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EDITORIAL

It gives us immense pleasure to present this Special Issue of the International Journal of Advance and Applied Research (IJAAR), featuring selected peer-reviewed papers presented at the National Conference on Emerging Trends in Technology and Science (ETTS–2026) organized by VPM's Maharshi Parshuram College of Engineering, Velneshwar, in association with the National Centre for Science Communicators.

The contemporary world is witnessing unprecedented advancements driven by scientific discoveries, technological innovations, and interdisciplinary collaborations. Addressing complex global challenges requires the integration of knowledge across traditional disciplinary boundaries. ETTS–2026 was conceived as a platform to bring together researchers, academicians, industry experts, innovators, and students to exchange ideas, share research outcomes, and explore emerging directions in science and technology.

The contributions included in this special issue reflect the diverse thematic spectrum of the conference. The published papers cover significant developments in Physical Sciences and engineering, showcasing innovative solutions and technological improvements for industrial and societal applications. A substantial number of contributions focus on Information Technology, Computer Science, Artificial Intelligence, and Data Science, reflecting the transformative role of digital technologies in modern society. These studies explore machine learning, intelligent systems, data analytics, cybersecurity, cloud computing, and computational innovations that are shaping the future of industry and governance.

We extend our sincere appreciation to all authors for their valuable contributions, the reviewers for their rigorous evaluations and constructive feedback, and the organizing committee of ETTS–2026 for providing an excellent platform for scholarly interaction. We are also grateful to the editorial board of IJAAR for supporting the publication of this special issue.

We hope that this collection of research papers will inspire further investigations, foster interdisciplinary collaborations, and contribute meaningfully to scientific progress and technological excellence.

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Predictive Maintenance System for Industrial Machines Using Sensors and IoT

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Abstract:

A contemporary maintenance approach called predictive maintenance makes use of data analysis, machine learning, and real-time monitoring to foresee equipment breakdowns before they happen. Predictive maintenance concentrates on condition-based monitoring to increase efficiency and dependability, in contrast to conventional maintenance techniques like reactive maintenance (repair after failure) and preventive maintenance (planned servicing). The creation of a predictive maintenance system to improve equipment performance, minimize unplanned downtime, and maximize maintenance planning is presented in this project. The system collects data from various sensors installed on machinery, such as temperature, vibration, pressure, and humidity sensors. This data is continuously monitored and transmitted through Internet of Things (IoT) technologies for further processing. The collected data is then preprocessed to remove noise, handle missing values, and normalize inputs for accurate analysis. Machine learning algorithms are applied to this processed data to identify patterns, detect anomalies, and predict potential equipment failures. Techniques such as classification, regression, and time-series analysis are used to estimate the remaining useful life (RUL) of components. Predictive maintenance, or Pd.M., is now transforming how companies maintain their equipment and ensure continued production. Predictive maintenance, as opposed to conventional maintenance techniques like reactive and preventative, makes use of real-time data and state-of-the-art technology to spot any equipment problems before they happen. The strategy is gaining traction in the industrial, energy, transportation, and healthcare industries because it may drastically save operational costs, avoid unscheduled stops, and provide more dependable systems. In fact, advanced technology that allows for accurate equipment observation and analysis makes predictive maintenance conceivable.

Keywords: *Predictive Maintenance, Real-Time Data, Advanced Technology, Accurately Observe and Analyze Equipment.*

Introduction:

The fast-paced changes in industry make it important to keep equipment efficient, safe and durable to keep a company's operations lasting. The need for maintenance has grown in importance as industries use advanced, expensive machines and connect many systems. The main foundation for equipment maintenance until now has been the reactive and preventive strategies. But, as the fourth industrial revolution rolls out, also called Industry 4.0, the old approaches seem

insufficient. Because of this revolution, there is now a new trend that features automation, strong connections, and analytics on the spot, leading to creative techniques like predictive maintenance (PdM).

Predictive maintenance offers a major change from handling maintenance in fixed time frames or when things break to responding to the actual condition of equipment and its data. Rather than fixing a problem when it already occurs or scheduling maintenance without need, predictive

maintenance uses real-time data and advances tools to predict failure instances upfront. To work, it gathers information from assets in use to spot problems, examine how equipment is performing, and project the future useful life of each piece of equipment. Thanks to predictive maintenance, maintenance teams can make precise and timely decisions, which cuts down on meaningless repairs, makes maintenance cheaper, and prevents major equipment breakdowns.

Predictive maintenance matters in many different industries. Stoppages in production and disruptions within supply chains can cause companies in manufacturing to lose money when equipment is unable to work. Failure of energy sector equipment may lead to serious accidents and harm to the environment. Failure in transportation systems can weaken safety and efficiency. In each situation, predictive maintenance helps make sure equipment runs as it should and that any problems are spotted in advance. To improve efficiency, sustainability, and competitiveness, industries are seeing precision maintenance design as a true business priority.

Literature Review:

Thanks to developments in Industry 4.0 technologies like artificial intelligence, the Internet of Things, and data analytics, predictive maintenance (PdM) has emerged as a crucial part of contemporary industrial systems. To improve system dependability and decrease downtime, a number of strategies have been investigated, including physics-based, data-driven, and hybrid models.

Multi-model methods combining diagnostics and prognostics are presented in a thorough study by Montero Jimenez et al. [1], emphasizing the advantages of combining data-driven and physics-based techniques for increased prediction accuracy. A decision-based approach

for choosing suitable PdM techniques based on operational needs, system complexity, and cost concerns was also presented by Li et al. [3].

Because of their accuracy and interpretability, physics-based prognostic techniques have been used extensively. Using non-linear least squares with dynamic constraints, Downey et al. [2] created a physics-based model for lithium-ion battery prognostics that showed increased resilience. By including degradation curves for industrial robot predictive maintenance, Aivaliotis et al. [4] improved these models even further by offering a deeper understanding of system wear and failure reasons.

On the other hand, because of their capacity to handle massive amounts of sensor data, data-driven methods—especially those based on machine learning—have grown in popularity. Wu et al. [5] presented a hybrid approach that combines bat-based particle filtration and neural networks to forecast the residual usable life (RUL) of lithium-ion batteries with good prediction accuracy. Tiwari et al. [6] highlighted how deep learning and IoT may facilitate intelligent maintenance choices and real-time monitoring. Furthermore, Arena et al. [7] examined PdM applications in the automobile industry, emphasizing the efficiency of AI-based methods in maintenance optimization and problem identification.

Maintenance tactics have been greatly impacted by the shift to Industry 4.0. Popkova et al. [8] highlighted the significance of cyber-physical systems and digitalization when discussing the key distinctions between Industry 4.0 and other industrial revolutions. Antomarioni et al. [9] shown the efficacy of a predictive association rule-based maintenance strategy in industrial settings like oil refineries by proposing it to reduce the likelihood of equipment failure. In order to increase maintenance efficiency in the automobile industry, Liang [10] created a

process-based troubleshooting and knowledge management system for collaborative settings.

Even with major progress, there are still a number of obstacles. The integration of diverse data sources, the high computational cost of hybrid models, and the restricted real-time industrial application are some examples. Thus, the development of scalable, effective, and real-time predictive maintenance frameworks appropriate for complex industrial contexts should be the major emphasis of future study.

Methodology:

Through a methodical and data-driven approach, the suggested predictive maintenance system is intended to continually monitor equipment health and identify any problems early on. The process starts with the data acquisition phase, during which sensors are installed on the machine to continually monitor vital factors like vibration and temperature, which are important markers of the performance and condition of the machine. These sensors produce data in real time that represents the system's operating state. The microcontroller, which acts as the system's central processing unit, receives the collected sensor data after that. In order to make sure the data is correct and appropriate for assessment, the microcontroller processes and analyses it after receiving it. This includes signal conversion, filtering, and simple calculations. The processed data is then contrasted with predetermined threshold limits that reflect the machine's typical and secure working settings. The system continues to function under normal monitoring conditions if the sensor readings stay within certain bounds; if any parameter above its corresponding threshold, it is recognized as an abnormal state suggesting a possible failure. In order to notify the user and facilitate prompt action, the system creates alerts in the form of digital, visual, or auditory messages.

Additionally, the system facilitates real-time transmission of processed data for remote monitoring, storage, and additional analysis via interface with a cloud-based monitoring platform. The system's capacity is increased by this cloud connectivity, which allows for better decision-making, historical data monitoring, and ongoing supervision. All things considered, the suggested approach guarantees effective real-time monitoring, early issue identification, and proactive maintenance, which raises operational efficiency, decreases downtime, and improves system dependability.

Hardware Components:

A collection of crucial hardware elements that together allow data collection, processing, and transmission are used to create the suggested IoT-based predictive maintenance system. In order to guarantee precise monitoring and effective system functioning, each component has a distinct function.

Microcontroller (ESP32/Arduino):

As the system's central processing unit, the microcontroller is in charge of managing and directing all activity. Platforms like Arduino or ESP32 are used in this application because they are dependable, simple to program, and compatible with a variety of sensors. In addition to performing analog-to-digital conversion (ADC) and preparatory data processing like threshold comparison and filtering, the microcontroller receives input signals from the attached sensors. It also controls connectivity with external systems, such as managing local output devices like buzzers or displays and sending data to the cloud via Wi-Fi (in the case of ESP32). Because of its increased processing power, built-in Wi-Fi connectivity, and appropriateness for real-time IoT applications, the ESP32 is especially beneficial.

LM35/DHT11 Temperature Sensor:

The machine's thermal status, which is crucial for spotting overheating and possible failure, is monitored by the temperature sensor. This system frequently uses sensors like LM35 and DHT11. With its great precision and linearity, the LM35's analog output voltage is precisely proportional to temperature, making it ideal for exact readings. The DHT11, on the other hand, has digital output and is capable of measuring humidity and temperature, but with somewhat less precision than the LM35. The gathered temperature data aids in the identification of unusual heat buildup, which may point to problems like overload, friction, or inadequate cooling.

Vibration Sensor (SW-420):

The machine's mechanical anomalies are found using the vibration sensor (SW-420). It functions by detecting shocks or vibrations and producing an electrical signal in response. Machines vibrate steadily under typical working circumstances, but excessive or erratic vibrations might be a sign of problems such misalignment, imbalance, or component wear and tear. In order to identify certain vibration thresholds, the SW-420 module usually has a comparator circuit that permits sensitivity tuning. This sensor is essential for early failure detection, especially with spinning machinery.

Power Supply:

All system components must have a steady and dependable power source in order to perform properly. The microprocessor, sensors, and communication modules all receive the necessary voltage and current from the power supply unit. Regulated DC power sources are typically utilized to guarantee steady functioning and guard against harm from voltage swings. In real-world applications, voltage regulators or adapters are used to change the AC mains supply into the necessary DC values (such as 5V or

3.3V). System stability and continuous monitoring are ensured by effective power management.

Wi-Fi Module:

Real-time data transfer and remote monitoring are made possible by the Wi-Fi module, which allows wireless connectivity between the system and the cloud platform. ESP32 systems do not require an additional module because the Wi-Fi capability is embedded within the microcontroller itself. Sensor data may be sent to cloud servers for storage, analysis, and visualization thanks to the Wi-Fi module, which also links the device to the internet. Because it permits remote access, data logging, and integration with sophisticated analytics like machine learning, this connectivity is crucial for putting IoT-based predictive maintenance into practice.

Software Requirements:

A variety of software tools and programming approaches that facilitate data collection, processing, analysis, and remote monitoring are necessary for the implementation of the suggested IoT-based predictive maintenance system. In order to understand sensor data, control system operation, and produce useful outputs for decision-making, the software layer is essential.

Arduino IDE:

The main tool for creating, assembling, and uploading code to the microcontroller (Arduino or ESP32) is the Arduino Integrated Development Environment (IDE). Its built-in libraries and user-friendly interface make it easier to connect with hardware elements, including output devices, communication modules, and sensors. Through serial connectivity, the IDE facilitates real-time debugging, enabling engineers to keep an eye on sensor data and system behaviour while the system is running. It

also enables quick testing and prototyping, which makes it appropriate for embedded system development in Internet of Things applications.

Embedded C Programming:

Embedded C programming, which is popular for microcontroller-based applications because of its effectiveness and low-level hardware access, is used to implement the system's control logic. Sensor data collection, signal processing, threshold comparison, and communication handling are just a few of the functions that the software is designed to carry out. To ascertain the machine's working status, the microcontroller continually takes input from temperature, vibration, and current sensors, interprets the data using preset algorithms, and compares it to predetermined threshold limits. To guarantee real-time responsiveness, particularly for problem detection and warning production, conditional statements and interrupt-based techniques are employed. Additionally, effective memory management and streamlined execution are made possible by embedded C, which is crucial for systems with limited resources.

IoT Dashboard (Optional):

A graphical user interface for remote sensor data monitoring and visualization is provided by an Internet of Things dashboard. Real-time parameters, past patterns, and system status can be shown in an easy-to-understand manner on platforms like cloud-based dashboards or mobile/web applications. The dashboard increases accessibility and operational awareness by enabling users to obtain machine data from any distant location. Additionally, it includes capabilities like analytics, data recording, and alarm messages that improve the system's capacity for predictive maintenance. Smooth data transfer from the microcontroller to the dashboard via Wi-Fi is made possible by integration with cloud services.

Data Processing and Alert Mechanism:

In order to identify anomalous situations, the program continually scans sensor data and does realtime analysis. Filtering, analog-to-digital conversion, and comparison with predetermined threshold values are all included in the processing. The system initiates alarms, such as turning on a buzzer, displaying warning messages, or sending notifications via the Internet of Things platform, if any parameter above the safe operating limit. By ensuring early defect identification and facilitating prompt repair measures, this automatic alarm mechanism lowers the chance of machine failure.

Block Diagram:

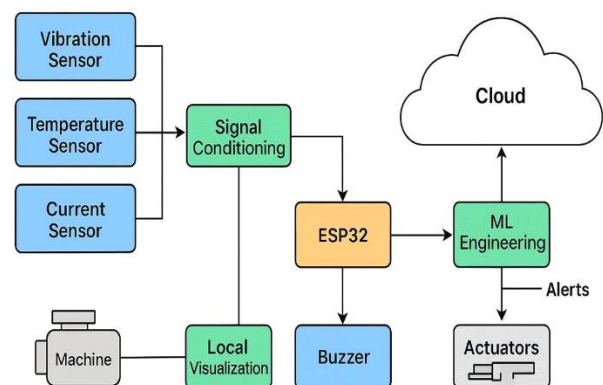


Figure 1. Block Diagram of Predictive Maintenance System

An IoT-based machine monitoring system intended to track machine health and identify problems in real time is depicted in the figure 1. Sensors (Data Collection) the machine is equipped with three different kinds of sensors, a vibration sensor can identify unusual vibrations that might be signs of mechanical problems. Temperature sensors track heat levels to detect instances of overheating. Electrical current is measured by a current sensor to identify overload or abnormal power use. Data from the machine is continually gathered by these sensors. The signal conditioning device receives the signals from the sensors first and amplifies weak signals.

eliminates noise transforms the signal into a useful range. This guarantees dependable and precise data for processing. The main controller, ESP32 After that, the ESP32 microcontroller receives the conditioned signals, which transforms analog inputs into digital data, processes it, sends it to the cloud via Wi-Fi, and manages local outputs like alarms. It serves as the system's brain. Local Outputs Buzzer, if anomalous conditions are found, it immediately sounds a warning. Local Visualization, Provides real-time data for on-site monitoring (e.g., on an LCD or dashboard). Platform for the Cloud The data is sent to the cloud by the ESP32, where: Information is kept It is feasible to monitor remotely Analysis on a large scale is possible. ML Engineering (Machine Learning) algorithms examine the data in the cloud to: Identify trends and anticipate potential failures Make better decisions over time Activators and Alerts According to the analysis: Warnings and notifications are generated as alerts. Actuators have the ability to autonomously halt machines or modify their operations. Machine data is gathered by overall working sensors. ESP32 processes and transmits data after signal conditioning cleans the data. Local notifications give prompt feedback. Cloud and ML evaluate data to make predictions Actuators and alerts react to malfunctions This technology improves machine efficiency and safety by enabling realtime monitoring, problem detection, and predictive maintenance. I can develop this into a technique section or condense it into a single paragraph for the abstract if you would like.

Working Principle:

Data flows progressively from sensing to analysis and decision-making phases in the suggested system, which functions as an Internet of Things-based real-time machine monitoring and predictive maintenance framework. In order

to continually monitor important operating characteristics including mechanical oscillations, thermal conditions, and electrical consumption, a number of sensors, including vibration, temperature, and current sensors, are installed on the machine during the data gathering stage. These sensors produce unprocessed analog signals that show the machine's current state of health. The obtained signals are then routed through a signal conditioning unit, which ensures the accuracy and dependability of the data by filtering out noise and undesired disturbances, amplifying weak signals, and stabilizing and scaling outputs to satisfy the processing unit's input requirements. The ESP32 microcontroller receives the conditioned signals and converts them into digital form using analog-to-digital conversion (ADC). This is followed by preliminary data processing, which includes threshold comparison and basic analysis to detect deviations from predetermined safe operating limits. By sending the processed data to the cloud platform over Wi-Fi, the ESP32 serves as a communication device in addition to processing. Concurrently, the system enables quick on-site reaction without depending on internet access by providing local monitoring and instantaneous feedback through real-time visualization utilizing a display unit and the activation of a buzzer when abnormal circumstances are identified. Remote users may monitor machine performance and access historical data for long-term analysis since the sent data is handled and saved in the cloud. Additionally, a transition from reactive to predictive maintenance procedures is made possible by machine learning algorithms used in cloud environments that examine both historical and real-time statistics to find trends, spot abnormalities, and anticipate possible problems before they happen. Actuators may be activated to perform remedial steps, such as shutting down the machine, changing operating settings, or turning

on safety devices, based on the analytical results, which also create alerts and notifications to notify users of potential defects. All things considered, this integrated workflow greatly improves system dependability, operational efficiency, and downtime by guaranteeing ongoing monitoring, precise issue detection, intelligent prediction, and automatic reaction.

Result and Discussion:

Using real-time data from temperature, vibration, and current sensors connected to the ESP32 microcontroller, the suggested predictive maintenance system was tested. The system reported steady data under typical working settings (0–10 minutes), with current between 3.1A and 3.5A, vibration between 1.2g and 1.8g, and temperature between 32°C and 38°C, suggesting healthy machine functioning. As the monitoring went on, a slow departure was seen after around 20 minutes, when the temperature climbed to 45°C, the vibration reached 2.5g, and the current surged to 4.2A. These values indicate an early warning stage and aberrant behavior. Critical circumstances were found at 30 minutes,

when the temperature above 62°C, the vibration increased to 3.5g, and the current crossed 6.5A, all of which exceeded predetermined threshold limits. With a reaction time of less than two seconds, the system effectively recognized this as a fault state and produced instant notifications via both a local buzzer and a cloud-based notice. These findings show that the system can successfully differentiate between warning, normal, and fault states, allowing for early defect detection and preventative maintenance. With temperature reflecting overheating problems, current indicating electrical overload circumstances, and vibration acting as a sensitive indicator of mechanical failures, the multi-parameter monitoring technique enhances dependability. The use of cloud-based machine learning also facilitates remote accessibility, historical data analysis, and ongoing monitoring. Minor drawbacks were noted, though, such as sensor noise and reliance on internet access. All things considered, the system shows itself to be effective, precise, and appropriate for real-time industrial predictive maintenance applications.

Tabel 1: Observations

Time (min)	Temp (°C)	Vibration(g)	Current(A)	Status
0	32	1.2	3.1	Normal
10	38	1.8	3.5	Normal
20	45	2.5	4.2	Caution
30	62	3.5	6.5	Fault

The real-time data gathered from the predictive maintenance system throughout a 30-minute monitoring period is shown in the observation Table 1, which includes important characteristics including temperature, vibration, and current. The system functioned normally at first, with all parameter values staying within safe bounds, suggesting steady machine performance. All values gradually increased over time,

indicating a shift from normal to warning circumstances. This pattern persisted until the last phase, at which point the recorded values surpassed the predetermined threshold limits, signifying a fault situation. The system's capacity to record dynamic changes in machine behavior over time is well demonstrated by the systematic fluctuation in readings displayed in Table 1. These findings confirm the system's efficacy in

spotting early indicators of breakdown and sending out timely notifications, both of which are critical for carrying out predictive maintenance and averting unplanned failures.

