprises multiple nodes, including standard IoT devices, gateways, and designated attackers. The simulation environment is configured with parameters such as initial energy, data rates, and modulation schemes to reflect realistic conditions. Various attack scenarios are tested to evaluate the protocol's performance. The network is simulated within a 200x200 grid with 100 nodes, each initialized with an energy capacity of 100 joules, reflecting the energy constraints typical of IoT devices in LoRaWAN networks. LoRa-based routing is employed to model the low-power, wide-area characteristics of the network, and the communication is configured with a data rate of 1.75 Mb/s, using Frequency Shift Keying (FSK) as the modulation scheme.

The physical layer parameters, including carrier sense and reception thresholds, are fine-tuned to ensure accurate simulation of LoRa communication characteristics. The simulation also includes energy management features, with specific power consumption parameters for transmission and reception, reflecting the real-world constraints of battery-powered IoT devices in LoRaWAN deployments. An environmental sensing agent is introduced to simulate network activity, with attack scenarios initiated during the simulation to test the detection mechanisms. Simulation results are logged in trace files for further analysis. This setup allows for comprehensive testing of LoRaWAN communication, energy usage, and security vulnerabilities, providing

valuable insights into network behaviour under various attack scenarios.

Performance Metrics

The performance metrics for network attack detection using a BRNN inspired model typically include accuracy, precision, recall, and the F1-score. These metrics measure the model's ability to correctly classify network attacks. Energy Consumption and Network Throughput are also evaluated to govern network performance.

Results

The network has been integrated with AES encryption and decryption within the DLBA LoRaWAN framework, and its performance has been thoroughly evaluated below.

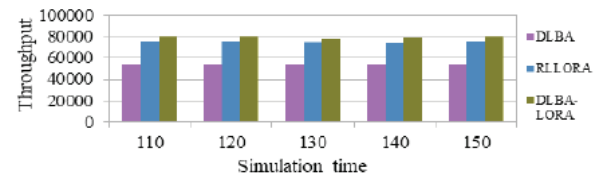


Fig. 1 Simulation time vs Throughput

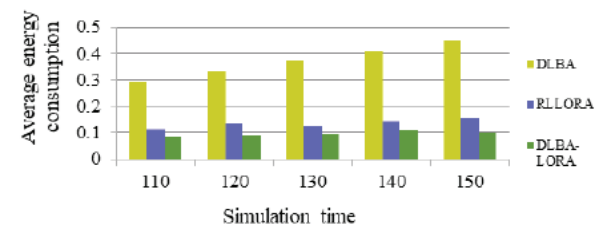


Fig. 2 Simulation time vs Average energy consumption

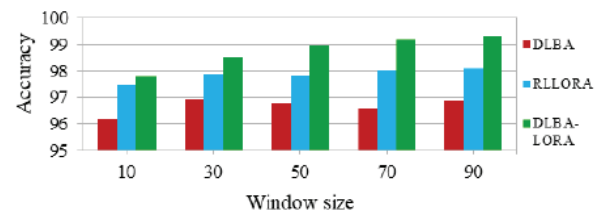


Fig. 3 Window size vs Accuracy

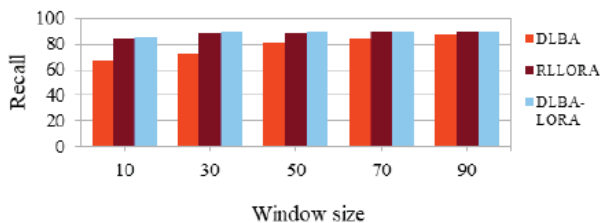


Fig. 4 Window size vs Recall

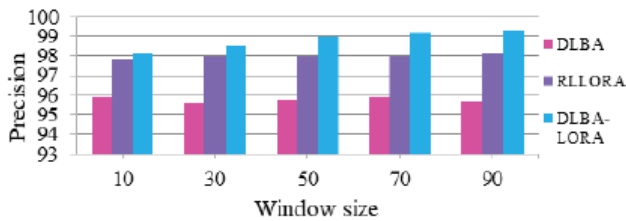


Fig. 5 Window size vs Precision

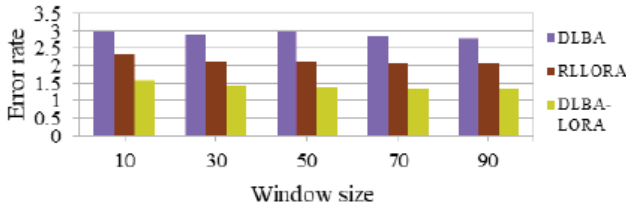


Fig. 6 Window size vs Error rate

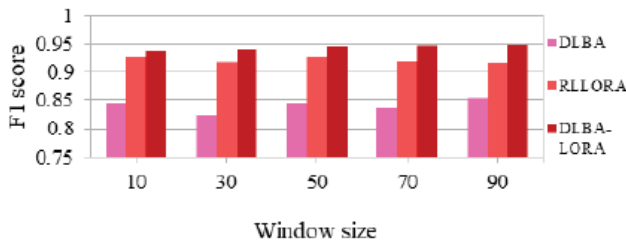


Fig. 7 Window size vs F1 score

DISCUSSION

The simulation results show that, DLBA-LORA protocol achieves the highest throughput (around 79,224.32) and lowest average energy consumption (approximately 0.09504) compared to DLBA and RLLoRa ensuring timely data transmission even under congested conditions. Its minimal energy consumption is crucial for IoT devices operating on limited power sources. The protocol surpasses others in accuracy (98.76888) by effectively classifying and transmitting data, which enhances network reliability. Its robust detection algorithms provide a high recall rate (88.346), enabling the identification and management of most network attacks. Precision (98.6119) is also a key strength, as it accurately identifies malicious nodes while reducing false positives. With a notably low error rate (1.428656), DLBA-LoRa ensures data integrity through secure methods such as AES encryption. Achieving the highest F1 score (0.944164), it demonstrates a balanced performance between precision and recall, making it adept at managing complex network scenarios. Despite

its advantages, the protocol introduces computational overhead due to its reliance on machine learning, which must be carefully managed in resource-constrained environments.

CONCLUSION

DLBA-LoRa outperforms other protocols in key performance metrics, achieving the highest throughput and effectively handling larger data volumes compared to DLBA and RLLoRa. It optimizes energy consumption to extend the battery life of sensor nodes, ensuring the sustainability of IoT networks. In terms of security, DLBA-LoRa demonstrates superior accuracy, recall, and precision in detecting and identifying malicious activities, resulting in a low error rate and more reliable network operations. The high F1 score indicates a well-balanced approach to maintaining network security. Future work aims to optimize the machine learning models and broaden the protocol's applicability to address challenges in IoT networks, including efficient bandwidth utilization, energy conservation, secure data transmission, and enhanced threat detection.

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Classification of Soybean and Tomato Diseases Using Digital Image Processing and Machine Learning

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ABSTRACT

Crop diseases cause a large economic loss to the country as well as yield production also decreases. The most important thing is to increase crop production, so it is very necessary to analyze the early occurrence of crop diseases to implement effective control measures. This paper discusses to recognize and classify the soyabean and tomato diseases using image processing and machine learning. These two crops affected by various types of diseases like fungal and bacterial, these diseases can be differentiated by observing the parts of the crops. This proposed method recognizes the crops diseases and classifies whether affected region and healthy includes various steps namely image pre-processing, segmentation, feature extraction, training of the classifier and classification. The collectively sample images of the crops resized/enhanced using the BPDFHE. K-means clustering and GLCM are used to extract the affected region and features of the crops. The extracted features are training and classifying using the three different classifiers like K-NN, Decision tree and SVM. The performance of the K-NN classifier obtained better Accuracy than the other two state-of-the-art classifiers.

KEYWORDS: BPDFHE, k-means clustering, Gray-Level Co-occurrence Matrix (GLCM), K-Nearest Neighbour (K-NN), Decision Tree (DT), Support Vector Machine (SVM).

ABBREVIATIONS

RGB	Red Green Blue
BPDFHE	Brightness Preservation Dynamic Fuzzy Histogram Equalization
GLCM	Gray Level Co-occurrence Matrix
ROI	Region of Interest
SVM	Support Vector Machine
DT	Decision Tree
K-NN	K-Nearest Neighbours
MATLAB	Matrix Laboratory
CHD	Coronary Heart Disease
DIP	Digital Image Processing
GUI	Graphical User Interface
ML	Machine Learning

LBP	Local Binary Pattern
DLQP	Directional Local Quinary Patterns

INTRODUCTION

Advanced technological advancements make it feasible to generate sufficient food quantities required by society. Farmers require ongoing maintenance of crop and food grain safety despite technological progress. Farming activities face greater difficulties because of crop diseases together with unpredictable climate patterns and diminished pollinators and other factors. Crop diseases stand as an important factor that requires immediate attention [1,2]. Indian farmers assess their crops by visible examination because they must identify diseases by relying on their expertise level and past experience. Subjective diagnosis of crop diseases carries the consistent danger of incorrect disease identification. The professionals sometimes commit errors in disease identification of crops which results

in incorrect management techniques. The procedure of correctly identifying crop diseases while determining that infections require prompt medical intervention stands as the hardest agricultural challenge to solve. Current machine learning advancements constitute a part of Artificial Intelligence research. Agriculture professionals increasingly adopt technologies which enable them to identify and differentiate patterns and structural similarities that appear in images. Research teams use machine learning methods to examine crop diseases in their analysis of agricultural diseases. We split the complete algorithm into three operational levels yet we use existing database resources during recognition and analysis and classification activities.

The main analysis of crop leaf diseases faces crucial obstacles which research organizations identify as important [3,4]. This text will explore the key points presented below.

- The quality of leaf pictures acquired from crops needs to be of high resolution.
- The need for publicly available datasets
- The leaf color transformations result from environmental conditions.
 - Noisy image data from leaf samples creates difficulties in their processing.
 - Detection of crop leaves disease faces its most critical obstacle during segmentation and classification procedures.

Plants present different diseases between each other so disease identification remains challenging. A new approach has been designed to achieve superior classification results through the utilization of Digital image processing (DIP) and Machine Learning (ML) methods for dealing with the discussed challenges. The proposed system uses DIP alongside ML to create an automatic detection method for crop leaf diseases while considering all previous challenges.

Three sequential steps define the proposed method. The BPDFHE algorithm together with k-Means clustering process allows segmentation of leaf samples within their Region of Interest (ROI) through improved quality enhancement. The analysis of leaf samples' features in diseased ROI regions uses both GLCM and LBP

extraction methods. The classification of features takes place with ML-based SVM along with KNN.

Section 2 provides in-depth details regarding leaf disease techniques from the literature survey. This paper presents the leaf disease region detection strategy in section 3 while Section 4 shows analysis of the proposed system on three infected leaf samples followed by conclusion in Section 5.

LITERATURE SURVEY

Image processing research on leaf disease detection has attracted scientists to conduct their research activities in this field for an extended period. Using image processing with machine learning methods has become crucial for automatic leaf disease detection in recent times. The researchers presented in [5] established a system for identifying plant diseases and their categories. Directional Local Quinary Patterns (DLQP) calculate important key points with SVM during the first process step while predicting plant disease results. The identification accuracy of plant diseases reaches better levels according to this approach. The system's operational performance can reach higher levels through implementation of the image input's shape and color data. Plant disease identification and classification forms the topic of discussion in Pantazi et al.'s research [6]. Research emerged with two steps that began through GrabCut segmentation of input pictures then executed HSV methods on segmented results. The LBP tool operated over segmented ROIs in this stage to compute features that the SVM classifier employed to train the class system before achieving good plant disease classification results but produced poor detection accuracy for noisy image examples. S. Arivazhagan et.al.[7] have examined how image processing and neural networks work for leaf disease detection. The researchers use color Co-occurrence method for extracting texture features from the images. A multiclass SVM classifier performs disease classification functions. The detection and classification of plant disease forms the topic discussed by Narmadha et al. [8] A digital camera acquired the images and a median filter improved picture quality. The K-Mean clustering algorithm and SVM technique are employed for segmentation together with classification. Controlling the region of interest with a k-Mean clustering algorithm

followed a process where Pooja et al. [9] transformed Otsu's detection image RGB to HIS for spot and boundary detection algorithm segmentation. Rukaiyya et al. [10] pre-processed using contrast adjustment and normalization methods. The YCBCR algorithm with Bi-level color transform serves to execute thresholding functions. The computer performs feature extraction and classification by implementing both GLCM and HMM methods [11]. 3.

METHODS

Dataset preparation

Soyabean and tomato serve as fundamental crops in Indian daily life because these crops contain vitamins B, phytic acid, dietary minerals alongside protein, folate, potassium, vitamin C and provide substantial amounts used for chemical substance production. The extreme changes in environmental conditions during the last few years have led to an increase in crop diseases which makes disease prediction critical [12]. Image acquisition occurred for training and testing purposes as the research collected specimens throughout different locations spanning both Sangli and Kolhapur districts. Diseased and healthy leaves of soybean and tomato crops were utilized to create the image database. The plant species of soybean and tomato experience infections from bacterial and fungal diseases. These diseases spread by wind combined with water to affect plant remains that remain on soil surfaces during winter. [12,13]. The high-resolution cameras took all collected images for the study.

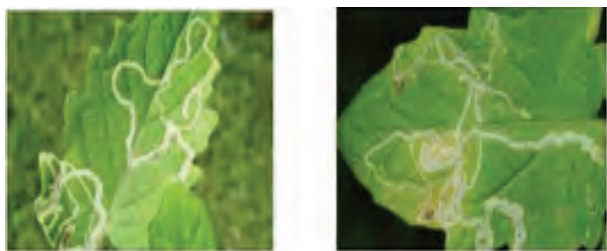


Fig. 1. Leaf Miner [14]

a) Powdery Mildew: the front surface of diseased leaves is generally covered with a dusty, white to grey powdery growth. The severely infected leaves may turn brown and curl up [14].



Fig. 2. Powdery Mildew [14]

b) Downy Mildew: Initially, the infection was seen in large, angular, and yellow areas on the upper surface of the leaf. Their infrequently yellow patch representation can also identify them [15].

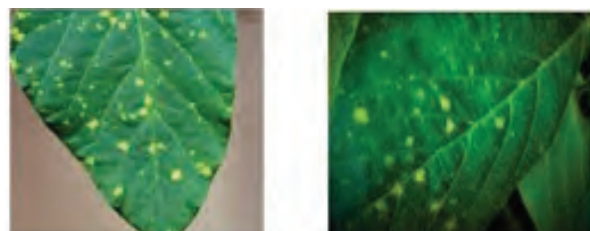


Fig. 3. Downy Mildew [15]

c) Frog Eye: Initially, infection was seen on leaves with circular to angular spots. They originate in brown spots surrounded by darker purple to red-brown rings. The centers of the lesions turn light brown and light gray over a long time [15].



Fig. 4. Frog Eye [15]

Proposed methodology

The research approach for DIP-based disease recognition and classification of soybean and tomato plants will be explained during this section. Image acquisition represents the first stage of the proposed methodology followed by image pre-processing along with image segmentation and feature extraction and classification tasks. The image depiction of the framework appears in fig.5.

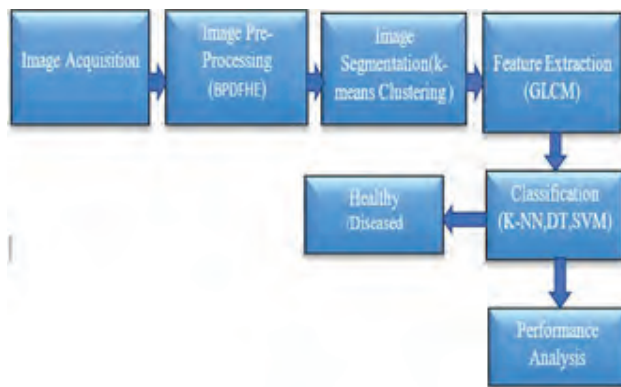


Fig. 5. The Pictorial representation of the proposed work

Image Acquisition

The research approach for DIP-based disease recognition and classification of soybean and tomato plants will be explained during this section. Image acquisition represents the first stage of the proposed methodology followed by image pre-processing along with image segmentation and feature extraction and classification tasks. The image depiction of the framework appears in fig.5.

Image Pre-Processing

The goal of image pre-processing consists of both distortion reduction and feature enhancement to benefit future processing operations. Pre-processing includes

Three steps: image resizing combined with color transformation and image enhancement according to [17]. The segmentation process along with feature extraction operation takes less time due to image resizing the processed image to 256x256 pixels [15]. Through BPDFHE algorithm the brightness and sharpness along with image quality improved [18,19].

Image Segmentation

Image segmentation stands as the following essential procedure which transforms pictures into separate Regions of Interest through labeled image generation. An image becomes easier to analyze through subgrouping which then enables more efficient examination of each individual object. A variety of image segmentation methods exist which belong to boundaries, regions, clustering, edge and threshold classifications. The researchers applied color-based k-means clustering to divide objects in this project [18].

The k-means clustering algorithm works according to this process:

1. I Initialized the number of k-clusters.
2. The data space contained k-centroids which were randomly placed at the beginning of the process.
3. Each datum received assignment to its nearest k-centroid through the process.
4. The new k-centroid can be created through averaging all the objects within the clusters.
5. The sequence of steps 2 and 3 should be repeatedly run until all objects stop moving between cluster centroids.

Feature extraction

The feature extraction method simplifies large image data sets containing unneeded information into a distinct set of features through dimensional reduction. Image feature extraction requires three foundational image features of color, texture and shape to obtain meaningful image characteristics from the region of interest area. Gray-level co-occurrence matrix (GLCM) functions as the statistical regimen that examines pixel spatial patterns while bearing the alternate name gray-level spatial dependence matrix. The function starts by determining specific value pairs with particular spatial conditions within images which produces the GLCM before extracting statistical values from this matrix. The tomato and soybean leaf disease symptoms undergo analysis through the Homogeneity, Contrast, Correlation, Entropy and Energy texture

Feature values in the GLCM process. Machine learning depends on the classification process for transforming image data into defined classes that enable automatic disease or healthy type identification. The supervised machine learning algorithm KNN serves as a tool for identifying classes that share closest relations with already known classes. A model functions strictly from training image data because the Model learns all complete training data while making predictions by selecting the majority rule among computed 'k' closest neighbors based on distance metric [20]. The training data keeps the extracted features from images while

KNN training classifier receives it to produce results for disease or healthy classification of tomato and soybean leaves.

PERFORMANCE METRICES

The performance of the proposed classifier is calculated based on the various matrices, namely Accuracy, sensitivity, and specificity [16] given below (1), (2), (3):

$$\text{Accuracy}(\%) = \frac{TP+TN}{(TP+FN+TN+FP)} \quad (1)$$

$$\text{Sensitivity}(\%) = \frac{TP}{(TP+FN)} \quad (2)$$

$$\text{Specificity}(\%) = \frac{TN}{(TN+FP)} \quad (3)$$

Where TP – True Positive, TN – True Negative, FN – False Negative, FP – False Positive.

RESULTS AND DISCUSSION

Second section was to argue and discuss the experimental result of machine learning and image processing or detection and classification of tomato and soybean diseases. The experimental work is executed by using the software MALAB 2019a. Datasets associated with Tomato and soybean leaf disease are considered different types such as Frog eye, Powdery Mildew, downy Mildew, Leaf Miner, Septoria Leaf Spot and Healthy Leaf for training and testing (Predication) purposes. During the sampling, the resolution of the sample images of Tomato and soybean were resized to 256x256 pixels using nearest neighbor interpolation, to reduce computational difficulty and so that the same size was kept during the experiment. fig.6(b), fig.6(c) also shows that the image is enhanced with Brightness Preservation Dynamic Fuzzy Histogram Equalization as by figure 6, it is enhanced image contrast; [19]. By performing this clustering using tomato/soybean leaf images, it is shown that Apple disease (diseased region of the leaf) has been detected with accuracy very close to 100% and the clustering result is as shown in fig. 7.



Fig. 6(a).Sample Leaf image form the dataset



Fig. 6(b). Resized image

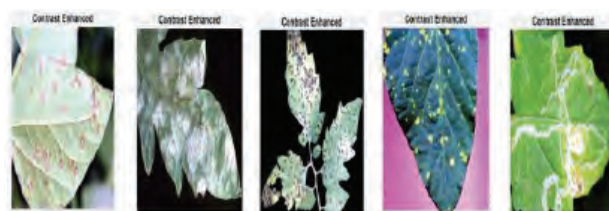


Fig. 6(c). Enhanced contrast image

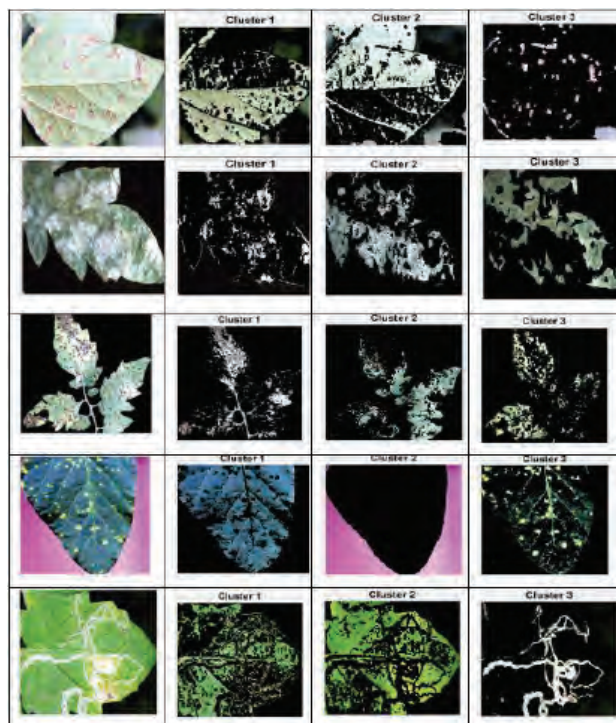


Fig. 7 K-Means clustering Segmentation results.

The main five features, such as Contrast, Homogeneity, Correlation Energy, and Entropy, are selected and extracted from the diseased ROI region of the Tomato and soybean. Table.1 depicts the extracted average values of the feature for both diseased/healthy leaves. These feature vector values are created in the dataset, which is used in the next step for classification purposes.

Table.1. Extracted average values of the features for both diseased/healthy leaves

Crops	Healthy/ diseased	Diseased name	Average features values of the GLCM				
			Contrast	Homogeneity	Energy	correlation	Entropy
Tomato leaves	Healthy	-----	0.89571	0.92128	0.16235	0.94227	5.9104
	Diseased	Leaf Miner	1.03343	0.91922	0.16208	0.93351	5.8867
		Septoria Leaf spot	0.89363	0.92138	0.16184	0.9423	5.91955
		Powdery Mildew	0.18084	0.91708	0.12292	0.97976	7.43762
Soybean leaves	Healthy	-----	1.25461	0.92259	0.35008	0.85556	3.88705
	Diseased	Frog Eye	0.89571	0.92128	0.16235	0.94227	5.9104
		Downy Mildew	1.03343	0.91922	0.16208	0.93351	5.8867

The three classifiers are used to classify the image data into two classes such as; diseased/healthy leaves. The classifier with the best accuracy results is selected for the calcification purpose. Table. 2.shows the classifier results for using performance metrics and fig. 8(a), fig. 8 (b), fig. 8(c). shows graphical reseparation of Accuracy, Specificity, Sensitivity.

Table. 2. Classification results for using performance metrics

Features	Classifiers	Performance Metrics		
		Accuracy (%)	Specificity (%)	Sensitivity (%)
GLCM	SVM	97.72	0.9054	0.8757
	DT	94.56	0.8512	0.8056
	KNN	99.20	0.9522	0.9432

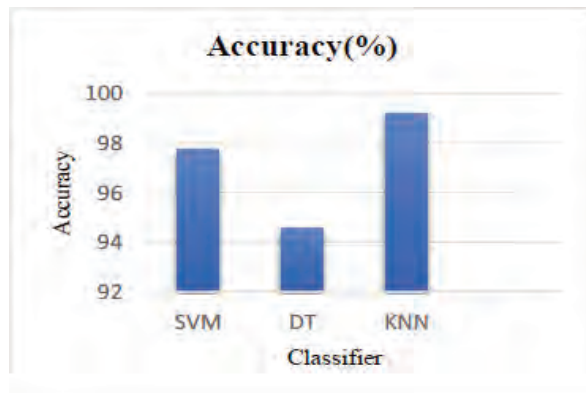


Fig. 8(a).Graphical reseparation of Accuracy

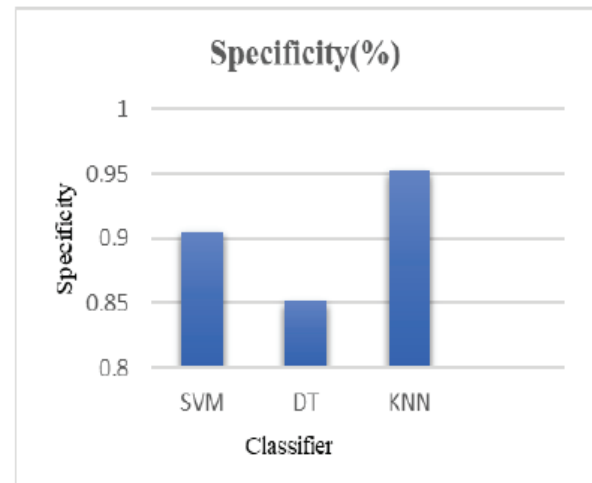


Fig. 8(b).Graphical reseparation of Specificity

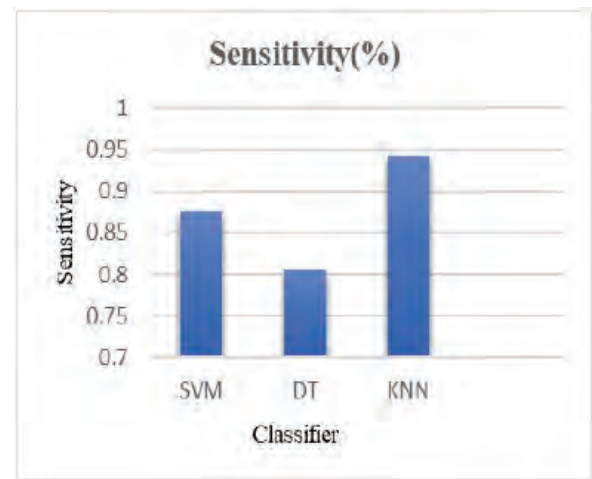


Fig.8(c). Graphical reseparation of Sensitivity

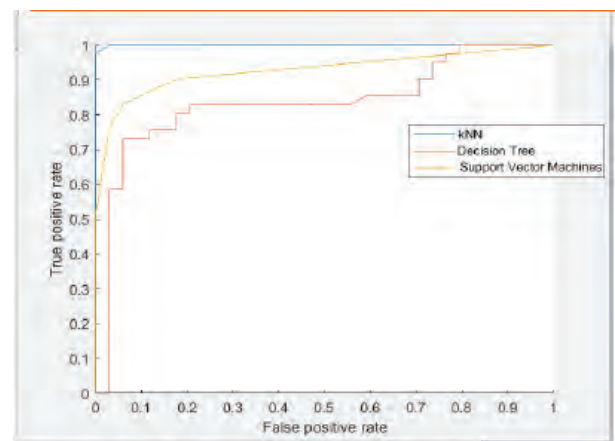


Fig. 8. AUC results for SVM , DT, and CNN

The Area Under the Curve is plotted in Fig. 8. using SVM, DT, and kNN classifiers. It is observed from the plot KNN better performance of classifying the positive class in the dataset.

CONCLUSIONS

The proposed work uses digital image processing techniques like RGB to Gray conversion, nearest-neighbor interpolation, and BPDFHE are used in pre-processing. The k-Means clustering and GLCM are used to segment the diseased ROI region of leaf samples and extract the important features of the leaf. The machine learning techniques of SVM, DT, and K-NN are used to recognize diseased or healthy leaves. The experimental results show Tomato and soybean diseases were successfully detected and classified with an accuracy of about 99.20%. The performance of the proposed K-NN classifier model obtained better Accuracy than the other two state-of-the-art classifier models. In future work, use a large number of datasets for the detection and classification of more crop diseases, and it will improve the results for using hybrid techniques to extract important features.

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Development of Fiber Optic Sensor for Milk Adulteration Detection

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ABSTRACT

Milk is a primary big food source consumed worldwide, valued for its rich nutritional profile and versatility. Milk provides a balanced mix of macronutrients and micronutrients essential for human health. Milk adulteration has become a growing concern as fraudulent practices are employed to meet the increasing public demand for milk. Milk adulteration involves adding harmful substances like urea, hydrogen peroxide, and toxins, compromising its quality and posing serious health risks, making it a critical issue for consumer safety. Detecting adulteration is a complex challenge that requires innovative and efficient solutions. This paper proposes an intensity modulation-based fiber optic sensor (IMFOS) for the detection of cow milk adulteration. The fiber optic sensor configuration includes a light source, a fiber optic cable, and a photo-detector. The light source transmits light through the fiber optic cable, and the photo-detector detects changes in light intensity corresponding to the milk's refractive index. The sensor output is observed when cow milk is adulterated with water. There is linear relationship between the various concentration of milk and the sensor output voltage. IMFOS is valued for its affordability, and low cost.

KEYWORDS: *Milk adulteration, Water, Intensity modulation, Extrinsic, Non- contact fiber optic sensor.*

INTRODUCTION

One of the most prevalent food sources in the world, milk is prized for its outstanding nutritional value and adaptability. In addition to a wide variety of vital micronutrients like vitamins and minerals, it provides a well-balanced combination of macronutrients including proteins, carbs, and fats [1,2]. Because of its special makeup, milk is a staple food in many cultures and plays a vital role in human growth and health. Milk continues to be an essential component of diets for people of all ages, whether it is consumed straight or as

a base ingredient in a wide range of foods and drinks.

Milk adulteration has appeared as an important concern in recent years, driven by corrupt performs aimed at meeting the increasing demand for milk. The materials like water, urea, hydrogen peroxide, and other poisons are frequently added during this adulteration process, which lowers the quality of milk and puts customers' health at considerable danger. Since milk is a common food in many countries, maintaining its purity is essential for everyone's health and safety. However, detecting milk adulteration is a multifaceted challenge

that demands the development of innovative and efficient solutions to safety consumer well-being and maintain belief in this vital food source [3,4]. Intensity modulation Fiber Optic Sensor (IMFOS) are simple and cost-effective, utilizing light-emitting diodes (LEDs) as their light source.

In contrast, coherent detection sensors, such as interferometry sensors, are more complex and expensive but provide higher sensitivity and resolution. The affordability of IMFOS makes them an attractive option for various applications. IMFOS detect environmental changes by measuring variations in light intensity. These changes occur due to light attenuation caused by factors such as transmission loss and reflection. These mechanisms are fundamental to the sensor's operation, making it effective for monitoring changes in the surrounding environment [5-7]. IMFOS is a widely used technique for detecting changes in light intensity in response to environmental variations. Various techniques are employed for milk adulteration detection, including contact-based methods and chemical analysis [8-10]. However, the development of a fiber optic sensor offers a non-contact approach, making it highly hygienic compared to traditional systems. Unlike contact-based methods, which require direct interaction with the milk, or chemical techniques that may involve introducing reagents, fiber optic sensors operate without physical contact, eliminating the risk of contamination. This feature makes them particularly suitable for applications demanding stringent hygiene standards. Moreover, while some sensor types may fail under specific conditions, fiber optic sensors are designed for reliable performance, enhancing their appeal for milk quality monitoring.

DESIGN OF NON-CONTACT IMFOS

A 20 cm bundled plastic fiber optic cable probe that serves as a light transmitter and receiver makes up an IMFOS. While the receiver probe is attached to a photodetector that detects changes in the light signal, the transmitter probe is coupled to an LED light source that emits light with wavelengths between 400 and 700 nm. With a wide wavelength response range of 400–1100 nm, the photodetector agreements precise environmental change detection. The photodetector converts the detected light signal into an electrical

signal, generating an output voltage that a digital voltmeter measures.

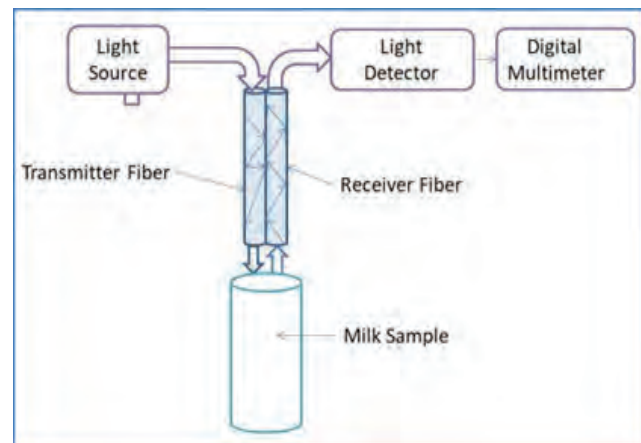


Fig. 1: Design of non- contact IMFOS

EXPERIMENTAL SETUP

In a setup designed to detect cow milk adulteration, a light source, such as an LED, emits light through a transmitter fiber, directing it onto the milk's surface. Pure milk has a higher refractive index due to its dense and complex composition. Pure milk typically has a refractive index between 1.35 and 1.37, depending on temperature and fat content. By contrast, water has a refractive index of roughly 1.33 [11,12].

A receiver fiber gathers the reflected light from the milk's surface and sends it to a photodetector, which transforms the light's intensity into a voltage. A digital multimeter is then used to measure this output voltage. When the cow milk is pure, it reflects the maximum amount of light due to its natural optical properties, resulting in a higher output voltage. However, as adulterants such as water are added to the milk, the concentration of pure milk decreases. This dilution alters the refractive index and scattering properties of the milk, reducing the amount of light reflected from the surface.

For instance, adding 10% water to pure milk diminishes the reflected light, causing a corresponding decrease in the photodetector's output voltage. As the concentration of adulterants increases, the intensity of reflected light and output voltage decrease progressively. This makes the method a sensitive and effective approach for detecting milk adulteration.



Fig. 2: Experimental setup

RESULT AND DISCUSSION

The sensor response was assessed by measuring the output voltage of milk with varying water concentrations. The experiment used 10 mL of pure cow milk, to which water was added incrementally at concentrations of 0% (pure milk), 10%, 20%, 30%, 40%, and 50%. Thorough mixing was achieved by shaking the samples to ensure uniform distribution of water. The results showed that for every 10% increase in water content, the sensor's output voltage decreased by approximately 2.1 mV.

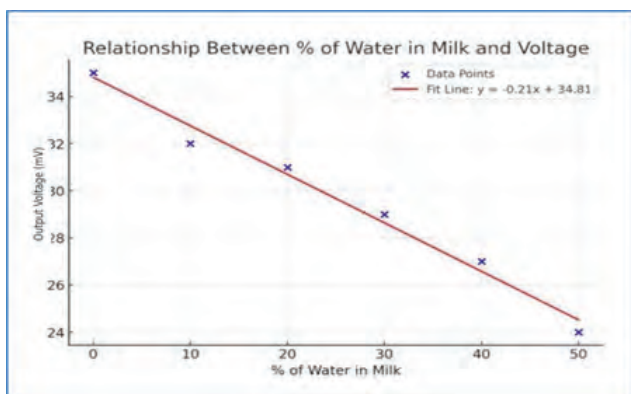


Fig. 3: Sensor response for different milk concentration

In fig.3: the graph exhibits a negative correlation, indicating that as the percentage of water in milk increases, the output voltage decreases. This trend is likely due to the dilution effect of water on the physical or chemical properties of milk, which directly impacts the sensor's voltage measurements. This behavior highlights the sensor's capability to detect minor changes in milk composition caused by water adulteration. The sensor offers sensitivity of -0.21 mV per 1% water in milk.

CONCLUSION

The IMFOS demonstrates high sensitivity with intensity-based modulation, effectively detecting significant concentrations of water adulteration in milk. A notable advantage of this sensor is its non-contact operation, ensuring a hygienic and efficient detection process. This makes it a reliable and practical tool for maintaining the quality and purity of milk.

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Joystick-Controlled Wheelchair: A User-Friendly Mobility Solution for the Physically Challenged

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ABSTRACT

This paper presents the design and development of a joystick-controlled wheelchair aimed at enhancing mobility for physically challenged individuals. The approach makes use of robotic and cognitive control technology to provide a wheelchair that is user-friendly and efficient in settings like public spaces and hospitals. A joystick, an L293D motor driver IC, two DC motors, and an Arduino ATmega328P microprocessor are used to accomplish the essential functions. The microcontroller utilizes an analog-to-digital converter (ADC) to handle the analog voltage signals that are converted from user inputs via the joystick. The wheelchair's left, right, forward, and reverse motions can all be precisely controlled using microcontroller, which is programmed using the Arduino IDE and transmits digital signals to the motor driver. Because directional motions correlate to certain motor activities and the neutral position of the joystick stops the wheelchair, the design guarantees intuitive operation. The system is powered by a 12V battery, which guarantees effective operation.

The concept presents a cost-effective and easily accessible alternative for those with mobility issues by successfully implementing joystick-based wheelchair control. The system's usefulness for individuals with more severe physical restrictions can be further increased by future improvements including speech recognition, picture processing, and sensor-based obstacle identification. This effort is an important step in using assistive technology to empower people with impairments.

KEYWORDS: *Wheelchair prototype, Arduino ATmega328P, DC motor, Physically challenged.*

INTRODUCTION

This study highlights the importance of wheelchairs in improving the lives of millions of people with disabilities. It is estimated that 113.8 million people need wheelchairs for mobility, and wheelchair technology has advanced significantly over time. Traditional wheelchairs either require assistance from a third party to push the chair or rely on manual control of two wheels, but people with several disabilities or

muscle weakness may not be able to operate manual wheelchairs, which makes them dependent on others for mobility. This dependency makes it difficult for people with physical disabilities to become independent, and this paper investigates the creation of a system that allows wheelchair control via a smartphone application. This research investigates the creation of a system that permits wheelchair control via a smartphone application in order to address this problem and encourage autonomy for people with mobility disabilities. Wheelchair users

may now operate the equipment independently thanks to this creative solution, which also improves their quality of life [1-3].

Our project's goal is to create a wheelchair with motors that can be driven by a joystick for those with physical limitations. To improve usability and usefulness, the project makes use of robots and sophisticated control systems. Particularly in settings like hospitals or public areas where wheelchairs are regularly used, the system's accurate and user-friendly joystick-based navigation makes it extremely useful. The goal of this creative strategy is to provide those with physical limitations more freedom and movement.

LITERATURE REVIEW

For those with physical disabilities who are unable to move like regular people, a wheelchair with a joystick control is essential. They may use the joystick to manually control their mobility in this wheelchair. An Arduino board receives commands from the joystick, and the ATmega328p controller interprets them. The wheelchair's motion is then managed by the motor driving IC. The wheelchair is easy to use and is made for people who are unable to walk. To identify impediments in its route, the circuit might be equipped with an extra sensor unit. Wheelchairs with voice recognition and image processing can also be utilized by people who are unable to move their hands or legs [4]. The researcher evaluates the affordability and cost effectiveness of Economy Priced Electric Wheel Chairs (EWC) for the disabled people.

This project can also be counted as a brilliant initiative for the betterment of physically handicapped and disabled people's lifestyle [5].

The researcher introduces an innovative automated wheelchair controlled by the user's neck position, utilizing sensor technologies, radar, and ultrasonic systems. This innovative system uses LEDs, photo sensors, motors, and a microcontroller to enable seamless wheelchair movement. The system is accessible to most disabled individuals, except those unable to turn their necks. The design enhances independence and mobility, and the wheelchair's functionality can be expanded and refined with advanced technologies in the future.

[6]. The proposed voice-activated powered wheelchair,

which combines joystick control with joystick control, is designed to be suitable for physically disabled individuals who cannot control their movements, especially hands. The system uses a voice recognition system to recognize voice commands and sends coded digital signals to a microcontroller, controlling the wheelchair accordingly. The prototype wheelchair can handle a pay load of 120kg and can deliver up to 37.5A at 12V. The paper discusses the joystick control algorithm, closed-loop current control, and voice recognition system, highlighting the reduced effect of jerk with closed-loop current control [7]. Advancements in AI and robotics have spurred interest in intelligent wheelchairs (iWheelchairs), which enhance mobility for the elderly and disabled, promoting independent living. This paper introduces a newly developed iWheelchair utilizing advanced DSP technology to process data from a joystick and eight ultrasonic sensors. These sensors enable real-time environmental detection, ensuring safe navigation and obstacle avoidance during joystick-controlled operation [8]. This review highlights advancements in electric-powered wheelchair (EPW) control technologies, focusing on velocity, traction, suspension, and stability control, as well as innovations in stair-climbing and navigation systems. By synthesizing past research, it emphasizes the progress in enhancing functional mobility for EPW users and offers insights into future directions for improving these technologies [9]. This paper focuses on the design and control of an electric-powered wheelchair (EPW) by implementing a PID controller optimized through a genetic algorithm for DC motor speed control. Simulations conducted in MATLAB/SIMULINK demonstrate the effectiveness of the PID controller in achieving precise speed regulation, validating the approach for efficient EPW operation [10].

This paper discusses the design and implementation of three self-controlled wheelchair schemes: joystick-controlled, gesture-controlled, and voice-controlled wheelchairs. Using UPPAAL software for design verification, various test cases were applied under different environmental conditions. The results highlight the benefits of a hybrid model combining voice and gesture control for improved efficiency. Additionally, the prototype designs have potential applications beyond wheelchairs in other domains [11].

This study introduces a novel hand gesture- controlled electric wheelchair (EWC) designed for patients unable to operate a standard joystick. The system uses a camera to capture hand movements, which are processed in real-time using visual recognition algorithms and AI software. Unlike traditional interfaces that offer limited directional control at a fixed speed, this new system enables movement in multiple directions with variable speed, providing flexibility comparable to a joystick and enhancing user experience [12]. The review highlights limited evidence on the effectiveness of current power wheelchair control interfaces. A survey of 200 clinicians revealed significant challenges in teaching individuals with severe disabilities to maneuver power wheelchairs. Case studies and anecdotal evidence suggest a subset of patients face severe limitations or inability to achieve mobility with existing technologies, emphasizing the need for innovative navigation solutions [13]. This paper introduces an intelligent wheelchair controlled through head gesture recognition. The system identifies commands like head up, down, left, and right by tracking the lips' position within a fixed rectangular frame. These gestures correspond to wheelchair movements. Experimental results demonstrate the system's effectiveness in enabling wheelchair control through head gestures [14-16].

METHODOLOGY

The joystick starts in its neutral, central position. While in this position, the motors remain stationary. When the joystick is moved, it adjusts potentiometers that generate analog voltage values corresponding to the movement. These values are sent to the Arduino board through analog input pins. Through the use of an inbuilt Analog-to-Digital Converter (ADC), the Arduino converts these analog impulses into digital data. Digital output pins are then used to transmit this digital data to the motor driver IC (L293D). The L293D IC features two H- bridge circuits, which allow for precise control of the two DC motors. These motors can rotate in forward or reverse directions and steer left or right based on the input logic applied to pins 2 & 7 and 10 & 15 of the IC. For example:

- Moving the joystick slightly forward increases the voltage at the ADC, causing the motors to drive forward.

- Returning the joystick to the center stops the motors.
- Moving the joystick backward decreases the voltage at the ADC, making the motors reverse.

The same logic applies to left and right movements of the joystick. The system is controlled by a software program embedded in the FLASH memory of the ATmega328P microcontroller, which interprets joystick inputs and sends corresponding instructions to the motor driver IC, enabling smooth operation of the wheelchair.

We developed a prototype chair model to validate the functionality and performance of the joystick-controlled wheelchair system before scaling to a full-sized version. Numerous benefits are provided by the wheelchair, including as safety and stability, autonomy in usage, intuitive design, accurate navigation, adjustable settings, extendable functionality, and sensor integration. Its regulated pace reduces fear and increases the user's sense of safety by ensuring steadiness, particularly on hills. Users can independently drive the wheelchair thanks to the joystick controls, which is in line with their natural expectations. The Arduino-based device is appropriate for small or cramped areas since it makes it simple to adjust the joystick's sensitivity and reaction. Future additions like GPS navigation or Bluetooth connectivity can improve usage even more [17-20]. Figure 1 shows complete block diagram of proposed system and Fig.2 shows circuit diagram.

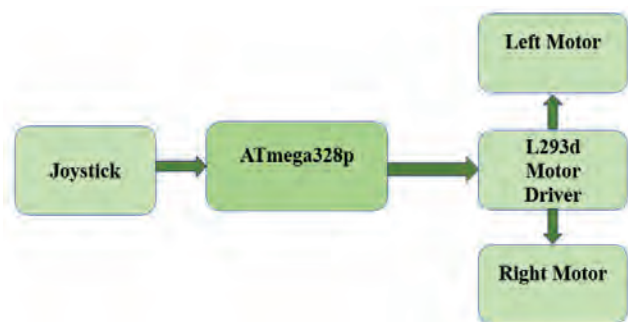


Fig.1. Block Diagram of proposed system.

WORKING PRINCIPLE

To begin, the joystick is positioned exactly at its center. While it remains in this central position, the motor stays inactive. When the joystick is moved, the potentiometer generates analog voltage values, which are transmitted

to the Arduino board via an analog data pin. The Arduino processes these values and sends them to an Analog-to-Digital Converter (ADC). The ADC converts the analog signals into digital form, which is then delivered to the motor driver IC (L293D) through the digital data output pin.

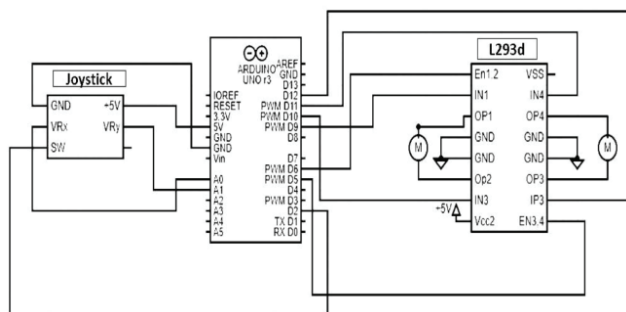


Fig. 2. Complete system Diagram

The L293D includes two integrated H-bridge driver circuits, allowing simultaneous control of two DC motors. These motors can move in forward, reverse, left, or right directions based on the logic inputs provided to pins 2 and 7 or pins 10 and 15. When the joystick is slightly pushed forward, the input voltage to the ADC rises, causing the motor to rotate forward. Returning the joystick to its center stops the motor. Similarly, moving the joystick backward reduces the voltage, triggering reverse motor rotation. To stop the motor again, the joystick must return to the central position. The motors' forward, reverse, left, and right movements are determined by corresponding joystick actions. A software program embedded in the internal flash memory of the ATmega328P microcontroller manages these operations. The two DC motors are controlled by the L293D motor driver IC and the Arduino ATmega328P microcontroller based on joystick inputs. Figure 3 shows presents snapshot of proposed Joystick-Controlled Powered Wheelchair Prototype.

RESULT

The programming for the system was developed using the Arduino IDE and successfully uploaded to the Arduino board. The joystick effectively provided seamless control over the wheelchair's movements. After integrating all components according to the circuit diagram, the system functioned as expected, delivering the desired outcomes. The final implementation

included key components such as a joystick, Arduino ATmega328P microcontroller, L293D motor driver IC, two DC motors, and a 12V battery. The project was successfully completed, demonstrating smooth operation and control of the wheelchair system.

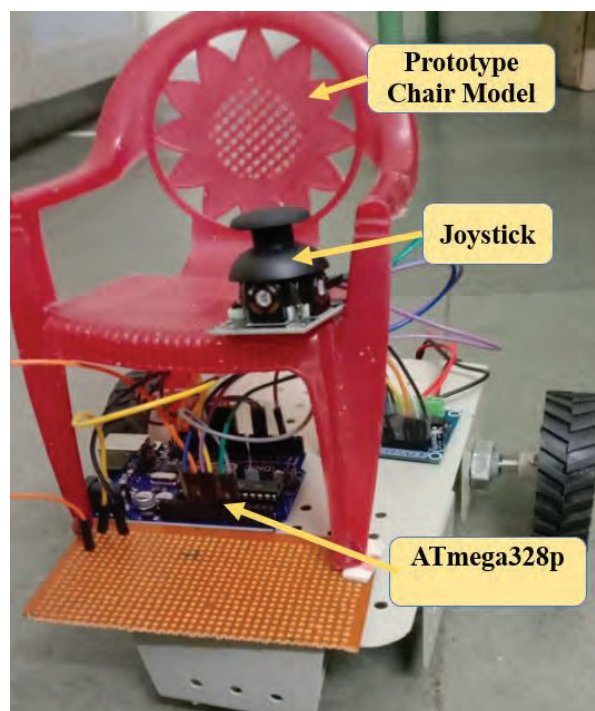


Fig. 3. Proposed Joystick-Controlled Powered Wheelchair Prototype

CONCLUSION

This project presents the design and development of a joystick-controlled wheelchair tailored for individuals with physical disabilities who cannot walk. The system enables users to independently navigate using hand-operated joystick controls, providing a practical and user-friendly solution.

For individuals unable to move both their hands and legs, alternative technologies such as voice recognition or image processing-based wheelchairs can be explored to address their specific needs. Furthermore, the functionality of the system can be enhanced by integrating additional features such as obstacle detection sensors to ensure safer operation and improved usability.

This design serves as a stepping stone towards creating more inclusive and intelligent mobility solutions for people with diverse physical challenges.

FUTURE OF WHEELCHAIR TECHNOLOGY

- Advanced sensor integration for obstacle detection, environmental mapping, and autonomous navigation.
- Smart technology integration for remote monitoring and control via smartphones or other devices.
- Machine learning algorithms for personalized user experience.
- Use of voice-activated systems or touchscreens for wider accessibility.
- Energy-efficient technology and intelligent battery management for extended wheelchair usage.
- Advancements in accessibility features like movable seats and assistive technology for improved user comfort.

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Comparative Analysis of MFCCs, Wavelets, and Time-Frequency Features for Sign Language Recognition

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ABSTRACT

Sign language recognition plays a pivotal role in fostering inclusivity by bridging communication barriers for individuals with hearing and speech impairments. Multimodal approaches, integrating surface electromyography (sEMG) and accelerometer signals, a rich foundation for gesture recognition. However, the effectiveness of various feature extraction techniques in capturing critical patterns for accurate recognition remains an area of active exploration. This study leverages Mel-Frequency Cepstral Coefficients (MFCCs) as a feature extraction method for processing sEMG and accelerometer data. The dataset includes both modalities along with class labels representing different signs. The performance of MFCCs is evaluated against alternative techniques, including Wavelet Transform, Short-Time Fourier Transform (STFT), Hilbert Transform, and time-domain features. A random forest machine learning algorithm is employed to classify the gestures and assess accuracy. Feature fusion methods are also explored to enhance recognition by combining complementary strengths of the multimodal data. The MFCC-based approach achieved a remarkable accuracy of 94%, outperforming other feature extraction methods. The results underscore the ability of MFCCs to capture essential spectral and temporal patterns from multimodal data, making it a robust choice for sign language recognition. Additionally, the study highlights the potential of feature fusion techniques to further enhance recognition performance by leveraging multimodal synergies. The findings emphasize the efficacy of MFCC-driven feature extraction in developing accurate and efficient real-time sign language recognition systems. This comprehensive analysis provides valuable insights into the role of spectral features in multimodal gesture recognition, paving the way for advancements in assistive technologies.

KEYWORDS: *Sign language recognition, Mel frequency cepstral coefficient(MFCCC), sEMG signals, Wavelet, Time-frequency, STFT, Random forest, Machine learning techniques.*

INTRODUCTION

Sign language recognition is a transformative area of research aimed at enabling seamless communication for individuals with hearing and speech impairments. As sign languages are inherently multimodal, they combine hand gestures, facial expressions, and body movements to convey meaning. The ability to accurately recognize these gestures is vital for developing assistive technologies that can bridge communication barriers. However, the complexity and variability of sign gestures present significant challenges, necessitating

robust methods for feature extraction and classification. Surface electromyography (sEMG) and accelerometer data have emerged as promising modalities for gesture recognition [24]. sEMG captures muscle activity, providing insights into fine-grained motor movements, while accelerometer signals complement this by tracking dynamic motion. The fusion of these signals enables a more comprehensive understanding of gesture dynamics. Despite their potential, effectively processing and classifying these signals requires advanced feature extraction techniques capable of capturing both spectral and temporal characteristics.

This study introduces a novel application of Mel-Frequency Cepstral Coefficients (MFCCs) for feature extraction in sEMG and accelerometer-based sign language recognition. Traditionally used in speech processing, MFCCs excel at extracting spectral features from non-stationary signals, making them well-suited for capturing the intricate patterns in multimodal gesture data. The research explores the efficacy of MFCCs in recognizing sign gestures and compares their performance with other feature extraction techniques, including Wavelet Transform, Short-Time Fourier Transform (STFT), Hilbert Transform, and Time-Domain Features.

By integrating MFCC features with advanced machine learning classifiers, this work achieves high recognition accuracy, demonstrating the viability of MFCCs as a core feature extraction method. Additionally, this study evaluates the contribution of multimodal feature fusion in enhancing recognition performance, underscoring the complementary strengths of sEMG and accelerometer data. Through comprehensive experimentation and analysis, this research provides valuable insights into the role of spectral features in multimodal gesture recognition, paving the way for developing real-time, robust sign language recognition systems.

LITERATURE SURVEY

Gesture recognition has been a critical area of research, especially for applications such as sign language interpretation, robotics, and assistive technologies. Leveraging multimodal data, including surface electromyography (sEMG) and accelerometer signals, offers a promising avenue for robust and accurate recognition systems. This section reviews the key contributions in sEMG-based gesture recognition, accelerometer-based approaches, feature extraction techniques, and multimodal fusion methods.

W. Wei et al. proposed a multi-view deep learning approach for sEMG-based gesture recognition, emphasizing temporal and spectral feature extraction for robust performance [1]. Phinyomark et al. introduced novel time-domain features for EMG pattern recognition, demonstrating their effectiveness in low-complexity systems [2]. These studies underline the importance of feature selection in enhancing

the performance of sEMG-based systems but often lack integration with complementary modalities like accelerometers.

Bao and Intille et al. demonstrated the efficacy of acceleration data in activity recognition, providing foundational techniques for segmentation and feature extraction [3]. Ravi et al. (2005) explored the classification of acceleration-based features using machine learning, offering a baseline for gesture-related studies [4]. However, these approaches often face limitations in distinguishing fine-grained gestures without additional signal modalities.

Atzori et al. (2014) employed multimodal fusion techniques combining sEMG and motion data for robotic prostheses, showcasing the potential for enhanced accuracy [5]. Chung et al. (2019) explored fusion techniques for human activity recognition, emphasizing the complementary nature of multimodal data sources [6]. These studies demonstrate the benefits of multimodal approaches but lack comparative evaluations of feature extraction methods.

Logan (2000) introduced Mel-Frequency Cepstral Coefficients (MFCCs) for signal processing, which have since been widely adopted in speech and audio applications. Their application to sEMG and accelerometer data, however, remains underexplored [7]. Phinyomark et al. (2012) reviewed wavelet transform-based techniques for EMG signals, demonstrating their effectiveness for time-frequency analysis [8]. Tsinganos and Skodras (2018) compared various feature extraction methods, including MFCCs, STFT, and wavelets, for EMG signal analysis, providing a basis for this study's comparative framework [9].

Breiman (2001) introduced the Random Forest algorithm, which has become a popular choice for multimodal gesture recognition due to its robustness and interpretability [10].

While previous studies have explored sEMG and accelerometer data independently or in combination, there is limited research on comparative evaluations of feature extraction methods, particularly the application of MFCCs to multimodal gesture recognition. Furthermore, most approaches lack systematic analyses of feature fusion's impact on classification performance.

PROPOSED METHODOLOGY

The methodology for gesture recognition using sEMG and accelerometer data involves pre-processing the raw signals and extracting both time-domain and frequency-domain features to capture the dynamic nature of gestures. Initially, features like Root Mean Square (RMS), Mean, Variance, and Zero Crossing Rate (ZCR) are computed to characterize the amplitude, variability, and frequency of the signals. Frequency-domain features are derived using methods such as the Short-Time Fourier Transform (STFT), Hilbert Transform, and Mel-Frequency Cepstral Coefficients (MFCC), which provide rich time-frequency representations of the data. Wavelet transforms and recurrence plots are also used to capture localized and temporal signal patterns. The extracted features from sEMG (9000 columns) and accelerometer data (3600 columns) are normalized and concatenated into feature vectors. These vectors are input into a Random Forest classifier for training and classification. Comparative analysis of the different feature extraction methods reveals MFCC and STFT as highly effective, achieving recognition accuracies of 94% and 95%, respectively, underscoring their suitability for capturing the nuanced characteristics of multimodal gesture signals.

Dataset Description

This study utilizes a multimodal dataset consisting of surface electromyography (sEMG) and accelerometer signals collected during the performance of various sign language gestures. The dataset comprises:

- sEMG Features: 9,000 columns representing muscle activity.
- Accelerometer Features: 3,600 columns from three tri-axis accelerometer sensors capturing motion dynamics.
- Class Labels: A single column indicating the 6 classes of each gesture.

Six different sign gestures used in this study with detailed movement are tabulated in table 1:

Table 1 Sign gestures with hand movement description

Sr. No	Sign Gesture	Encoding	Description
1	Good	0	Position the right zero hand in front of the chest, facing out.
2	Bad	1	Place right Fist, facing out, at chest level, move forward and end as Five hand, facing down.
3	Sorry	2	Place right Fist, facing in, on the left side of the chest and move in circles.
4	Thank You	3	Place both Open hands, facing in, on the chin, move forward and apart.
5	Right	4	Make a checkmark with your right hand at chest level, facing in.
6	Wrong	5	Make a multiplication mark with your right hand at chest height, facing forth.

The dataset is pre-processed to ensure uniformity, remove noise, and standardize feature scales for compatibility in the feature extraction and classification pipeline. The details of dataset can be found at [12]

Feature Extraction

This study is concentrated on to compare various feature extraction methods for sEMG & accelerometer signals which can be applied to machine learning algorithms. The feature extrication methods are listed below.

1) Mel-Frequency Cepstral Coefficients (MFCCs)

MFCC has achieved improves accuracy in feature extraction of sEMG signals [23]. MFCCs are extracted from both sEMG and accelerometer signals to capture spectral and temporal information. The process involves:

- Pre-emphasis: The pre-emphasis filter is applied to enhance the high-frequency components of the signal:

$$y[n] = x[n] - \alpha x[n-1] \quad (1)$$

where

$x[n]$: Original signal.

$y[n]$: Pre-emphasized signal.

α : Pre-emphasis coefficient (commonly 0.95)

- Frame Segmentation: Dividing signals into overlapping frames.

$$x_k[n] = x[n + k.H] \quad (2)$$

$$k = 0, 1, 2, \dots, N_f - 1$$

where

$x_k[n]$: frame k.

H: Frame Hop size.

N_f : Number of frames

- Windowing: Applying a Hamming window to reduce spectral leakage.

$$w[n] = 0.54 - 0.46 \cos\left(\frac{2\pi n}{N-1}\right) \quad (3)$$

The windowed frame becomes:

$$x_k[n] = x_k[n].w[n] \quad (4)$$

- Discrete Fourier Transform (DFT)

The Fourier Transform is applied to each frame to convert it to the frequency domain:

$$X_k[m] = \sum_{n=0}^{N-1} x_k[n] e^{-j \frac{2\pi mn}{N}} \quad (5)$$

Where:

$X_k[m]$: Frequency domain representation of frame k

N: Number of samples per frame.

- Mel Filter Bank

The Mel scale is applied to approximate human auditory perception:

$$f_{mel} = 2595 \cdot \log_{10} \left(1 + \frac{f}{700} \right) \quad (6)$$

The filter bank energy for each Mel filter is computed as:

$$E_m = \sum_{m=f_{low}}^{f_{high}} |X_k[m]|^2 \cdot H_m[m] \quad (7)$$

where $H_m[m]$ is the triangular filter bank weight.

- Logarithmic Compression

To compress the energy, the logarithm is applied:

$$S_m = \log(E_m)$$

- Discrete Cosine Transform (DCT)

The DCT is applied to decorrelate the Mel coefficients and produce compact MFCCs:

$$C[n] = \sum_{m=0}^{M-1} S_m \cos\left(n \cdot \frac{(2m+1)\pi}{2M}\right) \quad (8)$$

$$n = 0, 1, 2, \dots, N_c - 1$$

where N_c is the number of MFCC coefficients.

Wavelet Transform (Comparative Method)

The wavelet transform is widely used in biomedical signal analysis [11]. In this study the wavelet transform is applied to both signals i.e. sEMG & Accelerometer signals to decompose these signals. The wavelet transform decomposes the signal into approximation and detail coefficients:

$$W(s, t) = \int_{-\infty}^{\infty} x(t) \Psi^* \left(\frac{t - \tau}{s} \right) dt \quad (11)$$

$\Psi(t)$ Wavelet basis function

s: Scale parameter.

τ : Translation parameter.

STFT (Comparative Method)

The Short-Time Fourier Transform (STFT) is one of the earliest techniques developed for time-frequency analysis. It involves transforming a longer time-domain signal into shorter segments of equal length. The Fourier Transform is then applied to each of these shorter segments, enabling the analysis of the signal in both time and frequency domains [12] [13].

The STFT decomposes a signal into its frequency components while preserving temporal information.

For gesture recognition:

- It captures the time-varying nature of gestures.
- It provides a spectrogram, which is a visual representation of frequency vs. time.
- Extracted features from the spectrogram can enhance classification performance.

The Short-Time Fourier Transform is defined as:

$$\text{STFT}(x(t)) = \int_{-\infty}^{\infty} x(\tau)w(\tau - t)e^{-j\omega t}d\tau \quad (12)$$

where $w(\tau - t)$ is the window function.

Hilbert Transform

The Hilbert Transform is used in the context of signal analysis to extract the analytic representation of a signal, which provides both amplitude and phase information. For sEMG and accelerometer signals, this can help analyse the temporal and frequency characteristics, capturing intricate patterns that are not directly visible in the raw signal [22].

The analytic signal generated by the Hilbert Transform is defined as:

$$z(t) = x(t) + j\mathcal{H}[x(t)] \quad (13)$$

Time-Domain Features

The time domain represents the behaviour of a signal over time and has been widely utilized in biological systems, engineering applications, and research. Many researchers favor time-domain methods for signal classification due to their reduced complexity in feature extraction, low sensitivity to environmental noise, and ease of implementation. This approach is particularly effective for calculating features directly from raw EMG data in time series [14] [11]. The performance of a pattern classification system heavily relies on the selection of features used to represent the raw EMG signals [17]. In gesture recognition using sEMG and accelerometer data, time-domain features like Root Mean Square (RMS), Mean, Variance, and Zero Crossing Rate (ZCR) are essential for capturing signal characteristics. These features provide statistical summaries and temporal dynamics, making them valuable for classifying gestures.

Root Mean Square (RMS): The RMS is a measure of the signal's energy and provides information about the signal's amplitude over a time window:

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N x_i^2} \quad (14)$$

- sEMG Data: RMS represents muscle activation levels, differentiating gestures based on the intensity of muscle contractions.
- Accelerometer Data: RMS reflects the magnitude of motion or acceleration, distinguishing between slow and fast gestures.

Mean Absolute Value (MAV): The MAV is commonly used in muscle activation detection [20]. The Mean is the average value of the signal over a time window:

$$mean = \frac{1}{N} \sum_{i=1}^N x_i \quad (15)$$

- sEMG Data: The mean reflects baseline muscle activity and helps detect gestures involving sustained or relaxed muscle states.
- Accelerometer Data: The mean provides information about the steady-state motion or posture during gestures.

Variance: Variance measures the signal's dispersion or variability over a time window:

$$mean = \frac{1}{N} \sum_{i=1}^N x_i \quad (16)$$

- sEMG Data: Variance identifies gestures with variable muscle activations, such as transitions between movements.
- Accelerometer Data: Variance highlights variability in acceleration, distinguishing between jerky and smooth gestures.

Zero Crossing Rate (ZCR)

The ZCR is the rate at which the signal crosses zero within a time window:

$$ZCR = \frac{1}{N-1} \sum_{i=1}^{N-1} \mathbb{I}((x_i, x_{i+1}) < 0) \quad (17)$$

- sEMG Data: ZCR represents the frequency of muscle activation changes, distinguishing between high-frequency and low-frequency muscle movements [19] [21].
- Accelerometer Data: ZCR captures rapid oscillations or reversals in motion, differentiating between subtle and vigorous gestures.

The extracted features of each modality was split into training (80%), validation (10%), and test (10%) sets. This split facilitates robust model training, validation, and testing for gesture recognition tasks.

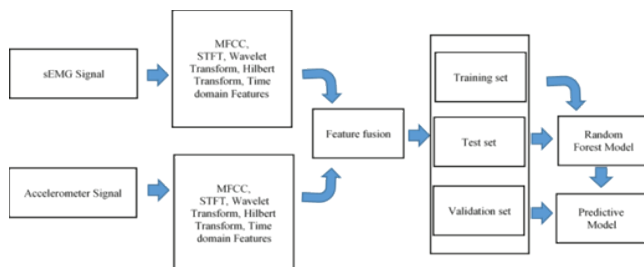


Fig. 1 Proposed methodology

To ensure the authenticity of the results, rigorous experimentation was conducted using WEKA Tool (Data Mining Tool) and Python, which are widely recognized for their robustness in signal processing and machine learning applications. The dataset, comprising sEMG and accelerometer signals, was preprocessed to eliminate noise and standardized to maintain consistency across all feature extraction methods. Multiple trials were performed to validate the reliability of the outcomes, and cross-validation techniques were employed to minimize overfitting. The random forest classifier was optimized using grid search for hyperparameter tuning, ensuring optimal performance. This comprehensive approach guarantees the credibility and reproducibility of the findings.

RESULTS AND ANALYSIS:

Performance of MFCC-Based Feature Extraction

The proposed method using MFCC features achieved an accuracy of 94.44%, demonstrating its effectiveness in capturing the spectral-temporal characteristics of both sEMG and accelerometer signals. The results validate that MFCC can effectively represent the dynamic and non-stationary nature of multimodal gesture signals.

Confusion Matrix Analysis

The confusion matrix reveals minimal misclassifications, with most gestures correctly identified. Classes with overlapping motion patterns showed slightly higher confusion rates, indicating the need for further feature refinement or additional contextual data.

Precision, Recall, and F1-Score

The high precision and recall values across all classes suggest robust gesture recognition with minimal false positives and negatives.

Comparative Analysis with Other Feature Extraction Methods

- MFCC and STFT achieved the highest accuracy, highlighting the importance of spectral features.
- Time-domain features and Hilbert Transform showed lower accuracy due to their inability to capture fine-grained spectral patterns.
- Wavelet Transform showed moderate performance, suggesting it captures multi-scale features but lacks the precision of MFCC or STFT.

The detailed comparative analysis for feature extraction technique is tabulated in Table 2.

Table 2 Comparative Analysis for feature extraction techniques

Feature Extraction Technique	Confusion Matrix	AUC-ROC Curve.
MFCC		
Wavelet Transform		
Short-Time Fourier Transform (STFT)		

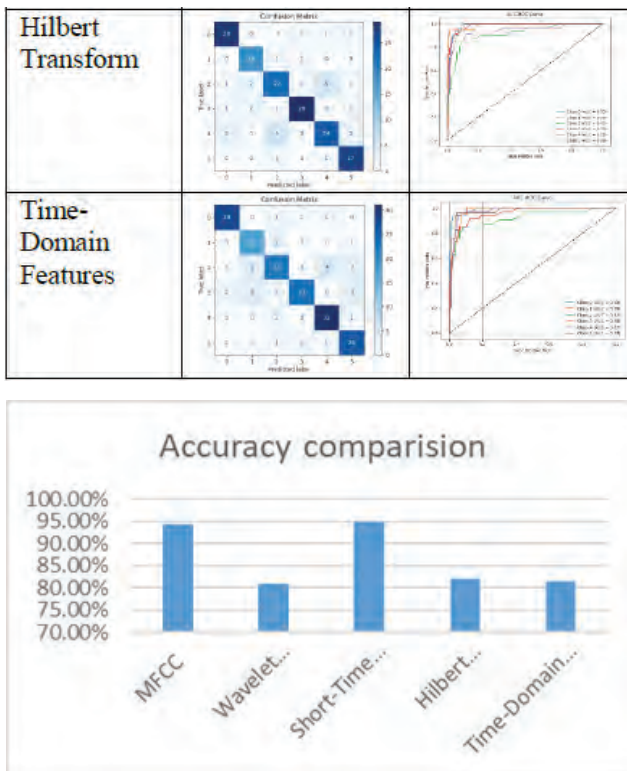


Fig. 2 Accuracy Comparison

CONCLUSION

This research demonstrates the efficacy of Mel-Frequency Cepstral Coefficients (MFCCs) in multimodal sign language recognition using surface electromyography (sEMG) and accelerometer data. By leveraging the spectral and temporal characteristics captured by MFCCs, the proposed approach achieved an accuracy of 94.44%, surpassing other feature extraction techniques, including Wavelet Transform, Short-Time Fourier Transform (STFT), Hilbert Transform, and Time-Domain Features. The results underscore the ability of MFCCs to represent non-stationary and dynamic patterns in multimodal gesture data effectively.

The study also highlights the importance of feature fusion, with the combination of sEMG and accelerometer signals significantly improving recognition accuracy compared to individual modalities. This fusion exploits the complementary nature of muscle activation and motion dynamics, enhancing the system's robustness in recognizing diverse gestures.

Furthermore, comparative analysis reveals that while

STFT offers similar performance to MFCCs, it comes with higher computational demands, making MFCCs a more suitable choice for real-time applications. Error analysis identified challenges in gestures with overlapping motion patterns, suggesting that incorporating additional modalities, such as visual data or contextual information, could further improve accuracy.

Declaration of No Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript titled "Comparative Analysis of MFCCs, Wavelets, and Time-Frequency Features for Sign Language Recognition." All authors have approved the manuscript, and no financial or personal relationships have influenced the research or its outcomes.

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A Comprehensive Review of Bidirectional Rectifiers and PWM Converters in Egenerative Energy Applications

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ABSTRACT

Regenerative energy plays a significant role in energy conservation by minimizing wastage, particularly in systems like elevators. Traditionally, braking energy was dissipated as heat, resulting in inefficiency. However, with advancements in technology, it is now possible to reuse this energy and redirect it back to the grid. Multilevel converters offer a promising solution for both medium and high-power drives, providing a more efficient alternative. Moreover, renewable energy systems often face fluctuations due to weather conditions, but harnessing regenerative energy helps counterbalance these inconsistencies, supporting a sustainable energy ecosystem. AC/DC converters, commonly built using thyristors and diodes, are used to generate controlled or uncontrolled DC power. They facilitate both unidirectional and bidirectional power flow, depending on the circuit design and application requirements. However, these rectifiers suffer from drawbacks like poor power quality due to harmonics, low efficiency, voltage distortion, rippled DC output, poor power factor, and large filter sizes. Modern advancements have introduced converters using solid-state devices like MOSFETs, IGBTs, and GTOs, commonly referred to as PWM rectifiers or multilevel converters. These offer improved efficiency and performance. Single-phase AC/DC PWM converters are widely used as utility interfaces in grid-connected renewable energy systems, ensuring efficient use of distributed energy resources (DERs) and enhancing power system stability.

KEYWORDS: *Regenerative energy, Elevators, Braking energy, PWM rectifiers, Multilevel converters.*

INTRODUCTION

Regenerative power involves the process of harnessing and reusing energy that would typically be wasted during mechanical or electrical operations. This principle plays a vital role in promoting energy conservation and sustainability and is extensively utilized across various industries to enhance efficiency and minimize energy usage. Diode rectifiers are unidirectional devices that prevent power transfer from the load back to the power supply [1], thereby inhibiting regeneration. However, certain applications, such as elevators and downhill conveyors, require converters with regenerative capability to enable bidirectional power flow. Various approaches can be employed to achieve this, including the use of bidirectional rectifiers or converters. This study provides an overview of general converter designs and conducts a comprehensive review of different bidirectional rectifier technologies [4].

PWM Rectifier

A single-phase three-level inverter, commonly referred to as an H-bridge, requires a complex input transformer to mitigate low-order harmonics. However, due to the diode bridge configuration, it is incapable of reversing power flow from the load to the supply [2]. To address this limitation in applications requiring regenerative capability, PWM rectifiers are employed as the front-end for individual cells.

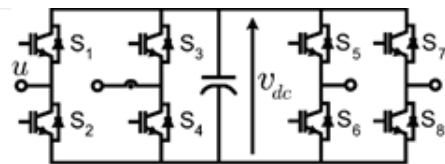


Fig. 1 H-bridge

This configuration shown in fig (1), known as the H-H cell configuration[2], necessitates a less complex transformer compared to the H cell topology and achieves

a high input power factor with appropriate transformer connections. The H-H cell has many advantages, but it also produces a DC-link ripple at twice the input voltage frequency ($2f_s$). This ripple can affect system performance and may require additional filtering. Proper design and control strategies help minimize its impact. Since rotating reference frames cannot be used for input current control, the control must be applied in the stationary frame. In this approach, sinusoidal references are used in the control loop to ensure proper operation. This method helps achieve accurate current regulation despite the limitations. Under such conditions, proportional-integral (PI) controllers are not recommended due to their inability to achieve zero steady-state error [2].

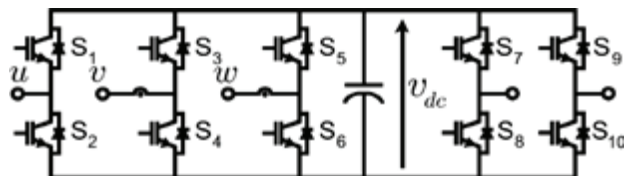


Fig. 2 H-H cell

In a three-phase PWM rectifier, as illustrated in Fig. 2, the circuit configuration requires combination semiconductor devices and extra current sensor. Complex transformer is required for three phase power conversion. These components work together to regulate the rectification process efficiently. However, this topology minimize the size of capacitor and eliminates pulsating power at double the input frequency. A most important benefit of this combination circuit is its capability to control currents. This increase control precision and system performance.

Six-Pack Inverter

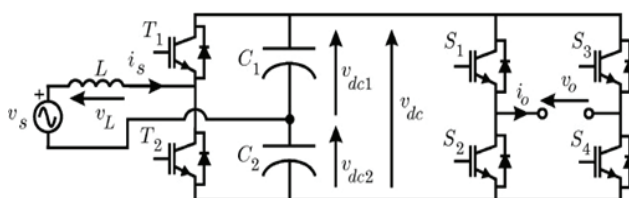


Fig. 3 Six pack inverter

Fig. 3[2] illustrate the six pack inverter, this allows the entire system to fit into a standard six-pack inverter module. The rectifier circuit is designed to work within a standard six-pack inverter module, utilizing only two

power semiconductors for rectification and four for the H-bridge inverter [2]. It naturally doubles the DC-link voltage to , requiring the input voltage to remain below. To maintain the same power rating as an H-H cell, the input current needs to be doubled. The DC-link voltage remains the same in both cases. By increasing the input current, the system ensures that the required power level is maintained. The rectifier-side IGBTs must handle voltage and double the current compared to an H-bridge rectifier. The DC-link consists of two capacitors, each operating at , and their capacitance must be doubled due to their series configuration. Proper operation mandates complementary switching of and to prevent short-circuiting or open-circuiting, with the DC-link voltage on each capacitor always exceeding the input voltage. This design optimizes power conversion efficiency while addressing specific current and capacitance requirements.

Single Phase Bidirectional Rectifier (SPBR)

This study presents the design and control of a single-phase bidirectional rectifier (SPBR) for EV (Electric Vehicles) battery charging, focusing on efficiency and power quality. It analyzes switching sequences, power losses, and device selection to optimize performance. The SPBR operates in two modes: boost rectifier with power factor correction (PFC) and SPWM (sine pulse width modulation) inverter, with minimal adjustments required. A key challenge of selecting the optimal operating frequency is addressed through comparative loss analysis of various power devices and magnetic circuits. A 10 kW prototype achieved 97.5% efficiency, unity power factor, and THD (total harmonic distortion) below 7%, demonstrating its effectiveness for energy-efficient EV charging.

SPBR Configuration

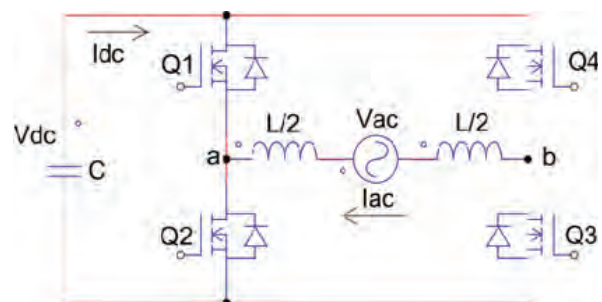


Fig. 4 Bidirectional Rectifier

The bidirectional converter works in two modes. When power flows from the DC side to the AC side, it acts as a Voltage Source Inverter (VSI). When drawing power from the mains, it functions as a PFC active boost rectifier, improving power quality. This dual operation makes it useful for applications like energy storage and renewable systems. The Sinusoidal Pulse Width Modulation (SPWM) technique is used to generate switching signals. This is done by comparing a sinusoidal voltage with a triangular wave, which helps maintain a high power factor and reduces total harmonic distortion (THD) on the AC side.

To improve performance, Unipolar PWM (UPWM) is used instead of Bipolar PWM (BPWM). UPWM doubles the switching frequency, which helps reduce DC-side current ripple and lowers harmonics on the AC side. This makes the system more efficient and ensures smoother power conversion. It is especially useful for fast bidirectional charging of lithium-ion EV batteries, making charging more reliable and effective.

Bidirectional AC– DC Converter

This section explains a high-efficiency isolated bidirectional AC-DC converter. It is designed for a 380-V DC power distribution system. It is built to control power flow in both directions while improving power conversion efficiency. This makes it useful for applications requiring stable and efficient energy transfer. The single-phase non- isolated bidirectional rectifier typically utilizes a conventional full-bridge structure. It can operate with two sinusoidal pulse width modulation (SPWM) techniques: bipolar and unipolar switching modes. A notable drawback of the bipolar switching mode is its need for a larger inductor to reduce input current ripple, as the peak-to-peak voltage of the inductor is more than double that of the unipolar mode. This requirement increases system complexity and component size.

High-power rectifiers face limited options for switching devices due to the limited availability of components suitable for high-power capacities.

Typically, IGBT modules or intelligent power modules (IPMs) are used in these applications. A fast recovery diode (FRD), characterized by a small reverse recovery

time (t_{rr}), is commonly employed[7]. In contrast, medium-power rectifier systems around 5 kW, such as those used in residential buildings, offer a broader selection of switching devices, including discrete IGBTs and MOSFETs. In bidirectional rectifiers using the unipolar switching method, the turn-on period of low-side switches is approximately 1.5 times longer than that of the high-side switches. To improve power conversion efficiency, low-side switches should have low conduction losses. This helps reduce energy waste and enhances overall system performance. To address this, soft-switching techniques employing additional passive or active snubber circuits is used. Specifically, commercial IGBTs without antiparallel diodes can be paired with SiC diodes to replace antiparallel FRDs, as SiC diodes do not exhibit reverse recovery (t_{rr}), mitigating reverse recovery issues. This combination of IGBTs and SiC diodes improve efficiency and reduce reverse recovery problems.

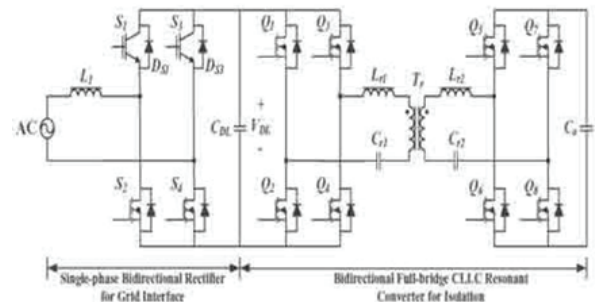


Fig. 5 Bidirectional AC to DC converter

CONCLUSION

The analysis of the Bidirectional Rectifier and Multilevel Converter highlights their key role in power conversion systems, offering efficient bidirectional power flow with high reliability. The Bidirectional Rectifier facilitates energy exchange between AC and DC systems, supporting applications like regenerative braking and renewable energy integration. The PWM Converter ensures precise control of voltage and current, improving system efficiency and minimizing harmonics. Together, these technologies enable energy-efficient solutions in modern power electronics, particularly in areas requiring reversible power flow, such as electric vehicles, grid-tied inverters, and energy storage systems.

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Speech-Driven Image Exploration for Visually Impaired Readers

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ABSTRACT

This paper presents a comprehensive system aimed at aiding visually impaired individuals in reading printed documents by integrating Optical Character Recognition (OCR) in addition with Deep Learning models. The system is structured with three main phases: Image-to-Text Synthesis, Image Separation from Documents, and Text-to-Speech (TTS) output. OCR is utilized to extract text from images, which is next converted to speech through TTS, providing auditory feedback to the user.

The system was evaluated using two distinct datasets: Higher Secondary School History Books (HSSHB) and the Flickr 8K dataset. The evaluation results demonstrated significant accuracy, with a greater success rate more in image-to-text conversion, accuracy in separating images from documents, and in generating captions. To enhance accessibility, NVDA (Non-Visual Desktop Access), an open-source software, was employed for seamless interaction. The system is characterized by its affordability, compactness, and simplicity while using. A detailed performance analysis confirms that the system offers reliable text and image processing, enhancing the reading experience for visually impaired persons. The design of the system, featuring a portable and foldable hardware assembly, contributes to improved usability. The findings underscore the capability of this system in fostering ease of use and self-reliance for visually impaired users when interacting with printed documents.

KEYWORDS: *Deep learning models, OCR, Image processing, Visually impaired people.*

INTRODUCTION

Visual impairments affect millions of people worldwide, creating significant barriers to interacting with the visual world. For people with such impairments, exploring and understanding images, whether they are photographs, illustrations, or complex scenes, can be a major challenge. Despite advancements in assistive technologies, many visually impaired users still encounter difficulties in interacting with and interpreting images [1]. Existing assistive technologies primarily focus on text-based content or rely heavily on limited descriptions of images [2]. However, a more sophisticated approach that enables image exploration through speech still has more scope for improvement.

In this paper, we propose a novel system designed to enhance the image exploration experience for

visually impaired users. Our system leverages Deep learning models, OCR, Image exploration Techniques to generate Text description and Image Captions for Document which are subsequently converted into speech for auditory feedback. This allows users to access the information hidden in the visual content of an document without relying on sight.

RELATED WORK

Recent advancements in assistive technologies have explored ways to help visually impaired individuals interact with the world around them. Various systems have been proposed that focus on translating visual information into accessible formats such as text or speech.