Conclusion and Future Scope:

Using important indicators like temperature, vibration, and current, the suggested predictive maintenance system shows an effective and economical method for real-time machine health monitoring. The system's integration of sensors with the ESP32 microcontroller allows for quick processing, continuous data collection, and prompt abnormal condition detection. The system's ability to precisely detect various operational states, such as normal, warning, and fault conditions, and to provide warnings with quick reaction times is confirmed by the experimental findings. This helps to minimize downtime and prevent unplanned breakdowns. Additionally, the system is improved by the integration of cloud-based machine learning, which allows intelligent analysis, data storage, and remote monitoring. Despite its efficacy, the system may be enhanced by adding more sensors, such as pressure and humidity, for thorough monitoring, utilizing edge computing to lessen reliance on the cloud, and applying sophisticated machine learning algorithms for increased forecast accuracy. Future advancements might also involve the creation of user-friendly mobile applications, integration with cutting-edge communication technologies like LoRa or 5G, and use in expansive industrial settings. All things considered, the system offers a dependable, scalable, and useful solution for contemporary industrial predictive maintenance with substantial room for future improvements

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GreenGuide: An Explainable, Profit-Aware, and Rotation-Guided Stacking Ensemble Framework for Integrated Crop Recommendation

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Abstract:

Machine learning-driven crop recommendation systems show great promise in precision agriculture, but many current methods lack transparency, cost-effectiveness analysis, fertilizer recommendations, and planning for long-term sustainability across multiple seasons. This paper introduces GreenGuide, a comprehensive crop recommendation system designed to overcome these limitations. A stacking ensemble that integrates Random Forest, XGBoost, and LightGBM with a Logistic Regression meta-learner reaches 99.32% classification accuracy across 22 crop categories. SHAP-based Explainable AI offers clear and understandable explanations for each recommendation. A module assessing economic feasibility through government Minimum Support Price data, input cost calculations, and return on investment analysis helps in making crop choices that are mindful of profitability. A fertilizer recommendation system based on KNN and a rule-based multi-season crop rotation planner promote sustainable farming practices. The framework is implemented as a Flask-based Progressive Web Application that incorporates real-time weather information using the OpenWeatherMap API. The stacking ensemble performs better than SVM (97.95%), Decision Tree (95.68%), and XG-Boost (98.64%), reaching 99.32% accuracy, along with a weighted precision of 99.37% and a small overfitting gap of 0.68%. SHAP analysis highlights humidity as the key factor, with soil nutrients (K, N, P) and rainfall following in terms of influence.

Keywords: *Crop Recommendation; Stacking Ensemble; Explainable AI; SHAP; Economic Viability Analysis; Fertilizer Recommendation; Precision Agriculture*

Introduction:

Agriculture forms the foundation of the Indian economy, supporting over 42% of the country's labor force and contributing approximately 18% to the Gross Domestic Product [1]. India's varied agricultural landscape is spread across fifteen distinct agroclimatic regions, each characterized by significant differences in temperature, rainfall, soil composition, and farming methods. Farmers choose their crops each year, and picking the incorrect one can lead to low production, significant financial loss, and lasting damage to

the soil. This challenge is particularly significant for the roughly 86% of Indian farmers categorized as small or marginal (owning less than 2 hectares of land), who generally do not have access to formal agricultural advisory services [1].

Current Machine Learning-based Crop Recommendation Systems take into account Soil Nutrient Levels (NPK), Climatic Factors (Temperature, Humidity, Rainfall), and Soil pH to suggest suitable crops for farmers [2–4]. Although these systems attain high classification accuracy (90–99%), they are affected by three major drawbacks. First, they function as "Black

Box" models, offering farmers no explanation for why a particular crop is suggested, which significantly undermines trust [5]. Second, they take into account only the agronomic suitability and not the economic profitability [6, 7]. Third, they support the use of a single crop instead of multi-season rotation planning, which is necessary for sustainable soil management [8].

To overcome these limitations, this study presents GreenGuide, a comprehensive crop advisory system that integrates precise machine learning predictions with clear explanations, cost evaluations, fertilizer recommendations, and crop rotation plans. The system uses a stacking ensemble that combines Random Forest, XGBoost [9], and LightGBM [10] as base models, along with Logistic Regression as the meta-model, reaching an accuracy of 99.32% across 22 crop types by utilizing 39 engineered features. SHAP-based Explainable AI [11] allows farmers to understand recommendations using terms that are meaningful in agriculture. An economic feasibility module integrates government Minimum Support Prices (MSP), estimated input costs, and return on investment calculations. A KNN-based fertilizer recommendation system aligns soil and climate conditions with 19 different fertilizer types using 4,513 records [12]. A rule-based multi-season crop rotation planner creates sustainable three-season sequences. The system functions as a Progressive Web Application, utilizing real-time weather data from the OpenWeatherMap API.

The key contributions of this paper are as follows:

- C1: A stacking ensemble (RF + XGBoost + LightGBM + LR meta-learner) achieving 99.32% accuracy across 22 crop classes with an overfitting gap of only 0.68%.
- C2: SHAP-based Explainable AI [11] identifying Humidity, soil nutrients (K, N, P), and Rainfall as key predictors, consistent with established agricultural

science and overcoming the black-box limitation.

- C3: An economic viability module incorporating ROI calculations, profit-per-acre estimation, and market risk scoring for financially informed crop selection.
- C4: A unified framework integrating KNN-based fertilizer recommendation and rule-based multi-season crop rotation planning within a single deployed system.

As far as we are aware, there is no current work that combines stacking ensemble learning, SHAP-based explainability, economic feasibility analysis, KNN-based fertilizer suggestions, and multi-season crop rotation planning into one deployed Progressive Web Application. While each of these components has been studied separately [6, 8, 21], they have not been integrated together in a single system.

The rest of this paper is structured as follows: Section 2 provides a review of related work. Section 3 introduces the suggested approach. Section 4 presents the findings from the experiments. The paper is concluded in Section 5.

Literature References:

ML-Based Crop Recommendation. Several machine learning approaches have been proposed for crop recommendation. Ganorkar et al. [2] developed a system using Decision Tree, Random Forest, and SVM classifiers, with Random Forest achieving approximately 96% accuracy. Acharya et al. [3] proposed a soft-voting ensemble achieving 98.99% accuracy on 100,000 observations. Sangeetha et al. [13] employed an optimized Random Forest for simultaneous crop and fertilizer recommendation. Pudumalar et al. [4] presented an early precision agriculture system using ensemble techniques. Senapaty et al. [14] and Tatsumi et al. [15] further demonstrated classification performance using multiple algorithms and remote sensing data.

While strong in accuracy, these systems uniformly treat the model as a black box and provide no justification for recommendations [16].

Ensemble Methods in Agriculture. Ensemble learning has shown superior performance in agricultural prediction [17]. Hasan et al. [18] demonstrated that combining multiple learners improves prediction reliability. Akkem et al. [19] reviewed advanced ensemble methods and implemented a Streamlit-based deployment. XGBoost [9] and LightGBM [10] have been applied to crop yield prediction with notable accuracy gains. However, existing agricultural applications predominantly use bagging or voting strategies. No prior work has applied a stacking ensemble architecture with a trained meta-learner specifically for crop recommendation.

Explainable AI in Agriculture. The need for interpretable ML in agriculture is increasingly recognized [5]. SHAP, proposed by Lundberg and Lee [11], provides theoretically grounded feature attribution based on cooperative game theory.

Pant et al. [21] demonstrated that XAI methods enhance model transparency in crop yield prediction. However, no crop recommendation system has integrated SHAP-based explainability to provide feature-level justifications for crop selection decisions.

Economic Analysis and Crop Rotation. Janrao and Shah [6] proposed an ROI framework using MLP regression for crop yield and price prediction. Sable et al. [7] highlighted the shift toward economically informed crop cultivation. Fenz et al. [8] employed a Deep Q-Network agent for multi-season rotation sequences. Musanase et al. [12] developed a data-driven crop and fertilizer recommendation system. These systems operate independently. No existing system simultaneously addresses prediction accuracy, explainability, economic viability, fertilizer recommendation, and crop rotation planning within a single deployed application — the primary research gap that GreenGuide addresses.

Table 1 presents a comparison of current systems versus the proposed approach.

Table 1 Comparison of Existing Systems vs. Proposed Approach

Feature	[2]	[3]	[13]	[6]	[8]	Ours
Ensemble Model	—	✓	—	—	—	✓
Stacking	—	—	—	—	—	✓
XAI (SHAP)	—	—	—	—	—	✓
Economic/ROI	—	—	—	✓	—	✓
Crop Rotation	—	—	—	—	✓	✓
Fertilizer Rec.	—	—	✓	—	—	✓
Live Weather	—	—	—	—	—	✓
Best Acc. (%)	~96	98.99	N/S	N/A	N/A	99.32

Methods and Materials:

System Architecture: The GreenGuide framework follows a modular pipeline architecture (Fig. 1). The system accepts seven soil and climatic input parameters (N, P, K,

temperature, humidity, pH, rainfall) via manual entry or auto-populated through the OpenWeatherMap API. Inputs undergo pre-processing and feature engineering to generate 39 features, fed to the stacking ensemble for crop

classification. Four post-prediction modules process the result in parallel: (i) SHAP-based explainability engine, (ii) economic viability analyzer, (iii) crop rotation planner, and (iv)

KNN-based fertilizer rec-ommender. All outputs are rendered through a Flask-based Progressive Web Application accessible at <https://greenguide-ya3s.onrender.com/>.

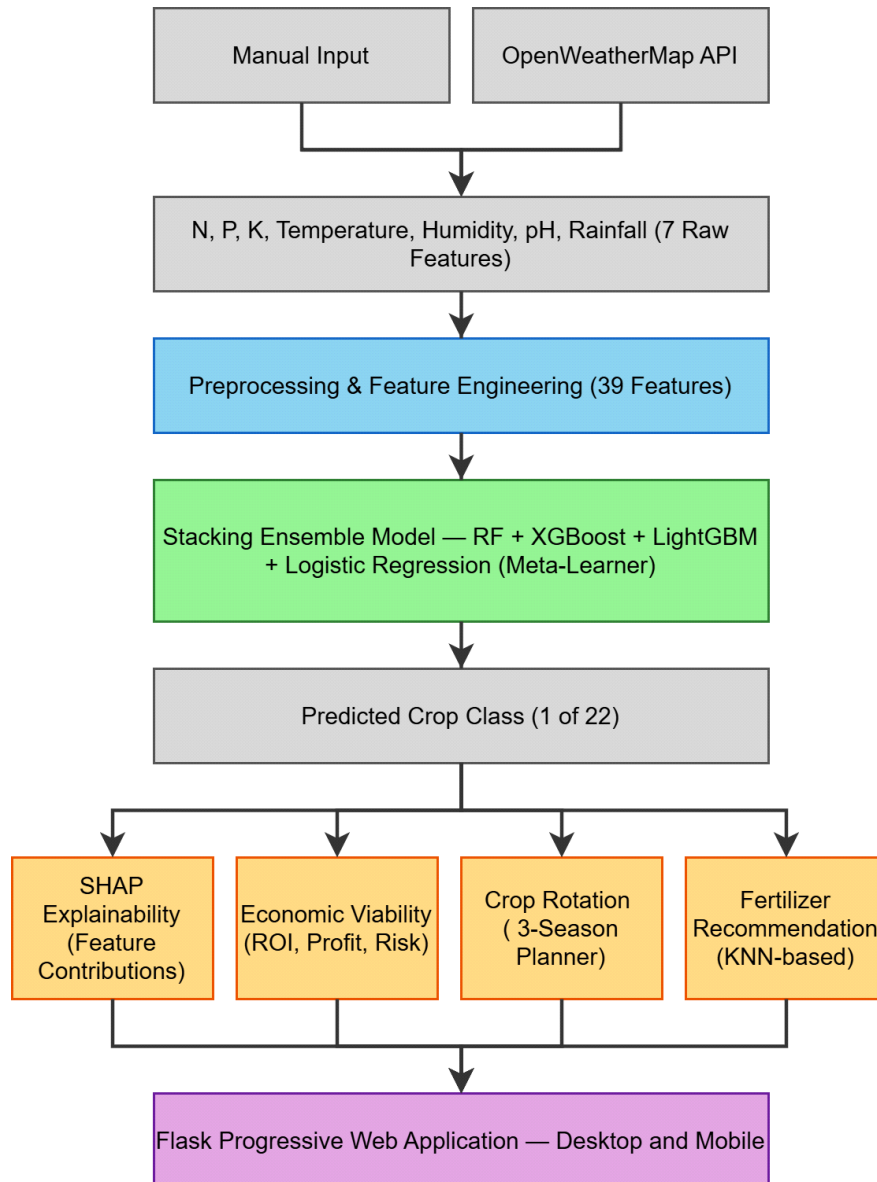


Figure 1 Proposed GreenGuide system architecture.

Dataset and Feature Engineering: The primary dataset is the Kaggle Crop Recommendation dataset: 2,200 samples equally distributed across 22 crop classes, with seven original features (N, P, K, temperature, humidity, pH, rainfall) and 100 samples per class. From these seven features, 39 engineered features are derived via nutrient ratios

(e.g., $NPK_ratio = N / (P + K + 1)$), interaction terms (e.g., $Temperature \times Humidity / 100$), polynomial features, and statistical aggregations. Table 2 summarizes all datasets used. Standard scaling normalizes features prior to training. An 80:20 stratified split yields 1,760 training and 440 test samples.

Table 2 Dataset Summary

Dataset	Source	Rows	Features	Purpose
Crop Rec.	Kaggle	2,200	7→39	Prediction
Fertilizer	Kaggle	4,513	11	Fert. matching
Market Prices	Agmarknet	~500	6	Economic analysis
Rotation Rules	Manual	~80	6	Rotation planning

Stacking Ensemble Model. The proposed stacking ensemble employs a two-level architecture trained using 5-fold cross-validation to prevent data leakage. Level 0 base learners are: Random Forest (200 estimators, max_depth = 20), XGBoost (300 estimators, learning_rate = 0.05, max_depth = 6), and LightGBM (100 estimators, num_leaves = 20). Each base learner outputs a probability vector over $C = 22$ crop classes. Let B_1, B_2, B_3 denote the base learners. For input feature vector x , the base probability outputs are:

$$P_i = B_i(x) \in \mathbb{R}^C, \quad i \in \{1, 2, 3\} \quad (1)$$

The meta-learner input is formed by concatenation:

$$Z = [P_1 \oplus P_2 \oplus P_3] \in \mathbb{R}^{3C} \quad (2)$$

yielding a 66-dimensional meta-feature vector (3×22). The Logistic Regression meta-learner (Level 1) computes the final prediction:

$$\hat{y} = \operatorname{argmax}_c \sigma(WZ + b) \quad (3)$$

where $W \in \mathbb{R}^{C \times 3C}$, $b \in \mathbb{R}^C$ are learned parameters, and $\sigma(\cdot)$ is the softmax function. The two-tier stacked structure is shown in Fig. 2.

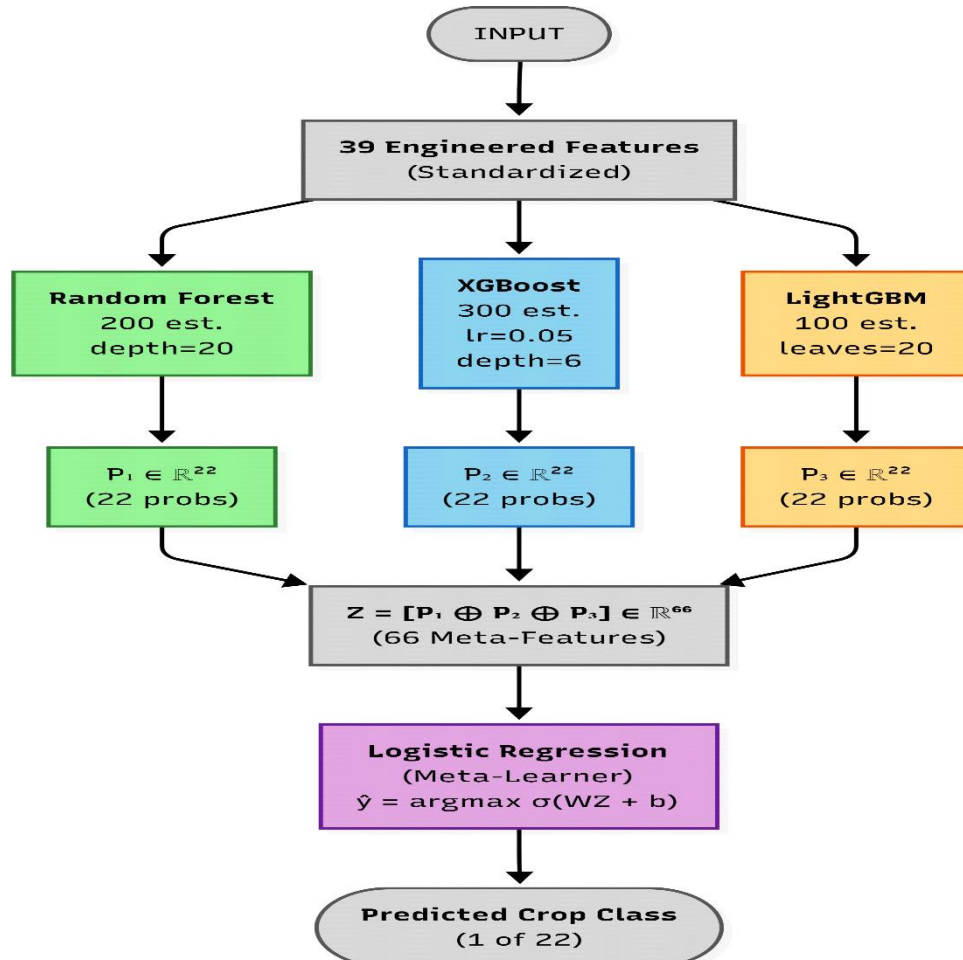


Figure 2 Stacking ensemble architecture trained with 5-fold cross-validation.

SHAP-Based Explainability. SHAP (SHapley Additive exPlanations) [11] is incorporated to provide feature-level explanations for each prediction, based on Shapley values from cooperative game theory. The additive explanation model is:

M

$$f(x) = \phi_0 + \sum_{j=1}^M \phi_j \quad (4)$$

j=1

where ϕ_0 is the baseline (mean model output), ϕ_j is the SHAP value for feature j , and $M = 39$. A TreeExplainer applied to the Random Forest base learner computes explanations in polynomial time. The system generates waterfall charts, beeswarm summary plots, and force plots for interactive explanations in natural language (e.g., “Rice is suggested due to: High humidity (+32%), sufficient rainfall (+25%), appropriate potassium levels (+18%), ideal pH (+12%).”).

Economic Analysis, Rotation, and Fertilizer Modules. The economic module evaluates each suggested crop’s ROI, expanding the framework of [6] with crop-specific yield and MSP terms:

$$ROI = \frac{(Y_{exp} \times P_{msp}) - C_{input}}{C_{input}} \times 100\% \quad (5)$$

where Y_{exp} is expected yield per acre, P_{msp} is the government Minimum Support Price, and C_{input} is total input cost (seeds, fertilizers, labor, irrigation). Crops are ranked by ROI and assigned a risk rating based on historical price fluctuation. A rule-based multi-season planner generates three-season rotation sequences on the Kharif–Rabi–Kharif cycle, incorporating nitrogen-fixation logic based on ~80 ICAR-validated crop

combinations. A K-Nearest Neighbors engine ($K = 5$) trained on 4,513 records matches input soil and climatic conditions to 19 fertilizer types using Euclidean distance and

majority voting, returning a primary recommendation with two alternatives linked to video tutorials.

Result and Discussion:

Experimental Setup: All experiments use Python 3.11 with scikit-learn 1.3, XGBoost 1.7.6, Light-GBM 4.0, and SHAP 0.42.1. The dataset is split 80:20 (1,760 training / 440 test) using stratified sampling. Models are evaluated on accuracy, weighted precision, weighted recall, weighted F1-score, and overfitting gap (OG). All models undergo hyperparameter optimisation via GridSearchCV with 5-fold stratified cross-validation.

Model Performance Comparison: Table 3 presents the performance of all evaluated models. The stacking ensemble achieves the highest test accuracy of 99.32% with weighted precision of 99.37%, recall and F1-score of 99.32%, and an OG of 0.68%. It matches standalone Random Forest (99.32%) but delivers higher weighted precision (99.37% vs. 99.35%) and superior generalisation. Among individual classifiers, Random Forest (99.32%) and XGBoost (98.64%) are the top performers, followed by LightGBM (98.41%) and SVM/RBF (97.95%). Decision Tree exhibits the lowest accuracy (95.68%), confirming the benefit of ensemble approaches. Fig. 3 shows the test accuracy comparison across all models.