The rapid advancement of deep learning has greatly impacted fields like Optical Character Recognition

(OCR) and assistive technologies, offering new opportunities to improve the lives of visually impaired individuals[3]. This survey explores how deep learning can enhance speech captioning systems for converting text documents into spoken words. While traditional tools like screen readers and Braille displays are helpful, they often struggle with speed, accuracy, and adaptability. Deep learning techniques, such as CNNs, LSTMs, and the SIFT algorithm, have shown promise in overcoming these limitations by efficiently processing complex data and capturing contextual information[5] [6]. Despite progress, challenges remain in ensuring accurate text recognition and producing high-quality, natural-sounding speech. This review aims to identify gaps in current research and guide the development of more effective deep learning-based systems for a more inclusive digital environment. Some notable works include:

OCR in Assistive Technologies: Optical Character Recognition (OCR) has been a cornerstone in assistive technology for visually impaired users, enabling the recognition of printed text from various sources, such as documents, books, and street signs. OCR technology converts visual text into machine-readable formats. most widely used OCR engines is Tesseract, which provides an open-source solution for text extraction in multiple languages and various image qualities. [1][9] [11]

Image Captioning Systems: These systems automatically generate textual descriptions of images using deep learning models such as CNNs and RNNs (Recurrent Neural Networks). which generates image captions based on scene recognition. [4][7][8]

Speech Synthesis for Visually Impaired Users: Several systems have explored converting textual descriptions into speech, allowing visually impaired users to hear descriptions of images or scenes. TTS systems like Google's TTS or OpenAI's Whisper are commonly used in these applications. [2][10]

Object Detection and Scene Recognition: Edge detection techniques and feature extraction methods like SIFT (Scale-Invariant Feature Transform) have been widely used in object and scene recognition tasks.

ResNet, a deeper CNN architecture, has further

improved the ability to recognize high-level features in images. [4] [6]

While these technologies are highly valuable, the integration of detailed object recognition, OCR, and context-aware captioning in a unified system for image exploration, as proposed in this work, remains unexplored.

METHODOLOGY

The system is designed to provide visually impaired users with a rich, auditory understanding of images by combining advanced image processing techniques, feature extraction, optical character recognition (OCR), and text-to-speech (TTS) systems. The system operates in several sequential stages, each responsible for extracting and processing different aspects of the image to generate a comprehensive description

Diagram Architecture & Control Flow

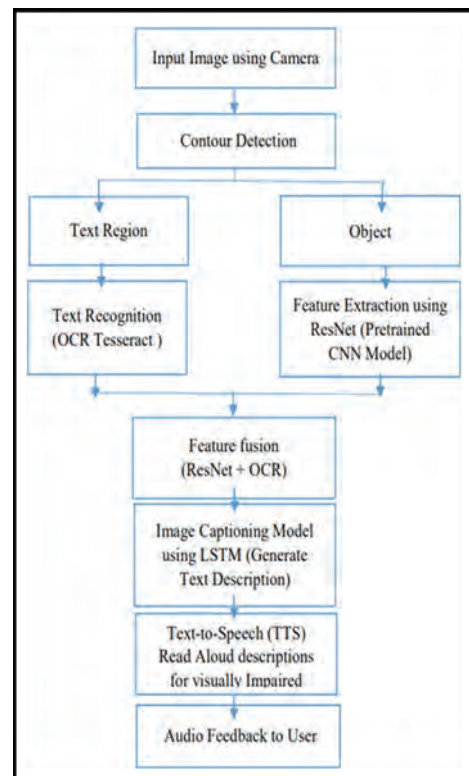


Fig. 1: System Flow

The system architecture shown in fig 1 consists of several components that work together to process an input image and generate an appropriate auditory

description. The stages of the system are as follows:
Input Image: The user provides an image via a camera or image selection interface.

Contour Detection: Edges and regions of interest within the image are identified using edge detection algorithms.

Text and Object Detection: Text regions are identified using OCR, and objects are detected using feature extraction techniques ResNet.

Feature Fusion: The extracted features are combined into a comprehensive image representation.

Image Captioning: A deep learning model generates a textual description based on the fused features.

Text-to-Speech (TTS): The generated caption is converted to speech and read aloud to the user

Experimental Set up

In this experimental setup, the seamless integration of advanced hardware and software is crucial for optimal performance. The hardware assembly focuses on improving design and functionality, ensuring that all components work together efficiently to enhance overall system performance. The software interface is designed for ease of use, offering intuitive controls that integrate smoothly with the hardware, providing a user-friendly experience for visually impaired individuals.

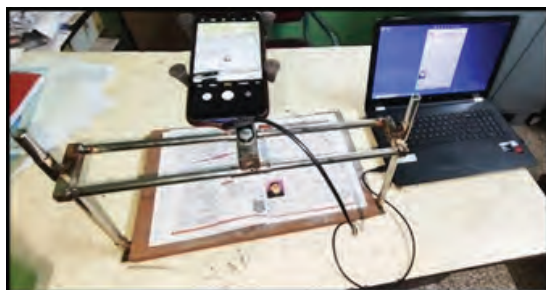


Fig. 2: Hardware Assembly



Fig. 3: Foldable, Easy to Carry Hardware Assembly Design



Fig. 4 : Adjustable height and position for Camera in Upward – Downward and left - Right Direction

The experimental set up shown in figure 2 for the text reader designed for visually impaired individuals is a well-crafted solution that prioritizes practicality, portability, and affordability. At its core is a sturdy wooden plywood base measuring 18 inches by 12 inches, providing a stable platform for the components. The structure is constructed from high- quality stainless steel, offering both durability and a sleek, professional finish. Standing at 12 inches tall, the setup features an adjustable mechanism that allows users to modify the height to accommodate various document sizes and ensure optimal text capture, enhancing comfort and usability for diverse user needs. Also as shown in figure 3 the structure is foldable and easy to carry so user can use it anywhere.

The document images are captured using a high-resolution mobile camera mounted on a secure holder on the plywood base. As shown in figure 4 The camera is adjustable, moving left to right for precise alignment over the text, ensuring accurate recognition. Connected to a computer and speaker, the system processes the images and provides audio output, converting printed text into speech for visually impaired users.

This experimental text reader setup for visually impaired individuals seamlessly integrates durability, portability, adjustability, and user-friendliness within an affordable framework. Its robust construction and meticulous design position it as an essential tool, significantly enhancing the independence and accessibility of visually impaired users.

DATASET

The dataset utilized in this research is derived from two distinct sources: one comprising natural images and the other consisting of sector-specific image documents. The first source, the Flickr 8K dataset, is a popular collection of 8,000 images with captions, commonly used in image captioning studies. It includes a variety of natural scenes such as urban areas, landscapes, and people, making it useful for testing general image description and caption generation systems. The second source focuses on sectoral images from Higher Secondary School History Books (HSSHB), specifically related to history education. This dataset is split into two categories. The first category includes over 300 page documents from Maharashtra state board history books, which has combination of text and images. The second category consists of 500 isolated images, such as historical photographs and Persons, each with a caption. These images are important for testing image captioning and recognition techniques, as they provide both visual context and textual descriptions necessary for evaluating the system's ability to generate accurate captions.

RESULT

The system was rigorously tested across a diverse range of image types to evaluate its overall performance and effectiveness. The process focused on two primary metrics: text recognition and object detection, both crucial for assessing the system's ability to process and interpret various visual elements accurately. In addition to it number of words and no of images in the image documents are calculated.

1. **Text Recognition :**For text recognition, the system's ability to identify and extract textual information from images was assessed with using OCR.



Fig. 5 : Sample Text Document

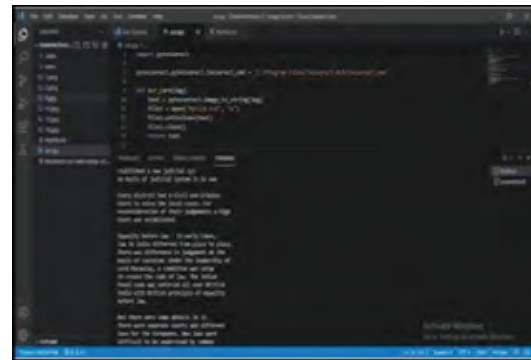


Fig. 6 : Text Recognition Output

Above mentioned figure 5 and figure 6 illustrates sample Text Documents and its corresponding Text Recognition results

Object Detection with generated Captions

The Object Detection results, combined with the generated captions, demonstrate the system's ability to accurately identify key objects within images and generate contextually relevant textual descriptions.

For Natural Images



Fig. 7: Object Detection for Natural Images

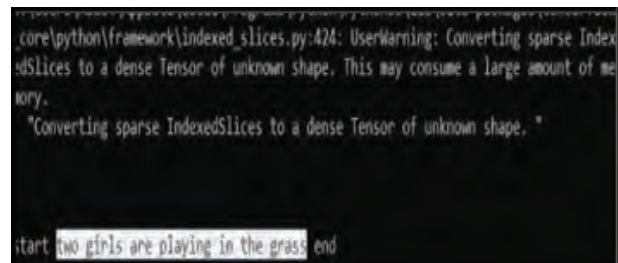


Fig. 8 : Generated Image Captioning for Natural Images

For Sectorial Images**Fig. 9: Object Detection for Sectorial Images****Fig. 10:: Generated Image Captioning for sectorial Images**

Figure 7 illustrates a representative sample of natural images, while Figure 8 presents sectorial images, with each figure accompanied by its respective caption, as shown in Figure 9 and Figure 10.

The generated captions provide detailed, accurate descriptions that include both identified objects and their significance within the historical context, validating the system's performance in producing meaningful and context-aware output for visually impaired users

Integrating Recognized Text and Image Captioning Result

The integration of recognized text and image captioning results significantly enhances the system's ability to generate comprehensive descriptions. By combining extracted text from the OCR process with the contextual information provided by the image captioning model, the system produces detailed and contextually rich captions that include both visual and textual elements. This integration allows for a more holistic understanding of the image, offering users a seamless, detailed narrative that includes text from documents, along with descriptions of visual objects and scenes. The results highlight the system's capacity to deliver a fuller and more informative experience for visually impaired users.

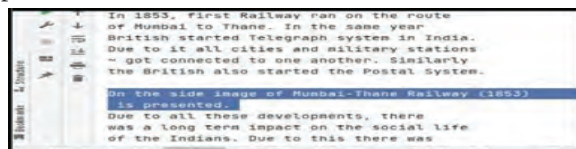
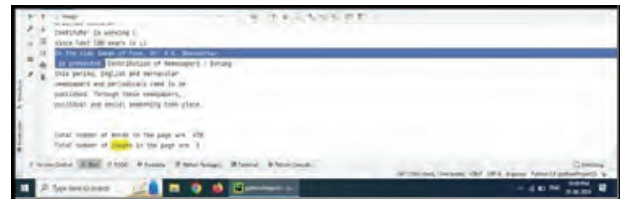
**Fig. 11: Integrating Text and image caption Results**

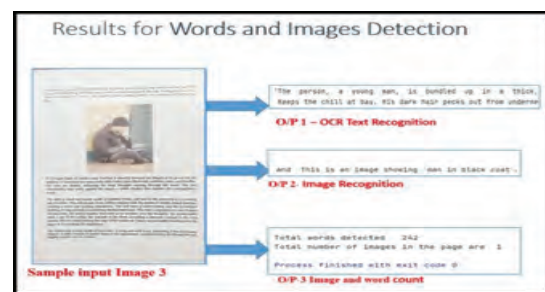
Figure 11 illustrates integrating Text and image Captioning Results

Counting words and images in documents

Counting words in documents is a crucial task for text analysis, especially when dealing with big datasets, where each document page contains a combination of text and images. Counting words in documents involves extracting text using OCR, pre-processing the extracted text, and then counting the individual words. This process can be applied to both single-page and multi-page documents, providing an effective way to quantify the textual content in a dataset. Also by leveraging some tools, it is possible to accurately detect and count the number of images, ensuring that both the text and visual content of the documents are effectively analysed and utilized for further tasks such as caption generation or accessibility enhancement.

**Fig. 12 : Generating Total no of words and images in single Page**

The figure 12 shows the total number of words and images in a single-page document.

**Fig. 13: Text recognition , Image detection with captions and total word Image count of sample page**

In figure 13 the overall results for sample page documents, including text recognition, image detection with captions, and the total word and image count for a single sample page, are presented.

Text to speech transformation



Fig. 14: Speech Output results of input samples

The process ends with the creation of an audio output that can be listened to through headphones or speakers. This output is the result of combining text and image recognition with our model. The generated audio includes both recognized text and captions, providing clear and understandable information about the images and documents. By offering this audio feedback, the system ensures accessibility, helping people with visual impairments.

CONCLUSION

This paper presents an innovative system for enabling visually impaired individuals to explore and understand images through speech-based feedback. By integrating Contouring, Feature Extraction techniques, deep learning models, image captioning and OCR text recognition, the system provides dynamic, context-aware descriptions of visual content, which are then converted into speech for auditory feedback. The system has been successfully evaluated through a series of tests, showing its potential to improve the autonomy and accessibility of visually impaired users. Future work will focus on further enhancing object recognition accuracy and developing personalized description generation models.

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Enhanced Hand Gesture Segmentation with Optimized YOLO Architectures on Parkinson's Disease Patient Hand Gesture Dataset

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ABSTRACT

Deep learning has advanced computer vision, particularly in hand gesture segmentation, essential for assistive technologies, augmented reality, and sign language. Accurate hand gesture detection is vital for real-time systems that support individuals with Parkinson's Disease. This research assesses the performance of various YOLO models such as YOLOv3, YOLOv5s, YOLOv5m, and YOLOv8 on hand gesture segmentation in an assistive system developed for Parkinson's Disease Patients (PDP). Each YOLO model was trained purely on a custom dataset of 3,000 hand gesture images taken from PDP. Results reveal that YOLOv3 struggles with segmentation accuracy and efficiency, achieving mAP@50, Precision, Recall, F1-Score and Execution Time of 0.84, 0.73, 0.86, 0.77, 0.056s respectively. Whereas, YOLOv8 delivers improved accuracy and speed, making it suitable for real-time hand gesture segmentation in PDP assistive system with mAP@50, Precision, Recall, F1-Score and Execution Time of 0.87, 0.98, 0.95, 0.96, 0.026s respectively. However, the pretrained YOLO models, when applied to the custom dataset showed reduced performance compared to models specifically trained for hand gesture segmentation in PDP assistive system. Thus, these findings have shown valuable insights into the strengths and limitations of different YOLO models and provide a solid foundation for future advancements in intelligent human-computer interaction assistive systems for Parkinson's Disease patients

KEYWORDS: *Hand gesture segmentation, YOLO models, Model optimization, Custom training, Parkinson's disease.*

INTRODUCTION

Parkinson's disease (PD) and related movement disorders significantly impact the lives of older adults, often necessitating assistance from care taker for daily activities [1]. Consequently, numerous assistive systems have been developed to support Parkinson's Disease Patients [PDP]. Recent research has focused on various technological approaches to assist PDP. Mughal et al. [2] reviewed wearable sensor technologies for diagnosis, monitoring, and management, emphasizing advancements in motor symptom management, emerging nanotechnologies, and the importance of addressing non-motor symptoms. Channa et al. [3]

analyzed wearable solutions like insoles and IMU systems, highlighting their potential to improve quality of life, automate assessments, and facilitate future telehealth care through multi-modal and invasive sensor applications. Goyal et al. [4] provided a comparative analysis of machine and deep learning techniques for PD classification, prediction, and monitoring, addressing the limitations of traditional clinical evaluation scales and emphasizing the role of early diagnosis and effective feature extraction. These studies collectively underscore the importance of innovative technological solutions for enhancing PD management and patient care. While these approaches offer valuable insights into

monitoring and management, effective communication remains a crucial aspect of care. Sign language presents a simple and intuitive communication method, making it well-suited for developing gesture recognition-based assistive systems for individuals with PD. Such systems empower patients to communicate their needs to caregivers through predefined hand gestures. However, the efficacy of these systems critically depends on precise hand gesture segmentation. This paper contributes a deep learning-based approach to hand gesture segmentation specifically designed for assistive systems intended to facilitate communication for individuals with PD based on hand gestures.

The YOLO model has seen wide applications in a for computer vision-related tasks such as object detection, segmentation, and instance segmentation. Originated to be real-time object detecting, YOLO has been extended to carry out the segmentation task with newer developments. Advances in YOLO models have impacted most industries, thus introducing the model, which is rapidly growing to become useful in the concerns of real-time object detection and instance segmentation. These studies highlight YOLO's effectiveness across diverse domains such as robotics, agriculture, environmental conservation, and medical application helpful for societal applications.

In one instance, YOLOv5 was used for ground robot retrieval in volcano-exploring systems, offering superior speed, accuracy, and real-time efficiency in drone detection, emphasizing its practicality for such applications [5]. In agriculture, YOLOv8-seg models were employed for lychee instance segmentation, with YOLOv8x-seg achieving the highest mAP accuracy, while YOLOv8-seg demonstrated nearly identical performance with fewer parameters, making it ideal for resource-constrained hardware [6]. YOLOv8 also demonstrated its potential in medical robotics by achieving high precision in laparoscopic suturing tasks, effectively tracking instruments and monitoring tissue seals [7]. YOLOv8-Seg models have proven effective in environmental conservation, with successful applications in underwater trash segmentation. These models enabled real-time detection of marine debris, showcasing their value in environmental monitoring [8]. In industrial quality assurance, YOLOv8 outperformed traditional methods and Mask R-CNN in leather defect

detection, contributing to improved process automation and defect identification [9]. Additionally, YOLOv8-DS, a variant optimized for low-light environments, significantly improved real-time segmentation in construction sites, addressing challenges posed by inadequate lighting [10]. In agriculture, YOLOv8 was applied for rice leaf disease detection, achieving high accuracy while maintaining efficient processing speeds, making it suitable for crop monitoring [11].

YOLOv5 also excelled in detecting and segmenting skin defects in rose apples, outperforming Mask R- CNN in terms of both accuracy and speed [12]. YOLOv8X proved effective in open-pit environments, offering superior performance in detecting and segmenting rocks after blasting, aiding in real-time blast quality control [13]. YOLO models have also been successfully used for pothole detection in autonomous vehicles, achieving high precision and recall, making them ideal for real-time geotagged detection [14]. The development of models like Insta- YOLO, which integrates object detection and segmentation into a single-stage model, has further enhanced real-time performance [15]. YOLO has also been applied to hand gesture recognition for human-computer interaction, with promising applications in manufacturing and production environments [16][17].

In medical and surgical robotics, YOLO demonstrated its potential for hand gesture recognition and fingertip localization, achieving high accuracy in complex tasks [18]. Beyond traditional object detection, YOLO has been widely applied in other areas, such as brain tumor detection, seafood freshness monitoring, and seabed exploration, demonstrating its robustness and versatility in real-time applications [23][24][25]. These advancements highlight YOLO's growing role in transforming industries by improving efficiency and enabling automation. In addition, further research into YOLO's applications underscores its continued development. A comprehensive review of the YOLO model family up to YOLOv8 explored its architectural developments, performance metrics, and real-world applications, emphasizing YOLO's superior accuracy and speed for object detection [19]. Moving Object Segmentation (MOS) techniques were analyzed, focusing on deep learning-based methods and architectures, and offering suggestions for future research directions [20]. YOLO's application in face

detection for video sequences was examined, where it outperformed traditional methods by offering enhanced accuracy, particularly when optimized with GPU hardware [21]. Additionally, an optimized YOLO V4 network was used for apple defect detection, employing pruning methods to improve model performance and classification accuracy, demonstrating its potential in commercial fruit grading systems [22]. Thus the extensive research on YOLO models across various applications highlights their remarkable versatility and effectiveness in real-time segmentation tasks.

The continued evolution of YOLO, particularly with advancements in YOLOv5 and YOLOv8 variants, showcases its ability to address complex challenges, improving efficiency, accuracy, and automation. Building on these insights, the subsequent sections of this paper will detail the systematic approach adopted to assess the performance of different YOLO models for hand gesture segmentation in assistive systems for PDP.

The study presented in this paper compares the performance of YOLO models (v3, v5s, v5m, v8) for hand gesture segmentation in assistive systems, showing that YOLOv8 outperforms the others in accuracy and speed. The findings provide insights for improving real-time human-computer interaction in assistive technologies. Section 2 will describe the methodology employed to evaluate these models, followed by discussion on the experimental setup in Section 3, which outlines the specific tools, dataset, and configurations used for the performance evaluation. The results of the experiments, including key performance metrics for each model, will be presented in Section 4. Finally, Section 5 will provide a comprehensive conclusion, discussing the implications of the findings and offering directions for future research.

METHOD

This section outlines the systematic approach adopted to assess the performance of YOLO models for hand gesture segmentation in assistive systems designed for PDP. The methodology involved the creation of a custom dataset performed by PDP, preprocessing of hand gesture images, training of YOLO models, and evaluation based on key performance metrics such as Mean Average Precision at 50% Intersection over Union (mAP@50), precision, recall, F1-score, Execution time.

Emphasis was placed on maintaining consistency in training parameters and testing environments to ensure a fair comparison across all models.

- **Dataset Description:** A custom dataset consisting of images of various hand gestures performed by PDP was created for this research. Initially 1466 images with different pose has been captured. The Data augmentation techniques, including rotation, scaling was applied to enhance dataset. The gestures included in the dataset represent common hand movements such as palm, fist, two fingers, thumb up, best sign and other actions typically used in by PDP to indicate daily need of PDP. This custom dataset was necessary because publicly available hand gesture datasets do not accurately reflect the need expressed by PDP.
- **YOLO Model Architectures:** This study evaluated four different YOLO models: YOLOv3, YOLOv5s, YOLOv5m, and YOLOv8.

Each model was selected to examine its capability for real-time hand gesture detection in an assistive system. YOLOv3 employs a Darknet-53 backbone and independent predictions at different scales, while YOLOv5 uses a Cross-Stage Partial (CSP) backbone with anchor-based detection. YOLOv8 builds upon previous versions with improved anchor-free detection and advanced training strategies. These models were trained and tested on the custom dataset to assess their performance in the context of PDP related hand gesture segmentation. The key differences between these YOLO models are summarized in Table 1.

Table 1 Summary of Key differences of various YOLO models

Features	YOLO v3	YOLO v5s	YOLO v5m	YOLO v8
Backbone	Darknet-53	CSP-Darknet	CSP-Darknet	Improved CSP-Darknet
Speed	Medium	Very fast	Fast	Very fast
Accuracy	Medium	Low	Medium	High
Size	Large	Very small	Small	Small

The evaluation metrics mentioned in [1] along with execution time were used to compare the performance

of each YOLO model and to assess the viability for deployment in real-time assistive systems for PDP.

- **Execution Time:** Execution time measures the average time the model takes to process a single image. This metric is critical for assessing the model's suitability for real-time applications, as lower execution times indicate better performance for assistive systems. Execution time was measured on the same hardware (Google Colab with Tesla T4 GPU) used during the training phase.

By evaluating both accuracy (mAP@50, Precision, Recall, F1-Score) and speed (Execution Time), we aimed to identify the most effective model for hand gesture recognition tasks.

EXPERIMENTAL SETUP

This section describes experiments designed to evaluate the performance of YOLO models for hand gesture segmentation in a PDP assistive system. We analyzed the models' accuracy, efficiency, and real-time performance to determine their suitability for this application.

The experiments were conducted using Google Colab with a Tesla T4 GPU to ensure the necessary computational resources for training deep learning models. The models were trained under the following parameters:

- Learning Rate : 0.01
- Batch Size : 16
- Number of Epochs : 10
- Optimizer : Adam
- Input Image Size : 256x256 pixels

The 3,000-image dataset was partitioned into training and validation sets using an 80/20 split, yielding 2,400 training images and 600 validation images. Training set served to optimize the model parameters, while the validation set was used to monitor performance during training. For final evaluation, real-time test images, distinct from the training and validation sets, were used as input to the trained model to assess segmentation accuracy and overall model performance based on pre-defined evaluation metrics.

Model performance was evaluated using mAP@50 (Intersection over Union threshold of 0.5), Precision, Recall, and F1-score. Execution time was measured on the same hardware used for training by averaging the inference time over the entire test set.

RESULT

As detailed in the methodology section, YOLOv3, YOLOv5s, YOLOv5m, and YOLOv8 were trained and evaluated on a custom hand gesture dataset. The results of these experiments, including performance metrics for each model, are presented in this section.

The loss metrics including train/box_loss, train/cls_loss, and train/df_l_loss, play a key role in segmentation by ensuring accurate bounding box predictions, correct object classification, and improved boundary localization, especially in challenging cases. Validation losses (val/box_loss, val/cls_loss, and val/df_l_loss) as shown in fig 1(a) and 1(b), also show a consistent decline, indicating effective generalization to new data. Performance metrics like precision, recall, and mAP demonstrate continuous improvement, reflecting enhanced detection accuracy, reduced gesture misses, and better localization. The smooth trends suggest that YOLOv8 is highly suitable for hand gesture segmentation in assistive systems.

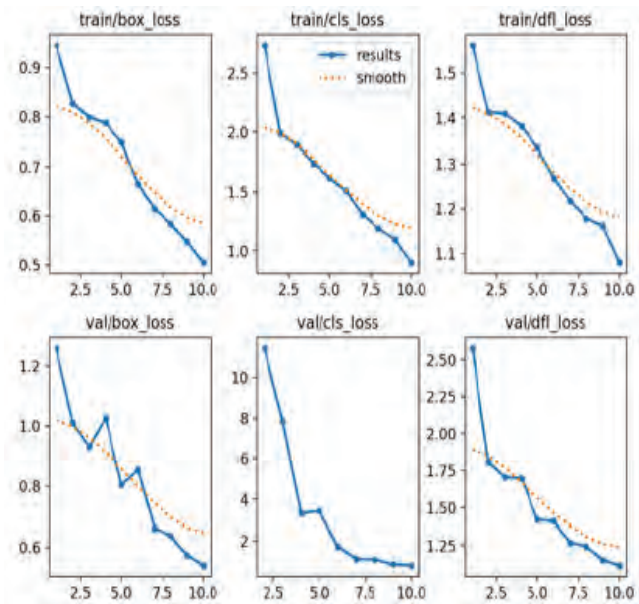


Fig. 1(a) Training Performance Analysis of YOLO model on a Custom Hand Gesture Data

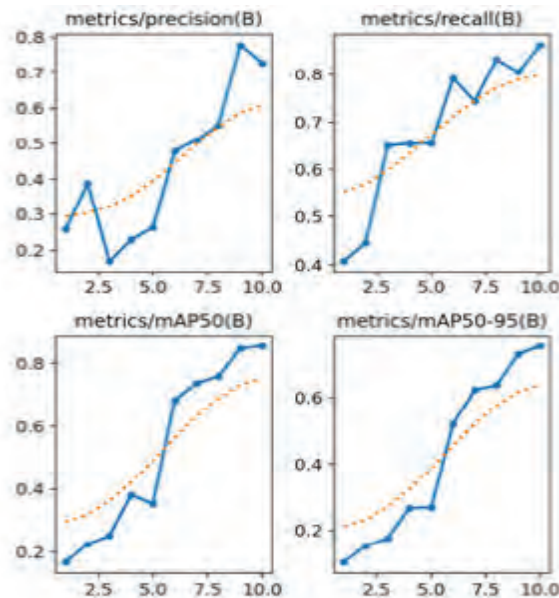


Fig. 1(b) Training Performance Analysis of YOLO model on a Custom Hand Gesture Data

YOLO models are initially pretrained using a public dataset [26], and these pretrained weights are subsequently used for hand gesture segmentation. The performance of pretrained YOLO models for hand gesture segmentation is as shown in Table 2

Table 2 : Performance Comparison of pretrained YOLO Models

Pretrained Model Performance on test data					
Model Name	mAP@50	Precision	Recall	F1-Score	Execution Time (s)
yolov3	0.82	0.73	0.83	0.74	0.058
yolov5s	0.85	0.95	0.95	0.96	0.035
yolov5m	0.85	0.97	0.95	0.95	0.048
yolov8n	0.86	0.96	0.93	0.93	0.028

The model's performance was evaluated based on various metrics, including mean Average Precision at IoU threshold 50 (mAP@50), precision, recall, F1- score, and execution time. Among the pretrained models, YOLOv3 achieved a mAP@50 of 0.82, with precision, recall, and F1-score values of 0.73, 0.83, and 0.74, respectively, and an execution time of 0.058 seconds per frame. YOLOv5s outperformed YOLOv3, achieving a mAP@50 of 0.85, with high precision (0.95) and recall (0.95), resulting in an excellent F1 - score of 0.96. It also demonstrated lower execution time of 0.035 seconds. YOLOv5m showed similar

mAP@50 (0.85) but exhibited slightly better precision (0.97), leading to an F1-score of 0.95, with a moderate execution time of 0.048 seconds. YOLOv8 had the highest mAP@50 (0.86) among the pretrained models, with a precision of 0.96 and recall of 0.93, yielding an F1-score of 0.93, and the lower execution time of 0.028 seconds. When trained on the custom dataset, all models showed improved performance as illustrated in Table 3.

Table 3: Performance Comparison of Custom trained YOLO Models

Custom Trained Model Performance on test data					
Model Name	mAP@50	Precision	Recall	F1-Score	Execution Time (s)
yolov3	0.84	0.73	0.86	0.77	0.056
yolov5s	0.86	0.96	0.96	0.96	0.031
yolov5m	0.86	0.99	0.96	0.97	0.044
yolov8n	0.87	0.98	0.95	0.96	0.026

In Table 3 it is seen that all models showed faster execution time than compared to corresponding time

shown in Table 2. When models trained in custom dataset, YOLOv3 model demonstrated performance, achieving a mAP@50 score of 0.84. Both precision and recall metrics were comparable to the pretrained version, with an improved F1-score of 0.77. Additionally, it exhibited a slight reduction in execution time, processing images in 0.056 seconds. For YOLOv5s, the custom model retained its high effectiveness, with a mAP@50 of 0.86. Precision and recall remained consistent at 0.96, resulting in an F1-score of 0.96. Moreover, the execution time improved further, with the model processing images in just 0.031 seconds, enhancing its overall efficiency. From Table 3, it is seen that YOLO8 performed best giving values of 0.87 & 0.98 for the parameters mAP@50 & precision and produced 0.95 & 0.96 respectively for recall and F1-score and lowest execution time of 0.026sec confirming its suitability for real-time applications. Overall, models trained on custom dataset consistently outperformed their pretrained counterparts (Table 2) in terms of accuracy and efficiency, with YOLOv8 offering the best combination of high detection performance and fast execution speed. These results demonstrate the effectiveness of custom training in improving model performance for real-time hand gesture recognition tasks. The evaluation results of pretrained models and

custom train models on test data are presented in Fig. 2 to Fig. 6, showcasing the performance of YOLO models across key metrics which collectively illustrate the effectiveness and trade-offs of each YOLO model for hand gesture segmentation in the PDP assistive system.

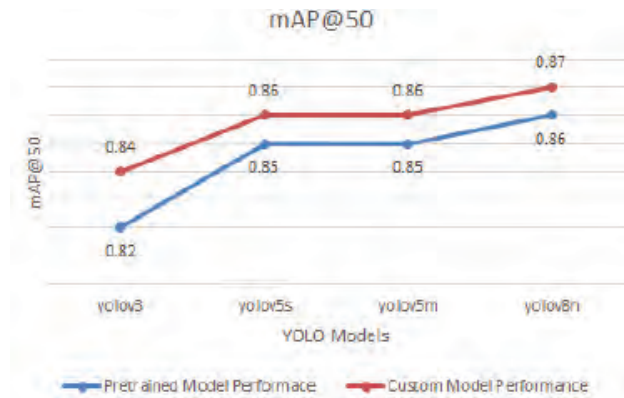


Fig. 3: Comparison of mAP@50 performance between pretrained and custom YOLO models

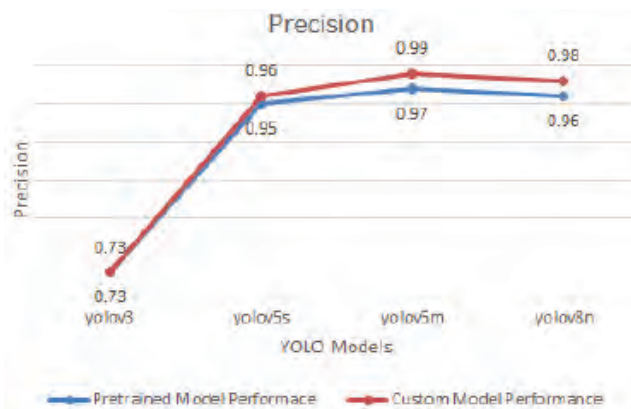


Fig. 4: Precision performance for both pretrained and custom YOLO models

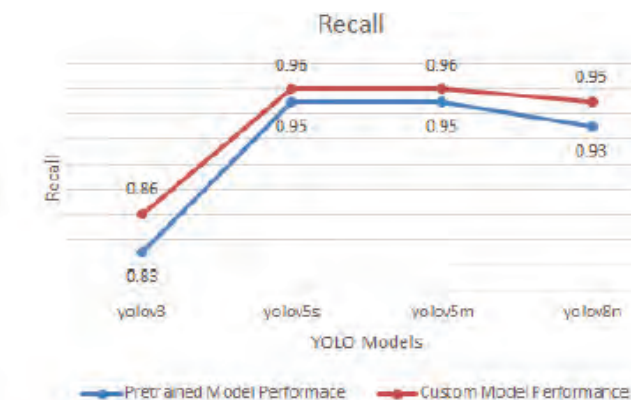


Fig. 4: Recall comparison to assess the detection sensitivity

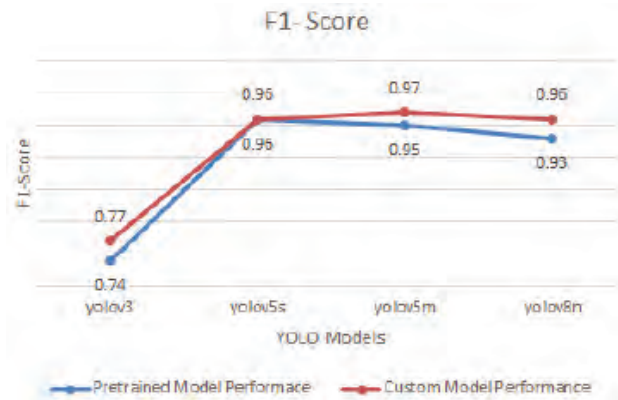


Fig. 5: F1-Score highlighting the balance between precision and recall

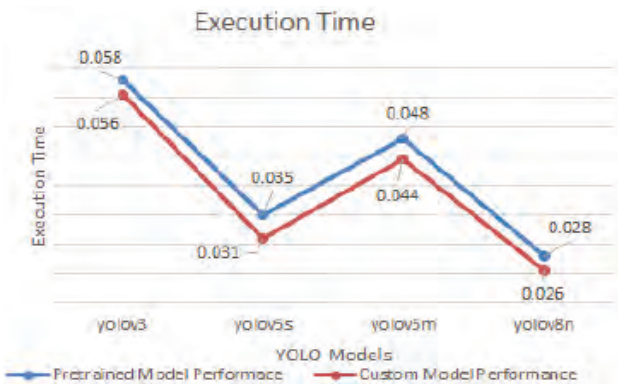


Fig. 6: Execution time comparison to evaluate computational efficiency

Table 4 illustrate the segmentation performance of YOLO models YOLOv3, YOLOv5s, YOLOv5m, and YOLOv8 trained on a custom dataset specifically designed for detecting hand gestures relevant to PDP. Each row represents an input hand gesture image, followed by the columns show comparative results across models, highlighting their detection accuracy and segmentation precision. YOLOv8 consistently outperforms other models. The bounding boxes and confidence scores highlight the accuracy of each model, with YOLOv8 showing the most precise and consistent results. This demonstrates the effectiveness of using a custom dataset tailored to specific assistive tasks, as it allows the models to focus on domain-specific features critical for real-time systems supporting individuals with Parkinson's Disease.

In our experiments with a custom hand gesture dataset, YOLOv8 emerged as the most accurate segmentation

model. This finding was further validated by testing on a publicly available dataset, where the evaluation parameters showed a difference of only 1%, confirming the model's robustness and reliability.

Table 4: Segmentation results of YOLO models trained on custom hand gesture data

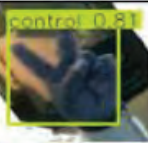
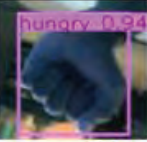
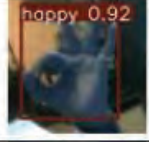
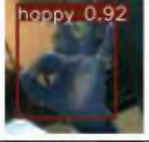
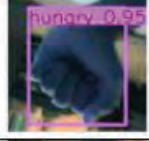
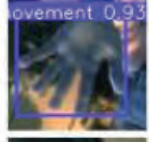
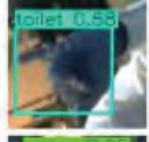
Test image	YOLOV3	YOLOV5s
		
		
		
		
		
		
		
		
		

Table 4: Contd.

Test image	YOLOV5m	YOLOV8
		
		
		
		
		
		
		
		
		

CONCLUSION

This research demonstrates the significant impact of custom training on the performance of YOLO models for hand gesture segmentation in assistive systems for Parkinson's Disease patients (PDP). While

pretrained YOLO models such as YOLOv3, YOLOv5s, YOLOv5m, and YOLOv8 offer decent performance out-of-the-box, their effectiveness is limited when applied to a custom dataset specifically designed for hand gesture recognition in PDP assistive systems. The results clearly show that custom training on the PDP-specific dataset enhances all models' performance, particularly in terms of accuracy and execution speed. Among the models tested, YOLOv8 consistently outperformed the others, delivering the highest mAP@50 of 0.87, precision of 0.98, and recall of 0.95, along with the fastest execution time of 0.026 seconds which is improved response time by 0.002 seconds. Custom-trained YOLOv8 thus proves to be the most effective choice for real-time hand gesture recognition, making it well-suited for assistive technologies aimed at improving the quality of life for individuals with Parkinson's Disease.

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Development and Implementation of a Wireless Sensor Network for Real-time Soil Moisture and Temperature Monitoring Using PIC16F877A and ThingSpeak

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ABSTRACT

This paper introduces an advanced automated irrigation system designed to enhance water conservation and optimize agricultural practices. The system integrates a network of wireless sensor units (WSUs), each equipped with soil moisture and temperature sensors to monitor key environmental parameters. These sensors collect critical data that is processed by the PIC16F877A microcontroller embedded in each WSU. The processed data is transmitted via Zigbee communication to a centralized wireless information unit (WIU), which also uses the PIC16F877A microcontroller. The WIU processes the incoming data, determines if the irrigation conditions are met based on pre-set thresholds, and controls a water pump accordingly to ensure efficient water distribution. Furthermore, the system features real-time data transmission to the ThingSpeak platform, an IoT solution for cloud-based monitoring. This integration enables farmers to remotely access up-to-date field conditions and make informed decisions regarding irrigation, ensuring that crops receive the necessary water without over-watering, thereby reducing water waste. The system's automation facilitates precise irrigation timing, further promoting water efficiency. Ultimately, the proposed system fosters sustainable agricultural practices by providing a reliable and scalable solution for optimizing water usage, particularly in regions facing water scarcity or irregular rainfall patterns.

KEYWORDS: PIC16F877A, IoT in agriculture, Wireless sensor network (WSN), Soil moisture monitoring, Sustainable agriculture.

INTRODUCTION

Water conservation is essential as global challenges such as climate change, population growth, and urbanization increasingly strain freshwater resources. Agriculture, a major consumer of water, is particularly impacted, especially in regions cultivating water-intensive crops. Traditional irrigation practices often lead to significant water wastage, environmental harm, and soil degradation, making sustainable water management a critical priority. The pressing issue of water scarcity demands innovative solutions to improve water use efficiency in agriculture, ensuring both environmental sustainability and agricultural productivity. Automated irrigation systems have emerged as promising

technologies to tackle these challenges. These systems integrate real-time monitoring of environmental parameters with intelligent water delivery mechanisms, enabling precise irrigation. By optimizing water usage, they minimize waste and ensure crops receive the necessary water for optimal growth. Additionally, automated irrigation systems enhance energy efficiency, a significant concern in modern agriculture. Given that water pumping and distribution are energy-intensive processes, often accounting for up to 15% of agricultural electricity consumption in some regions, these systems reduce unnecessary pumping, lowering both energy costs and the environmental footprint.

Traditional irrigation methods, such as manual or

fixed- schedule irrigation, fail to adapt to changing environmental conditions. This results in over-irrigation, causing waterlogging and nutrient loss, or under-irrigation, which stresses crops and reduces yields. These inefficiencies also contribute to long-term soil degradation and erosion, further compromising agricultural sustainability. Addressing these issues requires a technological approach capable of dynamic and responsive irrigation practices. This study focuses on developing a cost-effective, reliable automated irrigation system using advanced sensing and communication technologies. The system employs soil moisture and temperature sensors to collect real-time environmental data. A microcontroller-based platform processes this information to automate water delivery according to crop requirements. This approach optimizes water use, conserves energy, and reduces manual intervention.

Wireless communication capabilities, integrated into the system, allow for remote monitoring and control of irrigation processes. Farmers can make data-driven decisions, enhancing resource management and operational efficiency. The system's modular design supports scalability, enabling future enhancements such as the integration of additional sensors (e.g., light and humidity) to provide a more comprehensive understanding of environmental conditions.

The proposed system includes sensor nodes and a master node, both utilizing PIC16F877A microcontrollers. Sensor nodes measure soil moisture and temperature, transmitting the data wirelessly via Zigbee communication to the master node. Locally, these nodes also display readings for quick reference. The master node processes data from multiple sensors, controls the water pump based on pre-defined thresholds, and uploads the information to the ThingSpeak cloud platform using a GPRS module. This setup allows farmers to monitor and log data remotely, ensuring efficient and reliable irrigation management.

LITERATURE REVIEW

Automated irrigation systems have become essential in modern agriculture, offering substantial benefits in water conservation, crop productivity, and sustainability. Numerous studies have explored advancements in

technology, sensor integration, and cost-effective solutions to address agricultural challenges.

Joshi and Ali [1] emphasized the crucial role of automated irrigation in resource management and sustainability, highlighting the need for self-sustaining systems to overcome challenges such as electricity dependency. Various microcontroller-based systems have been proposed to optimize irrigation efficiency, including Rajpal et al. [2], who developed a system responding to soil moisture levels, and Doraswamy [3], who introduced an affordable solar-powered solution for remote farms. Other studies focused on enhancing system efficiency and reducing labor costs, such as the automated seeding and irrigation system using Arduino [4] and moisture sensor-based irrigation systems [5]. Technological innovations like GSM modules for real-time monitoring [6] and low-cost sensors in PIC controller-based systems [7] have made irrigation more accessible, especially in developing regions. Gowtham Deekshithulu et al. [8] showcased a significant reduction in water use with a microcontroller and moisture sensor-based system. Recent innovations in remote monitoring have included GSM technology for rainfall detection [9] and the use of solar power for system efficiency [10, 11]. The integration of light-based sensors for water conservation was advanced by Makana et al. [12]. Addressing global water scarcity, Sruthi et al. [13] highlighted the importance of integrating pH and humidity sensors for improved irrigation and fertilization. Other systems, like those by Shemul et al. [15], use automated valve control to adapt to changing moisture levels, optimizing water use. Efficient water management is also critical in arid regions, with WSNs providing real-time monitoring and control for greenhouse environments [16] and wireless lysimeters for soil moisture monitoring [17].

Hybrid network infrastructures combining wired and wireless systems have been explored for more reliable irrigation management [18, 19]. Environmental wireless sensor networks (EWSNs) have also been deployed for broader applications, offering reliable data collection and monitoring for agricultural and environmental needs [20-23]. The integration of wireless sensor networks in automated irrigation has proven to be effective in enhancing scalability and

resource efficiency [24]. ThingSpeak, an IoT platform, has been identified as a robust solution for storing and analyzing data in agricultural automation, enabling better decision-making and resource management [25]. Studies have also demonstrated the potential of IoT in automating irrigation systems, with real-time data storage on platforms like ThingSpeak [26-30]. These innovations offer promising solutions to address water scarcity, improve agricultural efficiency, and promote sustainable practices.

In conclusion, the literature reveals significant advancements in automated irrigation, driven by microcontroller systems, sensor integration, wireless communication, and IoT platforms. These systems offer practical solutions for improving water management and agricultural productivity, crucial for addressing challenges posed by climate change and population growth.

METHOD

This section outlines the systematic approach employed in the design, development, and implementation of the automatic irrigation system. It provides a detailed explanation of the block diagram, hardware design, and software design, emphasizing the purpose and implementation details of each stage. The block diagram illustrates the architecture of the automatic irrigation system, comprising two sensor nodes (Node I and Node II) and a master node. Each sensor node is responsible for monitoring environmental parameters, such as soil moisture and temperature, within its designated area.

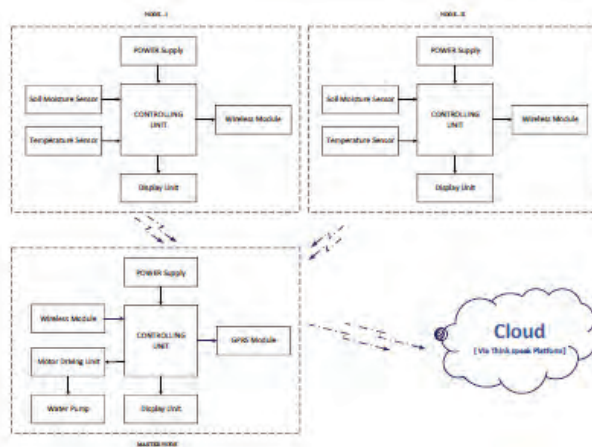


Fig. 1. Comprehensive overview of the implemented work

Sensor nodes communicate wirelessly with the master node, which controls the irrigation pump and uploads data to a cloud platform for remote monitoring.

- Sensor Nodes (Node I and Node II):

Each sensor node monitors soil moisture and temperature using respective sensors. A PIC16F877A microcontroller processes the sensor data and transmits it via a Zigbee module to the master node. Additional components include:

- 16x2 LCD Display: Displays real-time sensor data locally.
- 5V Power Supply: Powers the node.
- Master Node:

The master node collects data from sensor nodes and determines irrigation needs based on predefined thresholds.

- Key features:

- Motor Driver & Pump: Activates the pump when soil moisture is below the threshold.
- Zigbee Module: Receives data from sensor nodes.
- GPRS Module: Sends data to the ThingSpeak cloud platform for remote monitoring.

- Cloud Platform (ThingSpeak):

The GPRS module uploads real-time and historical environmental data to ThingSpeak, enabling remote monitoring of soil moisture, temperature, and irrigation status. The details of hardware's used along with its role is as outlined in Table 1

Table 1. Details of the hardware used in implemented work

Component	Function
PIC16F877A Microcontroller	Controls data processing, communication, and irrigation decisions.
Soil Moisture Sensor	Measures water content in the soil and provides an analog voltage output.
Temperature Sensor (LM35)	Measures ambient temperature and outputs an analog voltage proportional to temperature.

Zigbee Module	Enables wireless communication between nodes and the master node.
16x2 LCD Display	Displays real-time data and system status locally.
Motor Driver Unit	Controls the activation of the water pump.
Water Pump	Performs irrigation when activated by the motor driver.
GPRS Module	Uploads data to the cloud platform for remote monitoring.
5V Power Supply	Provides stable and regulated power to all components.

RESULT

This section presents the performance results of the automatic irrigation system, focusing on data from the sensor nodes, system responsiveness, and irrigation efficiency. It evaluates the system's ability to monitor environmental conditions and activate irrigation based on moisture thresholds. Additionally, it highlights the system's cloud integration for remote monitoring. The analysis demonstrates how the system optimizes water usage through automation. The results confirm the system's effectiveness in real-time monitoring and irrigation control.



Fig. 2(a) Master Node

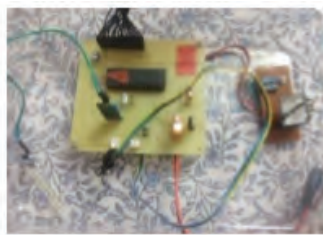


Fig. 2(b) Sensor Node

The irrigation system consists of two main modules: the master module and the sensor node. The master module, shown in Figure 2(a), acts as the central control unit, processing data received wirelessly from the sensor nodes and activating the irrigation motor through a motor driver circuit connected to the PIC16F877A microcontroller. This ensures that water is applied only when necessary based on soil moisture levels, optimizing water usage and automating the irrigation process. The sensor node, depicted in Figure 2(b), monitors soil conditions with key components: a soil moisture sensor that provides an analog output

corresponding to water content, and a temperature sensor that measures ambient temperature. The node's PIC16F877A microcontroller processes the sensor data, controls a 16x2 LCD display for real-time monitoring, and manages communication with the master module. Together, the master and sensor nodes enable efficient, responsive, and sustainable irrigation through continuous monitoring and automation.

The system's performance is evaluated under varying moisture levels and temperatures. The details are outlined in figure 3 – 5. Each time the sensor nodes detect parameters such as temperature and soil moisture, the corresponding data is displayed on a locally connected LCD. The fig 3 shows the system upon initial power-up. The LCD displays initial message. This indicates the system is functioning correctly and ready to monitor environmental data.

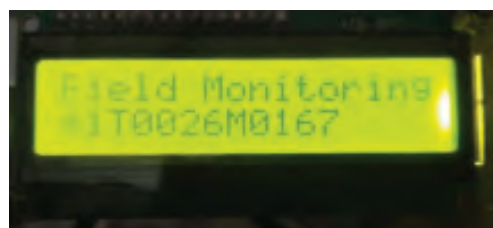


Fig. 3. Initial system display

The fig 4 shows the LCD displaying a moisture reading varying from 'M:97' to 'M:215' and a temperature reading of 'T:0026'.



Fig. 4 Real time reading displayed on LCD

This demonstrates the system's ability to accurately measure and display environmental parameters. This reading likely indicates relatively variation in the soil moisture levels with stable environmental temperature. Once the data is displayed, it is simultaneously transmitted to the cloud using the Zigbee module, where it is uploaded to the ThingSpeak platform. The

data is then visualized on a ThingSpeak dashboard, as shown in the figure, providing real-time updates with accurate readings.



Fig. 5 ThingSpeak Channel for data logging

Figure 6 displays the temperature and moisture data uploaded to the ThingSpeak cloud. The temperature chart (Field 1) shows temperature variations over time, with stabilization reflecting real-time environmental changes. The moisture chart (Field 3) represents soil moisture levels, indicating consistent readings with minor fluctuations. These charts highlight the system's capability to monitor environmental parameters effectively.



Fig. 6. Temperature and Moisture Data Visualization on ThingSpeak Cloud

The fig 7 present additional temperature (Field 2) and moisture (Field 4) data collected by the system. The temperature chart highlights precise monitoring of changes over time, while the moisture chart reflects stable levels, indicating effective irrigation or environmental control.



Fig. 7. Precise Temperature and Moisture Data Acquisition in Irrigation System

These results validate the system's reliability for data acquisition.

CONCLUSION

In conclusion, the proposed automated irrigation system effectively optimizes water usage in agriculture by integrating wireless sensor nodes, a master control unit, and cloud-based monitoring. The system demonstrates efficient irrigation control by continuously monitoring soil moisture and temperature, and activating irrigation only when necessary based on predefined moisture thresholds. The real-time data processing and cloud integration through the ThingSpeak platform enable remote monitoring, empowering farmers to make informed decisions and enhancing the sustainability of agricultural practices. The system's performance under varying environmental conditions, as evaluated through sensor data and cloud visualization, highlights its effectiveness in reducing water waste and promoting precision irrigation. The results confirm the system's capability to enhance agricultural efficiency, contributing to water conservation and more sustainable farming practices.

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A Review Article on Fractional N-PLL for Frequency Synthesizer

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ABSTRACT

This review article is related to fractional N-PLL and its Parameters how these are going to affect the phase noise. The basic architecture with feedback mechanism going to change the range of frequency what we desire but there will be some problems may occur that is noise in the architecture. This can be solved through employing a new approach. Developing a new PLL architecture that is appropriate for wireless applications with low noise levels. The PLL eliminates a number of difficulties, include high frequency, low area, and power reduction. This comparison of various PLLs is displayed using a diagram. The fundamental transfer function, noise source dividers, phase detectors, and fractional-N PLL operation will all be discussed in this paper.

KEYWORDS: Frequency detector, Fractional-N phase locked loop.

INTRODUCTION

PLL locks phase of the output to the input it is negative feedback control systems PLL goes through three stages it is also referred as frequency synthesizer. PLL consists Phase detector, a filter (low-pass), and VCO. Generate high speed oscillations Acquire and track signal of Radio frequency communication, it is having a wide range of application in communication area like radio and TV. Linear phase locked loop is the basic type of PLL it consist of Phase Detector, VCO and a LPF The operating voltage of a Oscillator is low frequency Draw backs of this PLL low frequency range of operation Disturbance for wide range of applications error unwrap Algorithm is used and it is valid for higher sampling rates. In digital PLL XOR as PD implementation the drawbacks of LPLL are overcome in this DPLL The output across the Oscillator generates periodic signal.

Delay modulation help in synchronization with other signals. Therefore, JK flip flop is used to reduce the draw backs. In Digital PLL one of the components is Phase detector it generates continuous signal as an input to LPF. ADPLL have some advantages such as, reduction of lock time. Moreover, accurate information is achieved using digital methods. It includes high pass and low pass paths which supports. it is subjected to delay with components.

LITERATURE SURVEY

Furthermore, Ye Zhang et. al., [2] (2018) studied and suggested a new technology that, without affecting system performance, reduces both area and power consumption. It is implemented by using the error masking technique for signal quantization and frequency synthesizer modulation. Zhang found a suitable word

length, decreased the hardware size, and increased SNR. Zhang created the LMS algorithm, which adjusts the loop filter output gain to minimize uncertainty. With the aid of this synthesizer, digital blocks are implemented using the z-transform for analog blocks and the Fourier transform for analog blocks. Differentiator and RC Mash are used for PLL design.

Moreover, Modi et. al., [4] (2018) developed a 45 nm cmos frequency divider and detector, determining the distinction between phase and frequency. Low power applications utilize it.

Moreover, Govind Patel et. al., [5] (2014) proposed PLL architecture for the synthesis of tidy signals. Because of its high frequency resolution and quick locking time, it is often used in wireless communication. The noise parameters in the fractional PLL are determined through mathematical modeling in this process. The CppSimsimulator is used to implement the design. A 5 dBc/MHz improvement is shown by the novel architecture.

In this research work, Mostafa Abedi et. al., [3] (2018) came up with a technique that uses 0.18um CMOS technology on an ADS simulator to decrease the reference spur using a simpler charge pump design. Instead of utilizing current mode logic, a real single phase clocking circuit divider with a spur level of -74 dB and a lock time of 1.9us is adopted.

Moreover, Nikolaos Georgouloupoulo et. al., [6] proposed a System Verilog DPLL for real number models with the goal of increasing simulation effectiveness without appreciably reducing accuracy. Additionally, the Verilog-A charge-pump model is implemented in the Cadence Simulator, which serves as the foundation for the DPLL design. An output frequency of 1.2 GHz is obtained using the previously outlined approach. As a result, it also applies to DPLL.

Furthermore, Zhipeng et. al., [7] suggested a Fractional-N Frequency Synthesizer designed using Verilog-AMS. The performance of the $\Delta\Sigma$ modulator has been confirmed, and the efficiency of the voltage domain simulation in this model has been enhanced by combining the frequency divider and VCO.

In this research work, Pradnya H. Golghate et. al., [8] (2008) developed D-PLL circuitry using a controlled

oscillator, loop filter, and Booth's multiplier. Xilinx 13.1 was used to implement this design via Verilog synthesis. This architecture's implementation uses less space and power.

In continuation, S. A. Osmany, et. Al., [9] proposed a simple model for noise detection in fractional-N PLLs that focuses on RF synthesizers. Jitter is another way that can affect the performance of the design and phase problem is reported.

Moreover, Anupama Patil. et. al., [10] (2016) implemented Hilbert transform to ADPLL. Anupama Patil implemented the phase detection system. It is more advantageous than the analog phase detector

Furthermore, Bharanidharan N et. al., [11] (2019) Dead zone avoidance in discrete PLL was used. FPGA is used in the implementation of this concept for improved outcomes.. A new formula can provide the entire tracking range. An accurate analysis of the Discrete PLL with less area and greater precision was achieved in this tracking duration and tracking range.

Matan Gal-Katziriet. al., [12] (2018) introduced a delayed locked loop in addition to the PLL. This design achieves a fine delay time and low noise. There is less rms jitter in this architecture. PLL is utilized in 5G technology for communication purposes, and it is made using 65nm CMOS technology. Low noise is achieved using this strategy.

Furthermore, Manas Kumar Hati et. al., [13] (2017) developed a methodology that is called pulse swallow based method for fractional-N PLL. A Programmable Pre-scalar Divider circuit implemented and compared with other design that is Swallow Based Divider. the arriving and settling time problem near the counter can be resolved.. The maximum operating speed is 5.133GHz. in this design better phase noise and jitter Performance is achieved.

Moreover, Yao Hanl et. al., [14] (2018) simplified the phase noise model and applied frequency modal analysis and feedback control. In this mathematical analysis done on input reference signal and VCO phase

In this research work, Mostafa Abediet. al., [15] (2018) designed aperture phase detector (APD) its purpose is to turn off the blocks which are related to the frequency locked loop. Amplitude Charge Pump is used to lower

the reference spur. CMOS technology is used to implement the design

Moreover, Chang-hong Shan et. al., [16] (2018) identified the most important current issues in ADPLL and implemented different approach to resolve it .first one is the automatic measuring the parameters value and control the parameters. In this speed is increased compared with previous work.

In continuation to this, Taekwang Jang et. al., [17] (2018) identified the advantage of the programmability compared with hardware circuit that is charge pump and it can be replaced. The noise circuits implemented with bang -bang phase and frequency detection

Further, Jung-Mao Lin et. al., [18] (2015) elaborated digital loop filter that operates in four different modes to have stable operation in ADPLL and always maintain stable in fast locking operations. Designed and implemented ML-BBPD which provides multilevel phase error with different outputs.

In this research work, Seok Min Jung et. al., [19] (2015) designed PLL for VCO Purpose; this PLL is designed with low jitter specifications that can be implemented in Oscillator. The c VCO is subjected to noise. It is reduced in this PLL design.

In addition to this, Saleh R. Al-Araji et. al., [20] (2013) implemented Zero crossing DPLL with multiple gain selection method for reliable locking, fast acquisition, improved jitter noise and performance

Moreover, ZakiaBerber et. al., [21] (2019) designed PLL for Frequency Synthesizer for wide band application like 5G .ZakiaBerber implemented third passive loop filter using phase frequency detector. Even though leakage current is present but it will not affect the system performance it is achieved by Design Loop Filter

Similarly, Ye Zhangn et. al., [22] (2014) implemented error masking technique for signal modulation along with Quantization. A new Design architecture is implemented which consumes less power and area and solve some of the issues related to Frequency Synthesizer

Furthermore, Jianfu Lin et. al., [23] (2017) implemented PLL for wide tuning range depend upon class -C, VCO

for IEEE 802.11ah A.AFC Algorithm to maintain oscillation avoiding the deterioration. The design provides gate bias to core transistor of Class-C, VCO

Moreover, BoJiang, et. al., [25] (2014) developed a Process to determine ADPLL circuit elements build on required design identification, includes fractional spur and locking time. An logical model is formulated to identify the effects of noise sources in ADPLL

In this research work, Debdu Biswas et. al., [27] (2019) implemented Sub-Sampling fractional-N PLLs (SSPLL) provide stronger in-band phase noise performance than traditional PLLs the source of spurs are modeled and differentiate. Further, a SSPLL is implemented with a control voltage sampler.

Moreover, Qing song Ca et. al., [28] (2018) implemented programmable charge pump to recoup the variation of VCO and attained constant loop bandwidth exceeding tuning frequency range is reached without modifying the filter parameter

Moreover, Yao Han et. al., [29] (2018) Modeling of PLL to reduce phase noise focusing on loop filter output In this research work, Zhipeng Liang et. al., [30] (2018) Implemented sub sampling phase locked loop to achieve lower phase noise

Further, Ahmed Elkholy et. al., [31] (2018) Implemented a high resolution digital-to-time converter to make oscillator to work efficiently and improved clock range of operation with less area

Moreover, Jingcheng Tao et. al., [32] (2019) Implemented $\Delta\Sigma$ fractional pll without digital to time converter, linear slope generator is employed

In this research, Mehmet Batuhan Dayanik Tao et. al., [33] (2018) Implemented anew third order continuous time time –to-digital converter that shapes the quantization noise

Similarly, Romesh Kumar Nandwana et. al., [34] (2015) Implemented phase detection and interpolation function into XOR Phase detector/interpolator quantization error cancellation is achieved

Moreover, Parag Kanjiya et. al., [35] (2016) implemented frequency locked loop in this disturbance rejection capability of the FLL is improved modified structure low-pass filter.

Further, Mohammad Sadegh Jalali et. al., [36] (2011) Implemented phase frequency detector for clock and data recovery applications To achieve low jitter

In this research work, Sitao Lv et. al., [37] (2016) Implemented a digital FLL with a 1-bit $\Delta\Sigma$ frequency detector. To avoid time to digital converter, constant gain low noise

Further, R.Prithivi Raj et. al., [38] (2012) Implemented to produce a rapid, phase-locked, low-jitter clock with a broad frequency range.

Moreover, Tae-Kwang Jang et. al., [39] (2013) Implemented the power and area efficient circuits with competitive performance, noise canceller is also included.

In this research Feng-Wei Kuo et. al., [40] (2018) Implemented a new method to achieve low noise and less spur in the architecture for 4G applications.

Similarly, Zhirui Zong et. al., [41] (2018) Implemented to reduce phase noise and power consumptions.

Moreover, Jahnvi Sharma et. al., [42] (2019) Implemented a new method to achieve low noise and less spur in the architecture for 4G application.

Table 1: Performance summary and comparison

Refer	Techn-ology	Area	Supply Voltage	Output Frequency	Jitter
[30]	65nm	0.27	.9v	6-8.25Ghz	190fs
[31]	28nm	0.43	2.2v	2 Ghz	2ps
[32]	130nm	0.45	2.0v	2.3 Ghz	358.5fs
[34]	65nm	0.48	1.5v	4-4.7Ghz	1.5ps

METHODOLOGY

Digital Techniques are used to lower the phase noise as well as spurs.in this process first design design of fractional PLL using Simulink with given parameter like frequency and lock time , then implementation of of design with different filters, 1st order and second order low pass filter . Then implemantation of delta sigma modulator to reduce the phase and reduce the settling time of the design Modulator varies over 2 values for first order, 4 values for the second, 3 values for the third and so on. Dithering concept is used to randomize the signals to eliminate the periodic spurs. Higher order delta sigma modulators are designed using this

technique [2,3]. This method transfers the combined output of one modulator step to the subsequent stage.

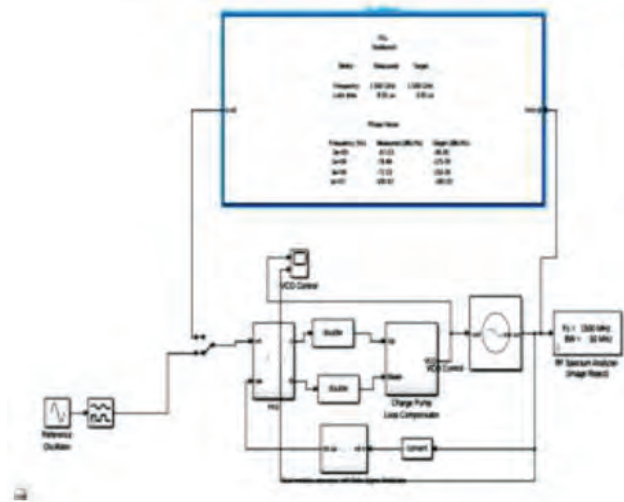


Fig. 1: PLL through DSM (Delta Sigma Modulator)

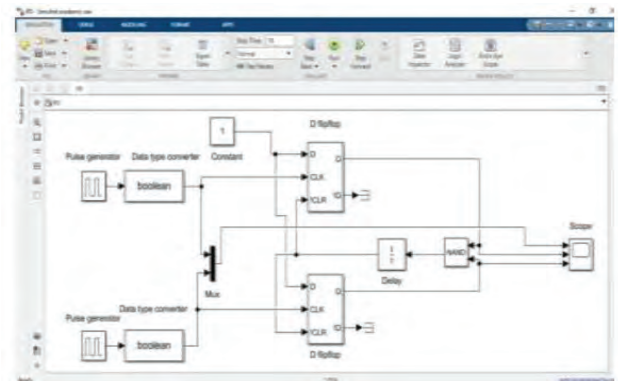


Fig. 2: Phase detector using D-flip flop

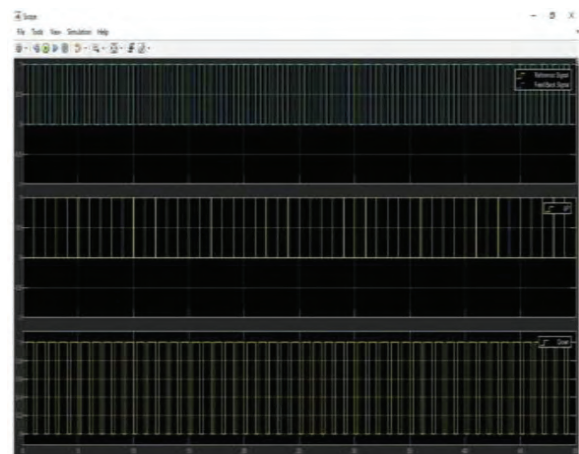


Fig. 3: Simulation results of Phase detector using D-flipflop

CONCLUSION

To Analyze the blocks of PLL and study the various parameters that are causing to Phase Noise and Jitter Noise. To Study various reasons for more power consumptions and identifying leakage currents which are effecting the performance of the PLL. Frequency synthesizer is capable of handling up to low frequency instead of this Fractional PLL is introduced to handle higher frequencies with less phase noise.

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Deep Learning Approaches for Copy-Move Forgery Detection in Videos: A Comprehensive Review of Methods and Techniques

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ABSTRACT

Copy-move forgery detection in videos is a critical task for ensuring the authenticity and integrity of visual content, especially in applications requiring high security and reliability. Traditional methods often struggle with the complexities of video data, including temporal dependencies, variations in resolution, and extensive computational requirements. This review explores the evolution of methods for detecting copy-move forgery in videos, emphasizing the integration of deep learning-based approaches. The study highlights the limitations of conventional techniques, including block-matching and keypoint-based methods, while analyzing the advancements brought by convolutional neural networks (CNNs), recurrent neural networks (RNNs), and hybrid architectures. Special focus is placed on leveraging temporal dynamics, spatial feature extraction, and attention mechanisms to enhance the detection of manipulated regions. A critical comparison of existing methods is conducted, outlining their strengths, weaknesses, and applicability to various forgery scenarios. Emerging trends, including generative adversarial network (GAN)-based detection and transformer models, are also examined for their potential to improve detection accuracy and robustness. This review provides insights into current challenges and opportunities in video forgery detection, emphasizing the importance of deep learning in addressing the increasing sophistication of video forgeries and paving the way for future innovations in this domain.

KEYWORDS: Copy-move forgery detection, Video forgery detection, Deep learning models, Temporal dynamics, Attention mechanisms.

INTRODUCTION

Copy-move forgery for digital manipulation is most commonly used approach. In this type part of the content from one region is copied and pasted in another region. In case of videos, this is performed by copying some content from one frame and pasted into same or other frames irrespective of sequence. This alters the content with significant exgeration. With the exponential growth of multimedia data and its ubiquitous sharing across digital platforms, the potential misuse of such forgery has increased significantly, posing critical challenges in fields such as journalism, forensic investigations, and surveillance [1]. Consequently, the authenticity analysis and reliability estimation of the content of image or video is performed by detection of forging attacks in which copy-move forgery attacks are also considered at the major scales.

Unlike still images, video forgery detection presents unique challenges due to its complex temporal and spatial dimensions. Forgery in videos often involves intricate manipulations, including frame duplication, object cloning, and regional tampering, which require advanced algorithms capable of analyzing temporal coherence and spatial consistency. Traditional methods for forgery detection relied heavily on handcrafted features, such as block-matching techniques and keypoint-based approaches, which are computationally expensive and struggle to generalize across diverse video content [2]. These limitations have driven researchers toward employing deep learning techniques. Especially in image and video processing tasks, Convolutional Neural Networks (CNNs), shows robust nature while extracting complex features even from high dimensional data. In copy move forgery detection tasks, CNN models also have shown their performance oriented hierarchical feature

extraction capabilities to improve the attacks detection performance. These models are particularly effective in capturing both spatial patterns and temporal correlations, which are essential for detecting subtle manipulations in videos [3]. Standard CNN architectures, such as VGGNet, ResNet, DenseNet, and EfficientNet, have been widely utilized and modified for forgery detection tasks, owing to their versatility and state-of-the-art performance in visual analysis. However, the direct application of these architectures to video forgery detection has revealed certain challenges, including the need for enhanced feature extraction capabilities, computational efficiency, and adaptability to various forgery types [4].

This review analyzes CNN models for copy-move forgery detection in videos, examining their evolution, strengths, limitations, and modifications for spatiotemporal challenges. It explores hybrid CNN-LSTM architectures, preprocessing techniques, data augmentation, and evaluation metrics. A comparative study across datasets highlights research gaps and practical applicability. By addressing challenges and emphasizing advancements, the review aims to guide researchers in designing robust models for video forgery detection, contributing to multimedia forensics innovation.

LITERATURE REVIEW

From 2007 to 2024, a total of 122 papers on passive video forgery detection were selected following a systematic three-step process: removal of duplicates, relevance-based abstract review, and detailed examination of the shortlisted papers. Among these, 99 high-citation papers were chosen for primary analysis due to their publication in reputed journals and conferences. In forensics analysis requirements, information security requirements and also some of the applications where information content of the videos are important such as insurance services or surveillance systems, passive techniques are popular these days. However, challenges persist in developing robust, standardized, and efficient solutions capable of addressing diverse tampering scenarios.

Active Detection Techniques

Active methods like fragile and semi-fragile watermarking require embedding watermarks during video recording. Fragile watermarking alters when tampering occurs, making forgery detection possible, while semi-fragile methods are less sensitive to changes. However, these approaches face hardware limitations as not all capture

devices support watermark embedding. Additionally, tampering performed before watermark insertion remains undetected [5] [6].

Passive Detection Techniques

1. **Camera Source-Based Techniques:** The original information from the camera contains the features such as fixed pattern noise (FPN) which are important while capturing and identifying the forged regions. Also sensor pattern noise (SPN) from the camera outputs are considerable while analyzing and detecting the forged attacks. Hsu et al. [7] considered the analysis of noise residuals and detected forgery by analyzing them using Bayesian classifiers, achieving a recall of 96% and precision of 55%. Similarly, Kobayashi et al. [8] utilized noise inconsistencies across frames, achieving 94% recall and 75% precision. Hu et al. [9] employed extrinsic camera parameters to detect region tampering, while Fayyaz et al. [10] leveraged sensor noise patterns for effective detection of object-based forgery.
2. **Compression-Based Techniques:** Artifacts from compression, such as double quantization (DQ) and group of pictures (GOP) structures, are exploited to identify spatial forgeries. Labartino et al. [11] used DQ artifacts to detect forgery in double-compressed videos, assuming tampering occurred before the second compression. Tan et al. [12] developed a method for identifying object-based forgery in advanced video encoding using GOP structures, achieving 80% accuracy. Bakas et al. [13] employed CNNs to detect double-compression-based forgery, achieving 90% detection and 70% localization accuracy.
3. **Statistical Features-Based Techniques:** Statistical properties disrupted during tampering can help detect manipulation. Wang et al. [14] used inter-frame correlations to detect duplicated frames, achieving accuracy rates of 85.7% and 95.2% for stationary and handheld recordings, respectively. Wang et al. [15] used coefficients of correlation obtained between gray values for frame insertion and deletion detection, achieving 96.21% accuracy. Singh et al. [16] Discrete Cosine Transform (DCT) features. This enhanced the duplication detection capability of the models with better accuracy levels.

4. **Frequency Domain Features:** Transform-based methods like DCT and Fast Fourier Transform (FFT) are commonly employed for feature extraction. Su et al. [17] used motion-compensated edge artifacts (MCEA) with respect to motion vectors in video frames along with DCT to detect frame deletion, achieving high precision for small datasets. Dong et al. [18] employed MCEA and FFT spikes for similar tasks but lacked localization capabilities.
5. **Texture-Based Techniques:** Texture descriptors such as Local Binary Patterns (LBP) are effective in detecting tampered regions. Zhang et al. [19] used sequential LBP coding, while Liao and Huang [20] employed Tamura texture features to identify duplicate frames. Although accurate, these methods struggle with small-scale or subtle manipulations.
6. **Deep Learning-Based Techniques:** Deep learning approaches have demonstrated high efficacy in video forgery detection due to their ability to extract spatiotemporal features. Zampoglou et al. [21] utilized pre-trained ResNet and GoogLeNet networks to detect spatial forgeries using DCT-based filters, achieving 85% accuracy. Kaur et al. [22] considered inter frame forgery detection in which CNN approach was used. They used REWIND and GRIP datasets for the performance evaluation which shows almost 98% accuracy. Fadl et al. [23] used 2D-CNN and RBF-MSVM for temporal tampering detection, achieving true positive rates (TPRs) of 98.7%, 99.9%, and 98.5% for frame deletion attack, also with addition of frame and insertion at specific sequence, and duplication of frames attack, respectively.

While deep learning techniques excel in detecting complex manipulations, their reliance on large datasets and computational resources limits their scalability. Future research must focus on creating robust, efficient, and universally applicable solutions for video forgery detection to address diverse tampering techniques effectively.

PROPOSED WORK

The work focuses on understanding the required features and extraction capability of different CNN models for development of an efficient framework for detecting copy-move forgery in videos, leveraging advanced preprocessing, feature extraction, and deep learning techniques. Spatial and temporal feature integration ensures high accuracy

across diverse manipulations, addressing key challenges in video forgery detection and enhancing video content reliability for forensic applications.

Input Video: The process starts by loading the video, validating its format, and extracting frames. These steps structure raw data into a format compatible with subsequent analysis.

Preprocessing: Frames are resized to uniform resolution, noise is filtered, and color channels are normalized. This standardization ensures consistent feature extraction and minimizes irrelevant variations.

Feature Extraction: Pretrained CNN models like ResNet, VGGNet, and EfficientNet extract spatial features, capturing texture anomalies and inconsistencies. Temporal features are analyzed to detect frame duplications, insertions, and deletions. Dimensionality reduction ensures computational efficiency while preserving essential information.

Forgery Detection Model: A trained deep learning model analyzes features to predict video tampering and localize manipulated regions. Advanced algorithms enhance accuracy in detecting diverse manipulations.

Output Results: Results include detailed reports, localization maps of tampered regions, and saved outputs for future use, supporting forensic investigations.

The workflow shown in Figure 1 systematically integrates preprocessing, feature extraction, model-based detection, and result generation to detect video copy-move forgery effectively.

Pre-trained CNN models such as ResNet, VGGNet, and EfficientNet are widely used for feature extraction due to their robust architectures and proven performance in diverse image and video analysis tasks [24]. These models are first proven on ImageNet dataset for effectively capture spatial features such as textures, edges, and patterns. The pre-trained models on this dataset are further used for feature extraction from video frames. By leveraging their learned weights, the feature extraction process becomes efficient, requiring minimal fine-tuning while achieving high accuracy. These models also reduce the need for extensive labeled data and computational resources, making them ideal for detecting tampered regions in videos.

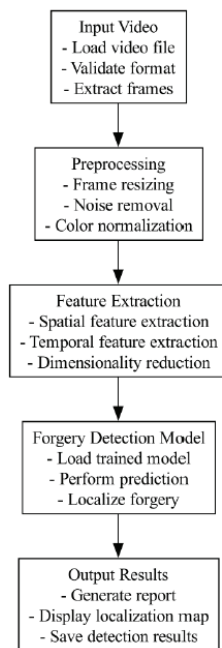


Fig. 1: Proposed System

RESULTS AND ANALYSIS

The MFC18 (Media Forensics Challenge 2018) [25] dataset, provided by NIST, is a comprehensive resource featuring authentic and forged videos created for multimedia forensics. It includes diverse manipulations such as frame deletion, insertion, duplication, and object tampering, along with metadata alterations, making it ideal for benchmarking. The VIRAT Video Dataset [26], primarily designed for surveillance applications, contains real-world videos annotated for various objects and activities. Researchers often use it to create synthetic forgeries like frame duplication and deletion, enabling robust evaluation of tampering detection algorithms.

To evaluate the performance of copy-move forgery detection models, several metrics are widely used to measure accuracy, robustness, and localization precision. These metrics are used for analyzing the performance in classification of copy-move forged videos.

$$\text{Accuracy} = \frac{TP + TN}{TP + FP + TN + FN}$$

The correctness in identification of tampered and authentic videos is estimated by accuracy. It provides an overall effectiveness of the model but may not fully reflect performance when the dataset is imbalanced.

Precision

In total detection capability of the model, correctly identified forged videos define the model's Precision. High precision reflects fewer false positives, making it critical for applications requiring high reliability.

$$\text{Precision} = \frac{TP}{TP + FP}$$

Recall (Sensitivity)

Actual tampered videos detection capability of the model is deduced by Recall. It is essential for evaluating the ability to detect manipulations comprehensively.

F1-Score

When harmonic mean from precision and recall is estimated the F1 score values is obtained. In this false positive and false negative detections impact the score which need to be minimum for maximum F1 score values.

$$\text{F1-Score} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$$

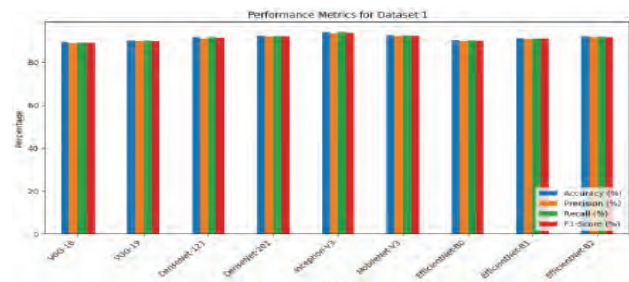


Fig. 2: Results on Dataset 1

The first graph illustrates the performance metrics of various pre-trained models evaluated on Dataset 1. Among the models, Inception-V3 demonstrates the highest performance across all metrics, with an accuracy of 94.1%, precision of 93.5%, recall of 94.0%, and an F1-score of 93.7%. This indicates its strong ability to handle spatial and contextual features in the dataset, making it highly effective for the task. DenseNet-201 and DenseNet-121 follow closely, showcasing their capacity to extract robust features due to their densely connected architecture. Their accuracy scores of 92.3% and 91.7%, respectively, emphasize their reliability. MobileNet-V3 also performs competitively, with an accuracy of 92.8%, highlighting its efficiency as a lightweight model suitable for resource-constrained environments. The VGGNet

models (VGG-16 and VGG-19) achieve moderate results, with accuracy hovering around 89.5%-90.2%. While they remain reliable, their performance lags slightly due to the absence of advanced optimization techniques seen in newer architectures. The EfficientNet models (B0, B1, B2) show consistent improvements in performance, with B2 achieving an accuracy of 92.0%. Their compound scaling strategy effectively balances accuracy and computational efficiency, making them versatile choices.

Overall, the results highlight Inception-V3 and DenseNet variants as top-performing models on Dataset 1, while EfficientNet models exhibit a promising both performance parameters accuracy and efficiency.

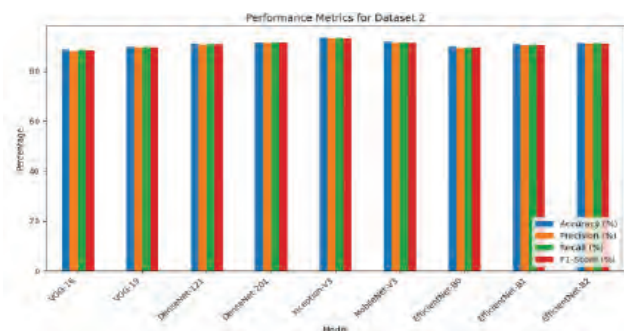


Fig. 3: Results on Dataset 2

The second graph presents the performance metrics of various pre-trained models evaluated on Dataset 2. Inception-V3 again emerges as the top-performing model, achieving the highest metrics with an accuracy of 93.5%, precision of 93.0%, recall of 93.3%, and an F1-score of 93.1%. This consistent performance across datasets highlights its robustness and superior feature extraction capabilities for diverse video forgery detection tasks. DenseNet-201 and DenseNet-121 continue to perform well, with accuracy scores of 91.8% and 91.0%, respectively, reflecting their ability to generalize effectively across datasets. MobileNet-V3 also demonstrates commendable performance, with an accuracy of 91.9%, emphasizing its efficiency as a lightweight yet accurate model. The VGGNet models (VGG-16 and VGG-19) achieve slightly lower metrics compared to others, with accuracies of 88.7% and 89.8%, respectively. While they remain reliable, their older architecture limits their competitiveness against modern models. The EfficientNet models (B0, B1, B2) show consistent improvements across metrics, with EfficientNet-B2 reaching an accuracy of 91.5%. These results underline the efficiency of their compound scaling approach for balancing computational

demands and accuracy. In summary, Inception-V3 and DenseNet models dominate Dataset 2's results, while EfficientNet variants provide a balanced trade-off, making them promising choices for forgery detection tasks.

CONCLUSION

This study evaluated the performance of various pre-trained models in copy move forgery detection from videos. The analysis included pretrained models such as VGGNet, DenseNet, Inception-V3, MobileNet-V3,

and EfficientNet. The results across two datasets demonstrated that Inception-V3 consistently achieved the highest performance metrics. This shows higher detection capabilities of the models in reliable manner for detecting tampered regions. Its superior spatial and contextual feature extraction capabilities make it well-suited for complex forgery detection tasks. The DenseNet variants, particularly DenseNet-201, showed excellent results, highlighting the effectiveness of densely connected layers in capturing intricate patterns in video frames. MobileNet-V3, despite being a lightweight model, performed competitively, offering an efficient alternative for resource-constrained applications. The EfficientNet models showcased consistent improvements with their compound scaling strategy, balancing accuracy and computational efficiency. EfficientNet-B2 emerged as a strong contender, achieving competitive metrics while maintaining lower resource requirements. VGGNet models, while achieving moderate results, demonstrated limitations due to their relatively older architecture and lack of advanced optimizations. Overall, the analysis highlights the importance of choosing models based on task complexity and resource constraints. While Inception-V3 and DenseNet variants are optimal for accuracy-focused applications, EfficientNet models are promising for real-time or large-scale deployments. Future work can explore hybrid architectures and fine-tuning to further enhance detection capabilities.