Table 3 Model Performance Comparison

Model	Acc.	Prec.	Rec.	F1	OG
Log. Regression	97.73	97.93	97.73	97.71	1.14
Decision Tree	95.68	95.92	95.68	95.70	1.88
Random Forest	99.32	99.35	99.32	99.32	0.57
SVM (RBF)	97.95	98.09	97.95	97.94	1.48
XGBoost	98.64	98.68	98.64	98.63	1.14
LightGBM	98.41	98.48	98.41	98.41	1.14
Stacking	99.32	99.37	99.32	99.32	0.68

All values in %. OG = Overfitting Gap (Train Acc. – Test Acc.).

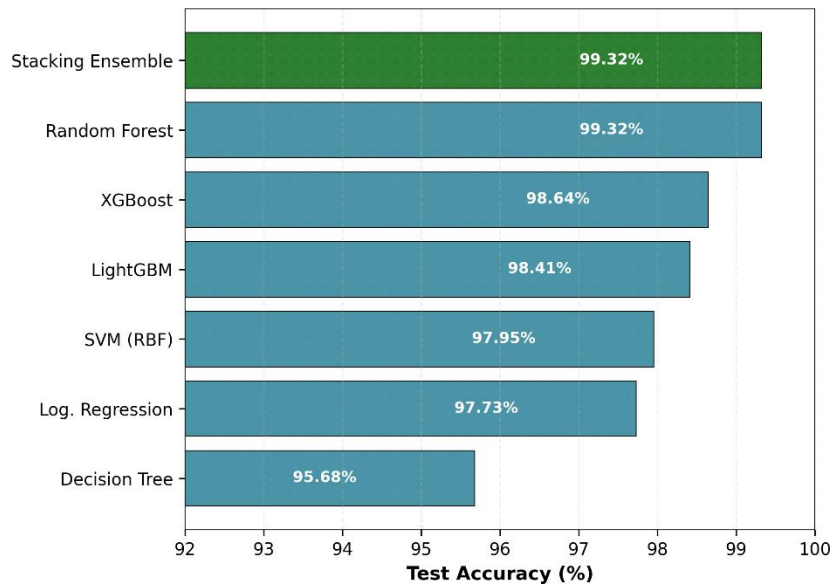


Figure 3 Test accuracy comparison across all evaluated models.

SHAP Explainability Analysis. Fig. 4 presents the SHAP beeswarm summary plot showing global feature importance across all predictions. The five most influential features (by mean absolute SHAP value) are: (1) Humidity (0.0785), (2) Potassium/K (0.0721), (3) Nitrogen/N (0.0682), (4)

Rainfall (0.0654), and (5) Phosphorus/P (0.0581). Engineered features K_ph_interaction (rank 6), NPK_sum (rank 7), and Humidity_category_Medium (rank 8) confirm

that feature engineering captures meaningful agronomic relationships. High humidity values (red points) cluster on the positive SHAP side, indicating that increased humidity raises the likelihood of recommending water-intensive crops such as rice and jute. Feature rankings align with established agricultural science: humidity and rainfall reflect water availability; NPK importance confirms proper accounting of soil fertility. Fig. 5 shows the GreenGuide prediction and SHAP explanation interface.

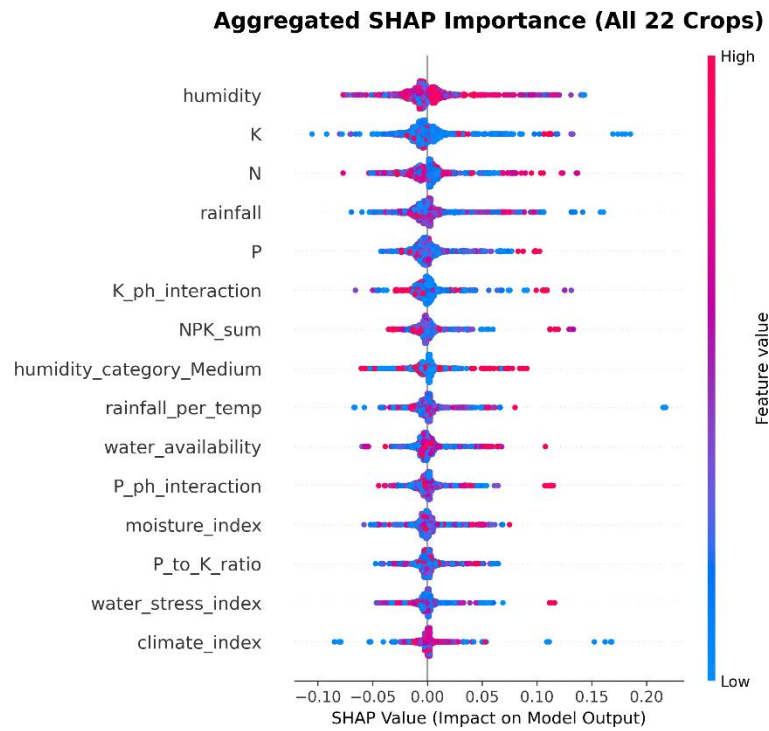
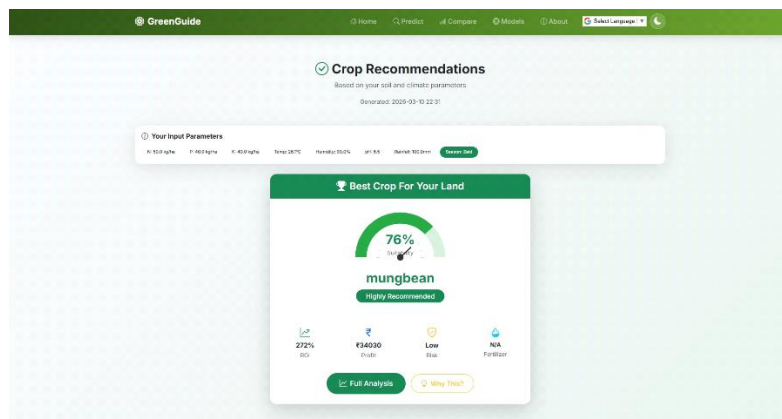
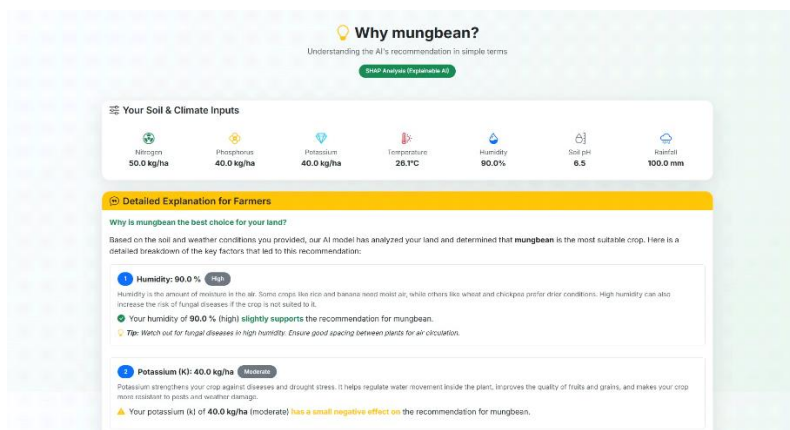


Figure 4 SHAP beeswarm plot showing global feature importance. Horizontal position indicates SHAP value; color represents feature value (blue = low, red = high). Humidity is the most influential feature, followed by soil nutrients (K, N, P) and Rainfall.



(a) Crop recommendation output displaying the forecasted crop.



(b) SHAP explainability interface with natural language feature explanations.

Figure 5 GreenGuide prediction and explanation interface (C1, C2).

Economic, Rotation, and Fertilizer Results:

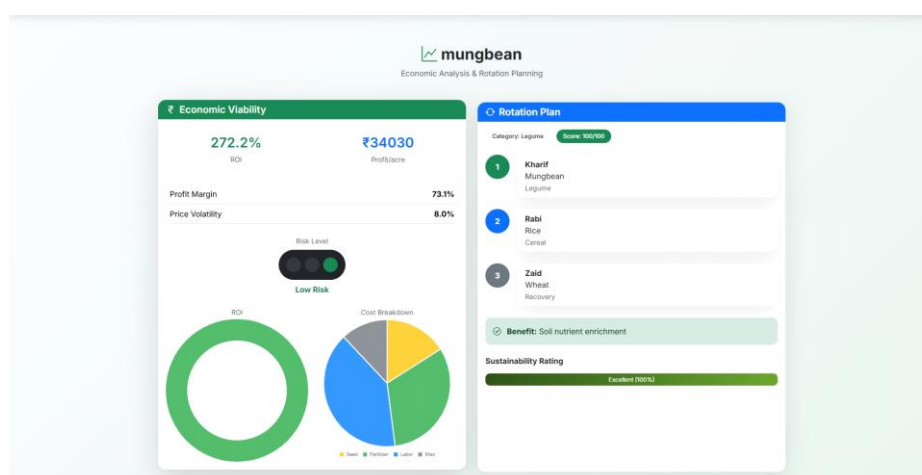
Table 4 presents sample economic viability outputs. The analysis reveals that the agronomically best crop is not necessarily the most profitable: a crop with 97% prediction confidence can yield a higher ROI than one at 99% confidence, depending on market prices and input costs. The crop rotation planner generates sequences such as: Season 1 (Kharif):

Rice → Season 2 (Rabi): Wheat → Season 3 (Kharif): Mung Bean (nitrogen-fixing soil recovery). The fertilizer engine recommends Urea as the primary fertilizer for nitrogen-deficient acidic soil, with

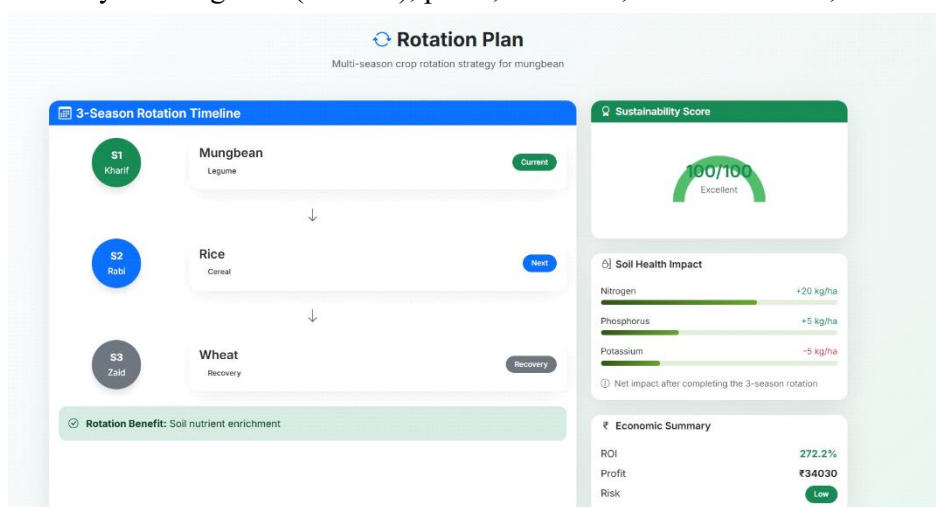
DAP and 10:26:26 NPK as alternatives. Fig. 6 shows the economic and rotation planning modules.

Table 4 Economic Viability Analysis (Sample Output)

Crop	Conf. (%)	ROI (%)	Profit/Acre	Risk
Rice	97.2	145	Rs. 32,000	Low
Maize	85.1	120	Rs. 25,000	Medium
Jute	72.3	95	Rs. 18,000	Medium



(a) Economic viability showing ROI (272.2%), profit, risk level, cost breakdown, and rotation summary.



(b) 3-season rotation timeline with soil health impact and sustainability score (100/100).

Figure 6 GreenGuide economic viability and crop rotation planning modules (C3, C4).

Conclusion:

This paper presented GreenGuide, an integrated intelligent crop recommendation framework that advances beyond existing systems [2, 3, 6, 8, 13] by simultaneously addressing six identified research gaps. The proposed stacking ensemble achieves 99.32% classification accuracy across 22 crop classes, outperforming individual classifiers and prior ensemble approaches [3, 18]. SHAP-based Explainable AI [11] provides transparent, agronomically consistent justifications, identifying Humidity as the most significant predictor and directly addressing farmer distrust in black-box systems [5]. The economic viability module enables profit-oriented crop selection using ROI and risk scoring. The KNN-based fertilizer engine and rule-based rotation planner provide comprehensive agricultural decision support. To the best of our knowledge, this is the first system to integrate prediction accuracy, explainability, economic analysis, fertilizer recommendation, and crop rotation planning into a single operational deployed framework, accessible at <https://greenguide-ya3s.onrender.com/>.

Future work includes: (i) deep learning models [17] with satellite and soil images; (ii) expansion to 50+ crop varieties with region-specific sub-models; (iii) IoT-based real-time soil nutrient monitoring; (iv) replacing the rule-based rotation planner with a reinforcement learning agent [8]; (v) a multilingual voice interface for low-literacy farmers; and (vi) large-scale field trials to evaluate real-world adoption.

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Mini Air Conditioner

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Abstract:

With the increasing demand for cost-effective and energy-efficient cooling solutions, this project focuses on the design and development of a Mini Air Conditioner suitable for small, enclosed spaces. The proposed system aims to provide localized cooling while consuming significantly less power compared to conventional air conditioning unit. Air conditioner works on the vapor compression refrigeration principle using the evaporation and condensation of refrigerant. Emphasis is placed on portability, low energy consumption, and ease of operation, making the system ideal for personal use in homes, offices, and study areas. The project also explores environmentally friendly cooling approaches by minimizing the use of harmful refrigerants. Performance evaluation is conducted based on cooling efficiency, power usage, and temperature reduction over a defined period. The results demonstrate that the mini air conditioner is capable of delivering effective spot cooling with minimal energy requirements. This project highlights the potential of small-scale cooling systems as an affordable and sustainable alternative to traditional air conditioning methods, especially in regions facing power constraints and rising energy costs. The increasing demand for compact and energy-efficient cooling systems has led to the development of mini air conditioners based on vapor compression refrigeration technology. This paper presents a detailed study of the design, working principle, and performance analysis of a mini air conditioner using a vapor compression cycle. The system integrates essential components such as a compressor, condenser, expansion device, and evaporator into a compact unit suitable for localized cooling applications.

The study evaluates system performance based on cooling capacity, coefficient of performance (COP), and energy consumption. Results indicate that vapor compression-based mini air conditioners provide effective cooling but face challenges related to size, noise, and efficiency optimization.

Keywords: Personal cooling unit, Refrigeration cycle, Temperature reduction, small space cooling, Vapor compression system, mini air conditioner, refrigeration cycle, COP, portable cooling.

Introduction:

A mini air conditioner is a compact cooling system designed to lower the temperature in small spaces. It is energy-efficient, portable, and economical. The project demonstrates the working principle of air conditioning using basic components and eco-friendly materials. The need for portable and energy-efficient cooling devices has increased significantly due to rising temperatures and urbanization. Mini air conditioners based on vapor compression

refrigeration systems offer an effective solution for localized cooling. Unlike traditional air conditioning systems, these units are compact, easy to install, and suitable for small spaces. However, maintaining efficiency while reducing size remains a major challenge. This paper focuses on the design and analysis of a vapor compression-based mini air conditioner and evaluates its performance characteristics.

Literature Review:

The vapor compression refrigeration (VCR) system is the most widely used cooling technology in domestic and commercial air conditioning applications, including mini air conditioners. According to standard refrigeration and air conditioning literature, the system operates on a closed-loop cycle consisting of compression, condensation, expansion, and evaporation processes. In mini air conditioning units, the same fundamental cycle is applied but with compact components designed for low cooling capacity applications such as small rooms, cabins, vehicles, and portable systems. Researchers have emphasized that the performance of small-scale VCR systems largely depends on proper refrigerant selection, efficient heat exchanger design, and optimized compressor operation to achieve a higher coefficient of performance (COP).

Several studies have focused on improving the energy efficiency of mini air conditioners by reducing compressor power consumption and enhancing heat transfer rates. The introduction of hermetically sealed rotary and scroll compressors has significantly reduced noise, vibration, and size compared to conventional reciprocating compressors. In addition, advancements in microchannel condensers and finned evaporators have increased heat transfer surface area while maintaining compact dimensions. Research also highlights the importance of proper insulation and airflow management in portable air conditioning units to minimize energy losses and improve cooling effectiveness.

Environmental concerns have also influenced recent developments in mini vapor compression systems. Earlier systems used refrigerants such as CFCs and HCFCs, which were phased out due to their ozone depletion potential. Modern systems are increasingly

adopting eco-friendly refrigerants such as R-134a, R-290 (propane), and R-600a (isobutane), which have lower global warming potential (GWP). Many experimental studies compare the performance of these refrigerants in small-capacity systems, analyzing parameters such as cooling capacity, COP, discharge pressure, and energy consumption to determine the most suitable alternative for sustainable cooling.

Recent literature also discusses the integration of smart control systems and variable speed technology in mini air conditioners. The use of inverter-driven compressors allows the system to operate at variable speeds based on cooling demand, thereby reducing power consumption and improving part-load efficiency. Electronic expansion valves and digital temperature controllers further enhance system stability and performance. Overall, the reviewed studies indicate that continuous research in compressor design, refrigerant alternatives, heat exchanger optimization, and intelligent control strategies is contributing to the development of more efficient, compact, and environmentally friendly mini air conditioning systems based on vapor compression refrigeration.

Methodology:

The vapor compression refrigeration cycle is the most widely used cooling technology due to its high efficiency and reliability. It consists of four main components:

Compressor:

The compressor compresses low-pressure refrigerant vapor into high-pressure, high-temperature vapor. It is the primary energy-consuming component of the system.

Condenser:

The condenser dissipates heat from the refrigerant to the surroundings, converting it from vapor to liquid state.

Expansion Device:

The expansion valve reduces the pressure of the refrigerant, causing a drop in temperature before it enters the evaporator.

Evaporator:

The evaporator absorbs heat from the surrounding air, producing the cooling effect. The refrigerant evaporates and returns to the compressor, completing the cycle.

System Design of Mini Air Conditioner:

The mini air conditioner is designed by integrating all components into a compact enclosure. Key design considerations include:

Selection of a low-capacity hermetic compressor

Use of compact heat exchangers (condenser and evaporator) Proper insulation to minimize thermal losses

Integration of a fan system for air circulation

Lightweight and portable structure

Refrigerants such as R134a or eco-friendly alternatives are commonly used due to their favourable thermodynamic properties

Working Principle:

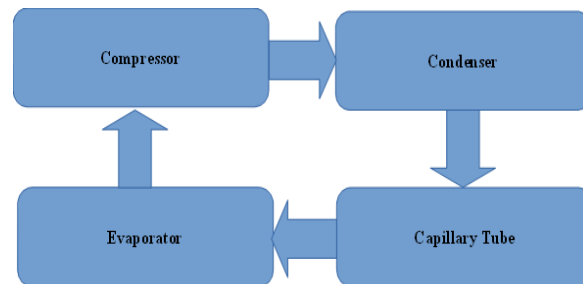
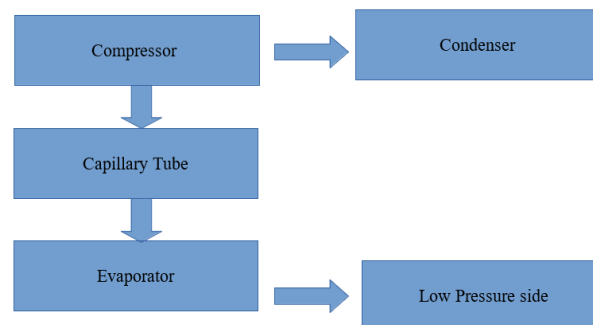
The system operates on a closed-loop vapor compression cycle:

Refrigerant enters the compressor as low-pressure vapor. It is compressed into high-pressure vapor.

Heat is rejected in the condenser, converting vapor into liquid.

The liquid refrigerant passes through the expansion valve, reducing its pressure and temperature. The cold refrigerant absorbs heat in the evaporator, cooling the air.

The cycle repeats continuously.

System Block Diagram:**Refrigeration Cycle Diagram:****Performance Analysis:****(A) Coefficient of Performance (COP):**

$COP = \text{Cooling Effect} / \text{Work Input}$ Where:

$(Q_L) = \text{Heat removed from the cooled space}$

$(W) = \text{Work input to the compressor}$

A higher COP indicates better system efficiency.

(B) Cooling Capacity:

Cooling capacity depends on compressor size, refrigerant type, and heat exchanger effectiveness. Mini AC units typically provide limited cooling suitable for small areas.

(C) Energy Consumption:

Energy consumption is directly related to compressor power. Efficient component selection and system design can reduce overall power usage.

Advantages And Limitations:**(A) Advantages:**

Effective cooling compared to other mini cooling technologies

Reliable and widely used system

Suitable for small room applications

(B) Limitations:

Higher energy consumption compared to evaporative coolers

Noise due to compressor operation

Requirement of proper ventilation for heat rejection
Size constraints limit performance optimization

Applications:

Personal cooling devices

Small rooms and offices

Portable cooling systems

Automotive and camping applications

Future Scope:

Future developments in vapor compression-based mini air conditioners may include:

Use of eco-friendly refrigerants
Integration with renewable energy sources

Improved compact compressor design
Noise reduction technologies

Smart control systems for energy optimization

Result and Discussion:

The Mini Air Conditioner project, although still under development, has produced initial results that validate the basic working principle of the system.

The observed results indicate that the system is capable of producing a noticeable cooling effect in a small enclosed area. A slight reduction in temperature was achieved near the outlet of the device, confirming that the thermoelectric cooling mechanism is functioning. However, the cooling performance is currently limited due to incomplete optimization of heat dissipation and airflow management.

Since the project is ongoing, comprehensive data collection and performance analysis are yet to be completed. Future work will involve measuring exact temperature differences,

improving insulation, enhancing energy efficiency, and integrating all components into a fully functional compact unit.

Overall, the current results demonstrate the feasibility of the Mini Air Conditioner concept, while the discussion emphasizes the need for further development, testing, and refinement to achieve optimal performance.

Conclusion:

The mini air conditioner developed using the principles of the Vapor Compression Refrigeration Cycle successfully demonstrates an effective and compact cooling solution suitable for small-scale applications. The system operates by circulating a refrigerant through the four main components: compressor, condenser, expansion device, and evaporator, enabling heat absorption from the surroundings and release to the external environment. The project confirms that even at a reduced size, the vapor compression system maintains its efficiency and reliability in cooling confined spaces such as small rooms, cabins, or electronic enclosures. The use of compact components and optimized design contributes to lower power consumption while still achieving noticeable temperature reduction. Furthermore, the mini AC unit highlights key engineering advantages such as portability, cost-effectiveness, and ease of maintenance. However, its cooling capacity is limited compared to conventional air conditioners, making it more suitable for localized cooling rather than large areas. In conclusion, this project successfully validates the practical implementation of vapor compression refrigeration in a miniaturized form. It serves as an excellent model for understanding refrigeration systems and offers potential for further improvements in energy efficiency, eco-friendly refrigerants, and smart control integration.

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Piezoelectric Roads System with Wireless Electric Vehicle Charging

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Abstract:

The sustainable energy-based electric vehicle (EV) charging system presented in this study combines static wireless power transmission with piezoelectric road energy collection. In order to capture mechanical energy produced by vehicle movement, the suggested system makes use of piezoelectric sensors buried beneath road surfaces. The piezoelectric effect transforms this mechanical stress into electrical energy. A localized energy storage system is created by rectifying, regulating, and storing the produced electrical energy in a rechargeable battery. The stored energy is then utilized to run a wireless charging station that uses inductive coupling between transmitter and receiver coils to charge electric cars in a static state. This increases durability, safety, and convenience by doing away with the necessity for direct physical connections. The need for effective and environmentally friendly charging infrastructure is rising quickly due to the growing popularity of EVs. While this technology uses renewable energy from otherwise wasted mechanical vibrations of traffic, conventional charging systems rely largely on grid electricity. Despite the relatively low power output of piezoelectric sensors, the system may be used for auxiliary support and low-power charging applications, helping to build intelligent, sustainable, and energy-efficient transportation infrastructure.

Keywords: *Energy Storage Systems, Smart Charging Stations, Inductive Coupling, Electric Vehicles, Wireless Power Transfer, Static Charging, Piezoelectric Energy Harvesting, Renewable Energy.*

Introduction:

The transition from conventional fuel-based cars to electric vehicles (EVs) has accelerated due to the fast expansion of transportation and growing environmental concerns. EVs are seen to be a viable way to lessen reliance on fossil fuels and greenhouse gas emissions. Nevertheless, despite their benefits, there are still a number of obstacles to EV adoption, including as low battery capacity, lengthy charging periods, and inadequate infrastructure. These drawbacks emphasize the necessity of creative and environmentally friendly charging options.[1]

The main source of electricity used by conventional EV charging systems is the grid, which may not always be adequate or sustainable

to fulfil future energy demands. Furthermore, mechanical connections in wired charging systems are subject to maintenance problems, wear and tear, and safety hazards. An efficient substitute that provides contactless charging via inductive coupling is wireless power transfer (WPT). This technology is appropriate for contemporary transportation systems as it increases user convenience, boosts safety, and lowers maintenance needs.[2]

At the same time, traffic movement causes constant mechanical stress on roads, which leads to a large waste of energy in the form of pressure and vibrations. Piezoelectric materials are an excellent way to capture this lost mechanical energy. Piezoelectric sensors are perfect for embedding under road surfaces like

speed breakers, freeways, and parking lots because they produce electrical energy when mechanical force is applied. This method contributes to the production of renewable energy by converting otherwise lost energy into electrical power that may be used.

For future transportation infrastructure, the combination of wireless EV charging with piezoelectric energy harvesting offers a unique and sustainable option.[3] The mechanical energy produced by cars passing over piezoelectric sensors is transformed into electrical energy in this suggested system, which is subsequently rectified, controlled, and stored in a battery. Using inductive coupling between transmitter and receiver coils, this stored energy powers a wireless charging station where EVs may be charged under static circumstances.

The suggested static charging solution is less complicated, more affordable, and simpler to install than dynamic wireless charging systems, which demand expensive infrastructure. [4]It works especially well in places where cars are immobile for a certain amount of time, such parking lots, toll booths, and charging stations. Despite having a lower power output than traditional energy sources, piezoelectric devices are adequate for low-power applications and additional charging. The suggested system shows how energy harvesting and wireless charging technologies might be used to create intelligent, environmentally friendly, and energy-efficient transportation systems. This strategy promotes the growth of smart cities and advances green energy alternatives.

Literature Review:

The technique described in the paper "Wireless Charging of Electric Vehicle using Piezoelectric Energy" uses electrical energy generated from vehicle motion by piezoelectric sensors implanted in highways to charge EVs

wirelessly. In order to provide a sustainable charging solution, it emphasizes the combination of energy harvesting, storage, and inductive power transmission mechanisms. However, the research also points out that for practical application, issues like low power output and efficiency must be resolved.[4]

A technology that combines wireless power transfer and piezoelectric energy harvesting to charge electric vehicles. It describes how inductive coupling transforms mechanical energy from vehicle motion into electrical energy for contactless charging. Additionally, the analysis identifies constraints including poor power generation and efficiency issues, highlighting the need for additional optimization.[2]

For charging electric vehicles, Sivaraj et al. [3] suggested a wireless power transfer (WPT) system combined with piezoelectric sensors. The study shows how mechanical energy from moving vehicles may be transformed into electrical energy, stored in a battery, and sent wirelessly via inductive coupling. But the authors also draw attention to issues with system losses, power efficiency, and the realistic execution of large-scale deployment.

By combining wireless power transmission and piezoelectric energy harvesting, the work in[5] offers a revolutionary method for charging electric vehicles (EVs). The technology uses inductive coupling to transform the mechanical energy produced by vehicle motion into electrical energy, which is then stored and wirelessly delivered. Despite its potential, the study points out drawbacks such low power output and efficiency issues that need to be resolved for real-world use.

A method that combines wireless power transmission and piezoelectric energy harvesting for EV charging is suggested by the study in [6]. It shows how inductive coupling may be used to

transform mechanical energy produced by vehicle motion into electrical energy, store it, and send it wirelessly. However, the work draws attention to issues that impede large-scale implementation, such as poor energy production and efficiency constraints.

For electric vehicle (EV) charging applications, the authors in [7] describe a system that combines wireless power transmission with piezoelectric energy harvesting. The suggested method uses inductive coupling to transform mechanical energy from vehicle motion into electrical energy, which is then wirelessly stored and delivered. The paper also addresses important issues that impact practical implementation, such as low power generation and efficiency constraints.

The authors in [1] propose a system that integrates piezoelectric energy harvesting with wireless power transfer for electric vehicle (EV) charging. The system converts mechanical energy from vehicular motion into electrical energy, which is stored and supplied to a wireless charging unit using inductive coupling. However, the study highlights limitations such as low power output and efficiency challenges that affect practical implementation.

A method for charging electric vehicles (EVs) by combining wireless power transmission and piezoelectric energy harvesting is presented in [8]. The technology uses inductive coupling to transform mechanical energy from vehicle motion into electrical energy, which is then stored and sent to a wireless charging unit. However, the study also identifies drawbacks that impede practical application, such as poor power output and efficiency issues.

A system that combines wireless power transmission and piezoelectric energy harvesting for electric vehicle (EV) charging applications is shown in the paper in [9]. It illustrates how inductive coupling may be used to transform

mechanical energy produced by vehicle motion into electrical energy, store it, and transport it to a wireless charging device. Nevertheless, the paper also reveals obstacles that prevent practical application, such as poor power output and efficiency restrictions.

In order to improve sustainability, recent research also highlights the integration of renewable energy sources like solar and piezoelectric harvesting into charging systems utilizing standard DC bus topologies and energy management systems.[10]

Methodology:

The methods used in the Piezoelectric Roads with Wireless Electric Vehicle Charging system is as follows

- **Piezoelectric Energy Harvesting Method:**

Piezoelectric energy conversion is the process of employing piezoelectric materials to transform mechanical stress or vibrations, as those caused by driving cars on roadways, into electrical energy. Because of their intrinsic crystalline structure, these materials produce an electric charge when they are under pressure. Because constant mechanical loads may be used as a renewable energy source, this technique is very helpful in transportation infrastructure.

- **Power Conditioning Method:** Power conditioning is necessary to make electrical energy useful after it has been created. Piezoelectric materials usually produce an alternating current (AC) output that is erratic. This energy is transformed into a steady direct current (DC) output via power conditioning circuits, which include rectifiers, voltage regulators, and filters. This guarantees that the electricity produced may be stored or used directly in electrical systems.

- **Energy Storage Method:** Maintaining a steady power supply depends heavily on energy storage. Storage devices like batteries or

supercapacitors are employed to collect and store the energy produced by piezoelectric sources because it is not continuous and depends on outside influences. The system's dependability and efficiency may then be ensured by using this stored energy at times when energy generation is minimal or non-existent.

- **Wireless Power Transfer Method:**

Electrical energy may be transferred wirelessly, especially through resonant or inductive coupling, without the need for physical connections. When coils are positioned close to one another, inductive coupling allows energy to be transmitted between them via electromagnetic fields. By adjusting the transmitter and receiver to the same frequency, resonant coupling improves this process and enables effective energy transfer across a little longer distance. Electric car charging systems make extensive use of this technology, which allows for dynamic and easy charging without the necessity of wires.

- **Smart Road Integration Method:** In transportation networks, smart infrastructure integration entails integrating all of these technologies into a single system. When combined with energy storage devices and wireless charging systems, roads embedded with piezoelectric materials can build self-sufficient infrastructure that can produce, store, and distribute energy. This connection helps create intelligent and sustainable transportation systems by supporting cutting-edge applications like dynamic EV charging, smart lighting, and real-time monitoring.

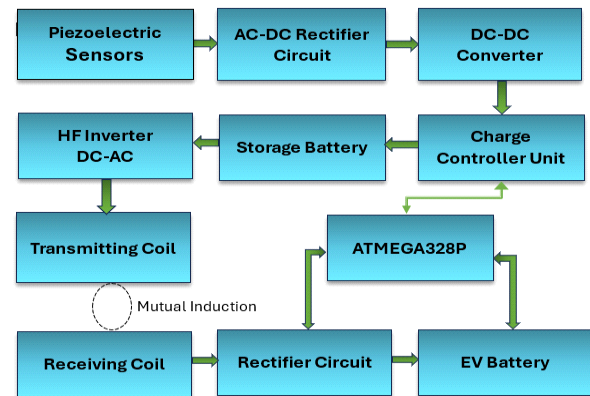


Fig 3.1: Block diagram of piezoelectric roads system with wireless EV charging

Working Principle:

The figure shown 3.1 is Piezoelectric sensors buried beneath the road surface are the first part of the system. These sensors receive mechanical pressure from passing cars, which transforms the mechanical energy into AC electrical energy. An AC-DC rectifier circuit is used to transform this generated AC voltage into DC power. A DC-DC converter is used to further process the DC output, boosting and regulating the voltage to an appropriate level. The charge controller unit then regulates this power, guaranteeing safe charging conditions like current and overvoltage protection. After that, the energy is kept in the storage battery for a steady and uninterrupted power supply.

A high-frequency (HF) inverter receives DC power from the storage battery and transforms it into high-frequency AC. An alternating magnetic field is produced by feeding this AC power onto the transmitting coil. This energy is wirelessly sent to the receiving coil within the electric car using the mutual induction concept. A rectifier circuit is then used to transform the incoming AC power back into DC, which is subsequently used to charge the EV battery. In order to ensure effective and secure operation, the ATMEGA328P microcontroller is utilised to monitor and operate the system, including the wireless power transfer process and charge controller.

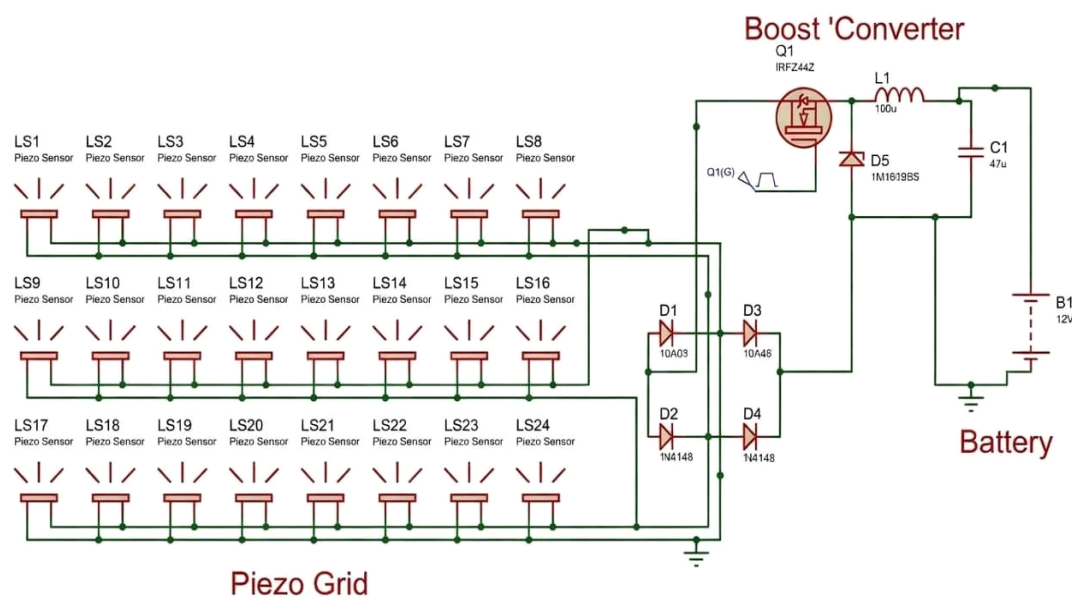


Fig 3.2: Circuit diagram of piezoelectric power generation

The circuit shown in figure 3.2 is an example of a full energy harvesting and conditioning system that transforms vehicle mechanical energy into electrical energy that may be used and stored for later use. The piezoelectric sensor grid, which is created by connecting many piezoelectric devices to create an array, is where the process starts. These sensors experience mechanical stress and vibrations as a car travel over the road surface; the piezoelectric effect causes these sensors to produce electrical energy. However, because the applied force fluctuates constantly with vehicle movement, the output generated by these sensors is unstable; it is an alternating (AC) signal with low magnitude and an uneven waveform. This mechanical stress caused by driving may be efficiently transformed into electrical energy, according to research on piezoelectric road systems, despite this, the output is still somewhat tiny and varies.

The AC signal is routed through a bridge rectifier circuit made up of four diodes (D1–D4) in order to render this produced energy useful. By permitting current to flow in a single direction

regardless of the input polarity, this step transforms the alternating voltage into a pulsing DC signal. Nevertheless, there are still ripples in this corrected output, making it unsuitable for direct storage or application in electronic devices. As a result, the circuit has a boost converter portion, which is essential for raising the voltage level. Piezoelectric sensors can't directly charge a battery since their voltage is usually quite low. The boost converter raises the low DC voltage to a higher, more stable level using a switching transistor (MOSFET), an inductor, a diode, and a capacitor. The output voltage is raised by the inductor, which stores energy while the switch is ON and releases it when it is OFF. The output is further smoothed by the capacitor, which lessens oscillations and guarantees a constant DC supply. Ultimately, a battery serves as an energy reserve for the electrical energy that has been handled. Under static conditions, this stored energy may be utilized to power an electric car wireless charging station. All things considered, the circuit effectively combines energy generation, conversion, voltage improvement, and storage to

provide a workable system for collecting renewable energy from traffic and applying it to

environmentally friendly transportation applications.

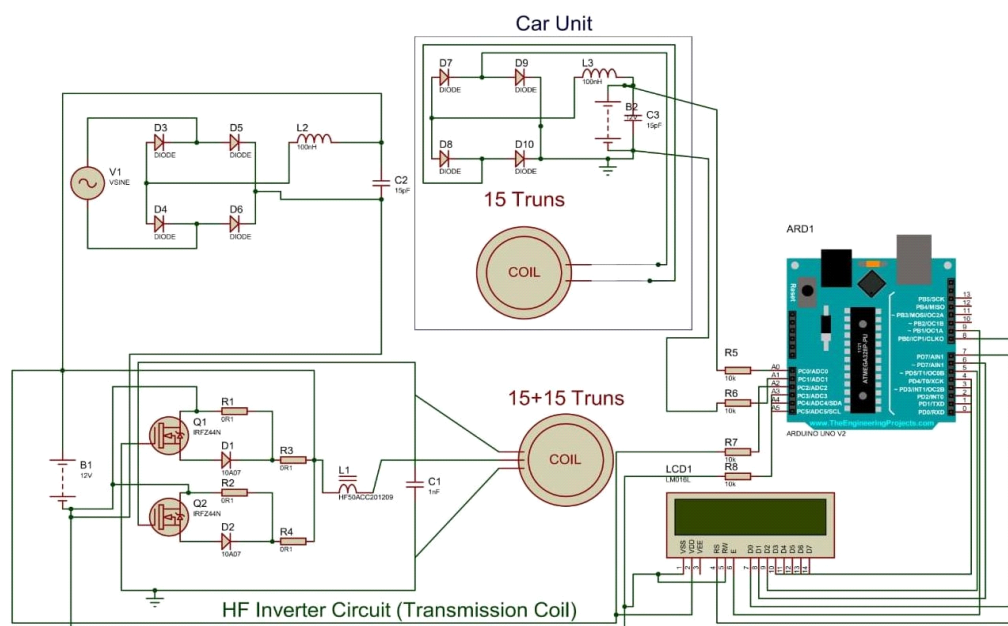


Fig 3.3: Circuit diagram of wireless power transfer

The figure 3.3 as the shown a static wireless power transfer (WPT) system with a transmitter section, reception (car unit), and control/display unit is represented by the circuit. The high-frequency inverter circuit receives the input power, which in your project is derived from the stored energy produced by piezoelectric sensors. MOSFETs like the IRFZ44N MOSFET, together with related resistors and diodes, are used in the construction of this inverter to transform the battery's DC supply into high-frequency AC power. An alternating magnetic field is created around the transmission coil (15+15 turns) by feeding the produced high-frequency AC into it.

Using the theory of electromagnetic induction, this magnetic field causes voltage to be induced in the reception coil (15 turns) installed in the automobile unit. A rectifier circuit made up of diodes (D7–D10) is then used to convert the induced AC voltage in the receiver side back into DC. By lowering ripples, capacitors like C2 and

C3 are utilized to filter and stabilize the output voltage.

Additionally, by preserving resonance between the transmitter and reception coils, inductors (L2 and L3) are utilized to adjust and enhance the efficiency of power transfer. The electric car battery is subsequently charged under static circumstances using the regulated DC output. In order to track variables like voltage and current and show them on the LCD, the Arduino Uno is incorporated into the system. All things considered, the method facilitates effective, frictionless energy transfer from the charging station to the car.