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An Integrated Approach to Real Time Anomaly Detection and Physical Layer Secured Routing in Wireless Multi-Hop Networks

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ABSTRACT

Objective: The paper considers a new PLSR algorithm for both the enhancement of security and performance in full-duplex multi-hop wireless networks. Its main goals here include combining the parameters of the physical layer along with advanced routing and security techniques for countering various types of threats in the network while remaining highly efficient. **Method:** The proposed algorithm eliminates the need for having an overall knowledge of the network, which helps in reducing computational complexity as well as the dependency toward network-wide synchronization. The system employs the utilization of sophisticated metrics like the Jaccard Coefficient, Cosine Similarity, and Levenshtein Distance for neighbor validation, attacker identification, and the routing of data. Real time anomaly detection is innovatively implemented within the system using dynamic and adaptive parameter tuning for effective handling of drastic changes in data behaviour. Moreover, the algorithm uses ECC for cryptographic key generation and data encryption, which provides high security with minimal computational requirements. The proposed method avoids reliance on global CSI and employs adaptive strategies to address significant deficiencies in the existing literature. **Results:** Simulation results confirm the effectiveness of the algorithm, showing significant improvements in network security, accuracy of attack detection, and overall system performance. With average packet delivery ratios of 82.14%, the average secrecy capacity was 3.30 bps, and the network attack detection ratio was 100%. These improvements are comparative ones in terms of data delivery efficiency and network security; therefore, the proposed algorithm is a robust, scalable, and efficient solution for future wireless networks

KEYWORDS: *Wireless full duplex nodes, Jaccard coefficient and distance, Cosine similarity and distance, adaptive filtering, Anomaly detection jamming attack.*

INTRODUCTION

The inclusion of PLS with routing protocols in full-duplex multi-hop wireless networks is an important step towards mitigating the issues associated with the fortification of both the security aspects and the operational capabilities of the network. Security consideration at the physical layer is focused by the innovative techniques introduced by the proposed Physical Layer Secured Routing (PLSR) algorithm

for the rigorous enhancement of the robustness of communications over wireless links against malicious interference attacks, including jamming and eavesdropping attacks. This method utilizes well-known metrics, including Cosine Similarity and Jaccard Coefficient, to make routing decisions in a reliable manner while also supporting real-time anomaly detection that can reactively address changes in the network and adversarial attacks. The motivation to integrate PLS with routing stems from the increased

vulnerabilities of traditional cryptographic techniques in dynamic resource-constrained environments. Traditional methods are not strong enough to prevent advanced threats, especially for applications like IoT and VANETs. Information-theoretic security, which is independent of computational powers, makes PLS a better choice than cryptography techniques [1]. In addition, PLSR offers secure key distribution that does not rely on the existence of previously shared keys [2] and improves the detection capability of attackers, thereby decreasing the chance that the adversary may recover keys [3]. Current approaches primarily rely on resource-intensive cryptographic techniques or those that cannot adapt to the real-time dynamic nature of network behaviors. To bridge these gaps, Rami, Ahmad et al (2024) employs an adaptive mechanism for anomaly detection based on OAKEF. Due to this mechanism, false positive and negative percentages are dramatically reduced, and up to 95.4% accuracy is found in real-time implementations [4]. More advanced models, like V-GCN, further improve toward anomaly detection. In such improved models, 95% AUC-ROC is found for anomaly detection performance [5]. In addition, the algorithm is resource-aware and uses frameworks like Mateen, which picks representative samples for reducing overheads while still allowing adaptability to benign behaviors [6]. This way, physical and cryptographic security to address vulnerabilities in multiple layers and provide a holistic defense against attacks of different types [7][8]. Statistical validation metrics, and also decision trees, random forests, and neural networks in the form of machine learning methods, allow real-time identification of anomalies in network behavior for rapid response to threats [9]. Another algorithm from this class that shows good adaptation to a wide variety of network setups, like smart grids of modern generations and IoT devices, is PLSR. Real-time performance of the model in such environments is tested with advanced models, including LSTM networks for the analysis of time-series data [11]. In combination, these characteristics and efficient resource utilization with a secure architecture make the physical layer security approach provides an innovative solution that is more effective in the context of modern wireless networks.[12].

SECTION -I

Proposed Physical Layer Secured Routing Algorithm (PSLR)

The PSLR algorithm presented here has achieved physical layer security enhancement by employing a comprehensive methodology that integrates a neighbor validation using changed technique, signal strength analysis, and attack detection. This multi-faceted approach effectively enhances the security of the wireless network at the physical layer, providing robust protection against various attacks.

Neighbor Validation

In wireless networks, the physical layer deals with the transmission and reception of signals, and is characterized by signal strength, propagation delay, and distance. Neighbor validation utilizes these physical layer characteristics to ensure that nodes claiming to be within communication range are actually present and behaving consistently with their declared status.

Cross-referencing the signal strength and the distance against the expected values for legitimate nodes can detect discrepancies those are indicating the presence of malicious nodes. If a node claims to be a neighbor but its signal strength is inconsistent with its claimed proximity, or if the similarity in neighbor lists deviates significantly from expected patterns, the node can be flagged as suspicious.

Jaccard Coefficient Calculation

The Jaccard coefficient quantifies the similarity between two sets of neighbors for two nodes i.e. set1 and set2. neighbor list is used to compute Jaccard Coefficient of similar neighbor's nodes. This coefficient ranges from 0 to 1, where 0 indicates no overlap between the sets (i.e. completely different sets) and 1 indicates complete overlap (i.e. identical sets). The coefficient is computed using following formula.

$$\text{Jaccard Coefficient} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|} \quad (1)$$

Where $|A \cap B|$ is the size of the intersection of the two sets that specify number of common elements and $|A|$ is the size of List set1 and $|B|$ is the size of List set 2.

Jaccard Distance Calculation

The Jaccard distance is derived from the Jaccard coefficient and represents the dissimilarity between two sets [9]. It is calculated as follows.

$$\text{Jaccard Distance} = 1 - \text{Jaccard Coefficient} \quad (2)$$

A low Jaccard coefficient i.e. high Jaccard distance, indicates malicious node and implies dynamic corrections to security parameters

Cosine Similarity Calculation

The Cosine Similarity is useful measure which represents data vectors but needs to know whether they point out the same direction. This in turn helps to determine the similarity of the data patterns between nodes [7]. It is calculated as follows.

$$\text{Cosine Similarity} = \frac{\sum A_i \times B_i}{\sqrt{\sum A_i^2} \times \sqrt{\sum B_i^2}} \quad (3)$$

Here, A_i and B_i represent individual elements of the vectors A and B. Cosine similarity set true/false flags to decide node's behavior is consistent or not consistent with the rest of the network. If Cosine similarity is true, it suggests normal behaviour; if false, it indicates a deviation that indicate malicious activities such as signal jamming, spoofing, or data injection attacks.

Anomaly Detection Using Node Distant Matric

The PLSR algorithm performs neighbor validation by computing Euclidean distance between two nodes (x_1, y_1) and (x_2, y_2) in the network and analyze network behavior patterns. It is computed as follows.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (4)$$

In eq.4, d is the Euclidean distance between the two points which helps 'DL_function' to identify problems at a network level by examining distance variation. The function calculates the costs of substitution, insertion, deletion, and transposition for all neighboring nodes to find the minimum distance metric 'min_d', which flag harmful patterns. The minimal distance classifies each node as normal or suspicious. The 'DL_result array' stores the computed results[13].

Adaptive Filtering for the Identification Of Anomalies

The PLSR algorithm facilitates the 'Automatic Lag Adjustment Method' for anomaly detection. The algorithm makes the system more sensitive to existing anomalies while preventing redundant positive results by dynamically recomputing the lag based on past and present data deviations. The baseline is computed using statistical metrics 'mean μ ' and the 'standard deviation σ ' of past data. [14][15].

Sensing Jamming Attacks

The most important function 'recvHello' detects jamming attacks by checking the occurrence of duplicated "Hello" messages from the same node with identical sequence numbers. If this duplication surpasses a threshold, then the node may be identified as a malicious node and appropriate countermeasures should be invoked against such a node. [10][11].

Encryption Of Data Packets

Cryptography plays vital role in the proposed algorithm which secures the communication in the wireless networks. The PLSR Algorithm has employed Elliptic curve cryptography (ECC). It generates public- private key pair, distinct for each node in the network. To generate the keys, the 'generate_key()' function uses the NIST B-163 elliptic curve. It is obtained using eq. 5.

$$y^2 + xy = x^3 + ax^2 + b \pmod{p} \quad (5)$$

In equation 4, a and b are curve constants, p is a prime number denoting the finite field.

Each node (r,s) uses the Elliptic Curve Digital Signature Algorithm (ECDSA) to authenticate, to ensure integrity and security as RSA but with the use of smaller key sizes such as 163-bit ECC keys compared to 1024-bit keys of RSA.

$$r = (kG)_x \pmod{n}, \quad (6)$$

$$s = k^{-1} (H_{(m)} + sr) \pmod{n} \quad (7)$$

In above equations, key k is a random number, n is the base point G order, and H(m) is the hash message.

Other nodes then validate the signature to authenticate the sender and message integrity.

SECTION-II

RESULTS AND DISCUSSIONS

Simulation Environment

The PLSR algorithm is simulated in NS2 platform. Two reference physical layer security enhancement schemes for full duplex nodes have been simulated. One scheme selects relay with source-destination and global CSI The Multi-Relay Node Management (MRNM)[13] has considered and second scheme Bi-Level Security (BLSF) [14] framework has used a composite signal approach with untrusted relay nodes. This simulation was chosen because it allows for the comparison of security in full-duplex wireless networks. Management of Multi-Relay Nodes (MRNM)[13] Using the source-destination pairs and global Channel State Information, several relay nodes in this approach have managed to provide network security; hence, this approach is the benchmark. Bi-Level Security Framework [14] BLSF was selected for its innovative composite signal technique for untrusted relay nodes Comparing

PLSR with BLSF shows how the proposed algorithm secures communication in untrusted relay nodes, proving its robustness in modern network conditions. The simulation uses MAC 802.11 along with the 'TwoRayGround' channel propagation model for a period of 200 seconds. It uses Constant Bit Rate (CBR) data generation and 100-byte packet size distributed over 50 nodes to create a stable comparative environment. Fig. 1 is compared with the reference methodologies presented above to estimate PLSR's security resilience, efficiency, and attack detection capabilities. The analysis is carried out on the basis of the parameters associated with Security Performance and Network Performance. Critical metrics include secrecy capacity, probability of non-zero secrecy capacity (PNZSC), packet delivery ratio (PDR), throughput, CPU usage by users, memory consumption, and latency. Fig 2 shows 3.11 bps as the highest secrecy capacity and maintained it at 3.45 bps during overall simulation time. Ability to preserve secrecy despite presence of attackers. This suggests that PLSR strikes a balance between security

and performance .Fig 1. Algorithmic representation of Proposed PLSR Algorithm.

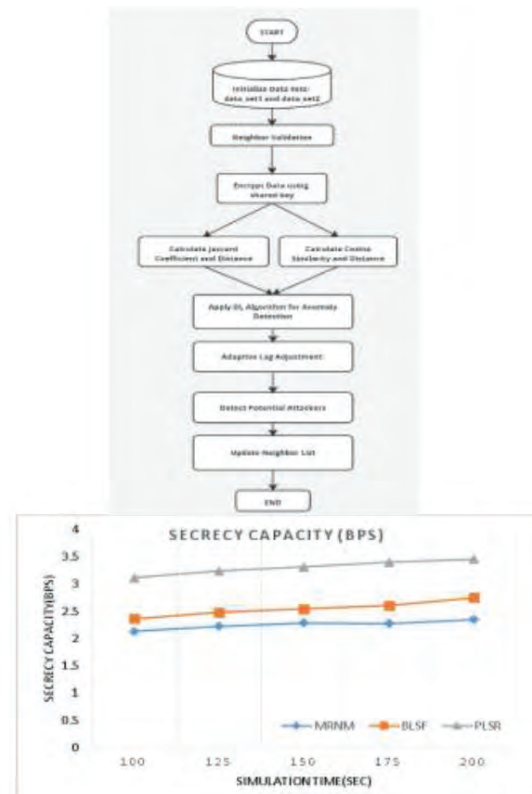


Fig. : 2 Secrecy Capacity

Fig. 3 shows the relationship between attacker and PNZSC. It shows the probability of positive amount of secret information that may be communicated consistently over a communication channel in presence of an eavesdropper. A high PNZSC suggests that the channel can send certain amount of secret information more securely and the network security is enhanced while sending the data. Thus, the PLSR has improved overall security as compared to other techniques.

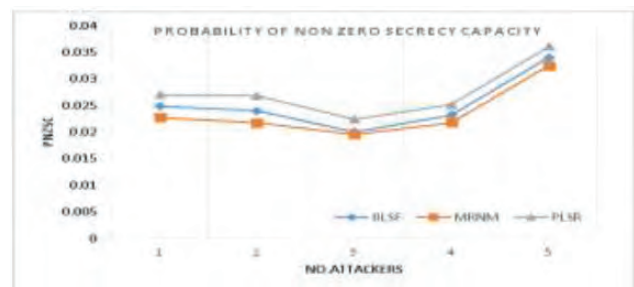


Fig. 3. Probability of Non-Zero Secrecy Capacity

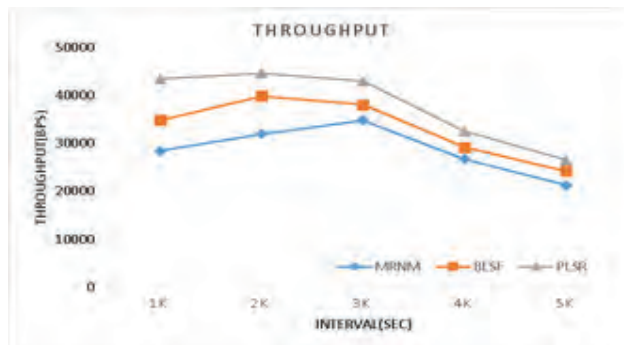


Fig. 4. Throughput

Figures 4, 5, 6, depicts Throughput, Packet Delivery Ratio & Delay as comprehensive network performance measures.

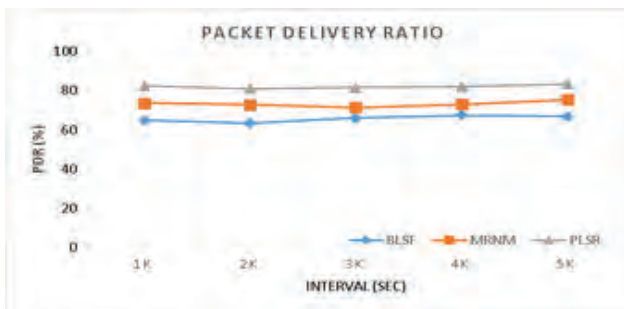


Fig. 5. Packet Delivery Ratio

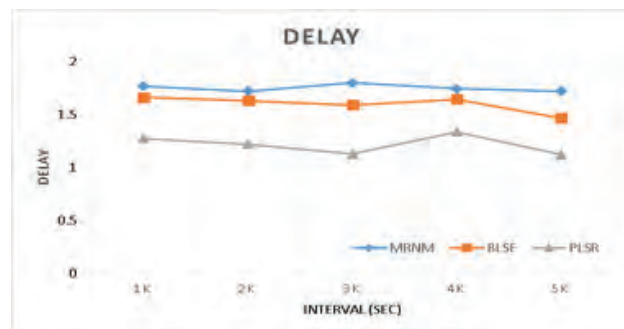


Fig. 6. Delay

The metrics indicate the favorable network transmission condition as security performance of the network is improved by employing the PLSR method. Figure 5 illustrates that the PLSR has achieved an average packet delivery ratio of 82.14%.

Fig 7 shows the percentage of CPU instructions executed in user space. In NS2 simulation, the CPU usage (%) shows the percentage of CPU time used by tasks or user-driven processes. Fig 7 shows that BLSF

requires the highest amount of computation, whereas PLSR provides superior memory usage. PLSR is the most memory-efficient with the lowest memory usage (395,008 kB). Its CPU usage at 3.3% of user space is much higher than MRNM and is still relatively moderate. Fig 8 shows plot of load average vs. time interval.

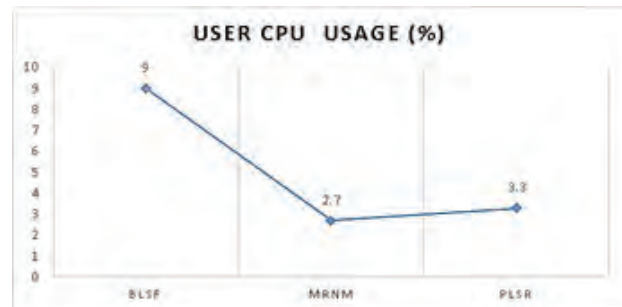


Fig. 7. shows User CPU Usage (%)

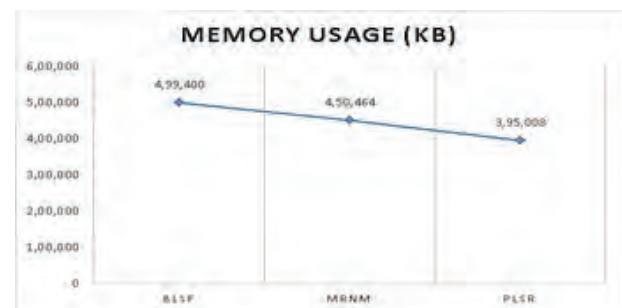


Fig. 8. Memory Usage (kb)

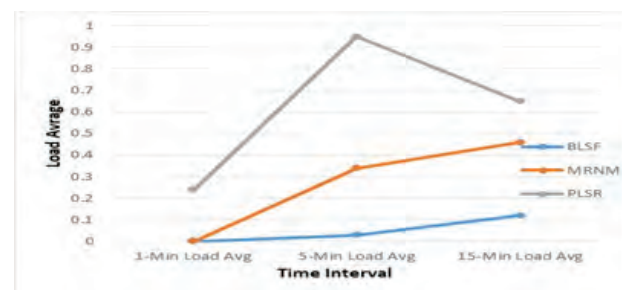


Fig. 9. Load Average

The Load average serves as a metric for CPU performance, reflecting the average quantity of processes awaiting execution and thereby signifying the system's effectiveness in managing its existing workload. The load average associated with PLSR is the most raised among the three metrics assessed, implying that the system's demand throughout the simulation period was correspondingly greater but such a high load average is

not followed by noticeable degradation in performance in term of delays as fig:6 shows or dropped packets then it is an indication that the algorithm could really work well even under heavy workloads.

SECTION-III

CONCLUSION AND FUTURE SCOPE

The proposed PLSR algorithm presents an innovative and secure framework tailored for full-duplex wireless communication systems, addressing some of the key constraints of the current approaches by combining sophisticated physical layer security techniques with effective routing protocols. Unlike the traditional methodologies that rely on global CSI or fixed thresholds, PLSR relies on adaptive approaches such as neighbor validation with the Jaccard Coefficient and Cosine Similarity. Real-time analysis of signal and noise is considered in order to identify and effectively counter threats of jamming and eavesdropping. Applying ECC, the algorithm is designed to ensure a safe key exchange with a minimum amount of computational overhead, while providing increments both in the security and network performance: packet delivery ratio is at 82.14%, average secrecy capacity at 3.30 bps, and 100% attack detection. However, latency in ultra-dense networks will be introduced, and the performance can be optimized in those environments that are significantly resource-constrained. The promising applications of PLSR towards 5G, IoT, and smart grids lie in areas where scaling and dynamic adaptation are major concerns.

Future research recommendations: integration of more advanced machine learning models for further improvement in anomaly detection, the compatibility of this scheme with ultra-dense network scenarios, and energy consumption problems in IoT devices. There are still some open questions concerning its robustness against coordinated multi-layer attacks, adaptability to evolving network architectures, and security-throughput trade-offs in very dynamic scenarios. These domains present potential areas for further improvement, thus ensuring the effectiveness of PLSR as a unified technique to secure communication in future wireless networks.

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Enhancing Object Sorting Efficiency: A Survey of Robotic Arm Systems Employing Image Processing and Machine Learning

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ABSTRACT

The advent of automation has significantly transformed manufacturing and logistics industries, with robotic arms playing a pivotal role in enhancing efficiency and precision. The integration of robotic arms with advanced image processing and machine learning (M.L.) techniques has revolutionized object sorting systems, enabling unprecedented levels of accuracy and efficiency. This review paper synthesizes recent advancements in robotic arm-based object sorting, emphasizing the synergistic role of image processing and machine learning (M.L.). The integration of these technologies allows for real-time identification, classification, and sorting of objects, thereby optimizing operational workflows. We explore the critical components and methodologies employed in the development of these systems, including image acquisition, feature extraction, object recognition, and sorting algorithms. Additionally, we evaluate a diverse array of machine learning (M.L.) models like Convolutional neural networks (CNNs), support vector machines (SVMs) and decision trees, which enhance the object classification process. The paper also highlights the practical challenges and solutions related to real-time processing, adaptability to diverse object types, and system integration. Through a comprehensive examination of current research, this review aims to provide insights into the technological trends and future directions in robotic arm-based object sorting, offering a valuable reference for researchers and practitioners in the field.

KEYWORDS: Machine learning, Microcontroller, Object detection, Robotic arm sorting, Raspberry Pi, Sensors components.

INTRODUCTION

In recent years, the integration of robotics, image processing and machine learning (M.L.) techniques has revolutionized various industries, offering innovative solutions to complex problems. One such application is the development of robotic systems for object sorting tasks. With advancements in technology, particularly in the fields of artificial intelligence and computer vision, robotic arms equipped with sophisticated algorithms are now capable of efficiently sorting objects based on various criteria. The need for automated sorting systems arises in numerous industries, including manufacturing, logistics, and recycling, where the demand for rapid, accurate, and cost-effective sorting processes is paramount. Traditional methods of manual sorting are not only labor-intensive but also prone to errors

and inefficiencies. Therefore, the adoption of robotic systems for object sorting holds immense potential for enhancing productivity, reducing operational costs, and improving overall efficiency.

This paper focuses on the implementation of a robotic arm-based object sorting system that leverages image processing and machine learning (M.L.) techniques. By utilizing computer vision algorithms, such as object detection and recognition, in conjunction with machine learning (M.L.) models, these systems can accurately identify and categorize objects in real-time. The inclusion of a robotic arm standards, including color, size, shape and material.

The key components of such a system typically include a camera or sensor array for capturing images or

data of the objects, image processing algorithms for extracting relevant features, machine learning (M.L.) models for classification and decision-making, and a robotic arm for physical manipulation and sorting. The harmonious integration of these constituents empowers the advancement of self-sufficient sorting systems that possess the ability to adapt to diverse surroundings and efficiently organize a broad spectrum of objects with utmost precision and effectiveness.

Throughout this paper, we will delve into the underlying principles, methodologies, challenges, and advancements in robotic arm-based object sorting systems. We will explore the different approaches employed for image processing and machine learning (M.L.), discuss the integration of hardware and software components, examine case studies of existing implementations, and identify potential areas for future research and development. The primary objective of this article is to present a comprehensive overview of advanced methods and technologies employed in object sorting systems based on robotic arms. By shedding light on their capabilities, limitations, and potential applications in various industries, this article aims to offer a holistic understanding of these cutting-edge systems. By understanding the underlying principles and advancements in this field, researchers and practitioners can leverage this knowledge to design and deploy more efficient and intelligent sorting solutions in the future.

LITERATURE SURVEY

Several research articles are reported on this topic by many researchers. A review of some of those is presented below,

Nikhil Patil et.al [1] developed Niryo-ned based autonomously object sorting robotic arm have 6DOF combined with USB webcam. A robot arm has in build Raspberry Pi controller and it is operated by Robot operating system (ROS) and Python application. In object detection, two models, faster RCNN and YOLO v7, are employed to categorize and organize objects. The evaluation and analysis of mAP, recall, and precision are used to compare these models. The outcome demonstrates that, in comparison to the Faster RCNN model, the YOLO v7 and Niryo-ned models sort the objects with higher accuracy.

Neha Sawant et.al [2] developed a smart robotic arm by using Faster R-CNN algorithm with Arduino ATmega328P controller. The author developed training and test models by using SSD Mobile Net and Faster R-CNN. In test module total 36 images tested with different scenarios. The accuracy of developed trained model is 78.76% and model require 1.2 sec for complete the task.

Snehal Kalambe et.al [3] introduced a weight-based food package sorting system using IoT. For measuring the weight of an object Load cells are used. The ESP 8266 Node Microcontroller, programmed with Arduino, can seamlessly integrate with a conveyor system and servo motors for packing and sorting products based on their weight, as determined by a load cell. The conveyor system ensures a seamless and uninterrupted flow of packing material, while the Servo motor guarantees precise and efficient control over the movement of the materials.

In their study, Md. Abdullah-Al-Noman et.al [4] presented a computer vision-based automated system that focuses on color sorting, shape detection, and size detection. The color of an object can be accurately detected by the system through the utilization of a PixyCMU camera sensor. It then employs an Arduino Mega and servo motors controlled robotic arm to pick and place the object in a specific location. The evaluation of this intelligent device's performance was conducted by detecting objects with random colors. Moving forward, the researchers suggest the use of a more advanced camera sensor to enable the detection of 3D objects. Additionally, they propose the utilization of Raspberry Pi or Jetson Nano for more efficient control of the device.

Salvatore D'Avella [5] introduced a project that detailed the utilization of an independent industrial cell consisting of an ABB IRB 1200-7-7 robot along with its IRC5 controller. This setup also included two linear guides for the movement of the hooking frame (HF) and the opening of the hooks, as well as four cameras to establish a vision pipeline for the detection of specific features. This approach aimed to enhance the adaptability and reliability of the task's execution.

Sahil Khadane et.al [6] developed a real time object or item is identifying system and detecting its edges. The proposed system estimating the dimensions that is length

and breadth of real time objects. When determining the dimensions of objects, it is possible to select a reference item that possesses distinct characteristics, making it easily recognizable and having a fixed measurement. The system used Open CV python module and Raspberry Pi for detecting dimension of an object. An accuracy of developed system is 94%.

Luo Niu et.al [7] introduced Self supervised Robotic arm control system by using dual channel visual pushing for Grasping (VPG) algorithm. A developed system tested in six different environments. A different 5 to 30 objects are randomly placed and run the system. An accuracy of developed system is 83.3%.

Zhongli Ma and colleagues [8] introduced a work piece sorting technique utilizing the YOLOv5 model. The work piece sorting system is comprised of a computer CPU model i91090k, an NVIDIA Jetson nano controller RTX380 GPU model with a memory size of 10 GB, operating on Windows 11. The system utilizes Pytorch as the deep learning framework with a learning rate set at 0.01. In this developed system, the evaluation of the robotic arm is achieved through the TsarLenz method and Zhang Zhengyou calibration method.

Bhakti Basutkar et.al [9] proposed technique provides a low-cost methodology for quick and faster sorting and detection of products that continuously take place. Manufacturing companies develop their products with different geometrical and visual aspects which include shape, size, height, color, edges. Sorting of this product is extremely doable task. A developing system operate firstly the object is determined, after investigating the object comes near the main station of the conveyor belt where an IR sensor and a camera are situated for further testing of the product. The purpose of the robotic arm is to choose the object and position it in its assigned location. With help of this advancement in robotics the utilization of the automated robotic arm is done by using a microcontroller, sensors, IR sensors. Thus, a system is implemented for carrying the end product from one spot to a designated location with automated techniques.

In their study, Zhuang-Zhuang Wang et.al [16] proposed a novel approach for detecting small objects by leveraging image super resolution techniques. In this developed system at input end add a feature texture transfer (FTT) module for improving the image resolution

and eliminate the noise in the image. Dens blocks are employed to minimize the quantity of network structure parameters and prevent superfluous computations. The effective fusion of multi-scale features can be achieved through the utilization of Spatial Pyramid Pooling Network (SPPnet) in conjunction with Personal area network (PAN). YOLOv4 effectively addresses the issue of imbalanced image backgrounds and foregrounds through its balance loss function. The system that has been developed produces effective experimental results for targets as small as 32*32 pixels, with an accuracy rate of 83.4%.

GAP IDENTIFICATION

While significant progress has been made in the development of robotic arm-based object sorting systems using image processing and machine learning (M.L.), several gaps and challenges persist in current research and implementations. It is crucial to identify these gaps in order to direct future research endeavors and enhance the functionalities of sorting systems. The subsequent points highlight several significant areas where gaps in the existing literature have been recognized.

Scalability and Adaptability

Many existing sorting systems demonstrate robust performance under controlled laboratory conditions or specific environments. However, there is a lack of research addressing the scalability and adaptability of these systems to real-world scenarios with varying lighting conditions, object orientations, and cluttered environments. Achieving robust performance in dynamic and unstructured environments remains a significant challenge that requires further investigation

Object Variability and Diversity

While some sorting systems excel in sorting objects with distinct features, such as shape or color, they often struggle with handling objects that exhibit variability or ambiguity in their characteristics. For instance, sorting systems may face difficulties when dealing with objects of similar shape but different materials or textures. Addressing the challenges posed by object variability and diversity is essential for enhancing the versatility and applicability of sorting systems across different industries and use cases.

Real -Time Performance and efficiency

Many existing sorting systems rely on computationally intensive image processing and machine learning (M.L.) algorithms, which may result in delays and reduced throughput in real- time applications. Improving the real-time performance and efficiency of sorting systems without compromising accuracy is critical for enabling seamless integration into industrial automation processes. Exploring novel algorithmic optimizations and hardware acceleration techniques could help bridge this gap.

Robustness to Environmental Factors

External factors such as lighting variations, occlusions, and background clutter can significantly impact the performance of object sorting systems. While some research efforts have addressed specific environmental challenges, there is a need for more comprehensive approaches that enhance the robustness of sorting systems to diverse environmental conditions. Developing adaptive algorithms capable of dynamically adjusting to changing environmental factors could mitigate these challenges.

Human-Robots Interaction and Safety

As robotic sorting systems become increasingly integrated into industrial settings, ensuring safe and efficient interaction between humans and robots is paramount. However, limited research has been conducted on addressing human-robot collaboration and safety considerations in the context of object sorting tasks. Exploring methodologies for safe human-robot interaction, ergonomic design of workspaces, and intuitive user interfaces could facilitate the seamless integration of sorting systems into collaborative work environments.

By addressing these gaps in current research and development, future studies can contribute to the advancement of robotic arm-based object sorting systems, enabling them to achieve higher levels of performance, versatility, and applicability across various domains. Moreover, bridging these gaps will pave the way for the widespread adoption of sorting systems in industrial automation and beyond, ultimately leading to increased efficiency, productivity, and cost-effectiveness.

Table1. Comparison of different models with its Hardware and Software

Reference Paper	Hardware Used	Software/Algorithm /Model Used	Accuracy of Designed System
Nikhil Patil et.al [1]	Raspberry Pi Controller, 6 DOF Niryo Ned Robot	Robot Operating System (ROS) and Python API Model YOLO7 and Faster RCNN	98.40%
NehaSant et.al [2]	Raspberry Pi 3 B+ Controller OV567 Camera	Model Single Shot Detector (S.S.D.) Mobile Net and Faster RCNN	78.80%
Snehal Kalamb et.al [3]	Node Micro controller ESP826 HX 711 amplifier	Arduino Integrated Development	99.80%
Md. Abdullah-Al Noman et.al [4]	Arduino Mega 2560R3 Tower Pro MG996R Servo motor, Pixy CMU smart sensor	Python	80%
Salvatore D'Avella[5]	ABB IRB1200-7-7 with IRC5 Controller, EGM control interface	Robotic Operating System (ROS)	95%
Sahil Khadane et.al [6]	Controller Raspberry Pi 3 B Version 1.2	Raspberry Pi OS, Python	94%
LuoNiu et.al [7]		Dual Channel fusion Visual Pushing for Grasping algorithm	96%
Zhongli Ma et.al [8]	NVIDIA RTX3080	Pytorch, YOLO v5 model	90%
Bhakti Basutkaret. al [9]	Raspberry Pi Cameras Logitech PN 960-000748 Servo motor G36 Bluebird 660DMG +HStyle Servo Motor S8203 high torque motor	Raspbian Operating System, Open CV	95%
Zhuang-Zhuangwang et.al [10]	NVIDIA GeForce GTX1660Ti with 8GB graphics memory	Python 3.7.0, Tensor Flow 1.15.0 Feature texture transfer (FTT) module, Darknet 53 framework, SPNet and PANet	83.40%

PROPOSED METHODOLOGY

System Design

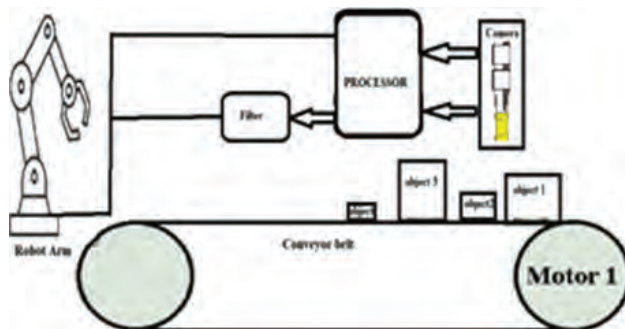


Fig. 1: The schematic diagram of an Object Sorting System based on a Robotic Arm

Above fig. 1 Shows a schematic diagram of an Object Sorting System based on a Robotic Arm using image processing and machine learning (M.L.). It consists of robotic arm, Servo motor for conveyor belt system, Web camera, processor, Filter Circuit and Python software.

The initial item is positioned on the moving conveyor belt. The conveyor belt is made of either leather, rubber, or a plastic compound that is combined with one or more layers of fabric material. The operation of the conveyor belt system is facilitated by a servomotor. The servomotor ensures precise positioning for both swift and long-distance movements. All servomotors are equipped with a closed loop configuration, making them suitable for handling varying loads. Additionally, they offer a diverse selection of gear options, as well as braking or load holding capabilities. The integrated controller, known as FLEX, also aids in system configuration considerations by storing relevant data.

An object is approaching the camera. The process of live camera visual search occurs in three distinct stages:

1. Sensing: Utilize the camera to observe and gather input.
2. Recognition: Detect and identify the object.
3. Communication: If a corresponding object is detected, relay this information to the user.

The output of camera is applied to the input of processor. The processor memory consist of number of images are store with the help of Python language and utilize object detection algorithms (e.g., CNN, YOLO) to identify

and locate objects within the images. Extract relevant features from the detected objects, such as internal diameter, Height, Width, shape, and size. The processor sends the command to robots for sorting the object. If the object is correct as per specification, the robot picks an object on conveyor belt and place a particular Bins or container. If an object is faulty then robot places an object in another container for rejection process.

Architecture Adopted

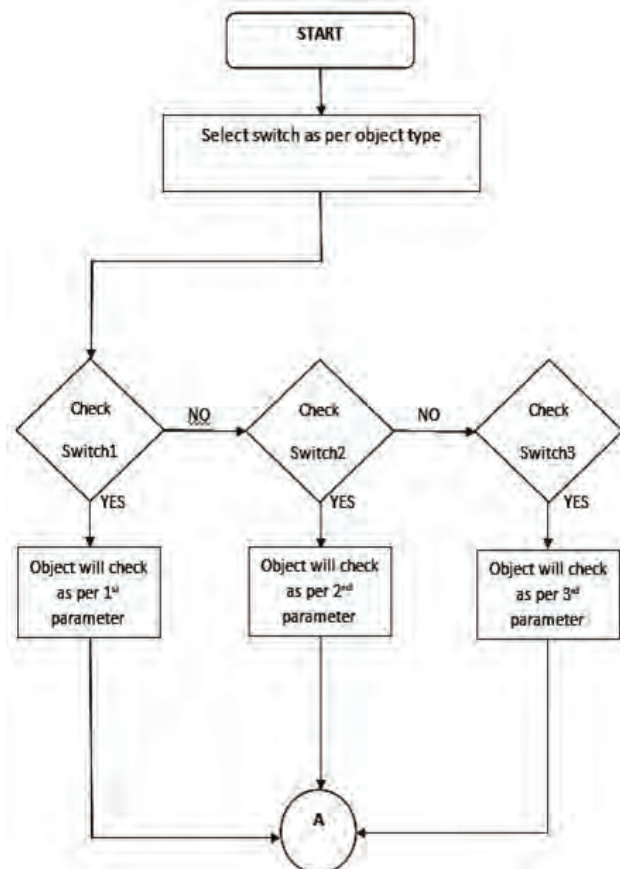


Fig. 2: Object parameter selection switch flow chart architecture Proposed

The simplified flow chart in Figure 2 illustrates the collective preferred stages. The fundamental concept of the model is to efficiently identify real- time objects based on their shape, size, color, width, and height using advanced image processing and machine learning (M.L.) techniques. The initial power is activated; select the parameter switch (1, 2, and 3).As per selection of switch parameter will be set at processor for further image processing.

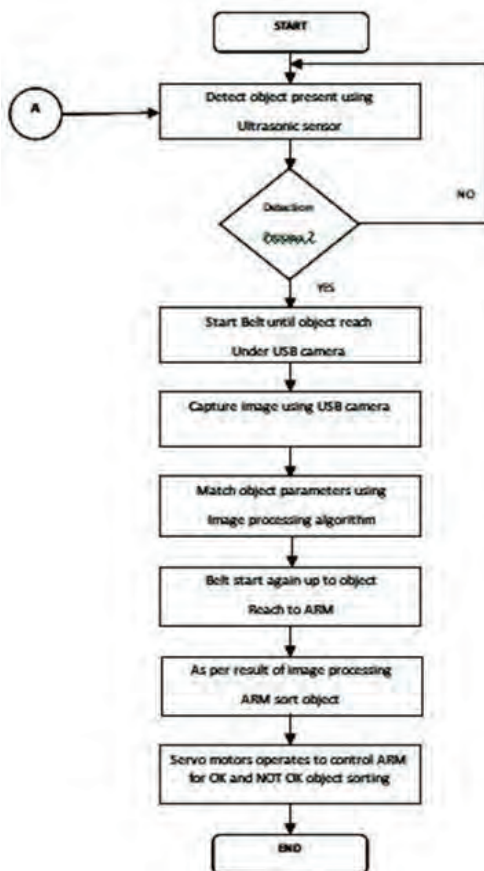


Fig. 3: Object detection and sorting architecture Proposed

The fig.3 shows object detection and sorting Architecture proposed. The model approach encompasses the following step.

1. After selection of parameter switch, ultrasonic sensors detect the object present on conveyor belt.
2. If the object is detected then start conveyor belt until the object reach under USB camera.
3. A USB camera capture image and save in memory.
4. Processor use image processing algorithm and match object parameter and result send to robotic arm for sorting purpose.
5. Belt start again up to object reach to robotic arm.
6. Servo motors operate to control robotic arm for OK and NOT OK object sorting.
7. According to resultative signal Robotic arm make the movement to pick and place.

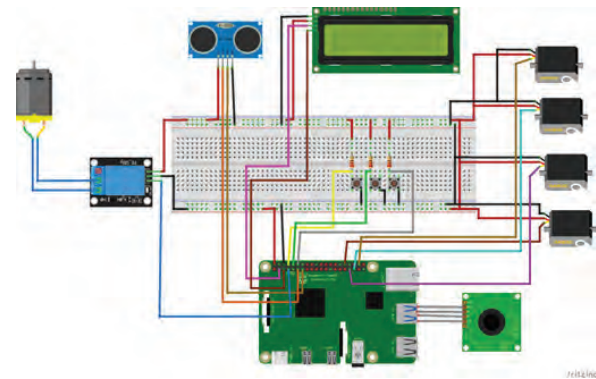


Fig. 4: Circuit diagram of peripherals connected to Raspberry Pi proposed circuit

The fig .4 shows a diagram of proposed circuit and peripherals connected to Raspberry Pi. Initial stages select a parameter switch. Ultrasonic sensors detect an object and 5v relay module run the DC motor operating conveyor belt. A conveyor belt starts until object reach under USB camera. Camera capture image and send to the processor for image processing.

Using Open CV library and machine learning software object detect is OK or NOT Ok and result send to robotic arm. As per result robotic arm make movement.

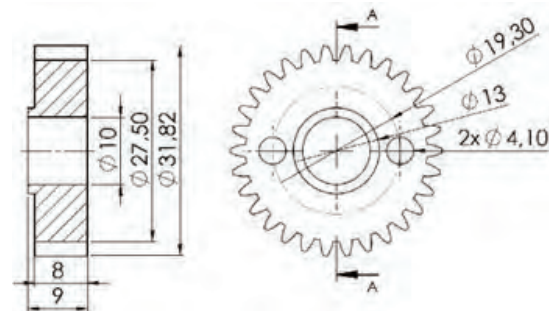


Fig. 5: Object 1Parameter Set to Switch1

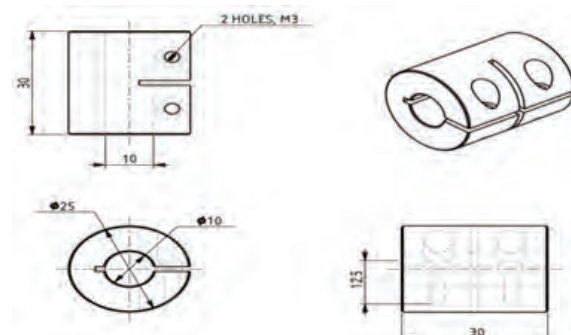


Fig. 6: Object 2Parameter Set to Switch2

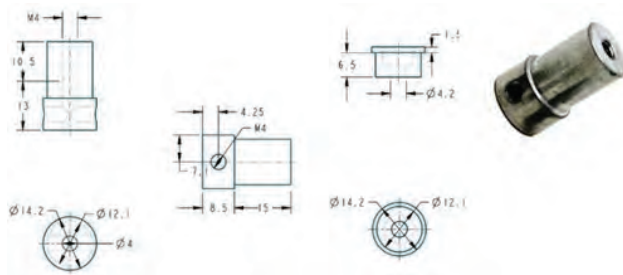


Fig. 7: Object3 Parameter Set to Switch3

The Fig.5, 6 and 7 are objects parameters such as (width, height, internal diameter, outer diameter, shape and size) are stored in memory. For image processing purpose each object has take a standard number of images stored in memory. In sorting process real time object image is compared with standard image and resulting signal send to robotic arm for sorting object.

RESULTS AND DISCUSSION

Table 2. Selection of parameter Switch and sorting Accuracy

Selection of switch ⇒	Switch1	Switch2	Switch3
Task ↓			
Task1	correct	CORRECT	YES
Task2	YES	YES	YES
Task3	YES	YES	YES
Task4	YES	YES	YES
Task5	YES	YES	YES
Task6	YES	NO	YES
Task7	YES	YES	YES
Task8	NO	YES	YES
Task9	YES	YES	YES
Task10	YES	YES	YES
Success	9	9	10
Failure	1	1	NIL
Success(%)	90%	90%	100%
Average=93.33%			
YES=Object detection and sorting correctly as per switch selection parameter			
No=object not detected			

We have repeatedly tested the object sorting part of proposed system to check the accuracy of parameter

such as height, width, internal diameter, external diameter, shape and size of object. From table 2 we can observe that the selected switch parameter and real time image capture by pixy CMU cam has successfully detected and sorting object with 93.33% accuracy. This process is repeated ten times for each of selection switch parameter such as (switch1, switch2, switch3). After the accurate detection of the object, robotic arm successfully pick the object and places in the container as per result.

Table 3. Shape and size detection Accuracy results

Object shape and size	Attempts	Success	Failure	Success
Object1	10	10	0	100%
Object2	10	10	0	100%
Object3	10	10	0	100%
overall	30	30	0	100%

Figure 5, 6 and 7 illustrates a sample object shape and size detection output of proposed system. Table 3 demonstrates the accuracy results for geometrical shape and size of an object. Here we test the object shape and size identification tasks ten times for different objects and each object shapes successfully detected. We use 16*2 LCD display for the showing the result. According to table III the accuracy rate for shape and size detection is 100%

Table 4. Comparison table of Hardware Components and software

Ref	Processor	Software
[1]	Raspberry Pi Controller	Robot Operating System (ROS) and Python
[2]	Raspberry Pi 3 B+Controller	Model- Single Shot Detector (S.S.D.) Mobile Net and Faster RCNN
[3]	Node Micro controller ESP8266	Arduino Integrated Development
[4]	Arduinio Mega 2560R3	Python
[8]	NVIDIA RTX3080	Pytorch, YOLO v5 model
[10]	NVIDIA GeForce GTX1660Ti with 8GB graphics memory	Python 3.7.0
Proposed	Raspberry Pi 5 BCM2712 version 2Gb	Python,CNN,YOLO

Table 4 shows the various hardware components and software tools are used in detection and sorting of object

.The different types of microprocessor and controller are used with different version like Arduino, Raspberry Pi, Node microcontroller etc.

According to table 4 this proposed device implements Automatic object detection and sorting with comparable low cost, less time consuming and simple model.

CONCLUSION

The integration of robotic arms with image processing and machine learning (M.L.) techniques has shown tremendous potential in the realm of object sorting systems. We have examined various methodologies, techniques, and implementations employed in the developing of such systems. The utilization of image processing algorithms has facilitated accurate detection, recognition, and classification of objects, enabling the robotic arm to make informed decisions in real-time. Additionally, the incorporation of machine learning (M.L.) algorithms has enhanced the system's ability to adapt and learn from new data, thereby improving its sorting accuracy and efficiency over time. This paper demonstrates the design and development of image processing and machine learning algorithm for object detection and sorting objects according to selection criteria. The object detect on belt is identify by ultrasonic sensor and object parameter detect using pixy CMU camera sensor. The robotic arm, developed with a Raspberry Pi, leverages various branches of machine learning to autonomously pick and place designated objects. Its primary objective is to minimize human intervention in industries where automation can be implemented effectively and efficiently. This will result in an improvement in the manufacturing lead time for a particular product.

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Smart Beds and IoT Technologies in Healthcare: A Review of Advancements in Patient Monitoring and Mobility Solutions

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ABSTRACT

The growing number of elderly and immobile patients in healthcare facilities demands for enhanced medical care systems. Pressure ulcers, resulting from prolonged immobility, have become a significant challenge. The integration of IoT and smart technology in healthcare has accompanied in new ways to manage patient care, especially for vulnerable populations requiring continuous monitoring and mobility assistance. This review combines recent research on IoT-driven solutions in smart bed technology and monitoring systems designed to improve patient comfort, safety, and healthcare efficiency. Key studies include innovations in pressure ulcer prevention, bed inclination classification, motorized hospital bed mobility, and deep learning-based patient monitoring. These advancements hold the potential to revolutionize hospital environments by enhancing caregiver efficiency, reducing patient complications, and streamlining healthcare processes.

KEYWORDS: *Smart beds, IoT in healthcare, Bed inclination, Patient monitoring.*

INTRODUCTION

Smart Bed Technology in Healthcare

A critical area of innovation is the development of smart beds that incorporate IoT capabilities to enhance patient monitoring and mobility management. Smart beds are designed to boost patient comfort, continuously monitor physiological parameters such as blood pressure and heart rate, and allow healthcare staff to respond promptly to any changes in a patient's condition. Equipped with sensors and automated systems, these beds provide real-time tracking of patients' health data, including vital signs like pulse rate and body temperature, enabling quick interventions to minimize risks related to hypertension, strokes, and

cardiovascular diseases, especially in patients with chronic conditions.

Smart Bed Inclination and Ventilation Systems

Smart medical beds with adjustable inclination and integrated ventilation systems are transforming patient care by addressing issues common with prolonged bed rest, such as pressure ulcers, respiratory complications, and poor blood circulation. These advanced beds allow for precise positioning to alleviate discomfort, improve circulation, and support specific medical procedures. By automating bed adjustments, they reduce the workload on nursing staff, allowing them to focus more on direct patient care [1]. IoT in healthcare involves continuous wireless monitoring of patients

using sensors to transmit vital signs to the cloud. This system enables remote analysis and feedback to medical professionals, improving patient care and reducing the burden on healthcare resources [2]. The study discusses an actuated tilt table for controlling cardiovascular parameters in bed rest patients through body tilting and leg mobilization, enhancing recovery and preventing complications. This approach represents a novel feedback-related therapy for stabilizing cardiovascular health [3]. The study discusses an automated tilting bed system that adjusts its angle in response to arterial pressure fluctuations, maintaining blood pressure within set bounds. This system enhances recovery times from induced hypertension and hypotension in animal studies [4]. It focuses on a smart bed with an advanced warning system that predicts falls using sensors and machine learning [5].

Integrated Ventilation for Infection Control

Integrated ventilation systems in smart beds offer a steady flow of filtered, positive-pressure air, which is especially important in hospital settings like operating rooms, to minimize contaminants and prevent infections. In healthcare facilities, HVAC systems play a critical role by regulating temperature, humidity, and air quality, thus ensuring a safe and comfortable environment for patients, staff, and visitors [6].

Cost and Patient Outcomes

While the initial implementation of smart bed technology incurs costs, the reduction in patient complications and faster recovery times ultimately lead to significant cost savings and improved patient outcomes in hospitals [6].

IoT in Continuous Monitoring and Position Tracking

The integration of IoT in blood pressure monitoring and smart beds enables continuous, real-time care and has proven effective in remote patient monitoring through various studies. For instance, systems that transmit patient data, such as blood pressure readings, wirelessly to central databases have shown substantial improvements in patient management and timely intervention. Additionally, IoT-enabled Inertial Measurement Units (IMUs) monitor patient positioning in ICUs to help prevent complications like ventilator-associated pneumonia (VAP) by ensuring proper tilt angles, reducing the risks associated with

incorrect positioning. IoT in healthcare enhances patient monitoring through digital networks, enabling precise data collection and analytics. It addresses challenges in healthcare delivery, particularly highlighted during the COVID-19 pandemic, and opens avenues for future research and improved healthcare solutions [7]. The Internet of Medical Things (IoMT) enhances healthcare through applications like mobile health, remote biomarker detection, and disease prediction using machine learning. Key challenges include privacy, device reliability, and data speed, with proposed solutions involving cryptography and blockchain for security [8]. IoT in healthcare integrates sensors, software, and actuators to monitor patients' physiological status, enabling remote data collection and evaluation. This technology enhances clinical care, supports smart hospitals, and allows individuals to track their health using wearable devices [9]. IoT in healthcare enables remote monitoring and personalized care while improving efficiency and addressing challenges like data security and interoperability [10].

Blood Pressure Monitoring

Blood pressure is a vital indicator for cardiovascular health, and while traditional methods lack continuous monitoring, IoT-enabled smart beds provide real-time tracking and NLP-driven analysis to enhance patient care and reduce routine visits [11].

Fig. 1 shows generalized block diagram of Smart Bed using IoT

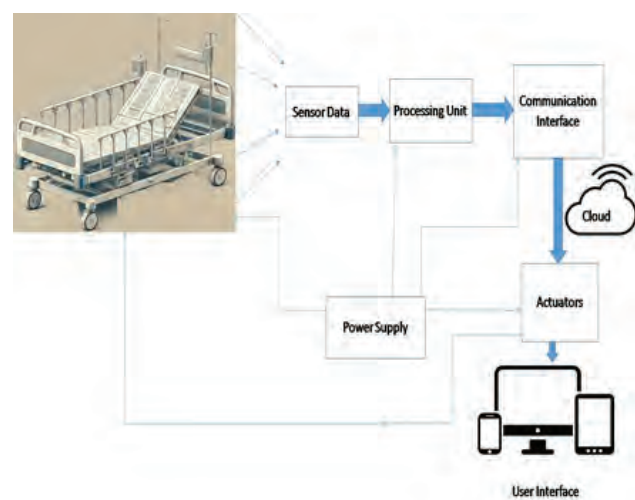


Fig. 1 Smart Bed using IoT

Significance

Smart bed inclination systems with integrated ventilation offer significant health and comfort benefits. They enhance breathing for patients with conditions like sleep apnea and asthma, reduce respiratory risks by providing fresh air, and alleviate issues such as varicose veins and back pain. These systems improve comfort through personalized adjustments, temperature control, and allergen reduction, as well as increase convenience with remote adjustments, aiding patients with limited mobility.

Statement of the Problem

Traditional hospital beds often fall short in addressing modern healthcare needs for patient monitoring, resource allocation, and prevention of hospital-acquired conditions. This highlights the necessity for smart beds that fulfill essential requirements like airflow, temperature regulation, and prevention of bedsores and respiratory complications, which are crucial for patient care and safety.

This overview provides a comprehensive look at the current advancements in smart bed technology and IoT applications in healthcare. By combining blood pressure monitoring with real-time patient position tracking, IoT solutions offer innovative, effective approaches for continuous health monitoring. These technologies provide healthcare professionals with critical insights into patient conditions, enabling faster and more accurate decision-making. This integrated approach not only improves patient outcomes but also reduces healthcare provider's workload, offering a sustainable solution for the demands of modern healthcare systems.

LITERATURE REVIEW

Smart Bed Systems in Healthcare: Adjustable and electric hospital beds improve patient comfort and flexibility, helping reduce pressure ulcers and enhance sleep quality by allowing various positioning options, including motorized adjustments [12]. Studies reveal that smart beds with sensors enable continuous monitoring of vital signs and patient movement, aiding early detection of health deterioration and reducing hospitalization costs [13].

WHO reports confirm that ventilation systems with HEPA filters effectively reduce airborne pathogens, lowering hospital-acquired infection rates and improving comfort for patients and staff (WHO, 2019) [14]. Combining smart beds with ventilation systems creates a holistic approach to patient care, addressing comfort, monitoring, and infection control simultaneously for better health outcomes. [15]. IoT in healthcare involves the use of wearable and monitoring devices for continuous data collection and remote patient monitoring, enhancing healthcare management. This technology enables healthcare providers to deliver improved care while empowering patients to manage their health effectively [16]. IoT in healthcare refers to interconnected digital devices that collect, send, and store data, enhancing service delivery, improving patient monitoring, and enabling timely diagnostics. [17].

IoT in healthcare enhances patient monitoring and health analysis through data generated by medical devices like glucose meters [18]. It improves decision-making for physicians but raises security and privacy concerns that must be addressed to fully utilize its potential [19]. The paper highlights IoT's transformative role in healthcare, enhancing diagnostics, patient care, chronic treatment, monitoring, and drug dispensing through advanced technologies[20].

Pressure Ulcer Prevention in Smart Beds

Pressure ulcers are a significant risk for immobile patients, and manual repositioning is often inconsistent. Brush et al. address this with a smart bed featuring an automated mechanical actuation system for improved PU prevention [21]. This system redistributes pressure across patients' bodies through a combination of mechanical plates and an alternating pressure air mattress, significantly reducing shear forces and enhancing comfort features multiple degrees of freedom and modular tiles that can operate independently to adapt to different patient needs [22]. Brush's team employed a computed-torque control law, refined for real-time application, ensuring precise, automated patient repositioning and minimal shear force on the skin [23]. The study's experimental validation demonstrated that this system could maintain low skin stress and effectively automate patient repositioning,

suggesting a promising solution for PU prevention in healthcare settings [24]. The paper discusses smart beds designed for monitoring pressure ulcers, emphasizing the importance of continuous health monitoring and therapy. While it does not specifically detail inclination systems, such systems could enhance pressure distribution and reduce shear forces on bedridden patients [25].

Classifying Bed Inclination Using Pressure Images

Bed inclination is a critical factor in preventing pressure ulcers and maintaining patient comfort. Pouyan et al. developed a method using pressure images and machine learning to classify bed inclinations (0° , 30° , 60°), aiming to improve pressure distribution and prevent ulcers [15]. The paper focuses on a smart mattress system with embedded pressure sensors to monitor body pressure and posture, but it does not specifically address smart bed inclination systems or their functionalities [26]. Smart bed inclination systems utilize pressure mapping to measure body posture and inclination angles, enhancing sleep quality and monitoring health. They can prevent conditions like sleep apnea and pressure ulcers by providing real-time data on user positions during sleep [27]. Pouyaology involved preprocessing the pressure images to remove noise, followed by feature extraction using four key metrics capturing pressure distribution variations. Using the k-Nearest Neighbor (kNN) classifier, the study achieved an average accuracy of 80.3% in identifying bed inclinations, highlighting the potential of using pressure images as a cost-effective method for real-time, non-invasive patient monitoring. This system could be easily integrated into existing hospital beds to assist caregivers in maintaining optimal patient postures and reducing the incidence of pressure sores.

Enhancing Bed Mobility with Swerve Drive Technology

Dhelika et al. developed a motorized hospital bed with a swerve drive mechanism for omnidirectional movement, easing patient transfer and reducing caregiver strain while maintaining a design similar to traditional bed casters [16, 28]. The Arduino-based control system that manages the motors and optimizes trajectory through PID control. Real-world testing showed that the bed maintained less than 3% motion

error in constant velocity but faced challenges during acceleration. Dhelika et al. suggest further refinement of control systems to handle dynamic load conditions, with minimal physical strain on staff [29].

Nurses Perceptions of Smart Beds

The adoption of smart bed in hospitals has introduced both opportunities and challenges for nursing staff. Tak et al.'s study, surveyed 349 nurses to understand their views on smart bed technology. Results showed a high level of acceptance. Despite the positive perceptions, concerns about device accuracy, frequent false alarms, and increased workload from patient inquiries were noted. Nurses also suggested enhancements, such as tele monitoring, fall prevention systems, and specialized skin-pressure sensors. The study underscores the importance of involving nurses and other stakeholders in the design phase to ensure practical, user-friendly solutions that meet real-world needs [30].

Deep Learning for Non-Invasive Patient Monitoring

Ayouni et al., present a cutting-edge smart bed design that leverages IoT, computer vision, and deep learning to monitor vital signs and body movement. The system uses a Mask Region Convolutional Neural Network (Mask-RCNN) to analyze patient posture and detect discomfort without invasive sensors, providing real-time alerts for healthcare providers when abnormal movement or postures are detected. With a high true-position (5%) and low false-positive rate (4%), the deep learning model proved effective in real-time patient monitoring. The integration of an IP camera and multiple sensors enables this system to maintain high patient comfort and continuous data acquisition. Ayouni et al. propose further development to include AI-driven data analysis and mobile applications to enhance provider communication and automate patient care, positioning this technology as a potentially transformative solution for smart hospital environments [31-36].

DISCUSSION AND FUTURE DIRECTIONS

The research reviewed demonstrates that IoT-enabled smart beds and monitoring systems have the potential to significantly enhance healthcare delivery. These technologies provide real-time, non-invasive patient monitoring and assist caregivers by automating labor-

intensive tasks. However, concerns remain regarding system accuracy, data security, and scalability. For instance, smart mattresses and beds that incorporate image-based or sensor-based monitoring must address privacy concerns and ensure consistent performance across diverse patient profiles.

Future research should focus on improving system adaptability for different patient demographics, refining data encryption to protect patient information, and testing these systems in larger hospital environments. Incorporating advanced AI algorithms to interpret data could further enhance predictive capabilities and foster more personalized healthcare solutions.

CONCLUSION

IoT and smart technologies are transforming patient care in hospitals by offering innovative solutions to age-old healthcare challenges, such as pressure ulcer prevention, patient mobility, and continuous monitoring. From smart bed systems equipped with actuators for automated repositioning to deep learning models analyzing patient discomfort, these advancements offer promising improvements in patient outcomes and caregiver efficiency. Although challenges remain, the ongoing development of smart beds and IoT-integrated healthcare technologies is poised to redefine how hospitals manage patient care, making it more efficient, proactive, and patient-centered.

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A Stacking-Based Hybrid Model for Heart Disease Prediction Using Random Forest and SVM

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ABSTRACT

Heart disease is a leading cause of mortality worldwide, claiming millions of lives each year. So, there is a desperate need for practical tools to aid in the early detection and treatment of heart disease. The successful application of machine learning in healthcare, such as in medical imaging for tumor detection and personalized treatment recommendations, has enabled the analysis of intricate datasets and accurate predictions. The research shows a mixed-model method, merging Random Forest (RF) and Support Vector Machine (SVM) systems to improve heart disease prediction accuracy. This process employs RF to detect complex, high-scale features inpatient data. The SVM system then takes this data to make final predictions. The mixed model performed well; it achieved an accuracy rate of 73.77%, a recall of 92.00%, and a ROC AUC of 86.67%. The results above show the model's efficiency in solving the diagnostic problem: finding real positive cases with high sensitivity. Mixed method models could be excellent for constructing good, fast, and easy-to-understand predictive models for heart disease. Future research aims to enhance the computational efficiency of this methodology by optimizing processing speed and memory usage, facilitating its practical implementation in real-world healthcare settings.

KEYWORDS: Heart disease prediction, Machine learning, Random forest, Support vector machine, Predictive healthcare, UCI heart disease dataset.

INTRODUCTION

Heart disease is a major global health challenge and the leading cause of death, responsible for millions of deaths annually. The World Health Organization reports that CVDs account for about 31% of global deaths [14]. The possibility of the reduction in morbidity and mortality of heart diseases makes the development of effective predictive approaches and diagnostic aids indispensable. Through analyses of the tremendous amounts of stored data, machine learning algorithms detect many patterns invisible to human observation. The data featured model enhances diagnosis accuracy significantly for predicting the possibility of diseases [2]. RF and SVM are very robust and predictive ensemble methods and classification algorithms. RF is an ensemble learning algorithm that deals with complex

datasets having non-linear relationships and feature dependencies.

It reduces overfitting by constructing multiple decision trees and aggregating their predictions [3]. However, RF's performance can be influenced by imbalanced datasets. SVM is good at finding the best decision boundary for small-to-medium-sized datasets and gives high classification accuracy by maximizing the margin between classes [4].

However, SVM is not efficient for high-dimensional data and requires high computing power to optimize the parameters. Stacking-based ensemble approaches can overcome these issues. Stacking combines the strengths of multiple base models through a meta-model for better generalization [5]. This paper proposes a new hybrid stacking model of RF and SVM for heart disease

prediction. RF extracts non-linear characteristics, which SVM then classifies. Their combined strengths offer improved accuracy and robustness.

This research further improves the precision and reliability of heart disease prediction algorithms, particularly for early intervention applications. This is because the proposed model can ensure high sensitivity and specificity through the utilization of RF's capacity to deal with complex feature interactions and SVM's precision in decision-making. The model was evaluated on a synthetic dataset based on the UCI Heart Disease dataset, incorporating key attributes such as age, cholesterol levels, and blood pressure. Performance metrics, including accuracy, precision, recall, F1 score, and the area under the receiver operating characteristic, were used to assess its prediction capabilities. This work contributes to predictive healthcare by highlighting the capabilities of hybrid stacking-based models. These models increase diagnostic accuracy while reducing healthcare costs and improving clinical decision-making.

LITERATURE REVIEW

One of the most important areas in medical informatics is heart disease prediction, which, if detected early and accurately, significantly reduces morbidity and mortality. Several machine learning techniques have been explored to improve diagnosis accuracy and efficiency. Various machine learning techniques have been explored to improve diagnosis accuracy and efficiency. This section overviews existing approaches, their limitations, and the scope for advancement using a proposed hybrid stacking-based model. Early research used traditional statistical techniques to predict heart disease. These methods often fail with non-linear interactions and high-dimensional data [6]. Decision Trees offered interpretability but were prone to overfitting, preventing generalization in noisy datasets [7]. Ensemble methods like Random Forest (RF) overcame single-classifier limitations. RF efficiently handles overfitting and high-dimensional datasets, making it suitable for heart disease prediction [8]. RF could handle complex, non-linear relationships. However, its predictive accuracy may plateau with highly imbalanced datasets, common in medical applications [10]. SVMs became applicable for heart disease prediction by classifying complex datasets by maximizing the margin between classes

[11]. Cortes and Vapnik's work [12] demonstrated SVM's capabilities for medical applications. Although advantageous, SVM's performance is sensitive to parameter tuning and suffers with large-scale datasets where computational efficiency becomes a bottleneck.. The stacking-based hybrid model integrates RF and SVM into a unified framework, combining their strengths complementarily. RF acts as a base learner extracting high-level features, and SVM as the meta-learner classifying those features. This framework eliminates individual classifiers' shortcomings, as RF is robust with feature interactions, and SVM correctly defines decision boundaries. The model obtained a high recall rate to minimize false negatives crucial in diagnosis. This study shows the possibilities of stacking-based models in medical applications, working toward optimizing hybrid frameworks for other health-related problems.

METHODOLOGY

The hybrid model in heart disease prediction uses the best features of RF and SVM algorithms to overcome classifier shortcomings and improve predictive accuracy. This methodology includes dataset selection, data preprocessing, feature extraction, model architecture development, hyperparameter optimization, and performance evaluation. Given the global impact of heart disease, it is important to develop accurate prediction models for early diagnosis and intervention. The chosen ML framework overcomes issues in medical data, such as class imbalance, noise, and complex feature interactions. Combined within a stacking ensemble framework, the RF and SVM aim to enhance robustness, precision, and reliability, especially in clinical applications where precision and recall are critical.

The process begins with careful data selection utilizing the UCI Heart Disease dataset, containing 303 samples and 13 predictive features from demographics and clinical tests for heart disease prediction.

Class imbalances and missing values are handled synthetically to generate algorithms, ensuring a larger dataset with maintained statistical characteristics. It covers imputation of missing values, feature normalization, categorical encoding, and outlier detection for proper quality input in the ML pipeline. This preprocessing ensures data quality and generalization.

Feature extraction in the hybrid model is the first step. This is performed using decision trees and a random forest model that can model nonlinear relationships and complex interactions between features. It computes the feature importance scores, retains the significant features, and discards the superfluous ones. This makes the input data more appropriate for further operations and reduces the computational costs.

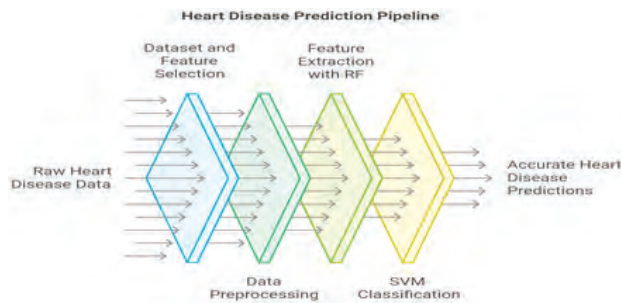


Fig. 1. Heart disease prediction pipeline

Dataset and Feature Selection

This research work employed the UCI Heart Disease dataset, which is often used in cardiovascular research and predictive modeling. The dataset consists of 303 records with 13 features of demographics and clinical factors. The presence of heart disease is represented as a binary target variable with the value of 1 for its existence and 0 for its non-existence. There is a considerable class imbalance, which means training could be biased toward the dominating class. It decreases overfitting and enhances learning from all samples, thus making the dataset more robust. Feature selection is critical. It uses statistical tests and expert knowledge to evaluate the importance of the 13 features to select only relevant features, eliminate redundant features, reduce complexity, and thereby reduce overfitting. Synthetic data augmentation and informed feature selection prepare the UCI Heart Disease dataset well, hence retaining balance within a comprehensive dataset and enabling accurate clinical-utility predictions in this proposed hybrid model.

Execution of the discussed stacking-based hybrid model was done with Python 3.8 as the core machine learning environment with Scikit-learn, whereas handling the data was done using Pandas and NumPy and visualization using Matplotlib. An experimental environment of Intel Core i7 processor, 16GB RAM,

and Windows 10 operating system was used in order to achieve efficient computation. Performance of the model was cross-validated with 5-fold cross-validation, and hyperparameter optimization was carried out with Grid Search Cross-Validation to tune the parameters of Random Forest (number of estimators, max depth) as well as SVM (type of kernel, regularization parameter C, gamma). These stringent approaches guarantee robustness and reliability of the derived results, affirming the performance of the proposed hybrid model.

Data Preprocessing

This process prepares the dataset for prediction models and ensures data quality. Good preprocessing reduces noise, enhances data integrity, and optimizes the performance of a machine learning algorithm. The UCI Heart Disease dataset has been highly preprocessed by handling missing values, improper scaling, categorical variables, and outliers.

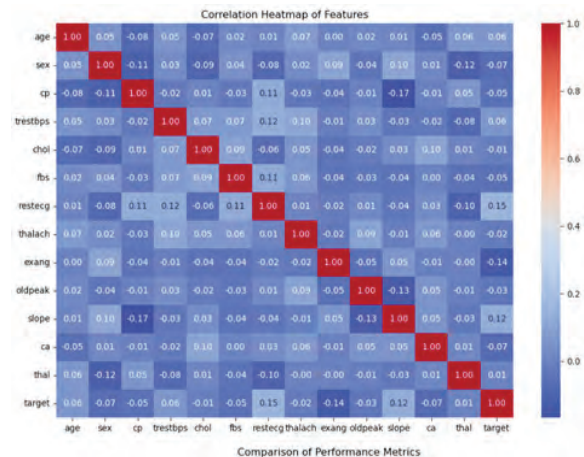


Fig. 2. Correlation Heatmap of Features

Handling Missing Values: Missing values can significantly impact model training and predictive accuracy. This study uses statistical strategies for imputation. Continuous data are addressed using mean or median imputation to preserve statistical characteristics, while categorical data use mode imputation, filling missing entries with the most frequent category.

2.2 Normalization and Scaling: The dataset is scaled to varying degrees and includes some high values that would cause the model to favor larger magnitudes. Min-Max scaling scales all features into a range of [0, 1], so that no feature would dominate the model.

Algorithms like Support Vector Machines exploit the feature scaling.

Feature Encoding: Categorical attributes are encoded into a numerical format using one-hot encoding, converting each category into a separate binary column. This prevents ordinal assumptions about categorical relationships in the machine-learning pipeline. **Outlier Detection:** Outliers that significantly deviate from other observations can distort model performance and lead to erroneous predictions.

Extracting Features through Random Forest

The newly proposed stacking-based hybrid approach is feature extraction through RF. RF is an ensemble learning algorithm, renowned for being robust, flexible and has strong performance in modeling non-linear relationships. This phase reduces the most prominent features from the dataset, thereby up-gradation of the overall predictive capability of the hybrid model.

Tree Construction: Random Forest constructs an ensemble of decision trees. Each of the trees is trained on a bootstrapped sample of the dataset. Every decision node has a random subset of features available for splitting. This randomness induces diversity among the trees, decreases overfitting, and maintains the model robust. RF aggregates predictions from many trees, thereby giving more accurate outputs.

Feature Importance Calculation: RF provides feature importance quantification. During training, RF evaluates each feature's contribution to the model's predictive performance by measuring the decrease in impurity at each split where the feature is used. Features that contribute the most to impurity reduction are ranked as more important. This computation gives a ranking of features by relevance to the prediction task.

Feature Selection Once feature importance scores are computed, features with low importance are removed. The model is left to represent the data in a compact form by keeping only the most relevant attributes, hence reducing computational overhead and overfitting. Hence, the process of feature selection ensures that meaningful yet concise attributes are used to feed into the subsequent classification stage.

High-Level Representations RF-based features are high-level and non-linear representations of the data

set. Features in these characteristics involve complex patterns and interactions amongst the original features.

Classification using Support Vector Machine (SVM)

The last stage of the proposed hybrid stacking-based model is an SVM classifier for final prediction. SVM outperforms well in linear and nonlinear classification tasks by maximizing the correct prediction accuracy by increasing the optimal hyperplane. Steps for SVM Classification include:

Kernel Selection

This paper used the RBF kernel that is appropriate for non-linear scenarios in higher-dimensional space. Input features and target variables of UCI Heart Disease dataset have intricate, non-linear interactions. The use of the RBF kernel would enable the classifier to capture nuanced patterns, improving discrimination between cases of heart disease.

Hyperparameter Optimization

Fine-tuning of key hyperparameters C and γ is done by grid search and cross-validation. C balances low training error and smooth decision boundary; high C can lead to overfitting, low C to generalization. γ shapes the decision boundary; small γ defines a smooth boundary, large values capture finer details but risk overfitting. Grid search evaluates C and γ combinations, and cross-validation assesses generalization, identifying the best parameter set for predictions.

Hyperplane Generation for Boundary Decisions

The SVM classifier generates an optimal hyperplane, which maximizes the margin between the two classes in transformed feature space. The margin is defined by the distance from the nearest data points (support vectors) to the hyperplane that minimizes errors during classification, hence increasing robustness. It thereby classifies correctly even if the classes cannot be linearly distinguished in the original feature space as being either having or not having heart disease. This makes it suitable for application in medicine because it generalizes well across unseen data, providing high predictive accuracy.

Stacking-Based Model Architecture:

The proposed stacking-based model architecture will combine Random Forest as the base learner and

Support Vector Machine as the meta-learner to enhance prediction accuracy and robustness in heart disease detection. RF aggregates outputs of several decision trees by transforming raw input features into higher-level representations. Bootstrapping and random feature selection are performed in order to avoid overfitting. The mechanism of ensemble for resistance against noisy data and outliers for reliable feature extraction is ensured by RF. The feature set thus enriched is then used by SVM to create the optimal decision boundary with the help of kernel functions, thus increasing the accuracy of the classification. Architecture pipelined - includes preprocessing, feature transformation, and classification. Pipelining eliminates manual errors, thus achieving modularity and ease in extensional modifications. It also exploits RF's capability of processing high-dimensional data and the intricate feature interaction that is inherent with SVM in the accuracy for the definition of a decision boundary, hence, offering a reliable model for the prediction of heart disease.

Hyperparameter Optimization and Model Tuning

The effectiveness of the hybrid stacking-based model depends significantly on the careful tuning of its hyperparameters. This process ensures optimal performance and robust generalization across diverse datasets.

Hyperparameter Optimization and Model Tuning

The performance and generalization capability of the stacking-based hybrid model depend on the precise tuning of hyperparameters. For the Random Forest (RF) base learner, critical adjustments balance bias and variance. The number of decision trees ($n_{\text{estimators}}$) is optimized for computational efficiency and model stability. The max_depth parameter is optimized to detect complicated patterns without overfitting. min_samples_split and min_samples_leaf parameters are fine-tuned for better regularization and to prevent overfitting.

For the SVM meta-learner, two important hyperparameters are: the regularization parameter (C), which controls the trade-off between minimizing training error and maintaining a smooth decision boundary, and the kernel coefficient (γ), which controls the shape of the decision boundary in the feature space. A systematic

grid search with cross-validation explores combinations of C and γ to ensure optimal SVM performance.

Model Evaluation

The stacking-based hybrid model was tested on the synthetic test set based on UCI Heart Disease, using inclusive performance metrics, to ensure reliable and effective classification of heart diseases.

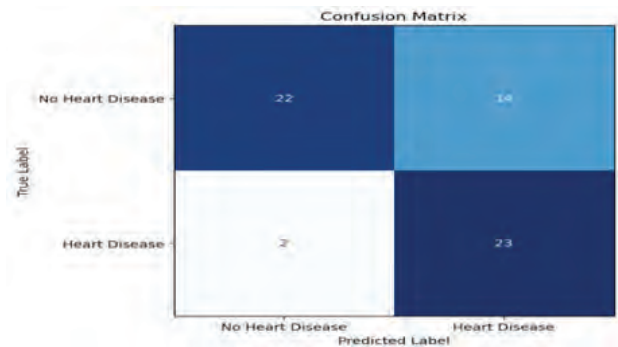


Fig. 3. Confusion Matrix Analysis

Detailed confusion matrix analysis shows the exact prediction errors and reveals that the hybrid model has a better recall and F1 score than the standalone RF and SVM classifiers. The model overcomes the limitations of individual classifiers, emphasizing recall to minimize missed diagnoses while ensuring precision and optimized resource utilization. The computational efficiency of the hybrid model is also improved, minimizing latency and resource usage, thus making it suitable for integration into real-world clinical decision-support systems.

RESULTS AND ANALYSIS

Sr. No.	Metric	Value
1	Accuracy	0.737705
2	Precision	0.621622
3	Recall	0.920000
4	F1 Score	0.741935
5	ROC AUC	0.866667

A full assessment was then performed for this proposed stacking-based hybrid model for performance evaluation against key performance metrics such as accuracy, precision, recall, F1 score, and ROC AUC. Confusion matrices analysis can also provide good insights into results of the classifier.

According to the performance result, it exhibits the success case of stacking hybrid model, being built upon a combination of two strengths, where Random Forest combined with Support Vector Machine yields up to an accuracy level of 73.77%. Compared to the accuracy level of its individual performance as high as 90.16%, the hybrid model shows precision and recall values at 62.16% and 92.00%, respectively, showing balance in the way false positives are handled versus false negatives.

The best single model was that of Random Forest, with the highest individual performance at 90.16% in terms of accuracy, 93.33% in precision, and 90.32% in F1 Score. Logistic Regression is better at recall, whereas SVM is marginally better in precision. However, the Decision.

In Stacking-Based Model Performance RF integrated with SVM This model presents RF as the base learner that combines with a meta-learner as SVM; by using both, it indicates that the system takes into consideration the trade-off between heart disease prediction tasks and has an F1 Score at 74.19%, depicting the fair distribution between precision and recall, which the ROC AUC of 86.67% shows robust discrimination between two classes.

The high recall of 92.00% in the hybrid model is especially significant, as it points out that the system can effectively identify patients with heart disease. This is an important feature in real-world applications, as missing true positive cases could lead to critical consequences. However, the model's relatively lower precision of 62.16% indicates a need to refine its handling of false positives to further enhance reliability.

CONCLUSION

In conclusion, this paper introduces a stacking-based hybrid model for heart disease prediction, based on the strength of multiple machine learning classifiers, in order to improve the accuracy and reliability of the diagnostic predictions. In this study, a multi-metric evaluation approach, including accuracy, precision, recall, F1 score, and ROC AUC, will be used in order to comprehensively assess the model's performance compared to standalone classifiers, showing the superiority of its recall and F1 scores. This would be sensitive not only to detect the at-risk patients but also

not to give them unnecessary false positives, hence very useful for clinical decision-making.

The computational efficiency of the hybrid model, under optimized resource usage and reduced latency, further underlines its practicality in resource-constrained settings for real-world applications. In addition, the results confirm that the model is able to bridge the gaps within current diagnostic systems and thus be able to achieve improved early detection and management of heart disease. Future work may concentrate on the introduction of advanced ensemble techniques and integration of EHRs in real-time. This will help the developed improved prediction capabilities flow out into healthcare with much less friction. Thus, the work underlines the transformative capability that machine learning possesses in healthcare settings, opening pathways to more accurate, accessible, and efficient diagnostics.

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Analysis and Design of a Buck Converter for Electric Bike

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ABSTRACT

High performance battery chargers are becoming more and more in demand for energy storage, renewable energy systems and electric automobiles. The development of battery chargers must take into account the demand for quicker charging and longer battery life. Electric bikes, also referred to as e-bikes are a common and practical mode of urban transportation. The performance of the battery is significantly influenced by the charger. To satisfy the growing demand for e-bikes, it is imperative to build a dependable and useful charger. Electric car charger input current is highly distorted and output voltage distortion has an impact on battery life and charging efficiency. This paper focuses on the analysis and design of a buck converter for electric bike applications. Using basic calculations for validation, the converter is optimized to deliver a steady current with high efficiency. Design calculations confirm the robustness, efficiency and low ripple output, demonstrating its suitability for electric bike systems.

KEYWORDS: Battery charger, Electric vehicles, Buck converter.

INTRODUCTION

Electric vehicles (EVs) encompass automobiles, bicycles and other transportation modes powered primarily by electricity instead of gasoline or other fossil fuels [1]. They play a crucial role in reducing greenhouse gas emissions, minimizing dependence on finite fossil fuel resources and alleviating urban air pollution. EVs are considered vital in transitioning to an eco-friendly and sustainable transportation system, as depicted in Fig. 1.

Figure 1 illustrates the evolution of charging technologies over time. High-power charging systems emerged in the early 2000s, with more recent advancements introducing high-power and wireless charging options. EVs have zero tailpipe emissions since they do not release pollutants or greenhouse gases like carbon dioxide while in operation [2]. When charged using electricity derived from renewable energy sources, they significantly reduce the transportation sector's carbon footprint [3].

EVs are less expensive to operate than conventional cars with traditional internal combustion engine

vehicles. Moreover, with fewer moving parts and reduced maintenance needs, their lifetime expenses for repairs and upkeep are typically lower [4]. Various types of chargers with distinct features and purposes are available for recharging EVs [5]. Among these, Level 1 chargers are the most basic and widely used [6].

Level 1 chargers are designed for home use and connect to standard 120-volt AC outlets. These chargers provide a slow charging rate, typically adding 2 to 5 miles of range per hour [7]. They are suitable for occasional or emergency charging of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). In contrast, Level 2 chargers, popular for both residential and commercial applications, use 240-volt AC power comparable to appliances like ovens and dryers [8]. These chargers deliver a faster charging rate, typically between 10 and 30 miles of range per hour [9]. Level 3 chargers, also known as DC fast chargers, use direct current to rapidly charge EVs, providing 60 to 80 miles of range in just 20 to 30 minutes [10]. These chargers are commonly found at public charging stations, urban areas and along highways. However, charging infrastructure tends to be more developed in urban regions, leaving

rural areas underserved [11]. Additionally, multiunit residences, such as apartment buildings, often lack of adequate charging options.

Challenges persist, such as limited availability of fast DC chargers for long-distance travel and slow charging speeds of some Level 2 chargers, which may not meet daily needs. Peak times often lead to long queues at public charging stations. Moreover, the lack of uniform charging connector standards necessitates adapters for cross-brand compatibility [12]. This lack of standardized global charging infrastructure results in fragmentation across the industry. Technical issues or maintenance downtime can also render chargers temporarily unusable.

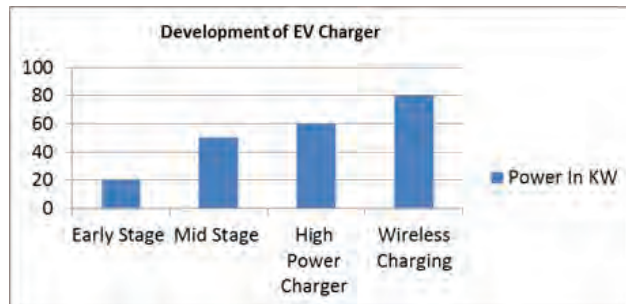


Fig. 1: Phases of development of EV

STUDY OF EXISTING CHARGER FOR ELECTRIC BIKES

EVs can be charged in several ways depending on their location and the demand for electricity. As a result, the charging infrastructure for EVs varies in type and is tailored for specific applications [13]. The specifications and standards for EV chargers, also known as electric vehicle supply equipment (EVSE), differ between countries. These variations are influenced by the EV models available in each region and the characteristics of the respective electricity grids [14].

The fundamental element of EV charging infrastructure is EVSE. The local electrical supply is connected to it, and a control system with a hooked connection for EV charging that is safe. Along with these features, the EVSE enables network management, data recording, charging authorization, user authentication, and privacy protection and security of user data [15].