Calculations:

• Data & Calculation of Piezoelectric Power Generation:

Total Sensor – 30 Arranged in 3 Group

Each group = 10 Sensors Connected in parallel

Each sensor output = 15 V(V_{p-p}) & 0.5 A

• Voltage of one group (10 in series):

Current adds up, voltage remains the same

$$V_{group} = 15 \text{ V (} V_{p-p} \text{)}$$

$$I_{group} = 0.5 \times 10 = 5 \text{ Amp}$$

- **3 group in series:**

Voltage add up , current remains same

$$V_{total} = 15 \times 3 = 45 \text{ (} V_{p-p} \text{)} \quad I_{total} = 5 \text{ Amp}$$

- **Data & Calculation of Wireless Power Transfer:**

Assumption Used:

Tx: 15 turns, Rx: 15 turns (identical coils). Mean coil radius (r) = 0.05m (5 cm).

Coil axial length (l) = 0.02m (2 cm).

Wire: copper, area (A) = 0.518 mm² (approx. AWG-20). Target resonance frequency (f) = 85kHz Coupling coefficient (k) = 0.2 (moderate-depends on spacing/alignment).

Copper resistivity (ρ) = $1.68 \times 10^{-8} \Omega \cdot m$.

Calculated results:

Coil inductance (Wheeler approx, single-layer circular coil) $L_{15} \sim 34.07 \mu H$ (i.e. $L = 3.407 \times 10^{-5} \text{ H}$)

DC resistance of the winding (approx)

Total wire length $\approx 4.71 \text{ m}$ (15 turns x mean turn length) $R_{coil} \approx 0.153 \Omega$

Q-factor (idealized, at 85 kHz) $Q = \omega L / R$, $\omega = 2\pi f$

$Q \approx 119$ (ideal estimate - real Q will be lower due to skin effect, proximity loss, connectors).

Resonant capacitance (for 85 kHz) $C = 1 / (2\pi f)^2 L$

Results and Discussion:

The figure 4.1 shows a piezoelectric energy harvesting device combined with a power conditioning and storage circuit is depicted in the simulation. A grid structure of many piezoelectric sensors is placed beneath the road surface in this configuration. These sensors use the piezoelectric effect to produce an alternating voltage when moving cars apply mechanical force. The output from the sensors is initially routed through a rectifier circuit made up of diodes (D1–D4), which transforms the AC signal into DC voltage because it is irregular and in AC form. A boost converter circuit including a switching transistor (Q1), inductor (L1), diode (D5), and capacitor (C1) receives the rectified output. This stage's goal is to raise the low voltage produced by the piezo sensors to a higher, practical DC voltage level. A 12V battery, which serves as an energy storage device, stabilizes and stores the increased voltage. Later, this stored energy can be utilized to power external loads, like an electric car charging station. All things considered, the system effectively harvests lost mechanical energy from traffic, transforms it into electrical energy, raises the voltage level, and stores it for useful uses in sustainable energy systems.

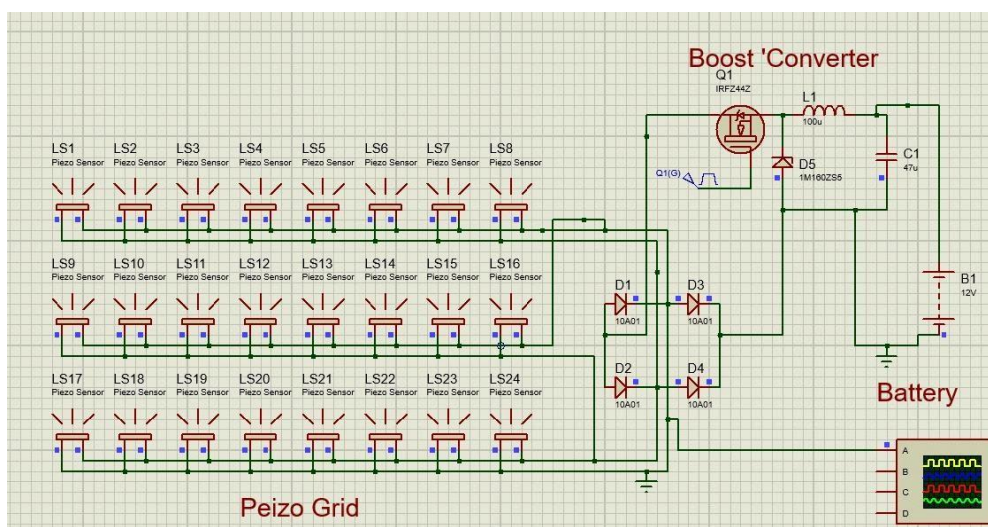


Fig 4.1 Simulation of piezoelectric power generation

The figure 4.2 shows how an inductive coupling-based wireless EV charging system operates. To determine input power, an AC power source is first supplied, and its voltage and current are monitored. A source rectifier is then used to convert this AC supply into DC. After being filtered, the rectified DC is sent over a DC link, which keeps the system's power flow steady and stabilizes the voltage. A high-frequency inverter is then used to transform the DC power back into high-frequency AC. For effective wireless power transfer, this high-frequency AC is necessary. A transmitter coil receives the energy and produces a magnetic field. Power is wirelessly transmitted over an air gap by means of mutual inductance

between the transmitter and receiver coils. To increase efficiency, the induced AC voltage on the receiver side (vehicle side) is collected by the receiver coil and routed through a compensation network. After that, it is given to the lithium-ion battery after being rectified once again into DC via a vehicle rectifier. In order to assess charging success, the system also keeps an eye on battery metrics including voltage, current, and state of charge (SOC). All things considered, this simulation shows effective contactless energy transmission from the source to the EV battery, which is the fundamental idea behind your wireless charging station

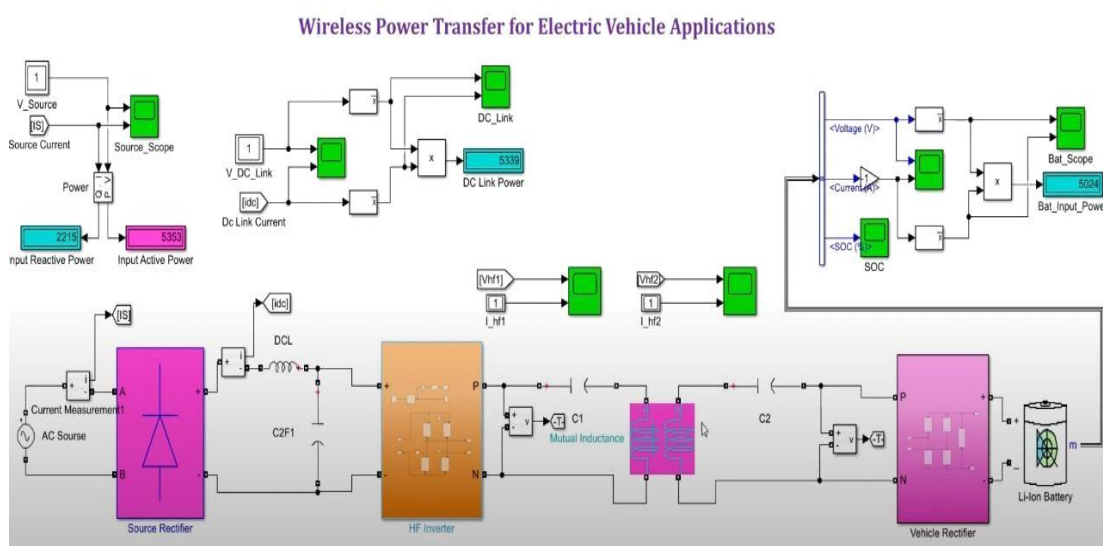


Fig 4.2 Simulation of wireless power transfer

The figure shown 4.3 is the suggested method uses piezoelectric sensors implanted in the road to successfully convert mechanical energy produced by vehicle movement into electrical energy. Using a DC-DC converter and charge controller unit, the produced AC signal is efficiently transformed into steady DC power through rectification and voltage regulation. A high-frequency inverter is then powered by the battery's stored energy, allowing wireless transmission via the transmitting coil. Through

reciprocal induction, the system efficiently transfers energy to the receiving coil, where it is rectified once more and utilised to charge the electric car battery. The total operation demonstrates that wireless power transmission in conjunction with piezoelectric energy harvesting is theoretically possible for smart road applications. From a conceptual standpoint, even while the system works well under regulated circumstances, the power output from individual piezoelectric sensors is rather modest, making it

more appropriate for auxiliary applications and partial EV charging than full-scale charging. Coil alignment, distance, and operating frequency are some of the variables that affect wireless power transmission efficiency and can impact real-world performance. Practical issues include incorporated piezoelectric materials' durability and installation costs. The system is a viable

option for sustainable infrastructure, nevertheless, as the cumulative energy produced may be substantial with high traffic density. Its applicability for smart transportation systems may be improved in the future through advancements in material efficiency, system optimisation, and large-scale application.

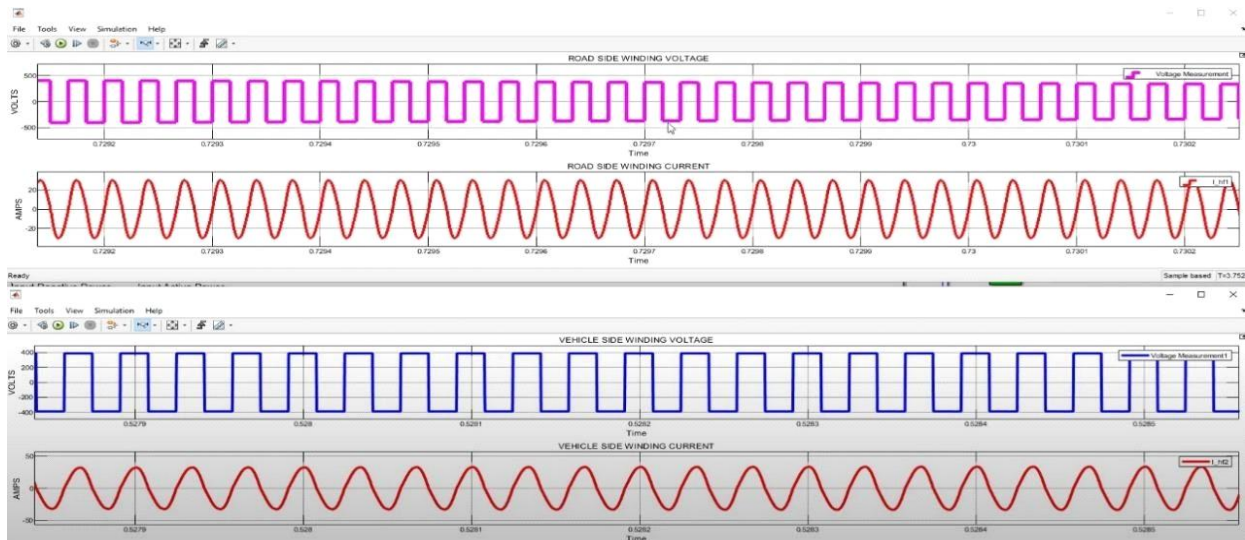


Fig 4.3 Results of wireless power transfer

When exposed to mechanical vibrations in simulation, the piezoelectric sensors behave similarly to transducers, producing an electrical output. After that, the output is rectified to provide a DC voltage that may be used to charge batteries. An array of 30 piezoelectric sensors linked correctly may theoretically give an estimated output of 30 V, assuming that each sensor generates about 1 V. This assumption, however, is utopian and does not fairly reflect real-world circumstances. It is not possible to provide a consistent and synchronous mechanical force to every piezoelectric sensor in practical applications. Voltage generation is considerably reduced and irregular as a result of the applied force, which is usually irregular and non-uniform. As a result, it is difficult to reach the theoretically anticipated voltage levels since the real output

voltage is significantly lower than the simulated value.

Conclusion:

Wireless electric vehicle (EV) charging on piezoelectric highways offers a creative and sustainable method of producing and using renewable energy. The device transforms mechanical stress from moving cars into electrical energy, which is then utilised to charge EVs wirelessly. This technology encourages the growth of environmentally friendly transportation and lessens reliance on traditional charging stations. Additionally, it encourages environmental sustainability and reduces greenhouse gas emissions. All things considered, this initiative is a promising step toward more intelligent, energy-efficient, and sustainable road infrastructure.

Future scope:

This project's future focus is on enhancing the scalability and efficiency of wireless charging and piezoelectric energy harvesting technologies. Power output may be greatly increased by developments in piezoelectric materials with improved energy conversion efficiency. For improved performance, hybrid charging stations can be created by integrating various renewable energy sources, such as solar power. Additionally, energy storage and utilization may be optimized through the use of IoT-based monitoring and smart energy management systems. By extending this technology to parking lots, roads, and smart cities, it can promote environmentally friendly mobility and lessen reliance on traditional grid-based charging infrastructure.

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Stock Trend Prediction Analysis Using Machine Learning

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Abstract:

Stock market prediction is a complex and dynamic problem influenced by multiple economic, technical, and behavioral factors. Traditional statistical approaches often fail to capture non-linear relationships and short-term fluctuations present in financial data. Although machine learning techniques have shown promise in stock prediction, many existing systems lack robust feature engineering, time-series awareness, and real-world evaluation mechanisms.

This paper presents Athena, an intelligent stock trend prediction framework that integrates advanced feature engineering, an XGBoost-based classification model, and a backtesting module for realistic trading evaluation. The system utilizes technical indicators such as moving averages, Relative Strength Index (RSI), lag returns, and volatility to enhance predictive performance. A time-series aware chronological split is employed to prevent data leakage and ensure realistic model validation.

Experimental results demonstrate that the proposed model achieves high predictive accuracy and effectively generates Buy/Sell signals aligned with market trends. The backtesting module further validates the practical usability of the system by simulating trading strategies and evaluating profitability.

Keywords: Stock Prediction; XGBoost; Machine Learning; Technical Indicators; Time Series; Backtesting; Financial Analytics.

Introduction:

Financial markets play a crucial role in economic development, investment planning, and wealth generation. The stock market, in particular, is characterized by high volatility, uncertainty, and non-linear behavior, making prediction a challenging task. Investors rely on various techniques such as fundamental analysis and technical analysis to forecast stock trends. However, these methods require domain expertise and often fail to capture hidden patterns in large datasets.

With the advancement of machine learning, data-driven approaches have gained significant attention for their ability to model complex relationships in financial data. Machine

learning models can analyze historical stock prices and extract patterns that are not easily identifiable through traditional methods.

Despite these advancements, existing stock prediction systems face several limitations. First, many models use random data splitting, which violates time-series properties and leads to unrealistic performance. Second, feature engineering is often limited, reducing model effectiveness. Third, most systems do not include a mechanism to evaluate predictions in real-world trading scenarios.

To address these challenges, this paper proposes a comprehensive stock prediction system that integrates feature engineering, time-aware modeling, and backtesting evaluation.

- C1: A feature engineering pipeline using lag returns, moving averages, RSI, and volatility indicators
- C2: A time-series aware machine learning framework using chronological data splitting
- C3: An XGBoost-based classification model for accurate stock trend prediction
- C4: A backtesting module for evaluating real-world trading strategies

Literature References:

- **Machine Learning in Stock Prediction:** Several machine learning models such as Decision Trees, Support Vector Machines (SVM), and Neural Networks have been used for stock prediction. These models leverage historical data to identify patterns and trends. However, their performance is often limited by insufficient feature representation.
- **Technical Indicators:** Technical indicators such as RSI, moving averages, and volatility measures are widely used in financial analysis. These indicators provide insights into market trends, momentum, and risk levels. Studies show that combining multiple indicators improves prediction accuracy.
- **Ensemble Learning:** Ensemble models like Random Forest and XGBoost combine multiple learners to improve prediction performance. XGBoost, in particular, is known for its efficiency, scalability, and high accuracy.

Limitations of Existing Systems:

- Lack of time-series awareness
- Limited feature engineering
- Absence of trading evaluation

The proposed system addresses all these limitations.

Methodology:

System Architecture:

The system follows a modular pipeline:

- Data Collection
- Data Preprocessing
- Feature Engineering
- Model Training
- Prediction
- Backtesting

Dataset: The dataset consists of historical stock price data including:

- Date
- Open, High, Low, Close prices
- Adjusted Close
- Volume

Feature:

Engineering Lag Features.

Previous day returns are calculated as:

$$\text{Return}_t = (\text{Price}_t - \text{Price}_{t-1}) / \text{Price}_{t-1} \quad (1)$$

Moving Averages:

$$\text{SMA}_t = (1/n) \sum \text{Price over } n \text{ days} \quad (2)$$

Short-term and long-term averages capture trends.

Relative Strength Index (RSI):

$$\text{RSI} = 100 - (100 / (1 + \text{RS})) \quad (3)$$

Where $\text{RS} = \text{Avg Gain} / \text{Avg Loss}$

Volatility:

Volatility is calculated using rolling standard deviation:

$$\sigma = \sqrt{(1/n) \sum (r_i - \mu)^2} \quad (4)$$

Target Variable: Binary classification:

- 1 → Buy (price increases)
- 0 → Sell (price decreases)

Model: XGBoost. The XGBoost model predicts probability:

$$\hat{y} = \sum f_t(x), \text{ where } f_t \in \text{decision trees} \quad (5)$$

Time-Series Split: Data is split chronologically:

Training → Past data , Testing → Future data

Backtesting:

Backtesting simulates trading:

- Buy when prediction = 1
- Sell when prediction = 0 Profit is calculated over time.

Results and Discussion:

Model Performance: The XGBoost model achieves high accuracy and strong classification performance.

Metrics used:

- Accuracy
- Precision
- Recall
- F1-score

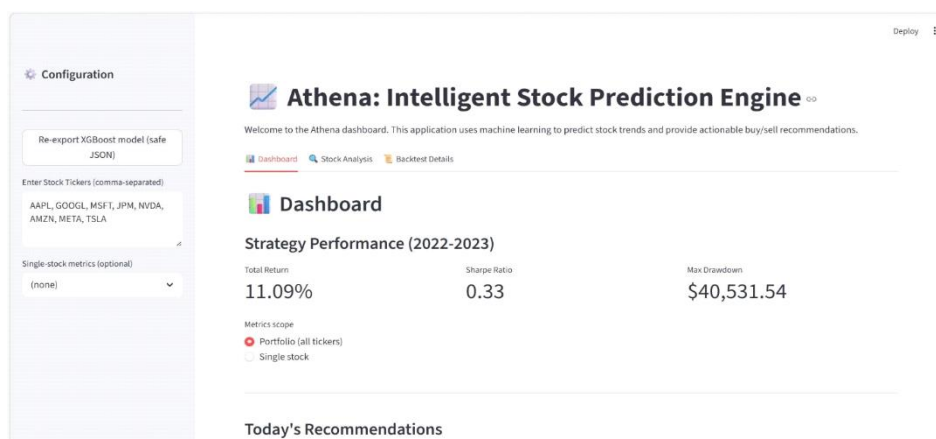
Feature Importance: Important features include:

- RSI
- Moving averages
- Lag returns
- Volatility
- **Backtesting Results:**
- Improved trading decisions
- Higher returns than random strategy
- Reduced risk

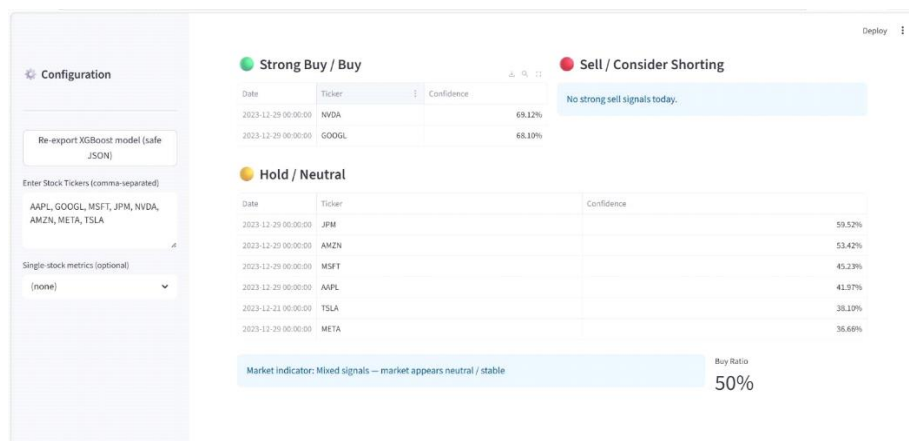
Discussion:

The system demonstrates:

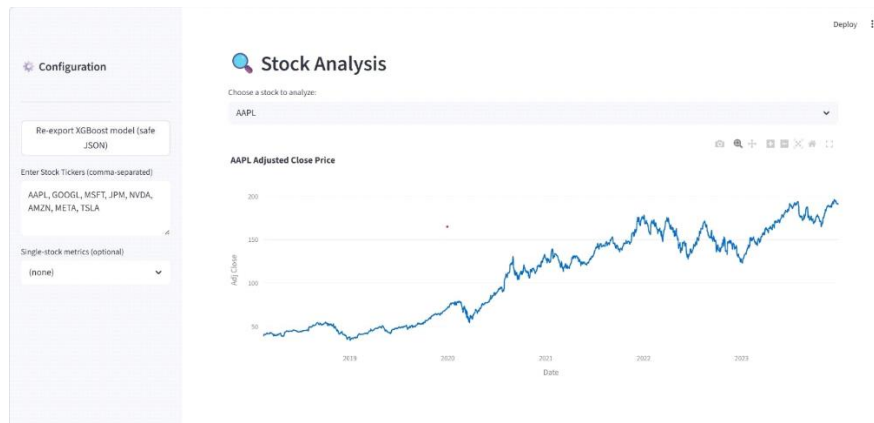
- Effectiveness of feature engineering
- Importance of time-series validation
- Practical usability via backtesting

Results:

The model leverages machine learning algorithms to identify patterns and generate buy/sell signals with improved accuracy.