In EV charging applications, a Two-Phase Interleaved Buck Converter (IBC) has been designed to enhance

efficiency. This design integrates a proportional-integral (PI) controller to improve performance under external disturbances [17]. While global adoption of EVs are accelerating, regions where e-bikes are prevalent still require improvements in charging infrastructure to support the gradual growth of EVs. Efficient power conversion is critical for the economic viability of EV chargers.

This research introduces an optimized solution for the DC-DC conversion stage in EV chargers for two-wheelers by implementing a Buck Converter. The proposed converter is equipped with a PID controller, which reduces steady-state errors and shortens the system's settling time by compensating for disturbances. The PID controller also removes the need for additional current-balancing controllers between the two branches of the IBC. This design offers several advantages, including lower ripple, reduced stress on components and more efficient battery charging.

The modified Buck Converter charging controller utilizes an improved proportional-integral (PID) controller to decrease overshoot and enhance charging times [18]. Additionally, a Buck Converter optimized for Lithium Ion Phosphate (LFP) batteries in EVs delivers efficient charging at a rate of 4 A during the initial phase, providing a reliable solution for battery performance and durability [19].

DIFFERENT CHARGING TECHNIQUES

EV charging requires adherence to the specifications of the battery, ensuring that power is supplied at appropriate voltage and current levels for safe and effective charging [20]. Broadly, three primary methods are employed for charging EV batteries: the conductive charging method, the inductive charging method and the battery swapping technique [21]. Among these, conductive charging is the preferred approach for electric bikes, as illustrated in Figure 2.

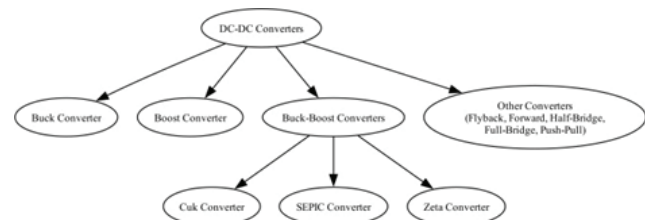


Fig. 2: Different types of Chargers

Conductive charging involves a direct electrical connection between the vehicle and the charging inlet, offering efficient charging through Level 1, Level 2, and Level 3 facilities [22]. Public charging stations primarily use Level 2 and Level 3 charging, with Level 1 and Level 2 having minimal impact on the power distribution grid [23].

The charging process for PHEVs and EVs depends on factors such as equipment, cost, power rating, time, location and grid impact. Proper distribution, demand strategies, charging time and infrastructure planning are essential for effective deployment [24]. Level 1 charging, commonly used in home garages, provides slow charging, while Level 2 charging, operating at 240 V, serves as the primary method for both public and private stations. Table 1 summarizes the various charging levels and their specifications [25–26].

Single-phase systems are typical for Level 1 and Level 2 charging, while Level 3 DC fast charging, functioning like a petrol station, is designed for public and private use [27–29]. Common locations for Level 2 and 3 chargers include shopping centers, hotels, and parking lots [30–32]. Inductive charging spaces must also be carefully selected [33].

Battery Charging Levels (Table 1 Summary)

- Level 1 (110–120V AC): Basic household charging, slow but widely accessible through standard sockets.
- Level 2 (220–240V AC): Faster charging, requiring specialized equipment, used in public stations and some homes.
- Level 3 (AC/DC 240–480V): High-speed charging, commonly used in public and private installations for rapid charging.

Table 1: Different charging levels

Charger type	Output voltage	power
Level 1	110–120V	1.8kw
Level 2	220–240v	3.3to22kw
Level 3	240–480V	25 to 350kw

DESIGN OF BUCK CONVERTER

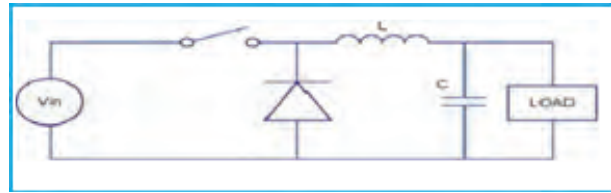


Fig. 3: Buck Converter Circuit

The Buck Converter operates using a PWM-controlled impulse device in Continuous Conduction Mode (CCM) [34]. The PWM regulator compares the reference voltage V_{ref} with the output voltage V_0 across the load R_L , generating pulses to control the switch. A PID regulator adjusts the control voltage V_c , which determines the PWM signal's duty cycle D . After stabilization, D reaches a fixed value when V_0 matches V_{ref} . The average output voltage V_0 is directly proportional to D .

Design Parameters

- Input Voltage: 323 V
- Output Voltage: 48 V
- Output Current: 5 A
- Switching Frequency: 50 kHz
- Current Ripple (ΔI_L): 10% of I_{out}
- Voltage Ripple (ΔV_{out}): 1% of V_{out}

A DC–DC converter called a Buck Converter is made to efficiently step down high input voltages to lower output voltages. For an e-bike application, the converter design parameters include:

Key Calculations

1. Duty Cycle (D):

$$D = \frac{V_{out}}{V_{in}}$$

2. Inductor Selection (L):

The inductor smoothens current and reduces ripple:

$$L = \frac{V_{out} \cdot (1 - D)}{f_s \cdot \Delta I_L}$$

Where f_s is the switching frequency and ΔI_L is the allowable current ripple (10% of I_{out}).

3. Capacitor Selection (C):

The capacitor minimizes voltage ripple:

$$C = \frac{I_{out} \cdot D}{f_s \cdot \Delta V_{out}}$$

Where ΔV_{out} is the allowable voltage ripple (1% of V_{out}).

4. Switching Frequency (f_s):

A high switching frequency (50 kHz) is selected to reduce component size and maintain efficiency.

5. Diode Selection:

A fast recovery diode ensures a continuous current path during switch-off periods. It must handle the full load current and withstand input voltage.

6. Efficiency Considerations

Efficiency is maximized by minimizing losses in the MOSFET, diode, inductor and capacitor. MATLAB/Simulink simulations confirm the converter's stable output, low ripple and high efficiency, making it suitable for electric bike.

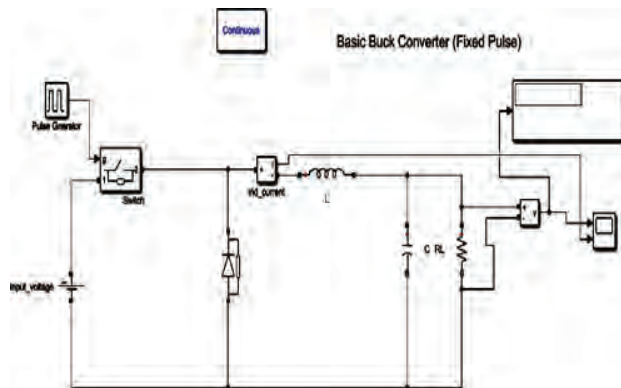


Fig. 4: Simulink model of buck converter

The circuit consists of two switches, a freewheeling diode and a solid-state device (power MOSFET) acting as the primary switch [35]. Combined with a low-pass LC filter, these components minimize voltage and current ripples, enabling a stable DC output [36]. A pure resistor serves as the load in the circuit configuration [37].

The circuit operates in two modes. In the first mode, when switch S1 (the power MOSFET) is closed, current flows through the circuit [38]. The inductor stores energy as a magnetic field and the capacitor accumulates charge, resulting in voltage across the load. However, as per Lenz's law, the energy stored in the inductor opposes the current that created it, reversing the inductor's polarity.

The simulation of the electric bike charger was performed using MATLAB/Simulink 2013a with the SimPower Systems toolbox. The main components include capacitors, inductors, IGBTs and a battery as the load. The buck converter's physical model (Figure 4) and its simulation parameters are summarized in Table 2.

Table 2: Parameters of buck converter

Sr. No.	Parameters	values
1	Source voltage	1 ϕ -230 V
2	Source frequency	50 Hz
3	Input voltage	323V
4	Buck inductor (Lin)	0.542mH
5	Capacitor(Cout)	3.09 μ F
6	Switching frequency	50khz

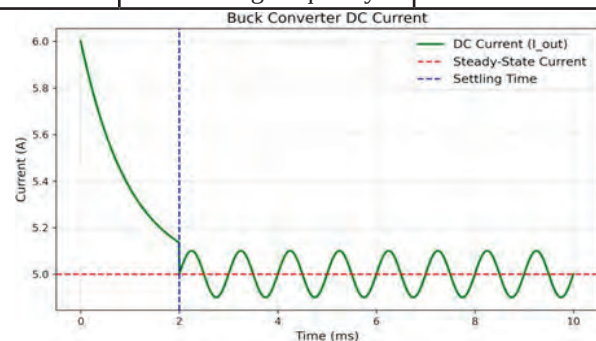


Fig. 5: Current from designed buck converter

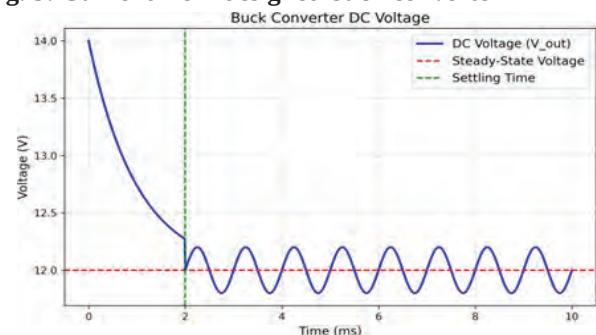


Fig. 6: Voltage from designed buck converter

Figure 5 illustrates the transient and steady-state behavior of the buck converter's DC current (I_{out}). Initially, the current exhibits a significant overshoot due to the inrush current caused by the inductor's energy storage process. The current gradually stabilizes as the system approaches its steady state, marked by the settling time ($t_s=2$ ms). Once steady, the output current maintains a nominal value of 5 A, with a ripple of ± 0.1 A caused by periodic switching. The ripple amplitude remains within acceptable limits, ensuring stable current delivery to the load.

Figure 6 depicts the DC output voltage (V_{out}) of the buck converter. During the transient phase, the voltage overshoots to 14 V before settling to the desired steady-state value of 12 V at $t_s=2$ ms. In steady state, the output voltage exhibits a ripple of ± 0.2 V due to switching, ensuring efficient regulation and minimal distortion.

Both figures demonstrate the converter's stable operation and effective ripple control.

CONCLUSION

Electrical vehicle charger enables fast charging of battery by using buck converter. Here we would like to propose a charger using buck for the electric bike. The proposed charger will provide a controllable and constant charging voltage for Electric bike and will be three stages of charging of battery. The input voltage is a relevancy correct synchronization between voltages and current, hence an efficient charging may be achieved. Therefore, this work solely considered for charging the battery of electric bike. The use of basic calculations combined with simulation tools ensures a straightforward yet robust approach to developing power converters. The results validate the suitability of this design for real-world applications in e-bike systems.

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Exploring Global Trends in Research Data Management (RDM) Practices: A Bibliometric Study through OpenAlex

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ABSTRACT

The bibliometric analysis was conducted to determine research trends in Research Data Management (RDM) practices. The required data was collected through the OpenAlex database using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. After employing the appropriate search filters, 986 records were retrieved in .csv (Comma-Separated Values) file format. The final dataset was analyzed using Biblioshiny and VOSviewer software, keeping the objectives in mind. The publication trend on RDM reveals that the highest number of citations and publications appeared in 2020 and 2024, respectively. It is significant to find that most RDM publications are related to the Sustainable Development Goals (SDGs), i.e. Industry, Innovation, and Infrastructure (SDG-9), Partnerships for the Goal (SDG-17), and Quality Education (SDG-4). The study observed CC BY as the publishers' most preferred Creative Commons (CC) license type. The study also identified highly cited papers and significant keywords in RDM research. The study's findings are useful to academic institutions while framing the RDM plan and policy. The policymakers and budding researchers get insight into the global trends in RDM research.

KEYWORDS: *Research data management (RDM), OpenAlex, PRISMA, Sustainable development goals (SDGs), Creative commons (CC).*

INTRODUCTION

Research data is considered a building block of any scientific innovation and discovery. Borgman [1] defined research data as “entities used as evidence of phenomena for the purposes of research or scholarship.” It involves various data such as documents, spreadsheets, laboratory notebooks, methodologies and workflows, questionnaires, transcripts, codebooks, standard operating procedures and protocols, database contents (video, audio, text, images), models, algorithms, scripts etc.[2]. The Research Data Management (RDM) encompasses the practices that support access to and use of data during the active stage of a research project, as well as after the project's completion [3]. There are several reasons for managing research data. Firstly, it saves time, frustration, and money of the researchers. Secondly, it enhances reproducibility by making the methodology more transparent.

Thirdly, it ensures data preservation and increases citations [4]. The present bibliometric study explores recent trends in Research Data Management practices.

REVIEW OF LITERATURE

Wilkinson et al. [5], in their article ‘FAIR guiding principles for scientific data management and stewardship’ published in Scientific Data, provided guidelines to improve the Findability, Accessibility, Interoperability, and Reuse of digital assets. Tripathi, Shukla and Sonkar [6] highlighted the role of libraries in research data management. They suggested that libraries should lead in curating university-generated research data and develop written policies for RDM in their universities. Thestrup et al. [7] have given the six pillars of engaging researchers in research data management. Chen et al. [8] examined the development of Dataverse, a global research data management consortium. They collected data from 67 participating institutions from the Dataverse project website. The results contribute to understanding the current development of the Dataverse project and the practices at the participating institutions.

Bhoi, Patel, and Dutta [9] surveyed the top 50 NIRF (National Institutional Ranking Framework) - 2020 ranked higher education institutions (HEIs) in India to investigate the current state of RDM and its aspects. The

results of the study demonstrate that, among India's top institutions, RDM is still in its infancy. David and Alaric [10] proposed SoVisu+, a new decentralized system for managing research data, building upon the foundation of the CRISalid consortium. A study by Mosha and Ngulube [11] investigated the approaches for implementing research data management (RDM) services in Tanzania's higher education institutions (HEIs). It reveals insufficient infrastructure and lack of skills and knowledge among the individuals tasked with implementing RDM services. Jose et al. [12] surveyed 652 researchers from Cuba, Peru, and Bolivia. The findings of the study reveal a frequent fear of misuse of research data and low awareness of legal aspects among the researchers.

OBJECTIVES OF THE STUDY

The main objective of the present study is to analyze the global trends in Research Data Management (RDM) practices through a bibliometric study using an OpenAlex database. In particular, the study aims to find:

- Publication Output.
- Sustainable Development Goals (SDG)-wise RDM publications.
- License-wise distribution of RDM publications.
- Highly-cited RDM documents.
- Significant keywords in RDM-related documents

METHODOLOGY

The bibliometric analysis was carried out to identify the research publications on the topic of research data management practices published from 2020 to 2024. To retrieve the relevant records, the OpenAlex database was searched on 28/12/2024 using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) technique [13]. OpenAlex database is selected for the study because it indexes over 250M scholarly works from 250k sources, with extra coverage of humanities, non-English languages, and the Global South [14]. OurResearch, a U.S.-based non-profit organization, publishes it. Recently, the CWTS Leiden Ranking Open Edition has also started to offer fully transparent information about the scientific performance of over 1500 major universities worldwide based on open data from OpenAlex [15]. After employing the search filters mentioned in Figure 1, a total of 986 records were retrieved in .csv (Comma-Separated Values) file format.

In the present study, the biblioshiny tool [16] is used to generate a statistical summary of the final dataset [Table 1], to know the publication output [Figure 2] and to identify the highly cited documents [Table 3]. In addition, the VOSviewer software (Version 1.6.20) [17] was used to find the significant keywords (Title and abstract fields) in the RDM documents.

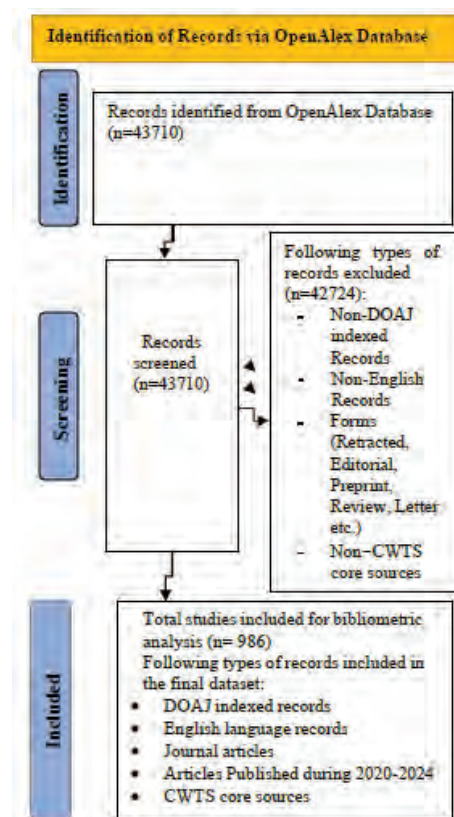


Fig. 1: PRISMA framework

Table 1: Summary of dataset

Description	Results
Timespan	2020:2024
Sources (Journals)	578
Documents	986
Annual Growth Rate %	3.77
Document Average Age	1.94
Average citations per doc	8.01
References	13879
Authors	4298
Single-authored docs	187
Co-Authors per Doc	5.44

RESULTS AND DISCUSSION

Publication Output

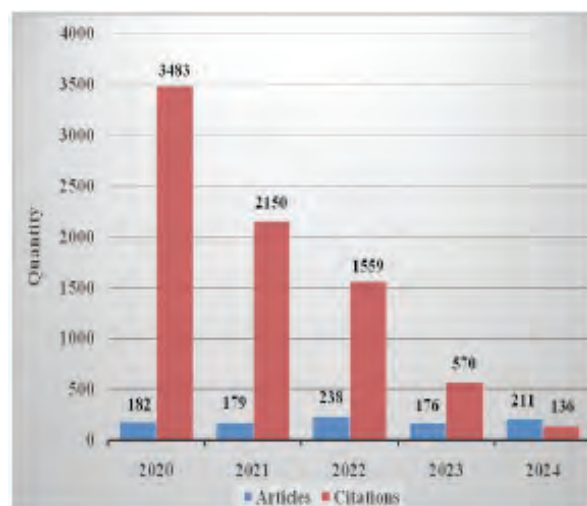


Fig. 2: Publication output on RDM practices research from 2020-2024

The number of publications and citations are bibliometric indicators used to gauge the development trend of scientific research in a particular subject domain. As Figure 2 shows, the highest number of citations, 3483 (44.10%) and 238 articles (24.14%) on RDM practices, appeared in 2020 and 2022, respectively.

SDG-wise RDM Publications

Table 2: Mapping RDM publications with SDGs

SDG Goals	No. of Publications
1	2
2	9
3	6
4	71
5	2
6	1
7	1
8	12
9	224
10	13
11	10
12	31

13	24
14	11
15	13
16	16
17	191
Total =	637

All United Nations Member States adopted the 2030 Agenda for Sustainable Development in 2015. It comprises 17 Sustainable Development Goals (SDGs) and 169 targets [18]. Mapping the research publications with SDGs helps to understand the global endeavours towards achieving these goals. The OpenAlex database uses a machine learning model to tag research publications relevant to these goals based on their OpenAlex SDG Classifier. Notably, 637 (64.60%) publications on RDM practices are aligned with SDGs. Table 2 shows that the highest number of the RDM publications, 224 (35.16%), are aligned with SDG-9 (Industry, Innovation, and Infrastructure), followed by SDG-17 (Partnerships for the Goal) with 191(29.98%) publications and SDG-4 (Quality Education) with 71(11.15%) publications. Together, these three SDGs contribute 76.29% of RDM publications. This highlights the prominence of these Sustainable Development Goals in research on research data management. SDG-6 (Clean Water and Sanitation) and SDG-7 (Affordable and Clean Energy), with a single publication each, are the least contributing SDGs in RDM.

License-wise Distribution of RDM Publications

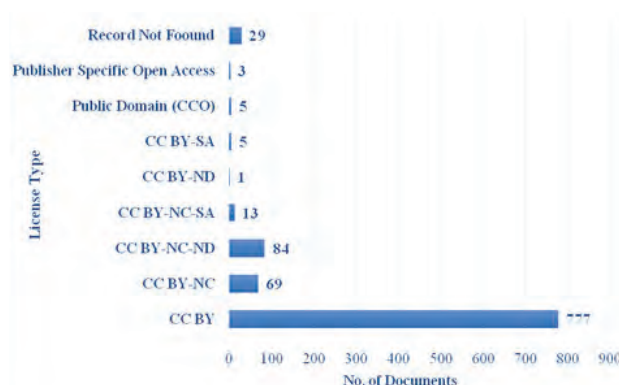


Fig. 3: License types

Creative Commons is a U.S.-based non-profit organization that offers individual creators to large institutions a standardized way to grant the public permission to use

their creative work under copyright law through the six different CC license types and the CCO (aka CC Zero) a public dedication tool [19]. Figure 3 indicates that the highest number of RDM-related articles, 777(78.80%), have used a CC BY license, which enables users to copy, distribute, transmit, adapt, and commercially use work [20]. The only thing is that attribution must be given to the creator. It is significant to find that five documents have used the CCO, which enables the authors to give up their copyright and release their works into the public domain. It is further observed that only a single document used a CC BY-ND license, which does not allow derivatives or adaptations of the work.

Highly Cited Documents

Table 3: Highly cited articles

Digital Object Identifier (DOI) of An Article (s)	TC
https://doi.org/10.5334/dsj-2020-043	618
https://doi.org/10.1038/s41597-020-0486-7	281
https://doi.org/10.1371/journal.pone.0230416	268
https://doi.org/10.1038/s41597-021-00892-0	230
https://doi.org/10.1038/s41597-021-00981-0	222
https://doi.org/10.1093/nar/gkab1053	215
https://doi.org/10.1038/s41597-022-01710-x	206
https://doi.org/10.1371/journal.pone.0229003	194
https://doi.org/10.1162/qss_a_00022	136
https://doi.org/10.1525/collabra.18684	114
Total =	2484
Where, $N \geq 114$ (N - No. of citations); TC = Total Citations	

Table 3 indicates the top 10 highly cited documents related to RDM practices. These top ten documents on RDM contribute a 31.45% share of the total citation output. The research paper based on CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) principles for indigenous data governance received the highest number of citations (618). It is significant to mention that four articles in Table 3 were published by the journal 'Scientific Data', an open-access, peer-reviewed, gold open-access journal published by Springer Nature. Interestingly, the top ten highly cited articles were published in Q1 journals based on SJR (Scimago Journal Rank) 2023. Table 3 shows that highly cited articles are related to FAIR, CARE, and TRUST principles and data-sharing practices.

Significant Keywords in RDM-related Documents

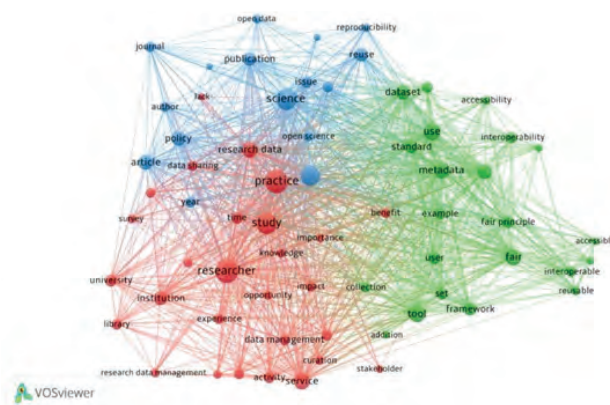


Fig. 4: Significant keywords

To retrieve significant keywords from the title and abstract fields of RDM documents, the API (Application Programming Interface) request was used in the VOSviewer software (Version 1.6.20). The keywords with minimum occurrences of 50 were selected. A total of 110 terms out of 22123 meet the threshold. A relevancy score will be determined for the 110 terms. The most pertinent phrases will be chosen based on this score. Of these, 60% of the most pertinent phrases are chosen by default. Finally, the network contains 66 items and 3 clusters: cluster -1 (Red colour; 28 items), cluster - 2 (Green colour; 22 items), and cluster - 3 (Blue colour; 16 items). The study found that keywords such as researcher, practice, study, science, paper, use, metadata, service, fair, etc., frequently occurred in titles and abstracts of the RDM documents (Figure 4).

CONCLUSION

The results of the present study reveal that the highest number of citations and research publications on RDM practices were published in 2020 and 2022, respectively. It is significant to note that the highest number of the RDM publications are aligned with SDG-9 (Industry, Innovation, and Infrastructure), followed by SDG-17 (Partnerships for the Goal) and SDG-4 (Quality Education). The results further reveal that SDG-6 (Clean Water and Sanitation) and SDG-7 (Affordable and Clean Energy) were the least contributing SDGs in RDM, indicating a research gap. It is observed that the highest number of RDM-related articles have used a CC BY, which is the most flexible type of license. The highest number of highly cited RDM documents were published by Springer Nature's open-access journal 'Scientific Data' with an impact factor of 5.8

and 6,408,593 downloads and 14,885 altmetric mentions [21]. Interestingly, the top ten highly cited articles were published in Q1 journals, which reveals the significance and impact of these journals. The study found that researcher, practice, study, science, paper, use, metadata, service, fair, etc., are frequently used keywords in the RDM documents. The present study is prone to certain limitations. Firstly, the data belongs to the period 2020 to 2024 only. Secondly, the study is restricted to OpenAlex database. It has its own merits and demerits. A comparative study with different citation databases like Scopus, Web of Science, and Dimensions etc. is suggested, which will be greatly helpful.

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Artificial Intelligence in Education: Advancing Sustainability and Ensuring Quality Education for All

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ABSTRACT

Artificial Intelligence (AI) has revolutionized various sectors, including education, by fostering sustainability and enhancing the quality of learning experiences. This research explores the transformative role of AI in addressing challenges such as accessibility, equity, and efficiency in education, aligned with the United Nations' Sustainable Development Goal 4 (SDG 4). AI applications in education have grown significantly, offering transformative solutions to improve teaching, learning, and administration. Here's an overview of how AI is shaping the educational landscape. In this era of information explosion the roles of educators, educational institutions, and academic leaders are evolving. This study aims to explore and highlight these transformations that, reveal different tools of AI that help teachers, professionals, academicians and students enhance the teaching and learning process with the help of these new AI tools and technologies. These tools play a crucial role in reshaping education, enhancing learning experiences, and preparing students with the necessary skills to thrive in the digital age. AI plays a significant role in several areas of library conservation and heritage preservation, bringing efficiency, accuracy, and innovation to the process. AI applications are wide spread, impacting industries like healthcare, finance, transportation, education, and entertainment.

KEYWORDS: *Artificial intelligence, AI tools, Education, sustainability, Sustainable development goal 4 (SDG 4), Adaptive learning platforms, Intelligent tutoring systems (ITS).*

INTRODUCTION

Education is one sector that has been profoundly impacted by the rise of artificial intelligence (AI), which is having a significant impact on sustainability efforts and the provision of high-quality education to all students. The United Nations' Sustainable Development Goal (SDG) 4 focuses on ensuring inclusive and equitable quality education while promoting lifelong learning opportunities for all.; educational institutions

can address issues like accessibility, equity, and personalised learning by utilising AI.

Intelligent, flexible, and productive classrooms are the goal of artificial intelligence (AI) applications in the field of education. Personalised learning experiences, administrative process automation, and predictive analytics to address learning gaps early are all made possible by these technologies. In addition, tools driven by AI make it easier to create accessible learning

materials for students with disabilities, which helps marginalised communities break down obstacles to education.

In addition to improving educational results, AI helps the environment by making better use of resources. Through the use of online learning environments, digital material distribution, and data-driven optimisation of both digital and physical infrastructure, it lessens the ecological impact of conventional classroom methods.

To rethink educational systems in a way that is inclusive, robust, and prepared for the future, AI is more than just a tool in this context. The immense potential of artificial intelligence (AI) in sustainable education is becoming more apparent as we explore its various applications; this might lead to a more just and empowered global learning ecosystem.

Definition of Artificial Intelligence

The “Father of Artificial Intelligence” is widely regarded as John McCarthy. He was an American computer and cognitive scientist who introduced the term “Artificial Intelligence” (AI) in 1956 during the Dartmouth Conference, which is considered the founding event of AI as a field of study. John McCarthy made significant contributions to AI, including the development of the programming language LISP, which became a primary language for AI research. His work laid the foundation for many modern AI concepts and techniques.

“AI is concerned with methods of achieving goals in situations in which the information available has a certain complex character. The methods that have to be used are related to the problem presented by the situation and are similar whether the problem solver is human, a Martian, or a computer program” (McCarthy, 1988)

METHODOLOGY

Research Approach

The study employs a qualitative research approach emphasizing theoretical exploration and conceptual analysis. This methodology is particularly effective for synthesizing existing literature, identifying recurring patterns, and constructing theoretical frameworks. By prioritizing conceptual depth over empirical data, it enables a nuanced understanding of the intersections

between artificial intelligence (AI) and sustainability in quality education. The focus on theoretical analysis allows for the critical examination of current educational paradigms, highlighting gaps and opportunities where AI can enhance equity, accessibility, and long-term educational outcomes. Furthermore, this approach supports the development of novel models that can inform policy recommendations and future empirical research on AI-driven sustainability in education.

LITERATURE REVIEW

- Purpose: To identify and analyze existing literature on:
- AI applications in education.
- Sustainability practices in education.
- The intersection of AI and sustainability in educational contexts.

Method

- Conduct a systematic review of peer-reviewed journals, conference papers, and authoritative reports (e.g., UNESCO, OECD, and UN SDG reports) to gather insights into AI and sustainability frameworks.
- Use databases like Scopus, Web of Science, and Google Scholar.
- Categorize the literature into themes, such as:
 - AI-driven personalized learning.
 - AI’s role in resource optimization.
 - AI applications for equitable access to education.

Output

- Identify research gaps where AI applications for sustainability are underexplored.
- Highlight best practices and current challenges in the field.

System Design for AI-Driven Education Framework

To build an effective AI-powered education system, a structured framework has been developed that integrates artificial intelligence with modern pedagogical strategies to enhance learning, streamline administrative tasks, and promote inclusivity.

Conceptual Framework

The system employs a multi-layered approach that guarantees seamless integration of AI tools into educational environments. It emphasizes accessibility, personalization, and sustainability, allowing students and educators to leverage AI in a manner that enhances learning experiences without introducing technological barriers.

Key Components

- **AI-Based Learning Platforms-** Adaptive learning systems that personalize content based on student progress (e.g., Coursera, DreamBox). Intelligent Tutoring Systems (ITS) such as Carnegie Learning, which provide AI-driven assistance. Personalized content recommendation engines that tailor educational resources to individual learning needs.
- **Automation of Administrative Tasks-** AI-powered grading systems that utilize NLP-based automated assessment tools to evaluate student responses. Attendance tracking using AI-driven facial recognition and biometric authentication. AI chatbots that provide academic assistance, answer student queries, and support administrative functions.
- **Accessibility and Inclusion-** AI-driven speech recognition and translation services to support students from diverse linguistic backgrounds. Text-to-speech technology and vision-based AI tools that cater to students with disabilities.
- **Data-Driven Decision-Making-** AI-powered predictive analytics that assess student performance trends and provide early intervention recommendations. AI-assisted curriculum development tools that help educators refine and optimize course content.
- **Gamification & Immersive Learning-** AI-powered virtual and augmented reality (VR/AR) applications that create interactive and immersive learning environments. AI-based engagement tracking tools that monitor student participation and adjust learning content accordingly.
- **Sustainability Integration-** AI-enhanced digital learning platforms that minimize paper usage and

reduce the need for physical resources. AI-driven optimization of infrastructure, ensuring efficient use of digital and physical learning spaces.

System Architecture

The AI-driven education framework is structured into multiple layers, each playing a critical role in ensuring seamless operation and user interaction:

1. **Data Layer** – Collects raw educational data from students, teachers, and institutional databases, including performance metrics, engagement statistics, and administrative records.
2. **Processing Layer** – Applies machine learning algorithms to analyze student behavior, predict learning trends, and provide personalized recommendations.
3. **Application Layer** – Connects with students and educators through AI-driven dashboards, chatbots, and intelligent tutoring systems, providing an interactive experience.
4. **User Interaction Layer** – Promotes user engagement through mobile applications, web-based platforms, and Learning Management Systems (LMS), ensuring accessibility and ease of use.

By implementing this structured framework, educational institutions can harness the full potential of AI to create a more efficient, inclusive, and engaging learning environment.

AI KEY APPLICATIONS

AI has significant potential to enhance sustainability in quality education by improving accessibility, efficiency, and inclusivity. Here are some key applications:

Personalized Learning

- **Adaptive Learning Platforms:** AI-driven systems like Dream Box, Knewton, and Coursera personalize content delivery based on a student's pace, strengths, and weaknesses.
- **Intelligent Tutoring Systems (ITS):** Tools like Carnegie Learning provide targeted support in areas where students struggle, simulating one-on-one tutoring experiences.
- **Customized Recommendations:** AI analyzes

performance data to recommend specific learning materials, courses, or activities for improvement.

Automation of Administrative Tasks

- Grading Automation: AI can grade objective tests and even subjective essays using natural language processing (NLP).
- Attendance Tracking: Facial recognition and AI-powered tools streamline attendance management.
- Streamlining Admissions: AI systems evaluate applications, rank candidates, and provide insights to improve decision-making.

Enhanced Accessibility

- Language Translation: Tools like Google Translate or AI-powered real-time transcription make learning resources accessible in multiple languages.
- Support for Special Needs: AI aids students with disabilities through tools like text-to-speech, speech-to-text, and vision-based assistance.
- 24/7 Assistance: Chatbots and virtual assistants provide constant support for students' queries.

Intelligent Content Creation

- Content Summarization: AI systems create concise summaries of textbooks, articles, or lectures.
- Interactive Simulations: AI-driven platforms like Labster allow students to experiment in virtual labs.
- Test and Quiz Generation: AI automates the creation of assessments based on syllabus content.

Data-Driven Decision Making

- Student Performance Analytics: AI identifies patterns and predicts outcomes, enabling teachers to intervene early.
- Curriculum Design: Data from AI analysis informs the development of more effective educational materials and teaching strategies.

Gamification and Engagement

- AI enhances gamified learning experiences, keeping students motivated through personalized rewards and challenges.

- Platforms like Duolingo use AI to adapt difficulty levels and ensure sustained engagement.

Virtual and Augmented Reality

- Immersive Learning Experiences: AI powers VR/AR tools, creating virtual classrooms, historical site visits, or lab experiments.
- Skill Training: Simulations for medical students, pilots, and engineers improve real-world readiness.

Teacher Support

- Professional Development: AI provides tailored training modules for educators.
- Classroom Management: AI tools help teachers identify behavioral patterns and foster inclusive environments.
- Feedback Mechanisms: AI systems analyze classroom interactions to provide feedback to educators on teaching efficacy.

Sustainability and Scalability

AI reduces the physical infrastructure and resource requirements of education (e.g., digital classrooms, e-books). It scales quality education to reach underserved regions without needing substantial physical resources.

Equity and Inclusion

AI can identify and address disparities in education, promoting inclusion by ensuring that learning opportunities are evenly distributed regardless of location, socioeconomic background, or disability.

Evaluation Metrics

The evaluation process will focus on key performance indicators that measure engagement, efficiency, inclusivity, and sustainability to assess the effectiveness of AI-driven educational tools.

- Student Engagement: AI-powered tools will monitor learning behaviors, participation levels, and interaction patterns to determine how effectively students engage with digital content and AI-driven resources. Metrics such as time spent on learning modules, frequency of interactions, and completion rates will be analyzed.
- Learning Outcomes: A comparative analysis will

be conducted between traditional learning methods and AI-enhanced educational techniques. This will evaluate improvements in student performance, retention rates, and comprehension levels.

- **Efficiency:** The implementation of AI in administrative tasks will be assessed by measuring the reduction in manual workload, time efficiency, and overall process automation in areas like grading, attendance tracking, and resource allocation.
- **Accessibility Index:** The extent to which AI-powered tools improve educational inclusivity for marginalized students will be examined, with special emphasis on AI-driven assistive technologies, such as text-to-speech and language translation tools, that enhance accessibility for students with disabilities and language barriers.
- **Sustainability Impact:** The role of AI in optimizing resource utilization will be assessed, focusing on the reduction of paper waste, energy consumption, and the need for physical infrastructure, contributing to an environmentally sustainable learning ecosystem.

Experiment Implementation

The AI-driven education framework will be implemented through a phased approach to ensure systematic integration and continuous improvement:

Phase 1: Pilot Testing – AI-powered tools will be introduced in selected classrooms or educational settings to evaluate their initial impact. This phase will involve gathering user feedback, testing system compatibility, and ensuring smooth implementation.

Phase 2: Performance Analysis – The effectiveness of AI in education will be assessed based on engagement metrics, improvements in accessibility, and overall learning outcomes. Data collected during this phase will inform further refinements.

Phase 3: Refinement – Based on insights from the performance analysis, necessary optimizations will be implemented in AI tools to enhance their functionality, adaptability, and ease of use.

Phase 4: Policy Recommendation – A set of best practices and guidelines for the integration of AI in education will be developed to assist institutions in

creating policies that support AI-driven learning while addressing ethical considerations and accessibility needs.

Challenges to Address

- **Ethical considerations:** Privacy, bias in algorithms, and fairness.
- **Digital divide:** Ensuring access to AI tools for all communities.
- **Training:** Educators need training to effectively integrate AI tools.

By addressing these challenges, AI has the potential to transform quality education, ensuring it is sustainable, inclusive, and universally accessible.

Challenges and Considerations

- **Bias in Algorithms:** AI tools may inadvertently reflect biases, necessitating ethical oversight.
- **Data Privacy and Security:** Handling sensitive student data requires robust cyber security measures.
- **Cost and Accessibility:** Not all schools can afford AI solutions, risking a digital divide.

Future Potential

- **Lifelong Learning:** AI can support continuous education by adapting to learners at all stages of life.
- **Global Collaboration:** AI-driven platforms connect students and educators worldwide, fostering knowledge exchange and cultural understanding.

References and Examples

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2. World Economic Forum insights on AI in learning: WEF on AI and Education
3. Practical implementations in remote education tools like Khan Academy and Edmodo.

CONCLUSION

In this study, we examined and evaluated the existing literature to gain a deeper insight into the possible

impacts of AI in the field of education. Our objective was to deliver both a broad overview and a more detailed exploration of different facets of the topic. Our review concentrated on three primary themes: applications, advantages, and obstacles. The use of AI in education encompasses personalized learning, smart tutoring systems, automation of assessments, and enhanced teacher–student collaboration, all of which can lead to improved learning results, increased efficiency, and broader access to quality education worldwide. Artificial Intelligence and the Future of Teaching, Learning and sustainability in quality education.

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Renewable Energy Utilization- for Rural Development

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ABSTRACT

Improving energy use efficiency and increasing level of energy supply are the key factors for improving socio-economic status of rural people. Renewable energy sources are the best alternative for conventional energy sources in the remote areas of developing countries. Sugar industry is one of the most important industries playing a vital role in the economic development of the nation and also a most advanced processing industry in the agricultural sector in India.

The role of energy in development is well known. Its importance in the economic development of developing countries needs no emphasis. New Technologies need to be developed for the production and utilization of Biomass, because traditional fuels are becoming progressively scarce and expensive as the forests diminish in india energy is a key factor in the economic and social development of the country with current awareness and the change in the energy scenario, Interest is turning towards Gasification of Biomass to meet the ever-growing needs of the industrial sectors as an efficient alternative for power generation at multi-megawatt scale. Scientific investigation is continuous process and in the field of energy, there is a no doubt that new Discoveries await us from time to time. The new methods of harnessing Biomass as energy source are continuously being developed to the possible extent.

Among these two methods, Biogasification and Pyrolytic gasification Technology is an emerging stage for powdery biomass. It was arrived in the present investigation to direct efforts towards the development of powdery tubular gasifier. Energy from biomass particularly farm residues is very important.

INTRODUCTION

Energy is an essential pre-requisite for the economic and social development of the country. Energy and environment are the two basic components of the new global of sustainable development. Development involves improving the material condition and the total quality of the vast majority of the human race living in developing countries.

Since the dawn of civilization, man has been dependent on energy in one form or the other. The story of the energy starts with wood, wood came to be replaced by coal and coal by oil only partially. Now a stage appears to have been reached when oil may also have to be substituted by Biomass. Sugar industry is one of the most important industries, playing vital role in the economic development of the nation and also a most advanced processing industry in the agricultural sector

in India. In our country more than 377 sugar mills, in which 0.25 million tones of sugar cane is crushed per day, 4% of cane crushed is press mud. After processing for can sugar, the precipitate otherwise down at the bottom of the clarifier is called press mud, otherwise known as sugar cane mud, sugar cane filter mud, filter press cake, and filter mud. Mostly the cane leaves are supposed to be nuisance to the farmers and are so called waste residues. The bagasse and cane leaves are good candidates for gasification.

The Gasifier: A Hopeful Technology for Rural Development

India has only limited reserves of petroleum fuels. Any energy technology which can reduce the country dependence on imported oil has a great future in India. Amongst the variety of technologies based on Biomass, gasification route offers the most promising scope because it helps in conservation of diesel and saving of foreign exchange needed for import of petroleum. In general gasifier is classified on the basis of the method of air supply, method of ash removal. The gas produced in the gasify is a clean burning fuel having heating value of about 950- 1200 Kcal/m³.

MATERIALS AND METHODS

At the time of harvesting sugarcane crop, the top of the cane are removed and the steers are cleaned of their leaves (trash), on the average the cane tops and trash constitute 25- 30% of the cane weight in the field.