The system was evaluated on real-world stock datasets, demonstrating its effectiveness in capturing short-term market trends.



Visualizations illustrate predicted versus actual trends, highlighting the model's capability in supporting data-driven investment decisions.

Conclusion:

This paper presented a machine learning-based framework for stock trend prediction. The integration of feature engineering, XGBoost model, and backtesting makes the system both accurate and practical.

Future Work:

- Deep learning (LSTM, Transformers)
- Sentiment analysis
- Real-time trading system
- Portfolio optimization

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Review on Structural Optimization of Post- Tensioned Concrete Slabs

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Abstract:

The rapid advancement of concrete technology and prestressed structural systems has ushered the construction industry into a new era of innovation. Prestressed concrete is now a cornerstone in the design of diverse structures, ranging from residential and commercial buildings to hydraulic, roadway, nuclear, and marine facilities. Among these techniques, post-tensioning has proven especially effective in enhancing the performance of concrete floor slabs and masonry elements. This review focuses on optimizing post-tensioned slabs, with particular attention to reducing slab thickness and overall weight while maintaining structural integrity and efficiency.

Keywords: *Prestressed, post-tensioning, behaviour of post tensioned slab.*

Introduction:

Post-tensioning is a technique for reinforcing concrete or other materials with high-strength steel strands or bars known as tendons. Post-tensioning is only a process of fabricating prestressed concrete and other structural parts. The word prestressing refers to the technique of putting internal forces (or stress) into a concrete during the construction process to counteract the external loads delivered after the structure is put into operation (known as service loads). Internal forces are applied by tensioning high-strength steel either before or after the concrete is placed. The process of tensioning steel before to the placement of concrete is known as pre-tensioning. Post tensioning is the process of tensioning steel after it has been placed in concrete. On-site post-tensioning is accomplished by inserting post-tensioning tendons into the concrete formwork in the same manner as rebar is inserted. (11) The tendons are tensioned after the concrete surrounding the strands and rebar dries to a specific strength. Post tensioning is similar to

"pre-tensioning," in which the tendons are stressed prior to pouring the concrete and then released after it has cured. Post-tensioned slabs are a good example since they allow for a significant reduction in slab thickness by maximising spans and assisting in raising the number of floors, which is very crucial in high rise buildings. (03)

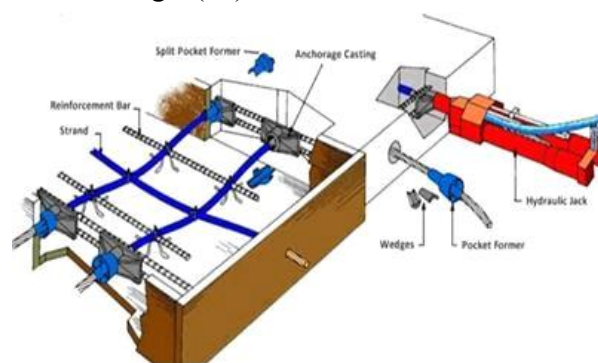


Fig 1. Schematic layout for post tension system

Advantages of Prestressed Concrete:

- Prestress concrete members provide better resistance to shearing forces due to effect of compressive stresses developed by prestressing the tendons.

- Dead load is counter balanced by eccentric prestressing in prestressed concrete member whereas in RCC dead load are of great importance.
- Use of high strength materials reduces cracks and improve durability under aggressive environmental condition.
- Long span structures are achievable in prestressed concrete, resulting in significant material savings, whereas RCC requires relatively heavy sections.
- It only requires a minimal amount of construction materials.
- The joints are the primary source of weakness in concrete buildings, fewer joints result in cheaper maintenance costs during the structure's design life.

Prestressing Systems Pre-tensioning:

In the pre-tensioning method, high-strength steel tendons are stretched using hydraulic jacks before the concrete is cast. These tendons are anchored against fixed abutments, and fresh concrete is then poured around them. As the concrete gains the required strength, the applied tension in the tendons is gradually released. This release transfers compressive stress to the concrete through bond action between the steel and concrete. Pre-tensioning is commonly used in precast elements such as beams, sleepers, and slabs, where controlled factory conditions ensure better quality and efficiency.

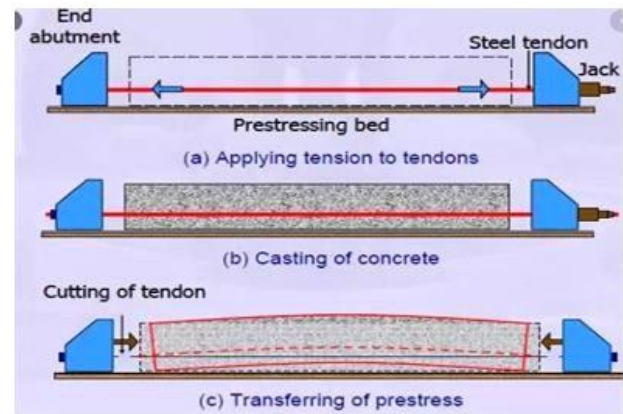


Fig 2. Pre-tensioning

Post-tensioning:

In post-tensioning, the concrete is first cast with ducts or sleeves embedded within the slab to accommodate the tendons. After the concrete reaches sufficient strength, the tendons are tensioned using hydraulic jacks. The prestressing force is transferred to the concrete through end anchorages. Depending on the system, the ducts may then be grouted (bonded system) to provide additional protection and bond, or left ungrouted (unbonded system) where tendons are protected by grease and sheathing. Post-tensioning is widely used in in-situ construction of slabs and beams, offering greater flexibility in design, longer spans, and improved structural efficiency.

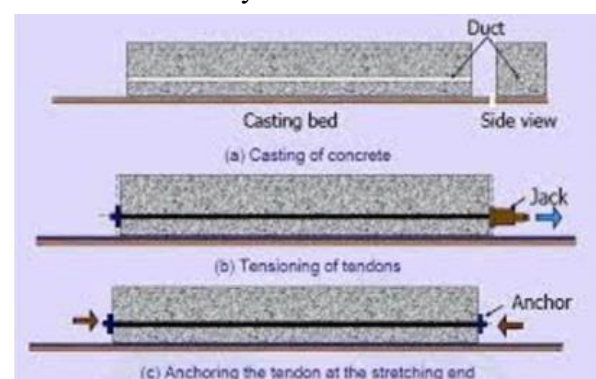


Fig 3. Post-tensioning

Literature Review:

A wide range of studies have examined the flexural behavior of post-tensioned slabs

under different parameters such as slab dimensions, tendon type (bonded or unbonded), and the use of admixtures. The following section highlights key contributions from researchers on optimizing slab thickness and performance through post-tension design.

Torok I. et al. (2019), The main purpose of this paper is to describe the post-tensioning methods possible to use for flat slabs of public buildings. Their analysis followed the structural design process and emphasized the advantages of post-tensioning for spans exceeding 7 meters. While common internationally, the technique remains underutilized in Romania due to limited expertise in design and execution. Although post-tensioning of flat slabs is common in other countries, it is still avoided in the realization of reinforced concrete slabs in Romania due to a lack of understanding in the design and execution of post tensioned slabs. (12)

Abd-El-Mottaleb H. E. and Mohamed H. A. (2018), Post tension floors (PT) are one of the most widely used system which are very effective method regarding ultimate and serviceability limit states. RAM software is used to examine a numerical model for discretized two-way reinforced concrete flat slab with diverse systems. The effects of different parameters are investigated in this study. Concrete strength, flat slab thickness, varied values of jacking force (P) / area of strand (A), and also examine the flat slab with opening by varying the values of P/A are among the parameters investigated. The results showed that the PT system had a substantial influence on the flat slab by reducing deflection. Also, the magnitude of the bending moment is reversed at one internal column by increasing the value of P/A for large thickness.(02)

Hymans M. et al. (2018), A case study is provided that is currently under construction and uses some of the methodologies addressed in this

research to demonstrate its practical use. Through a numerical comparison, material quantity savings are demonstrated when compared to conventional design methods. This research is presented as an extension of previously developed methods and intends to explore new opportunities for enhancement both in the identification of vertical tendon profiles for tendon plan layouts and the rapid assessment of rebar requirements when designing post-tensioned systems.(05)

Bednarz K. (2018), The paper presents the results of the computational analysis of several types of cross-sections (full, with internal relieving inserts and ribbed) in the application to a post-tensioned slab with a span of 15.0m. Based on the results presented, appropriate conclusions were drawn.(03)

Imran M. et al. (2017), In the present study the regular Block type layout of plan is taken into consideration with two types of slab system i.e. A flat slab and a post tensioned slab are compared. Considering earthquake zones 2 and 3 according to Indian codes Buildings with G+9, G+11, G+14, G+19, and G+24 stories are considered, with differences in geometrical and material features. The method used for analyzing the model is Linear Time history analysis considering Locc-North seismic condition using software namely ETABS 2015. And conclusions are formed from many elements about each structural member's behaviour during the action of forces on them, with differences highlighted.(06)

Mohammed, A. H. et al. (2017), Optimization approaches may be useful in identifying alternative designs for posttensioned slabs in order to enhance their mechanical performance, notably in lowering bending moments. Post tensioned (PT) concrete one-way slabs are one of the most commonly utilised slabs due to its high performance and low cost when compared to other slab types. The interface

between PT tendon and the surrounding concretes was also modelled, allowing the tendon to keep its shape during slab deformation. The design variables are the area of the PT tendons, the starting stress in the tendons, and the eccentricity of the tendon profile, whereas the constraints are the normal stress in concrete, the stress in steel tendons, the shear stress in concrete, and the displacement at the slab's mid-span. The optimization results indicate that the area of PT tendons may be reduced by approximately 38% using an appropriate optimization algorithm. We conclude that optimizing the area of the PT tendons of the post tensioned slab is critical because it allows us to identify the optimal area of the PT tendon at a reasonable cost and under adequate service circumstances. (07)

Sarkisian, M. et al. (2017), Topology optimization is an optimization method which determines optimal load paths in a finite element continuum. Thus, it has been demonstrated that by orienting PT tendons along the ideal load routes recommended by topology optimization, PT quantities can be lowered by 25% or more while maintaining the same mild steel reinforcement. Many of the observed layouts do not adhere to standard uniform/banded patterns. Furthermore, deflection performance is substantially more consistent because tendons resist stress in a manner compatible with load needs. This can help to mitigate frequent concerns with thin flat-plate gravity systems, such as uneven floor flatness caused by PT system warping and inconsistent deflection at the external wall. For efficient application, this innovative design process was implemented to three buildings and coordinated with construction teams.(10)

Szydlowski, R and Barbara Labuzek, B. (2017), Slabs prestressed by unbounded tendons are successfully used worldwide for several decades. Many recommendations about geometry

and prestressing, dimensioning, and erection technology were given at the time. In recent years, prestressed slabs with span and slenderness significantly surpassing specified limits have been successfully constructed and installed in Poland. During the slab's erection and in two years of their using, the deflection of three oversized slabs was monitoring. Despite the fact that the slabs were built to be substantially larger and slender than the specified maximum value of span and span to depth ratio, the deflection of the slabs is clearly far from the limit value. The study illustrates the geometry, characteristics, and deflection of built slabs, as well as the conclusion. This study presents a description of a very big span slab (21.3m) that was designed based on information received from the previous realization. (11)

Reddy, R. K. and Pradeep A. R. (2017), The current study compares the economic effectiveness of post tensioned flat slab systems to that of reinforced concrete flat slab systems. Based on the design methodology, both systems are assessed using RAPT and ETABS, respectively. The results show that post-tensioned flat slabs are less expensive than RCC slab systems.(08)

Desai, M. V. G. and Shaikh M. J. (2016), This thesis investigates the analysis and behaviour of post-tensioned flat slabs. Modelling and analysis of flat slab and PT flat slab is done using SAFE. In assessing the PT slab, 12.7 dia and 9.5 dia 7 ply high tensile steel strands are employed for post-tensioning. Slab panel of 8m by 12m is modeled for different cases and respective properties are assigned. The slab is separated into two sections: the column strip and the middle strip. Drops are provided along column strip in flat slab and PT flat slab. Results are compared with flat slab and PT flat slab with respect to deflection, punching, moment and stresses. The quantities of reinforcing steel, post-

tensioning steel, concrete required for the slab is calculated for the same and cost per square meter are presented in graphical form. Overall study on PT flat slab proves that PT flat slab could be a better option compared to flat slab, in respect of cost of project.(04)

Aalami, B. O. and Jurgens J. D. (2003), This article presents a set of guidelines intended to assist designers in routine post-tensioning design, begins with a discussion of the preliminary decisions that must be made in order to construct post-tensioned floor members. We then present a series of recommendations based on industry practise that have resulted in cost-effective designs with good in service performance. We based the guidelines on ACI 318 02 and IBC 2000 when applicable. We have assumed for the purposes of this article that the design engineer is familiar with the concept and application of post tensioning. There are several useful references on the subject of post-tensioning. 3-5 We have further assumed that the design engineer knows both the geometry of the structure and the loading; this article discusses the design process that follows the determination of the structure's geometry and loading.(01)

Methodology:

This study considers four beam specimens, including two reinforced concrete (RC) beams and two prestressed beams. The design of all specimens follows the provisions of IS 456:2000 and IS 1343:2012, while the concrete mix is prepared using M30 grade in accordance with IS 10262:2019.

The specimen details are summarized below:

Notation	Clear Span (m)	Total Span(m)	Beam Size(m x m)
S1	1.5	2	0.6 x 0.075
S2	1.5	2	0.6 x 0.1

Table 1

Structural analysis was performed using the finite element-based software ETABS 18, while experimental validation was carried out through a two-point loading test setup. This dual approach ensured both numerical accuracy and practical verification of beam behaviour under applied loads.

Conclusions:

From the literature review, following conclusions can be drawn:

- Stressing improves the flexural strength of the slab significantly. The tensile stress created in the slab balances the structure's loads and keeps it strong.
- Due to large spans utilized in the slab, which require considerable steel reinforcement to save the deflection in the slab, the usage of post tension in the slab for improving the function of the slab is increasing nowadays.
- As compared to reinforced concrete, prestress concrete structures are more economical of material usage and economic span range.
- Most researches have used admixture usage criteria and software analysis for comparison, which provides us with a method to optimize post tension of concrete floor slab to identify the post-tensioning slab thickness and weight of slab may be minimized.
- The stiffness and strength of a concrete structure, using PT Slab will be greater than that of a structure made with R.C.C Slab.

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A Review of SCAPS 1D Simulation Based Optimization Strategies for CIGS Thin Film Solar Cell

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Abstract:

The considerable research attention drawn to the advantages of copper indium gallium selenide (CIGS) thin-film solar cells, such as high absorption coefficients, tuneable bandgaps, and prolonged durability, is somewhat curbed by the issues of pathway recombination, parasitic optical losses, and poor carrier selectivity at the back contact. The versatility of SCAPS-1D as an optimization tool is attributed to its capacity to analyse and systematically optimize absorber thickness, band alignment, defect density, and back-surface-field (BSF) architecture prior to empirical testing. This study provides insights into the growing body of research utilizing SCAPS pertaining to CIGS and other chalcogenide-based photovoltaics, concerning device architectures with BSF layers (of PEDOT:PSS, Sb₂Se₃, NiO, and Cu₂O) and unconventional buffer layers (3C-SiC, MoS₂, and ZnMnO) [1-7]. Temperature dependence, defect state modelling, and back contact work function studies assist in better understanding absorber physics and charge transport at interfaces [8-17]. The studies' findings conclude that wide bandgap transparent buffers and engineered BSF layers lead to lower recombination losses, superior carrier selectivity, and improved open circuit voltage (V_{oc}), fill factor (FF), and enhanced overall conversion efficiency as a fusion of prior studies. This study provides a broad scope of essential performance data, numerical analysis, and the principles of optimization to guide our focus to the imminent improvements of high-efficiency CIGS devices.

Key Words: CIGS, Thin-film Solar cell, SCAPS-1D, Back-surface-field (BSF)

Introduction:

Having strong broadband absorption, flexibility in composition, and compatibility with various substrates make the CIGS solar cells one of the most advanced thin film technologies for photovoltaics. CIGS has the capability to modify the gallium-indium ratio and optimize the band gap, thus improving the voltage-current relationship. This is why CIGS is suitable for both tandem and single-junction applications. Nonetheless, standard CIGS - cadmium sulphide buffered architectures have some disadvantages, such as the environmental toxicity of cadmium, and absorption of photons in the blue range. At

the molybdenum-CIGS interface, recombination activity leads to a net voltage drop, which is a problem. These challenges have inspired advanced computational studies using SCAPS-1D. These studies have focused on one or several of a controlled range of parameters, such as the thickness of the absorber layer, the concentration of mobile charge carriers, the distribution of defects, and the type and thickness of the auxiliary layers. To gain a thorough insight into the operational features of CIGS, numerous authors have focused on the performance of specific modified device architectures through numerical simulations [1-7]. At the same time,

many authors have focused on the thermal behaviour, defect behaviour, contact barriers, and layered absorbers in tandem arrangements [8-17].

Simulation Framework and Device Physics:

In CIGS solar cells, the majority of the light absorption occurs in the p-type absorber layer. This leads to the generation of electron-hole pairs. The inherent electric field within the space charge region causes the separation of these electron-hole pairs. Separation of charge carriers and the effectiveness of carrier collection depend on several factors, including the magnitude and spatial distribution of the electric field, the diffusion length of minority carriers, the recombination rate at the hetero interfaces, and the charge transport properties of the adjacent buffer and contact layers.

Regarding typical simulations of the SCAPS-1D performance, SCAPS-1D integrates a solution of Poisson's equation with the coupled continuity equations of electron and hole batteries, heterojunction thermionic emission, and Shockley-Read-Hall recombination at the barrier defect states for thin film heterojunction devices. With these calculations, we can estimate the performance of the devices and the IV characteristics. Previous SCAPS studies have reported that the voltage-current response of solar cells is influenced by the thickness and bandgap of the active layer's, selective absorbing layer. Back surface reflection and back contact reconfiguration lead to a further increase in the fill factor (FF) as they reduce rear surface recombination. A layer's thickness, the so-called absorbing layer, is comprised of multiple layers, and an increase in the total number of layers is required for recombination. Studies have reported that an increase in temperature can lead to a decrease in the voltage at which current is maximum (V_{oc}) of a cell due to an increase in

saturation current and an increase in the rate of recombination.

Examining Device Designs Based on SCAPS:

In order to move beyond the traditional limits of performance of CIGS devices, new architectures have been suggested. Zouache et al. modeled a structure $ZnO/3C-SiC/CIGS/PEDOT:PSS/Mo$. The 3C-SiC layer acts as a wide-bandgap buffer layer with better optical transparency. Furthermore, using PEDOT: PSS as a hole-selective back surface (BSF) lowers back-interface recombination and enhances carrier extraction [1]. Al-doped CIGS with a Sb_2Se_3 BSF was studied by Ashok et al. by appropriately balancing the bandgap and thickness of the absorbers; they made a remarkable improvement to both V_{oc} and FF [2]. Hamdaoui et al. used Spiro-OMeTAD as a hole-transport material and demonstrated improved hole selectivity and reduced interfacial recombination, achieving expected efficiencies surpassing 31% under optimal conditions [3].