FIELD SURVEY-field survey was conducted to estimate the quantitative availability of cane leaves except cane tops. Five plots of one acre area of sugarcane cultivated fields were selected and marked. The total cane rows planted in each plot per acre were counted. The counts were made for number of cane plants per row and total leaves per plant. The leaves from randomly selected plants were collected and carried to the laboratory for the measurement of its weights and its proximate analysis. All samples were selected by Random sampling method.

Analytical methods-are moisture, total solids, volatile solids and fixed solids.

For moisture-randomly selected samples of feed stock was weighted and then heated at 80°C in oven

for evaporating the moisture. For total solids- the determination of quantity of solids is essential to observe the gasification efficiency. The weight of sample after the evaporation of the moisture was calculated as total solids.

Volatile solids- the weighted total solids where ignited in the muffle furnace at a temperature of 550°C+50°C for two hours. Difference between total solids and the weight of sample after ignition.

Fixed solids- biologically inert material is referred as fixed solids. The weight of sample residue after the ignition of dry matter at 550°C+50°C in muffle furnace was calculated as fixed solids.

FEED STOCK COLLECTION AND PREPARATION

Cane leaves were dried in muffle furnace 80°C for 48 hours to remove its moisture content as shown in fig 1. Electrical grinder (Nippon Ele. India) as shown in fig 2. Grinder used for the preparation of powder samples. The samples of four different particulate sizes were prepared and sieved through the respective sieves. The grain size employed in the present investigation was in table 1.

Sr. NO	Sample s	Mes h size (in mm)
1	A	0.5
2	B	0.8
3	C	2.5
4	D	3.5

Such samples shown in fig 3 cane leave samples.

PROCESS PRINCIPLE

Experimental set up is as shown in fig 4. This is schematic sketch. The various reactions that take place during the gasification process can be synthesized to elementary steps to have a clear understanding about the entire process. Gasification process is carried out in four distinct stages 1. Oxidation 2. Drying 3. Pyrolysis 4. Reduction. Oxidation process -required temperature 900-1200°C. The products of oxidation zone are high temperature gases containing products and water vapors. In drying- the drying process usually air dried biomass contains moisture in the range 13- 15%. It occurs below 110°C. Due to this, weight of a material

is reduced. In pyrolysis- this zone in which biomass loses all its volatiles' and get converted into two parts as 1. Primary pyrolysis zone- in 200-600°C range. And 2. secondary zone-300- 600°C range. Reduction- this zone is maintained within close temperature limits 900°C to 600°C. The final result is a gas consisting mainly CO, H₂, N₂, CO₂ steam and hydrocarbons

TABULAR GASIFIRE-A NEW CONCEPT

The availability of low density feed stock is considerable in India, especially the waste generated in agro-industries and farms. This include the bagasse, cane trash, rice husk etc. to overcome the difficulties in utilization of these wastes for energy generation through the thermal decomposition, the new concept of tubular gasifier is taking roots recently as shown in fig 3.

Experimental observations were summarized in tables 2 and table 3.

RESULTS AND DISCUSSION

The tubular powdery Gasifire was tested for its use to gasify the powdery biomass under the laboratory conditions. Gasification process was not observed for bagasse below 800°C, but little gasification was observed for cane leaves at the temperature above 600°C. The percentage of gasification for cane leaves was increased from 600°C to 1000°C. And attained the maximum possible percentage of gasification for lower powdery grain size. The overall percentage gasification for cane leaves was higher at smaller grain size of power and was decreased at larger grain size. For the small grain size their was the grain attachments to the surface. And formation of a layer was observed. But for higher grain size was less gasified. To have more gasification without layer formation of burned powder, the grain sizes of 1mm to 2.5mm are likely to be useful under continuous operations of gasification with least nuisance of layer formation and optimum percentage gasification.

CONCLUSIONS

The tubular powdery gasifier model is efficient for gasification of the powders of grain size up to 2.5mm. The laboratory results are encouraging to for the fabrication of pilot scale multitubular powdery gasifier to utilize the loose bagasse and cane leaves.

was decreased at larger grain size. For the small grain size their was the grain attachments to the surface. And formation of a layer was observed. But for higher grain size was less gasified. To have more gasification without layer formation of burned powder, the grain sizes of 1mm to 2.5mm are likely to be useful under continuous operations of gasification with least nuisance of layer formation and optimum percentage gasification.

Table 1:- For feeding rate 0.5gm per minute

Sample	Gasified percentage	Temperature in degree
A	40	6000
	48	800
	68	1000
B	35	600
	38	800
	63	1000
C	30	600
	31	800
	60	1000
D	27	600
	29	800
	58	1000

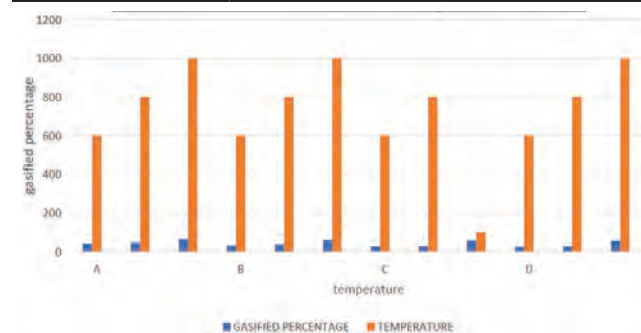


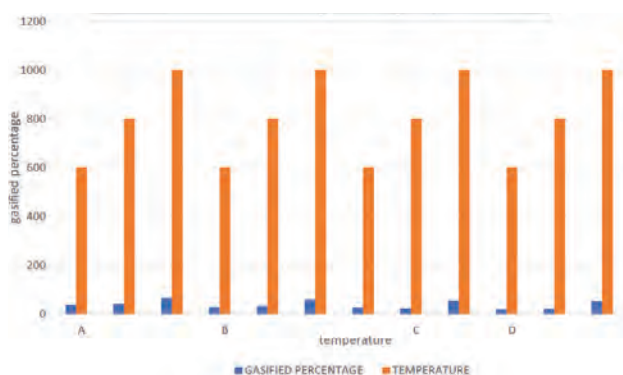
Table 1 For feeding rate 0.5 gm per minute

Graph 1 - Gasification at 0.5gm per minute
2:- for feeding rate 1gm per minute

Table 2 For feeding rate 1 gm per minute

Sample	Gasified percentage	Temperature in degree
A	37	600
	42	800
	66	1000

B	29	600
	32	800
	58	1000
C	27	600
	27	800
	55	1000
D	19	600
	22	800
	52	1000



Graph 2 - Gasification at 1gm per minute



Fig. 1 Muffle furnace



Fig. 2- Grinder



Fig. 3 – Samples of cane leaves

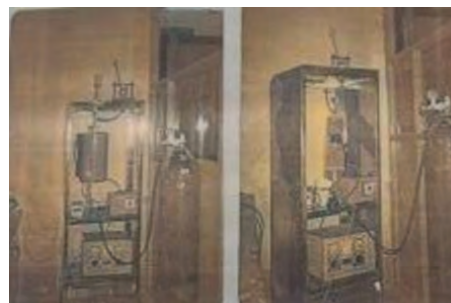


Fig. 4- Experimental set up

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Study of S4 Index and TEC Variation using IRNSS/NavIC Signals

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ABSTRACT

The Indian Regional Navigation Satellite System (IRNSS), designed to provide precise positioning services across India and its surrounding regions, represents a significant advancement in satellite-based navigation systems, joining the ranks of global systems like GPS. This study focuses on analyzing the occurrence of ionospheric scintillation in the L5 (1176.45 MHz) and S1 (2492.028 MHz) frequency bands. Severe scintillation events, which lead to signal instability in satellite receivers, pose significant challenges to the accuracy of position determination. It is well established that lower frequency signals are more susceptible to scintillation effects in the ionosphere, which can adversely impact signal reliability. The scintillation index, S4, is commonly used to quantify disturbances in signal amplitude caused by scintillation. In this Paper, we investigate the effects of ionospheric amplitude scintillation on the NavIC/IRNSS system operating in the L5 and S1 frequency bands. Using carrier-to-noise density ratio (C/No) data from NavIC/IRNSS receivers, the S4 index was computed to assess scintillation intensity. A comparative analysis of scintillation effects was conducted for the L5 band (1176.45 MHz) and the S1 band (2492.028 MHz). data for this study were collected from IRNSS satellites using receiver stations located at Panhala (Kolhapur, near the crest of the equatorial ionization anomaly) and Burdwan (west Bengal). These parameters such as TEC and the S4 index were derived and analyzed to explore the impact of ionospheric conditions on the performance of the IRNSS system.

KEYWORDS: IRNSS, S4 index, C/No ratio, TEC.

INTRODUCTION

NavIC is the regional satellite navigation system created by the Indian Space Research Organization (ISRO) in India. Positioning, navigating, and time (PNT) services are provided across the Indian continent by this system, which has a 1500 km coverage area. The seven satellites comprising NavIC are the following: three geostationary satellites IRNSS1C, IRNSS1F, and IRNSS1G). and four geosynchronous satellites

(IRNSS1A, IRNSS1B, IRNSS1D, and IRNSS1E). The height of each satellite is 36,000 kilometers over the ground of the earth. NavIC works in two separate frequency bands: L5-band at 1176.45 MHz and S1 band at 2492.028 MHz. A sudden or quick change in a radio signal's phase and amplitude, as it travels through the ionosphere, is known as ionospheric scintillation. [1] [2] [3] [4] [5]. In navigation applications, ionospheric scintillation plays a crucial role. Solar activity,

receiver location, local time, seasonal variations, and geomagnetic activity, frequency, and intensity all affect ionospheric scintillation [6]. Variations in the ionospheric electron density are the cause of scintillation effects. Excessive scintillations might cause the received signal to become weaker and might lead to the signal losing lock. Ionospheric scintillations may affect signals used in satellite management systems, high-frequency transmission, and the GNSS [7] [8].

Numerous observations about the dynamics of irregularities and the climatology in the area of the equatorial low-latitude zone have been published in the past. Summertime is when irregularities are most prevalent in the transition area and when irregularities are least common at the equator [9] [10] [11] [12]. The latitudinal extension of scintillation-producing abnormalities, occurring from the magnetic equator to a magnetic latitude of 24.8°N , is shown to be impacted by the development of irregularities in Equatorial Spread F during periods of high solar activity [13]. Numerous observations have been made, providing insights into the seasonal variation and dynamics of scintillation study in the vicinity of the equatorial low-latitude zone [14].

There was a significant rise in scintillation activity at the Equatorial Ionisation Anomaly (EIA) with increased solar activity, as compared to measurements obtained during both solar minimum and maximum periods [15]. The amplitude scintillation shows clear seasonal fluctuation, peaking around the spring and fall equinoxes and troughing down in the summer and winter [16]. Phase scintillation is more frequently observed in the post-midnight sector than in the pre-midnight sector [17]. Ionospheric influences are often seen stronger in low-latitude regions. Radio signals with sudden amplitude and phase are known as Ionospheric scintillations. NavIC's reliability in upper atmosphere research has previously been demonstrated by [18] [19].

To increase the positioning accuracy of IRNSS system, ionospheric effects need to be estimated and minimized [20]. comparison study of several ionospheric models must be done to enhance the position accuracy of upcoming NavIC/IRNSS systems [21]. The ionosphere and space weather are important in many domains,

including satellite communication, electrical systems and remote sensing [22]. It is important to investigate the ionosphere in geomagnetically disturbed conditions, especially in the dynamic Indian longitude sector and at low solar activity [23]. This current ionospheric gradient study is a useful tool to understand how these gradients affect dual-frequency NAVIC signals during geomagnetic storm conditions [24]. There are delays in radio wave propagation in the ionosphere that are dependent on both wave frequency and TEC [25]. The ionosphere above the Indian longitude sector is extremely dynamic and sensitive because of the existence of the northern crest of the EIA [26]. In the low-latitude zones, equatorial, and high-latitude, ionospheric scintillation is more intense. [27].

Ionospheric irregularities are more prevalent in low-latitude regions due to the existence of an equatorial anomaly [28]. The S4 index is a crucial component in determining amplitude scintillation and assessing the level of navigation signal quality [29]. For improving forecast accuracy over the Indian longitude sector, NavIC (Navigation with Indian constellation)/IRNSS is quite helpful [30]. The effects of ionospheric scintillation on the S and L5 band of the NavIC/IRNSS system have been studied by Researchers in Ahmadabad and New Delhi. The findings indicate that the L5 band (1176.45 MHz) exhibits more severe amplitude scintillation than the S-band (2492.028 MHz). C/No ratio measurements at S1 band and L5 band frequencies are used to analyze the Amplitude Scintillation Index (S4) for IRNSS 1A, IRNSS1B, and IRNSS1C satellite signals [31].

Ionospheric scintillations can disrupt various applications, such as positioning, navigation, communication, and remote sensing. Amplitude scintillation is typically the dominant effect in regions close to the equator (low latitudes); when the electron density is large and the plasma drift velocity is relatively slow [32]. After sunset, scintillation effects are typically more intense [33]. To determine location accuracy, ionospheric processes play a crucial role important [34]. Scintillation events become more frequent when solar activity rises because the ionization process quickens and increases the electron density in the ionosphere [35]. Studies discussing the use of NavIC signals for

ionospheric research are included in the references [36]. NavICs positioning accuracy is drastically changed by the ionospheric delay. Ionospheric errors have less of an impact on the location accuracy of receivers operating at S1 frequency than they do at L5. Consequently, greater positioning precision may be achieved by efficiently using S1 frequency as the working frequency in single-frequency NavIC receivers [37]. The GNSS community has acknowledged the increased potential benefits of utilizing S-band for future navigation services [40]. Nevertheless, there aren't many studies that concentrate on scintillation research associated with NavIC's S-Band signals [38].

The analysis of Total Electron Content (TEC) has gained significant attention in recent years due to its critical role in advancing satellite-based navigation technologies[39]. Numerous studies have utilized TEC measurements collected from various locations across India, leading to substantial contribution to this field of research [40]. Despite these advancements, only a limited number of studies have been conducted at the international level. The Development and deployment of ground-based GNSS receivers have enabled extensive TEC observations over broad geographical areas[41].Furthermore Simultaneous investigations of ionospheric irregularities using TEC mapping in conjunction with OI 630 nm airglow imaging have yielded valuable insights [42]. India's own navigation system is now in the fully operational stage and the utilization of its data to understand the conditions of the ionosphere for communication and navigation is going on from the different parts of the country.

This paper presents a detailed analysis of the amplitude scintillation index (S4) and its impacts on IRNSS/NavIC S1 and L5 band signals. While carrier phase Measurements are essential for investigating phase scintillation, carrier-to-noise density (C/N0) data are critical for assessing amplitude scintillation. Differences in TEC values during geomagnetically quiet and disturbed days have been observed, highlighting the ionospheric dynamic nature.

This paper analyzes the data obtained from the receiver station at Panhala (Maharashtra) and Burdwan (west Bengal). We calculated the derived parameters like TEC and S4 index.

Collection of Data

The radio signals L5 (1176.45 MHz) and S-band (2492.028 MHz) frequencies from the IRNSS satellite constellation have been continuously monitored at Panhala, Kolhapur since March 2016. The Indian space research organization (ISRO) initially launched nine satellites to establish the IRNSS constellation. However, two satellites, IRNSS 1A and IRNSS 1H, failed in orbit due to issues with their onboard rubidium atomic clock. Consequently, the constellation now consists of seven operational satellites, with four positioned in geosynchronous orbit and three in geostationary orbit. The IRNSS receiver operates in a dual-frequency mode, enabling it to simultaneously collect data from both the IRNSS constellation and GPS satellites. Data recording occurs at a rate of 1 Hz. Raw data files generated by the receiver are processed and converted into .csv format using the IRNSS user interface provided by the manufacturer. These processed files include key navigation solutions and additional parameters such as carrier-to-noise ratio (C/N0), ionospheric range delay, dilution of precision (DOP), azimuth and elevation angles for each satellite, and more.



Fig. 1: Shows the receiver location of Panhala (Kolhapur) and Burdwan (West Bengal).

For this study, data was collected from Panhala (16.80°N, 74.10°E); a hill station located approximately 18 km west of Kolhapur in Maharashtra. This site lies within the Equatorial Ionisation Anomaly (EIA) crest, making it an ideal location for studying ionospheric phenomena. Data for specific days were selectively chosen, taking into account the dynamic behavior of the IRNSS/NavIC system. Total Electron Content (TEC) was calculated using ionospheric delay values

derived from IRNSS receiver data, while the S4 index was determined from the carrier-to-noise ratio (C/No) values. The study examines the influence of these parameters on satellite-based communication and navigation systems, providing valuable insights into how ionospheric conditions affect the performance of the IRNSS constellation.

METHODOLOGY

The ionosphere experiences the highest levels of ionization during daytime due to intense solar radiation. To investigate the variability of the ionosphere, data was selected and analyzed with a focus on the vertical Total Electron Content (VTEC), a key parameter for assessing ionospheric electron density. The presence of free electrons in the ionosphere significantly influences signal transmission, causing delays in satellite signals. Signal transmission is impacted by free electrons in the ionosphere. The ionospheric delay can calculate the total electron content (TEC).

The Ionospheric range delay (R_{diono}), which is used to calculate TEC, may be found in the .csv files of the IRNSS data. The formula describing how TEC and ionospheric range delay are related is

$$TEC = \frac{R_{diono} \times f_1^2}{40.3} \text{ el/m}^2$$

Where f_1 is the receiving frequency (L5=1176.45 MHz).

To quantify the severity of ionospheric scintillation, a commonly used parameter is the scintillation index, often denoted as S4. In your study, S4 is calculated from Carrier-to-Noise Ratio (C/No) data recorded by the receiver, using the formula [34].

$$S4 = \sqrt{\frac{\langle Si^2 \rangle - \langle Si \rangle^2}{\langle Si \rangle^2}}$$

Where $Si = 10^{0.1 \times C/No}$.

Study of scintillation (S4 index) during 3rd, March 2022

For this study, specifically picked three dates: March 3rd, March 4th, and March 5th were selected. Were computed the S4 indices for the S1 (2492.028MHz) and L5-band (1176.45 MHz) and results were presented in

a figure. The graph showed the range of the S4 index for three days. The following criteria were used in this investigation to assess the intensity of scintillation events. The criteria that followed were used in this investigation to assess the intensity of scintillation events:

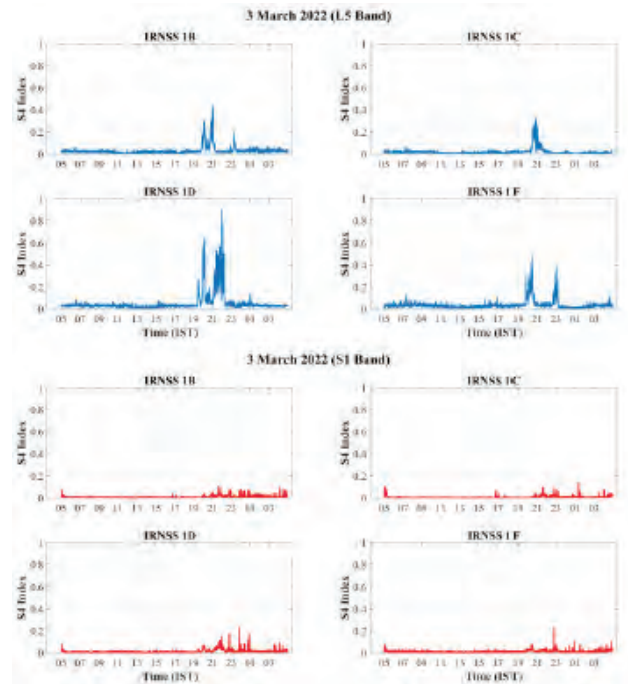


Fig. 2: plot shows L5 and S1 band S4 indices for 3rd March 2022

S4 values in the range of 0 to 0.3 were considered indicative of weak scintillation. Moderate scintillation was classified for values between 0.3 and 0.5. Higher scintillation was classified for S4 values greater than 0.6.

Moderate scintillation typically occurred during the period around sunrise, as well as a few hours before sunrise and after sunset. This figure 2 clearly showed that weak to moderate scintillation was present most of the time, with the S4 index primarily mostly ranging between 0.1 and 0.4. It briefly exceeded the 0.6 threshold, entering the strong scintillation range, but only for a very brief period. Figure 2 displayed the scintillation index data for the L5 band at the Panhala location in Kolhapur. Severe ionospheric scintillation in the L5 band of radio signals from all IRNSS satellites was observed during the post-sunset period.

The L5 band's S4 index was often measured to be equal to or higher than 0.6 during this period. In the low-latitude and equatorial zones, amplitude scintillations were comparatively greater than phase scintillations [3]. At low latitudes scintillations occurred very frequently and could be intense [43] [44].

The importance of IRNSS that it comes with a new additional band i.e., S-band which can be further studied for better understanding of ionospheric dynamics. Recently, Chakraborty et al., (2017) [6]. As far as the IRNSS system was concerned, the data of S band was available for the first time to research community to study the ionospheric effects on communication. A similar analysis was conducted in the S-band. In the S-band, it was observed that the S4 index is significantly lower when compared to the L5 band.

Study of scintillation (S4 index) during 4th March 2022 :

Amplitude scintillation, which was most noticeable in the equatorial ionization anomaly (EIA) area, was discussed here. the ionospheric fluctuations were mainly influenced by Geographical location, seasonal variations, and solar isolation.

These two figures helped in analyzing the variations in the signal strength of the received signals. It is clear from comparing Figures 3 that the S4 index showed somewhat different patterns of fluctuation and fluctuating values at the same time of observation when examined simultaneously from the two different frequencies, L5 and S-band.

The S4 index plots for 4 march 2022, showed the maximum S4 index values for reached around 0.6 to 0.8. on the other hand, the S band plots showed only very small S4 variation mostly below 0.2, indicating weak scintillation activity at higher higher frequencies. Although scintillations were observed throughout day, the strongest activity was recorded during the hours after sunset. Most notable scintillations were occurred after the post-sunset period. Amplitude scintillation index S4 at the L5 band was more severe than in the S-band. assessed the impacts of ionospheric scintillation on several GNSS signal types over the Indian zone by employing multi-frequency and multi-GNSS measurements [45].

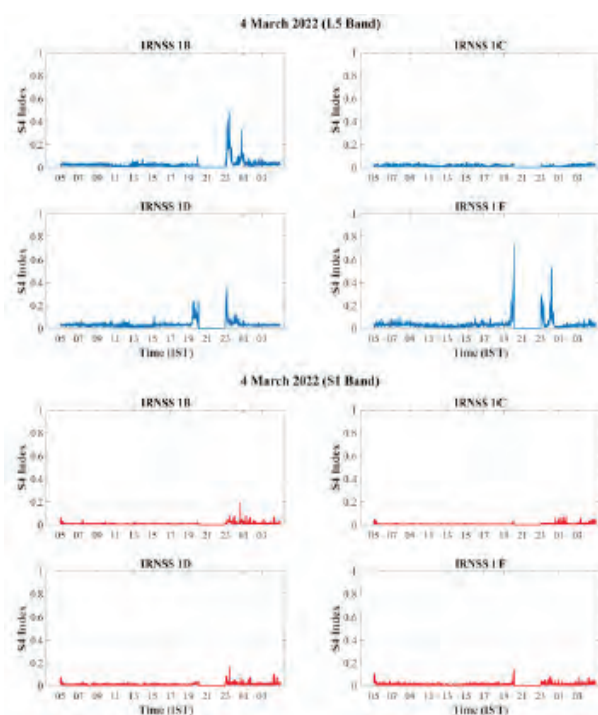


Fig. 3: Plot shows L5 and S1 band S4 indices for 4th March 2022

Study of scintillation (S4 index) during 5th March 2022

Day analysis was separated into two stages: the L5 band as the first phase, and the S-band as the second. Analysis During the initial phase, the analysis revealed that over the three days, the highest S4 value was observed in the L5 band at 0.8, and in the S1 band it was around 0.2. Similarly, it was also discovered that the highest Average S4 value for the chosen day in 5 March is 0.35 in the L5 band and 0.1 in the S1 band. The Panhala station recorded severe scintillations for signals in the L5 and S1 bands on the March equinox. On 5 march 2022, the S4 index plots for both the L5 band & S band were analyzed to study the ionospheric scintillation behaviour. The S4 index values remained low throughout the day for all satellites indicating mostly quiet ionospheric conditions.

The scintillation event is far less intense in the S-band than it is in the L5 band, as in Figure 4 illustrates. Regardless of solar activity, equinoxes consistently experience higher levels of scintillation events compared to solstices [37].

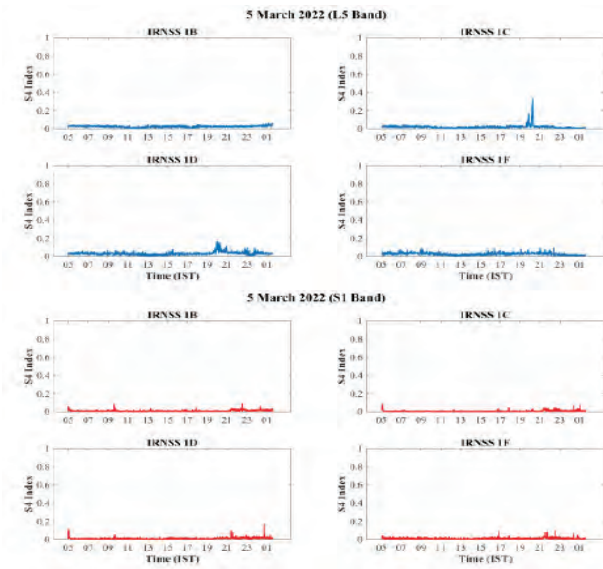


Fig. 4: plot shows L5 and S1 band S4 indices for 5th March 2022

However, a small increase in scintillation was seen during the post sunset hours, the S4 values in the S band remained very low almost stable throughout the day, showing very weak scintillation. It was clearly observed that the L5 band higher scintillation levels compared to the S band. The difference occurred because scintillation effects are stronger at lower frequencies & weaker at the higher frequencies.

Variation of VTEC month-by-month of quiet and disturbed day

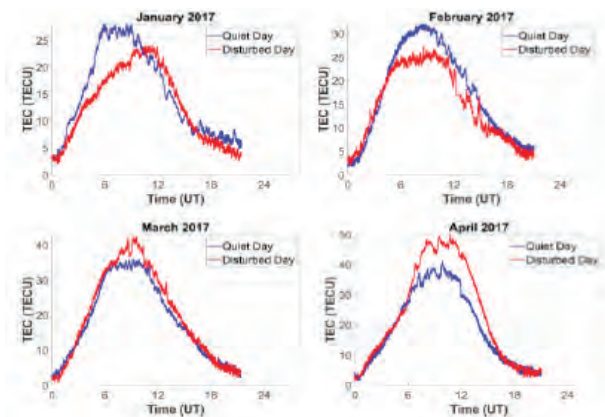
We created a month-by-month graph for the entire days. Solar isolation is a highly important factor in the variation of space weather, especially in the ionosphere. The equinox months (March and September) have Higher TEC value profile, as is evident that June and December which are solstice months, display a low TEC value profile. As the difference in the TEC profile between quiet and disturbed days is clearly visible. On both days' profiles, the TEC value gradually rises until 11:30 LT and reaches its maximum peak value for a short while during this time. There are fewer fluctuations during this time. TEC starts to drop in the late afternoon; at approximately 03:00 LT. The ionosphere is extremely sensitive to the solar flares' energy. According to the website <https://wdc.kugi.kyoto-u.ac.jp/qddays/>, select quiet and disturbed days for this purpose. The blue variation depicts the change

on quiet days; whereas the red variation depicts the change on disturbed days. The monthly variation of TEC has been separately examined for both quiet and disturbed days at the Panhala station for the year 2017. Pre-dawn TEC is usually at its lowest, followed by a gradual decrease after sunset, the highest in afternoon, and gradually rising in the early hours of the day. The peak value of TEC varies from day to day, and the time at which it reaches its maximum also differs daily.

Figure 5 displays the monthly variation of the average VTEC as well as the VTEC variation for, separately quiet days and disturbed days in the year 2017. The trend of variation, which includes a minimum during the pre-dawn hours, followed by a steady increase in the early morning, reaching an afternoon maximum, and then gradually decreasing after sunset, appears to be consistent.

Our results indicate that at Panhala, the behaviour of TEC during quiet and disturbed days appears to be in opposite nature, resembling a mirror image of each other. It has long been acknowledged that geomagnetic activity plays a prominent role in causing variability in the ionosphere [35]. The highest TEC value of January month is 30 TECU. With the exception of February, it has been noted that the TEC variation is lowest on calm days and highest on Perturbed days in every month. The highest TEC value for February month is 32 TECU.

It is found that every month on disturbed days, there were the most fluctuations between 0600 and 0800 UT; and there were fewer fluctuations on quiet days. The highest TEC value march is 43 TEC. In every month the difference in the value of TEC is observed between quiet and disturbed days. The highest TEC value of the month of April is 50 TECU.



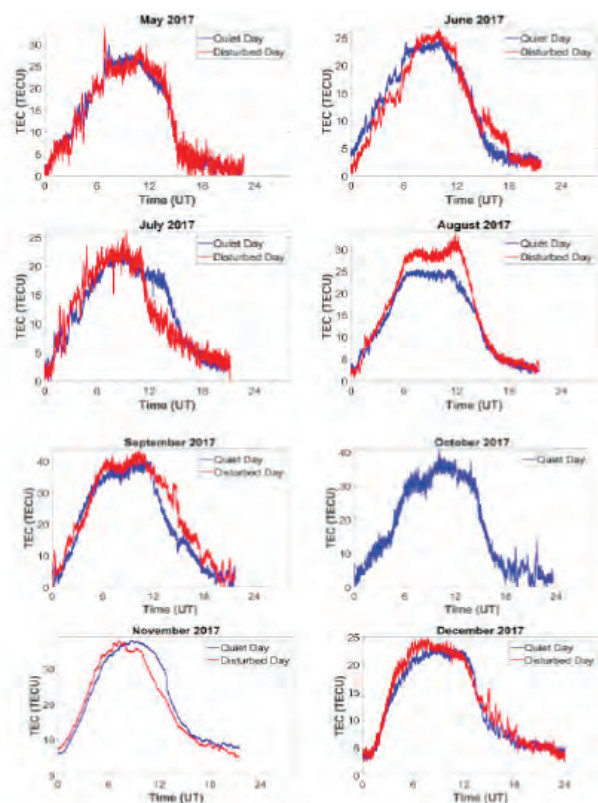


Fig. 5: A graph depicts the VTEC variation of year 2017 of quiet and disturbed days

Every month it appears that disrupted days have a higher TEC value than peaceful days. The highest TEC value of the month of May is 34 TECU. And for June month highest TEC value is 25 TECU. The study, which focused on the impact of magnetic activity on TEC, demonstrated that variations from Monthly means consistently exhibit a significant anti-correlation between magnetically calm and disrupted days. The difference between the five most disrupted days (DD) and the 10 calm days (QQ) is particularly noticeable at night. In July month the highest TEC value is 25 TECU.

This effect is purely statistical, meaning that minor variations in F2-layer electron density led to substantial percentage changes when compared to the low night-time mean values. Daytime variability, although modest in terms of percentages, entails more substantial absolute changes in plasma content. As a Result, it holds greater significance both in physical terms and for practical applications. The electric field plays a crucial role in sustaining the F2 layer in the equatorial region.

Figure 5 displays the monthly variation of the average VTEC as well as the VTEC variation for, separately quiet days and disturbed days in the year 2017. The trend of variation, which includes a minimum during the pre-dawn hours, followed by a steady increase in the early morning, reaching an afternoon maximum, and then gradually decreasing after sunset, appears to be consistent. It is observed that the approximately bell-shaped TEC variation for every month of some similarity in nature because the grossly similar atmospheric conditions. It has been noted that in august, the TEC variation is greatest on days that are disrupted and lowest on days that are peaceful. The highest TEC value of august month is 35 TECU. It is also observed that the variation is maximum in night time hours than day time hours. The highest TEC value of the September month is 44 TECU. The difference is observed to be greater at night than during the day. The blue variation depicts the change on quiet days, whereas the red variation depicts the change on disturbed days. In month of October, November and December TEC values rise throughout the morning and reach their maximum peak in the afternoon. The highest TEC value of October month is 40 TECU and month of November and December highest TEC value is 38 TECU and 25 TECU.

Determination of diurnal variation TEC, ROTI and S4 index in Kolhapur-

“TEC, short for Total Electron Content, is a measure of the total quantity of free electrons within a one-square-meter cross-sectional area along a specific path. This measurement is typically expressed in TECU (Total Electron Content Units), where 1 TECU is equivalent to 10^{16} electrons per square meter (el/m^2).” The Total Electron Content (TEC) within the ionosphere is inherently non-uniform and lacks homogeneity, primarily as a result of various factors. It serves as a fundamental indicator of the ionospheres structure and dynamics and is widely used in space-based radio communication application. Including satellite navigation, positioning, and orbit determination. This is because TEC is closely linked to the time delay experienced by radio waves as they traverse the ionosphere. Among the key contributors to TEC fluctuations are solar events, such coronal mass ejections. When charged solar particles interact with

Earth's magnetic field, they introduce perturbations in the ionospheric electron density, leading to variability in TEC. The ionospheric range delay can be derived from NavIC data, stored in .csv format, enabling precise TEC determination.

Ionospheric scintillations are sudden changes in the radio signal's amplitude and phase. Amplitude scintillation is quantified using the amplitude scintillation index, often denoted as S4, while phase scintillations are represented by the symbol $\sigma\phi$. Ionospheric scintillation plays a crucial role in navigation applications. Scintillation effects occur as a result of fluctuations in ionospheric electron density. Generally, ionospheric scintillation is characterized by the sudden and rapid changes in both the phase and amplitude of a radio signal as it passes through the ionosphere[47]-[50]. Ionospheric scintillations have a significant impact on various applications, including positioning, navigation, communication, and remote sensing [51]-[52]. Low latitude regions see more intense ionospheric impacts [53]. Ionospheric scintillations refer to swift variations in both the amplitude and phase of radio signals. Scintillation effects become more severe during the post-sunset periods [54]. Amplitude scintillation is dominate in low-latitude areas with high electron densities and slow plasma drift velocities [55]. In equatorial and low-latitude regions, there is a relatively higher occurrence of amplitude scintillations compared to phase scintillations.

In order to investigate the ionospheres diurnal fluctuations and their correlation with latitude, TEC and S4 data from two distinct receivers situated in Panhala (Kolhapur) and Burdwan (west Bengal) were examined. Amplitude scintillations are particularly severe in the EIA region, where the dynamics are influenced by the eastward electric field generated during the daytime at the equator. This field creates an $E \times B$ times drift at the dip equator, causing plasma to diffuse northward and southward along geomagnetic field lines due to pressure gradients and gravity. Consequently, the EIA region significantly higher plasma densities compared to the dip equator. This variation in TEC is strongly influenced by solar radiation, geographic location, and seasonal changes.

Figure 7 shows a direct correlation between TEC and ROTI and their apparent effect on scintillation

especially during post-sunrise hours, there was a sharp rise in the S4 index of scintillation when TEC had just begun to rise. In the post-sunset hours, we observe rapid fluctuations in the TEC. This, in turn, results in ROTI increasing quite significantly.

Throughout the day, TEC varies rather smoothly and hence causes the signal to scintillate relatively weakly. Moderate scintillation occurs at the onset of sunrise. According to each receiver has a particular fading margin which dictates the extent of scintillation and data loss. When this threshold value of the fade margin is reached, we experience a loss of lock, and the signal is lost.

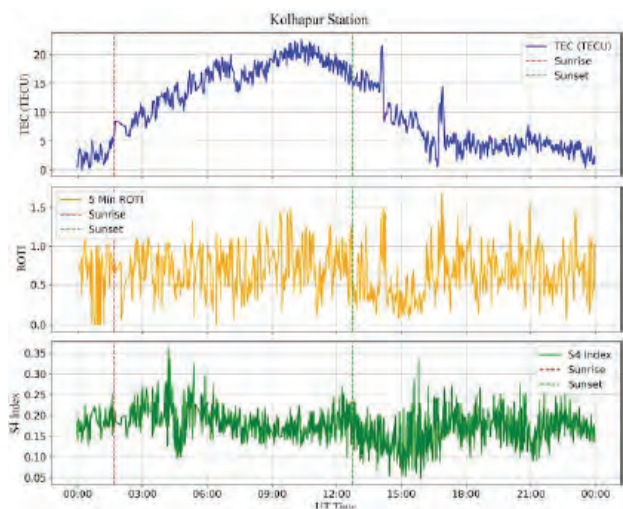


Fig. 7: S4 index of scintillation, Ionospheric VTEC, ROTI as of January 3rd, 2017 calculated with IRNSS-1B satellite data recorded at latitude station Panhala (Kolhapur), showing the variation of TEC, ROTI, and S4 respectively

Determination of diurnal variation TEC, ROTI and S4 in Burdwan

Data collection was also conducted at the GNSS laboratory in Burdwan (west Bengal). On January 3rd, both Panhala and Burdwan stations recorded significant variations in the signal over a relatively short period. The impact on the signal recorded concurrently are very different even though both these stations are located well inside the EIA crest. The Burdwan station records brief, intense scintillation bursts. However, the scintillations recorded by the Panhala station are longer but comparatively less intense. This indicates that the ionospheres local disruptions are extremely significant.

For instance, in the case of Burdwan, it can be inferred that due to the short duration of the scintillation event, the local ionosphere is dominated by severe but small-scale irregularities. Contrarily, the Panhala station is situated so far inside the EIA crest that the local ionosphere here is dominated by a volatile plasma density region stretching much farther than Burdwan. It is also evident from the immediate recovery of the signal that these disturbances are not stationary, and their drift is governed by the local conditions.

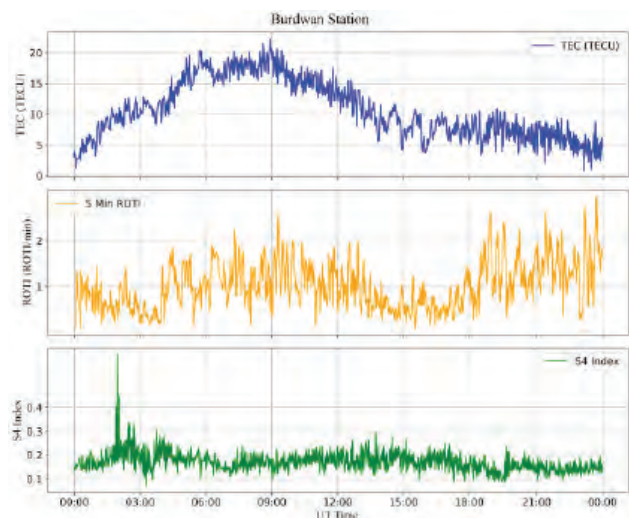


Fig. 8: S4 index of scintillation, Ionospheric VTEC, ROTI as of January 3rd, 2017 calculated with IRNSS 1B satellite data recorded at Burdwan, West Bengal showing the variation of TEC, ROTI, and S4 respectively

As is visible in Fig. (7) and Fig. (8), show the intense scintillation events typically occur in conjunction with fast variations and TEC depletion, which corroborates the findings of [57]. Which indicate that strong scintillation is primarily associated with rapid temporal variations in TEC rather than absolute high or low TEC values, provided the fluctuations remain minimal. The comparison between Burdwan and the Panhala highlights how erratic and latitude dependent ionospheric anomalies are. These observations reinforce the need to account for localized disturbances in studying and mitigating the impacts of ionospheric scintillations on communication and navigation systems.

CONCLUSION

In conclusion, this study examined the impact of ionospheric scintillations on NavIC/IRNSS S1 and

L5 signals at the Panhala station. Findings revealed that amplitude scintillations were more prominent in the L5 band signals (1176.45 MHz) compared to the S1 band signals (2492.028 MHz). It was observed that scintillation events predominantly occurred during post-sunset hours, often resulting in frequent signal loss for both the L5 and S bands during that time.

Analysis of the data showed that the S4 index generally ranged between 0.1 and 0.45, indicating weak to levels of scintillation. Strong scintillation events were rarely observed at the Panhala station. These results suggested that the IRNSS constellation offers robust signal integrity and reliable range, even under moderate ionospheric disturbances.

TEC variability was also analyzed to understand its behavior during calm and disturbed conditions. The study showed a positive correlation between TEC variations and solar activity. TEC values were observed to peak during the afternoon hours, with greater variation and higher values on disturbed days compared to calm days. During equinox months, TEC values were at their highest, whereas they were lower during solstice and winter months.

A comparison of TEC values recorded at the Panhala and Burdwan stations during simultaneous observations of signals from the same satellite reveals significant differences. TEC values at Burdwan were generally higher than those at Panhala for the same observation times. This highlights the influence of geographic location and local ionospheric conditions on TEC.

Fluctuations in the carrier-to-noise ratio (C/No) were studied by calculating and analyzing the S4 indices. The Burdwan station experienced abrupt and intense signal fluctuations within a short duration, while the Panhala station recorded less severe scintillations that persisted for longer periods. These observations suggest that local ionospheric disturbances played a critical role in scintillation behavior.

A comparison of signals from the two locations underscored the importance of latitude in determining positional accuracy. While both stations were situated within the EIA crest, the scintillation effects observed simultaneously at the two locations differed significantly. Burdwan recorded brief but severe

scintillation events, whereas Panhala experienced milder but more prolonged scintillations. This indicates that localized atmospheric conditions significantly influence ionospheric disturbances.

The findings emphasize the need for long-term studies involving simultaneous data collection from multiple locations across India. Such studies could provide valuable insights into local atmospheric conditions using IRNSS signals and offer methods to improve signal reliability and positional accuracy under varying ionospheric conditions.

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