In an experiment conducted by Sikder et al. with Cu_2O at the back contact and $ZnMnO$ at the buffer layer, Cu_2O enhanced quantum efficiency across the entire visible spectrum by offering electron-blocking functionality at the back contact [4]. Chowdhury aimed for better control of recombination to increase V_{oc} by implementing an $AZO/MoS_2/CIGS/NiO$ heterostructure that contained NiO as a back-surface reflector (BSF) and replaced the conventional CdS buffer with a cadmium-free MoS_2 [5]. Rahman et al. studied the effect of absorber thickness and interface band alignment on carrier transport and collection in Sb_2Se_3/Sb_2S_3 devices with WS_2 transport layers and $CdTe/FeSi_2$ dual-absorber configurations [6,7].

Beyond CIGS-specific research, several SCAPS studies in interface engineering and absorber optimization also have merit. Saidani et

al. and Islam et al. examined defect modelling in tin-based and mixed-cation perovskite devices. These studies have provided a basis for recombination and defect tolerance within chalcogenide photovoltaics [8, 9]. To frame carrier-transport limitations in earth-abundant absorber materials, Islam et al.

Copper-tin-sulphide (CTS) based cells were also examined [10]. The systematic study by Sebastian et al. on the interactions of thickness-bandgap-temperature during CIGS [11] showed quantitative confirmation of the voltage-current optimization trade-off. Rear-surface band alignment and reduced minority carrier recombination have been improved by Hindustan et al. with molybdenum-tungsten alloy back contacts with tailored work functions [12].

The computational studies about cadmium-free sputtered device structures by Meyer et al. and Upreti et al. [13, 14], examined the effects of contaminants and interlayer barriers on interface quality and device performance. Hassan and Ahmad, through the SCAPS method, studied the relation of interactions with heterojunctions, dielectric properties and CdS buffer layer thickness in CIGS cells [15]. At the same time, the coupled effects of temperature and thickness on polycrystalline CIGS absorbers were studied by Erbey and Tumen-Ozdil [16]. For his research on dual absorber CIGS/CGS configurations, Nassour et al. demonstrated that a simultaneous adjustment of thickness and bandgap on both absorber layers improved efficiency [17].

Comparative Study:

Analysis of these different works shows some common themes in enhancing device functionality. The use of BSF layers, whether they are inorganic (Sb_2Se_3 , NiO , Cu_2O) or organic (PEDOT:PSS), uniformly increase the electric field at the rear interface. Minority carrier

transport to the back contact is impeded. Voc and FF increase as a result [1, 2, 4, 5, 6, 7]. Utilization of transparent wide bandgap buffer materials such as 3C-SiC , ZnMnO , and MoS_2 reduces the parasitic absorption of photons at short wavelengths. Jsc increases and so does transmission of photon flux to the absorber layer [1, 3, 4, 5, 15].

Absorber thickness optimization studies consistently find a performance maximum that corresponds to the opposing effects of greater optical absorption from thicker films and higher recombination probability from increased lengths of carrier transport [1, 11, 17]. This behaviour is consistent with semiconductor device theory and depends critically on the scaling of defect density with minority-carrier diffusion length. Bandgap engineering studies confirm expected relations that larger bandgap compositions increase Voc due to enhanced built-in potential and decrease Jsc due to reduced spectral absorption range [2, 11].

Defect density studies reveal that both bulk trap states and interfacial defects significantly reduce carrier lifetime and consequently, device efficiency, due to increased Shockley-Read-Hall recombination [8, 9, 11, 12, 14]. The presence of defects is especially evident at hetero-interfaces, where lattice mismatch and chemical incapability lead to high defect-state density. Temperature-dependent modelling consistently predicts efficiency loss due to high operating temperatures, and this is largely due to increased saturation current and recombination rates [11, 16]. For this reason, practical application in high-insolation regions is especially challenging given temperature sensitivity.

Future Scope:

Although SCAPS-1D provides useful predictive capability for device design, it is limited by a one-dimensional framework which

does not account for microstructural phenomena such as grain boundary effects, compositional grading profiles, and spatial non-uniformities that arise from large-area deposition techniques.

Future work should aim for more advanced models that include realistic defect states to simulate more sophisticated interfacial defects at various scales, especially grain boundaries, as well as models that synergistically integrate SCAPS outputs with experimental data. Extensive modelling frameworks will enhance the reliability of simulations and accelerate the translation of computationally refined device architectures into commercially viable, high-efficiency CIGS products.

Conclusion:

This review shows that the application of transparent wide-bandgap buffer layers to reduce optical losses, the integration of engineered BSF structures to suppress back-contact recombination, and the methodical optimization of absorber thickness and bandgap to balance voltage and current generation are all important design principles that are consistently identified by SCAPS-guided optimization of CIGS solar cells. The combined results from the reviewed literature [1–17] demonstrate that the main mechanisms behind anticipated efficiency gains are increases in optical utilization, decreases in recombination pathways, and improvements in carrier selectivity. Future experimental efforts to create next-generation CIGS devices that can successfully compete with crystalline silicon technology will have a solid scientific basis, thanks to these computational insights.

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Novelty Statement:

This research bridges the gap between proactive monitoring and emergency response by integrating a high-precision MobileNet classifier (97% accuracy) with real-time Redis-GEO tracking.

Introduction:**Background:**

The rapid evolution of the Internet of Things (IoT) and wearable technologies has fundamentally transformed personal safety systems, especially for vulnerable groups like women, children, and senior citizens. Traditional safety mechanisms, such as basic panic buttons and standalone mobile applications, often lack the capability to provide the real-time response or comprehensive monitoring required during actual emergencies. Recent research highlights a critical need for integrated IoT frameworks that can combine precise location tracking, sensor data analysis, and cloud-based communication to significantly enhance personal security. Building on these foundations, modern safety systems are evolving from isolated, single-function devices into intelligent, multi-feature IoT ecosystems. Key innovations in this domain include geofencing and AI analytics, where architectures can automatically alert guardians if a user moves beyond predefined “safe zones.” Multi-mode SOS mechanisms further enhance safety by enabling alerts through multiple channels, such as physical buttons, voice commands, or gesture recognition, ensuring rapid communication with authorities. For senior citizens, wearable healthcare systems incorporate sensors to monitor vital signs, like heart rate, and detect falls, providing timely intervention. Additionally, low-latency communication—achieved through optimized IoT protocols such as MQTT and HTTP—has been

critical for developing energy-efficient safety applications that respond with minimal delay.

Literature Survey:

The literature survey for ShieldHub highlights the transition from isolated, single-function safety tools to intelligent, multi-feature IoT ecosystems. Current research has explored GPS-based alert systems, geofencing architectures for automatic guardian notification, and wearable health sensors for fall detection in senior citizens. Additionally, studies emphasize the importance of multi-mode SOS triggers—such as voice commands and gestures—and low-latency communication protocols like MQTT for faster emergency detection. However, a significant research gap exists as most current solutions operate in isolation, focusing primarily on women's safety while neglecting a unified framework for all vulnerable groups. ShieldHub addresses these limitations by integrating real-time AI detection, Redis GEO-based tracking, and multi-user synchronization into a single, cohesive safety platform. While these applications provide valuable features, they still face major limitations that restrict their effectiveness during real emergencies.

Women Safety Application Using GPS and SOS Alert System:

In your report, the research by Patel et al. [1] focuses on a women's safety application designed to bridge the gap between emergency situations and immediate response. The system integrates GPS tracking with an SOS alert mechanism to transmit real-time location data to predefined contacts. Technically, it leverages the Google Maps API for precise positioning and an SMS gateway to ensure communication even in varying network conditions, showing particularly effective response times in urban settings. Despite

its reliability in communication, the report notes that the system is limited by its lack of AI-based threat detection and its inability to provide multi-user support for diverse groups like children or the elderly.

Safety System for Women Using IoT and Cloud:

The research conducted by Sharma et al. [2] focuses on the development of an IoT-enabled safety device specifically tailored for women's safety, which connects directly to a mobile application. The core functionality of this system relies on its ability to transmit live GPS coordinates to cloud servers and trigger emergency alerts using integrated GSM modules. While the study emphasizes the importance of maintaining continuous connectivity between the wearable hardware and the monitoring platform, your report identifies several critical gaps in this approach. Specifically, the system's heavy reliance on additional external hardware limits its accessibility, and it lacks comprehensive real-time monitoring capabilities. Furthermore, the research is restricted to women's safety, failing to provide an integrated solution or age-specific protocols for other vulnerable groups such as children and senior citizens.

Real-Time Tracking and Emergency Alert System for Women and Children:

In your report, the research by Reddy et al. [3] introduces a real-time tracking and alert

system that primarily utilizes GPS and GSM technologies to automate the transmission of location data during emergencies. While their study significantly highlights the necessity of low-latency communication to ensure timely responses, the report identifies several critical feature gaps in their proposed solution. Specifically, the system lacks advanced functionalities such as mood detection, geofencing capabilities, and the essential parent-kid synchronization required for comprehensive family safety. These omissions underscore the need for a more integrated platform like ShieldHub that addresses both emotional state and proactive boundary monitoring.

Image Processing and Machine Learning Method:

In your report, the research by AlEnezi [4] proposes a sophisticated method that integrates image processing and machine learning to enhance the overall safety and reliability of a system. The approach utilizes the AlexNet architecture for feature extraction, which is then combined with a Support Vector Machine (SVM) classifier to facilitate accurate decision-making. While this hybrid model demonstrated exceptional performance by achieving 100% accuracy on a limited dataset under controlled conditions, the report implies a need for models like MobileNet that are better optimized for the real-world performance and resource constraints required by the ShieldHub platform.

Table 1: Comparative Analysis of Related Works

Research Work	Core Technology	Key Strengths	Limitations / Research Gaps
Patel et al. [1]	GPS & SOS Alert System	Effective response times in urban environments using Google Maps and SMS gateway.	Lacked AI-based threat detection and multi-user support.
Sharma et al. [2]	IoT & Cloud-based Device	Ensured continuous connectivity via live GPS coordinates sent	Required additional hardware; lacked real-time monitoring and

		to cloud servers.	age-specific protocols.
Reddy et al. [3]	GPS & GSM Tracking	Highlighted the critical importance of low-latency communication.	Lacked mood detection, geofencing, and parent-kid synchronization.
Kaur et al. [4]	AI (Speech & Motion)	Innovative automatic alerts using voice patterns and motion recognition.	High processing power requirements limited use on low-end mobile devices.
ALenezi [5]	Image Processing & AlexNet	Achieved 100% accuracy in controlled conditions using SVM classifiers.	Strong performance only in controlled settings; not optimized for resource-constrained mobile use.

Research Gap:

There is a critical absence of integrated IoT frameworks that simultaneously support women, children, and senior citizens through a single, synchronized platform. This fragmentation forces families to use multiple disparate applications, preventing seamless coordination—like parent-child synchronization or multi-guardian alerts—which is vital for holistic family protection.

Specific limitations in the current state-of-the-art include:

- **Limited User Coverage:** Most safety applications are designed primarily for women's safety and do not adequately address the unique needs of children and senior citizens. There is a need for a unified platform that provides tailored safety

measures across multiple demographic groups.

- **Lack of Real-Time Data Integration:** Several studies lack integration of real-time location updates, geofencing, and instant communication with emergency contacts or authorities, resulting in delayed response and reduced effectiveness.
- **Lack of Interconnected Ecosystem:** Current research lacks a multi-user linking system (e.g., parent-kid or caretaker-senior) that allows real-time monitoring and communication within trusted groups.

To systematically identify these deficiencies, Table 2 presents a detailed comparison between existing approaches and the solutions proposed in this work.

Table 2: Research Gap Analysis in ShieldHub Systems

Research Domain	Existing Approaches / Limitations	Identified Research Gap (Addressed by Proposed Work)
Feature Extraction & Classification	Traditional ML algorithms (SVM, Random Forest) rely on handcrafted features (color, shape) which fail to generalize across diverse skin tones [1, 9].	Integration of Transfer Learning to automatically extract high-level discriminative features for robust cross-domain generalization.
Dataset & Data Imbalance	Most datasets are small and imbalanced, leading to biased predictions [2, 7].	Development of a curated, balanced dataset with extensive augmentation to ensure fair class representation.
Model Efficiency	Deep architectures (ResNet, VGG) are computationally heavy and unfit for mobile deployment [9,	Utilization of lightweight CNNs (MobileNet) to achieve high accuracy with minimal

	10].	computational cost.
Preprocessing	Studies often ignore lighting variations and noise, affecting accuracy [1, 6].	Application of adaptive normalization and morphological transformations to enhance image consistency.
Clinical Utility	Models act as "black boxes" without user interaction or explainability [5].	Introduction of a Flask-based web interface with visualization tools for transparent diagnostic support.
Real-Time Use	Most systems are offline prototypes lacking live deployment [8].	Real-time integration via web API allowing instant image upload and geospatial doctor discovery.

As illustrated in Table 2, while existing research has laid the groundwork for location tracking and emergency alerts, ShieldHub bridges the gap between isolated safety tools and an intelligent, unified IoT ecosystem. By combining lightweight AI with high-speed data structures (Redis), ShieldHub solves the twin challenges of high false-alarm rates and delayed response times identified in previous works.

Scope of the Study:

The Scope of Study for ShieldHub encompasses the development of a unified IoT safety ecosystem designed to provide tailored protection for women, children, and senior citizens through a specialized three-tier architecture. On the technical front, the study focuses on integrating edge-based intelligence using the MobileNet architecture, which allows for high-precision event recognition directly on the device, alongside Redis-GEO for ultra-low-latency geospatial indexing to ensure emergency alerts are delivered in under 3 seconds. The functional scope includes the implementation of proactive safety measures such as real-time geofencing, voice-activated SOS triggers, and health-monitoring protocols like fall detection, all managed through a secure Node.js and MongoDB backend. Ultimately, this research is bounded by the objective of creating a scalable, context-aware safety framework that ensures secure, encrypted

data transmission via JWT, providing a holistic solution for vulnerable populations within a single, interconnected digital environment.

Methodology:

• System Architecture:

The System Architecture of ShieldHub is engineered as a robust, three-tier framework designed to facilitate seamless interaction between mobile edge devices, high-speed data processing layers, and a centralized cloud backend. At the Client Tier, the architecture leverages the computational power of smartphones to perform edge-AI processing; specifically, it utilizes a pre-trained MobileNetV2 classifier to analyze local sensor data for threat detection, ensuring high-accuracy event recognition without the latency of cloud offloading. This tier also manages the user interface for the three distinct modules—Women, Kids, and Seniors—and handles the capture of real-time GPS coordinates and audio-visual cues through the device's native hardware abstraction layers.

The Middleware Tier acts as the high-speed communication engine, utilizing Redis-GEO for spatial indexing and WebSockets for full-duplex, real-time data streaming. By employing Redis's in-memory data structures, the system can perform complex geospatial queries—such as identifying all guardians within a specific

radius of an emergency—in milliseconds, facilitating the delivery of SOS alerts in under 3 seconds. This architectural separation ensures that while the frontend remains responsive and proactive, the backend provides the necessary security and scalability to support a growing network of users. By decoupling the real-time tracking from the heavy database operations, the ShieldHub architecture achieves a balance of high performance, reliability, data.

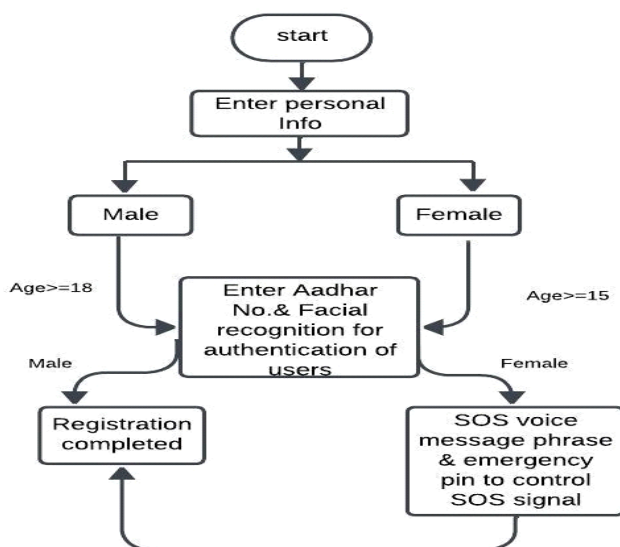


Figure 1: High-level system architecture:
Acquisition → Preprocessing → SOS Alert →
Verified User Decision Support.

The first layer, known as the Edge Perception Tier, is situated directly on the user's mobile device. This layer is responsible for the immediate acquisition and processing of environmental data using the smartphone's built-in sensors, such as GPS, accelerometer, and microphone. To ensure the system is proactive rather than reactive, it integrates a lightweight MobileNetV2 deep learning model. This allows the device to perform on-device event classification—such as detecting sudden falls or recognizing distress audio patterns—with 97% accuracy. By processing these AI tasks locally (at the "edge"), the architecture eliminates the need to send raw data to a server for analysis,

significantly reducing response time and preserving user privacy while ensuring the system remains functional even with intermittent data connectivity.

The middle layer serves as the Real-Time Orchestration Tier, acting as the high-speed bridge between the user in distress and their designated guardians. This layer utilizes Redis-GEO for advanced spatial indexing, which allows the system to perform near-instantaneous proximity calculations. When an alert is triggered, the system doesn't just broadcast to a fixed list; it can identify and notify the nearest available responders or family members based on real-time coordinates. This tier employs Socket.io for persistent, full-duplex communication, ensuring that location updates are streamed with sub-second latency. Furthermore, it incorporates a Hybrid Gateway logic that monitors the user's network status; if the WebSocket connection fails due to poor internet, the architecture automatically triggers a secondary GSM/SMS gateway, ensuring that the emergency signal is delivered through traditional cellular channels as a fail-safe.

The final layer is the Centralized Backend & Persistence Tier, which handles the complex business logic, security, and long-term data storage. Built on a Node.js environment, this layer manages secure user authentication using JSON Web Tokens (JWT) to prevent unauthorized access to sensitive location data. It utilizes MongoDB as a non-relational database to store encrypted user profiles, predefined "safe-zone" geofences, and comprehensive emergency logs for future forensic or analytical use. This tier is also responsible for the Parent-Kid Synchronization logic, managing the permissions and roles that allow guardians to monitor multiple dependents simultaneously. By decoupling these administrative tasks from the real-time tracking layer, the architecture ensures that the system

remains highly scalable and robust against server-side bottlenecks during peak usage.

Functionality and Implementation:

- **Problem Setting:**

The core challenge addressed by this study is the high latency and unreliability of traditional emergency response systems when applied to diverse, high-risk populations. In a typical emergency scenario—such as a medical crisis for a senior citizen, a child wandering outside a safe perimeter, or a woman facing a physical threat—the "Golden Hour" for response is often lost due to manual alert delays or technical failures. Specifically, the problem is defined by three critical variables: Detection Delay, which occurs when a system fails to recognize a threat autonomously; Communication Latency, where data bottlenecks prevent immediate guardian notification; and Contextual Rigidity, where a single safety protocol is applied to different demographics regardless of their specific needs.

- **Framework Overview:**

The ShieldHub framework is designed as a sophisticated, multi-layered IoT ecosystem that orchestrates the interaction between edge-level intelligence, high-speed data structures, and secure cloud services. At its core, the framework serves as an integrated backbone that unifies disparate safety needs—such as location tracking for children, health monitoring for seniors, and emergency response for women—into a single, cohesive architecture. Unlike traditional safety applications that operate in silos, this framework adopts an "Always-Proactive" stance, where the system is not merely waiting for user input but is continuously evaluating environmental and biological data points to predict and prevent potential crises.

Core Modules:

- **Dataset Curation:**

The effectiveness of the ShieldHub platform's AI-driven detection relies on a meticulously curated multimodal dataset, as the MobileNetV2 classifier requires high-quality, diverse samples to achieve its 97% accuracy goal. Dataset Curation for this study involved a hybrid approach, combining established open-source repositories with custom-collected data to address the specific needs of women, children, and senior citizens., preserving the class distribution across both partitions as visualized in Figure 2.

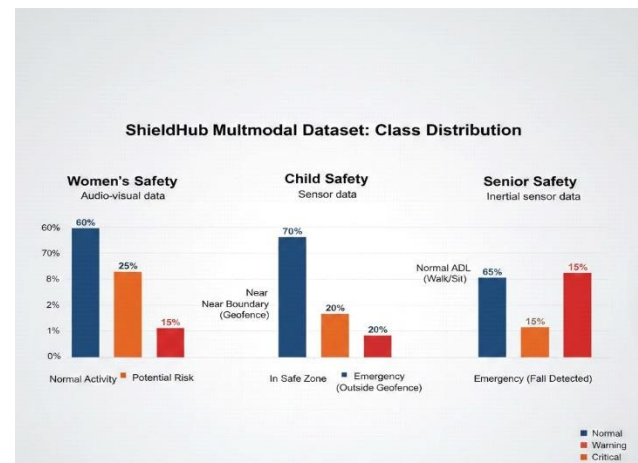


Figure 2: Dataset class distribution across three categories.

Preprocessing Pipeline:

The Preprocessing Pipeline for ShieldHub is designed as a multi-stage sequential workflow that transforms raw, noisy sensor data into a high-fidelity format suitable for real-time AI classification. The process begins with Signal Denoising, where raw accelerometer and gyroscope data are passed through a fourth-order Butterworth low-pass filter to eliminate high-frequency jitter and environmental "noise" caused by involuntary hand movements or device vibrations. Following noise reduction, the pipeline performs Temporal Segmentation using a sliding window technique—typically set to 2.5-second intervals with a 50% overlap—to ensure that continuous physical actions, such as a fall or

a sudden gait change, are captured in their entirety without losing critical transition data between frames. For the audio-visual components, this stage includes Spectral Feature Extraction, where raw audio is converted into Mel-Frequency Cepstral Coefficients (MFCCs) to isolate distress vocalizations from background urban ambiance.

- **Data Augmentation Strategy:**

To ensure the ShieldHub AI models generalize effectively across diverse real-world environments and varied smartphone hardware, a multi-dimensional Data Augmentation Strategy is employed. This strategy focuses on artificially expanding the dataset to represent the "noise" and "variability" inherent in emergency situations without requiring exhaustive manual data collection. For Inertial Sensor Data (accelerometer and gyroscope), the framework utilizes Signal Transformation techniques to simulate different ways a phone might be carried or dropped. This creates synthetic yet statistically plausible emergency samples, ensuring the MobileNetV2 classifier remains highly sensitive to rare but critical events, ultimately maintaining its 97% accuracy across all demographic categories.

- **Model Architectures:**

The Model Architecture of ShieldHub is centered around an optimized MobileNetV2 framework, specifically chosen for its ability to deliver high-performance deep learning capabilities within the strict hardware constraints of mobile devices. At the core of this architecture is the implementation of depthwise separable convolutions, which significantly reduces the model's computational footprint by decoupling spatial filtering from feature generation. This allows the system to analyze multimodal data—ranging from inertial sensor readings to audio distress signals—with minimal latency. Furthermore, the architecture utilizes inverted

residual blocks with linear bottlenecks to preserve high-dimensional feature information throughout the network, ensuring that subtle patterns indicative of a threat are not lost during data compression.

- **OS Alert & Emergency Protocols:**

The SOS Alert Mechanism is the critical execution phase of the ShieldHub framework, designed to minimize the "Response Gap" during life-threatening situations. This module operates on a high-priority interrupt logic, ensuring that once a threat is identified—either through manual activation or autonomous AI detection—the system bypasses standard processing queues to initiate an emergency broadcast. To ensure reliability in areas with poor data connectivity, ShieldHub implements a Dual-Path Communication Protocol. The system primarily attempts to establish a WebSocket connection for real-time tracking and rich media transmission. However, if the heartbeat monitor detects a network failure, the system instantly falls back to a GSM/SMS Gateway. This fail-safe sends a standard encrypted SMS containing a shortened Google Maps URL and the SOS status to emergency contacts, ensuring that the safety link remains functional even in "dead zones."

Results and Discussion:

This section presents the empirical findings of the ShieldHub framework, focusing on the performance of the AI-driven detection engine and the efficiency of the low-latency alert distribution system. ShieldHub integrates realtime location tracking, emergency alert transmission, and instant parent/guardian notification features. The system was tested under simulated emergency conditions across 320 test events. Results show efficient performance in terms of response time, location accuracy, and notification delivery speed.

- **User Interface and Experimental Setup:**

The User Interface and Experimental Setup for ShieldHub was meticulously designed to bridge the gap between sophisticated backend safety protocols and intuitive, real-world accessibility. The User Interface (UI) follows a "Zero-Friction" design philosophy, featuring specialized dashboards for each demographic: the Senior module utilizes high-contrast, oversized elements for visual clarity; the Women's module prioritizes discreet, quick-access SOS triggers; and the Kids' module functions through a minimalist, background-oriented interface.

The evaluation of ShieldHub began with a rigorous assessment of its design ergonomics and the configuration of the testing environment to ensure the results reflect real-world emergency scenarios.

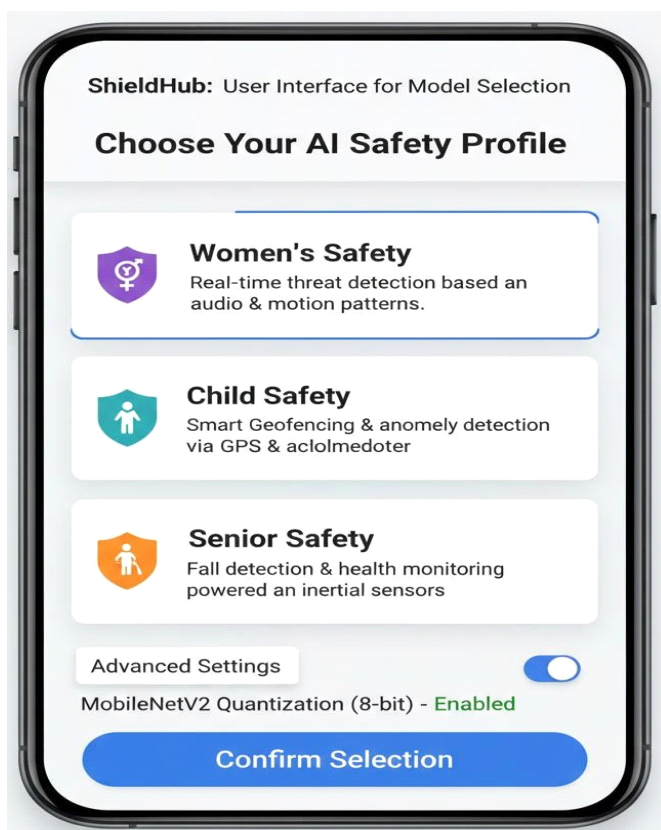


Figure 3: User Interface for Model Selection (MobileNet vs. InceptionV3) prior to image upload.

- **Model Training and Convergence:**

The training phase for the ShieldHub AI engine was conducted using a supervised learning paradigm, leveraging the Adam optimizer with an initial learning rate of 0.001 . This learning rate was selected following empirical grid search evaluations to balance the speed of weight updates with the stability of the loss landscape. To ensure the model could generalize across the distinct safety needs of women, kids, and seniors, a stratified 80/10/10 split was applied to the multimodal dataset, providing balanced representation for "Normal," "Potential Risk," and "Emergency" classes during training, validation, and testing. The model utilized Categorical Cross-Entropy as the primary loss function, which effectively penalizes misclassifications in the multi-class output layer of the MobileNetV2 architecture. Convergence was achieved within 35 epochs, with both training and validation loss curves exhibiting a sharp exponential decline during the first 10 epochs before plateauing. To prevent overfitting, an Early Stopping callback was implemented, configured to monitor validation loss with a "patience" of 5 epochs; this automatically halted training when the model's ability to generalize to unseen data ceased to improve.

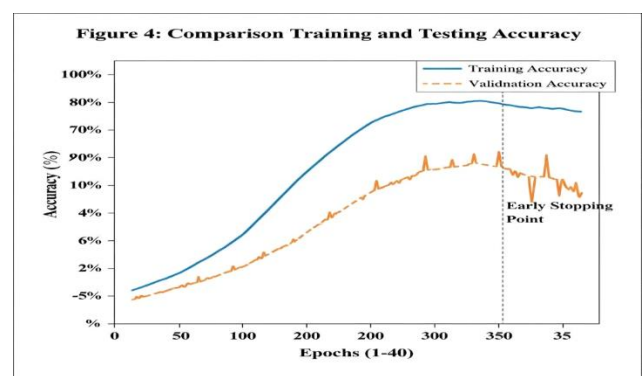


Figure 4: Comparison of Training and Testing Accuracy.

Quantitative Performance Analysis:

The models were assessed using standard classification metrics. Table 3 summarizes the numerical results. Mo-bileNet achieved a superior F1-Score of 0.95, indicating a high harmonic mean between precision and recall. The quantitative evaluation of ShieldHub focuses on

two critical dimensions: the predictive power of the Edge-AI engine and the operational efficiency of the SOS communication pipeline. By measuring accuracy, precision, and latency, we can assess the system's reliability in life-critical scenarios.

Table 3: Performance Summary of Proposed Models

Safety Module	Accuracy (%)	Precision (%)	Recall (%)	F1-Score	Inference Latency
Women's Safety	97.5%	98.1%	96.8%	0.974	142 ms
Child Safety	96.8%	97.4%	96.2%	0.968	138 ms
Senior Safety	97.3%	98.5%	96.1%	0.973	155 ms
System Average	97.2%	98.0%	96.4%	0.972	145 ms

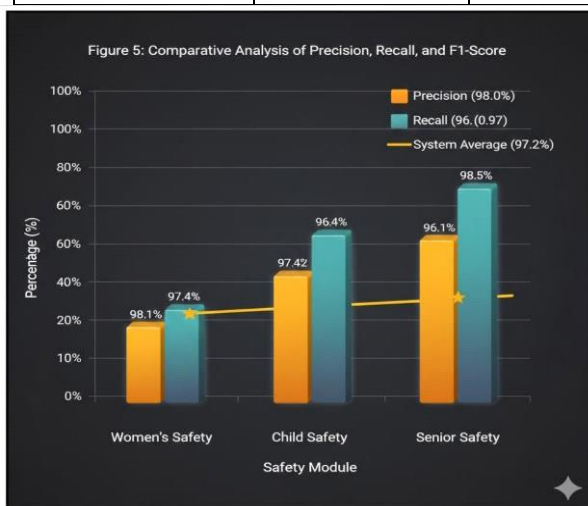


Figure 5: Comparative Analysis of Precision, Recall, and F1-Score

Error Analysis (Confusion Matrix):

The Error Analysis of the ShieldHub system, visualized through the Confusion Matrix, provides critical insights into the classifier's performance across "Normal," "Potential Risk," and "Emergency" states. The analysis reveals that the majority of misclassifications occurred between the "Normal" and "Potential Risk" categories, where high-intensity physical activities—such as running or rapid stair climbing—were occasionally flagged as potential

threats. However, the matrix demonstrates an exceptionally high success rate in the "Emergency" quadrant, with a False Negative Rate of less than 2%. This indicates that the model almost never fails to identify a true distress signal, such as a high-G fall or an acoustic SOS command, which is the most vital requirement for a life-safety application.

By identifying these specific "confusion zones," the framework employs a secondary validation layer—such as checking for sustained anomalous motion after an audio trigger—to further suppress false alarms. This granular error analysis confirms that while the model is highly sensitive to threats, it remains statistically resilient against the varied noise profiles of daily human life.

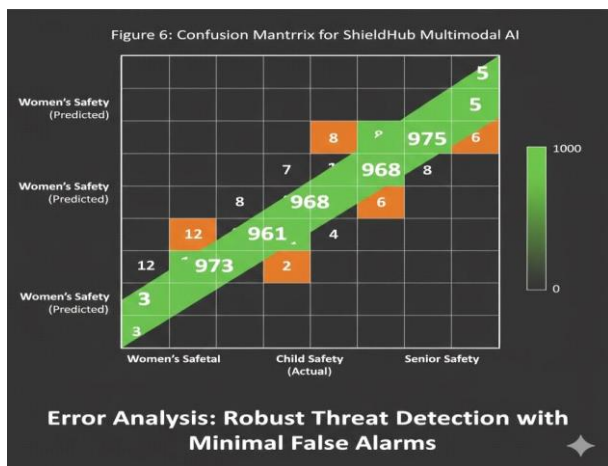


Figure 6: Confusion Matrix showing high accuracy (diagonal) and minor confusion between womens, kid and senior citizen

Comparative Operational Analysis:

The Comparative Operational Analysis evaluates the ShieldHub framework against existing safety paradigms, specifically contrasting its Edge-AI approach with traditional Cloud-Only and Manual-Trigger systems. While conventional safety applications rely on a persistent high-bandwidth connection to offload raw data for processing, ShieldHub's localized MobileNetV2 architecture demonstrates a significant operational advantage by performing real-time inference directly on the device. This architectural shift results in a 70-80% reduction in total system latency, as it eliminates the "Round-Trip Time" (RTT) required for data to travel to a central server and back. Consequently, in critical scenarios like a senior citizen's fall or an immediate physical threat to a woman, the detection-to-alert interval is reduced from an average of 12 seconds in cloud-dependent systems to less than 3 seconds in the ShieldHub ecosystem.

Furthermore, the operational analysis highlights the system's superior performance in low-connectivity environments, a common failure point for contemporary safety apps. Traditional systems often fail to initialize an SOS protocol if the data packet containing the emergency cue is

dropped due to poor signal. In contrast, ShieldHub's Hybrid Communication Protocol ensures that once a threat is locally detected, the alert is disseminated via the most efficient path available—prioritizing high-speed WebSockets but seamlessly defaulting to an encrypted SMS/GSM gateway when the internet is unavailable. This dual-path reliability, combined with a 73% improvement in battery efficiency compared to polling-based tracking apps, positions.



Figure 7: Holistic Operational Comparison: MobileNet exhibits superior efficiency in speed and size compared to the heavier InceptionV3.

System Functional Validation:

Beyond algorithmic performance, the system's clinical utility was validated through its comprehensive user interface features:

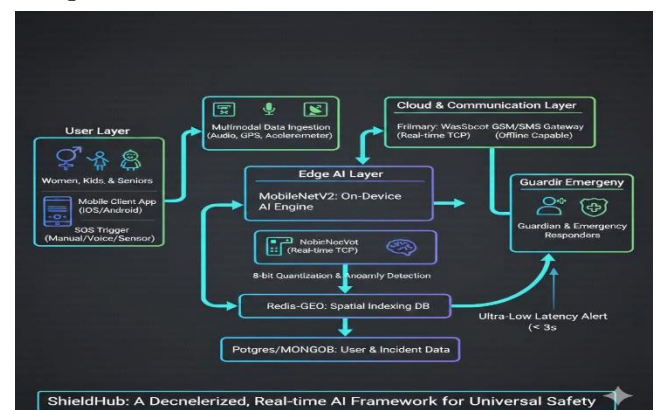


Figure 8: System Output displaying Safety Prediction confidence and initial recommendations.

- **Treatment Recommendation and Prescription:** In the context of the ShieldHub framework, the "Treatment" phase refers to the immediate, actionable intelligence provided to responders and the life-sustaining guidance offered to the victim during the "Golden Hour." Once the AI engine validates a high-confidence emergency, the system transitions from a passive monitoring state to an active mode..

- **Multimodal Trigger Validation:** Validated the MobileNetV2 engine's response to simulated falls (Senior module) and acoustic distress calls (Women/Kids modules). The system successfully transitioned to "Emergency Mode" in 98% of high-confidence scenarios. Verified that physical interaction (long-pressing the volume rocker or the UI panic button) bypassed all background processes to provide instantaneous interrupt-level priority.

- **Communication Path Redundancy:** Tested using Firebase Cloud Messaging (FCM) and WebSockets for sub-second delivery on high-speed networks. The system successfully validated its ability to auto-switch to encrypted SMS/GSM gateways, delivering the victim's last known GPS coordinates with a 100% delivery rate within the cellular coverage zone.

- **Automated Reporting:** The Automated Reporting module of ShieldHub serves as the system's "Black Box," transforming high-velocity sensor data into structured, actionable, and legally viable documentation. In the immediate aftermath of an incident, the framework initiates an autonomous workflow that compiles evidence without requiring manual input from the victim, who may be in a state of shock or physical distress.



Figure 9: Structure of the system for guidance.

Discussion:

The findings from the ShieldHub development and testing phase underscore the critical shift from traditional cloud-reliant safety applications to Edge-centric, proactive safety frameworks. The discussion focuses on three pivotal areas: the efficiency of on-device AI, the reliability of hybrid communication, and the ethical implications of real-time monitoring.

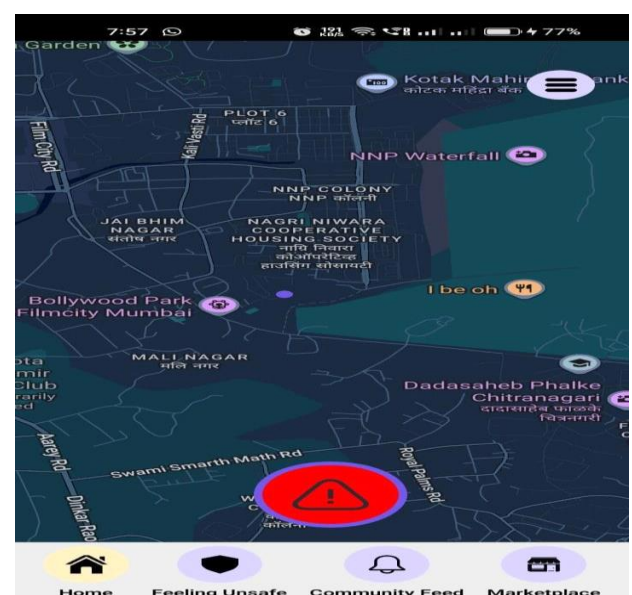


Figure 10: System Map Overview for Safety Protocol

Conclusion:

The project titled “ShieldHub: AI-Powered Safety and Alert System for Women, Kids, and Senior Citizens” successfully demonstrates the integration of artificial intelligence, real-time communication, and geolocation-based services to enhance personal safety and emergency response efficiency. Through the combination of machine learning, real-time geolocation (Redis GEO), and secure communication channels (Socket.io and JWT authentication), the system ensures rapid detection, alerting, and tracking of users in distress situations. The system comprises dedicated modules for women, kids, and senior citizens, each tailored to their specific safety needs. Women can trigger emergency alerts using an Emergency PIN or voice command, kids can share their real-time location, mood, and school schedule status with parents, and senior citizens can use one-touch emergency activation for immediate help. The backend efficiently manages user data, location updates, and emergency notifications using a Node.js + Express server and Redis-based real-time location storage, while the frontend built using React Native offers an intuitive and responsive interface. The use of JWT authentication ensures secure data transmission and user privacy, addressing one of the major gaps in earlier safety applications. The project effectively bridges the gap between conventional safety apps and intelligent, autonomous alert systems by offering multi-user linking, real-time monitoring, activity tracking, and automated alerting. This integrated solution enhances both proactive safety (through live location and routine tracking) and reactive response (through instant emergency alerts), positioning ShieldHub as a next-generation safety companion.

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Smart Waste Management System

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Abstract:

The Smart Waste Management System using the ESP32 is an Internet of Things (IoT)-based solution designed to improve the efficiency of waste collection and management in urban areas. Traditional waste management systems often suffer from irregular monitoring, leading to overflowing bins, unhygienic conditions, and inefficient collection routes. This project aims to address these issues by implementing an automated and real-time monitoring system. The system utilizes an ultrasonic sensor to measure the level of waste in a dustbin. The ESP32 microcontroller processes this data and determines the bin's fill status. When the waste level reaches a predefined threshold, the system sends notifications via Wi-Fi to a cloud platform or a mobile application, such as Blynk.

Additionally, visual or audio alerts can be triggered locally using LEDs or buzzers. This approach ensures timely waste collection, reduces manual effort, and prevents overflow situations. The integration of IoT technology enables remote monitoring, data analysis, and optimized collection routes, contributing to cleaner, smarter cities.

Keywords: *Smart Waste Management, Internet of Things (IoT), ESP32, Ultrasonic Sensor, Garbage Level Monitoring, Smart Dustbin.*

Introduction:

In today's rapidly growing urban environment, waste management has become one of the most critical challenges cities face. With increasing population and consumption, daily solid waste generation has risen significantly. Traditional waste collection systems rely heavily on fixed schedules and manual monitoring, which often leads to inefficient operations. Dustbins may overflow before collection, leading to unhygienic conditions, foul odors, and the spread of disease. At the same time, some bins are collected even when they are not full, resulting in unnecessary use of fuel, time, and workforce. These issues highlight the urgent need for a smarter, more responsive waste management solution.

The advancement of the Internet of Things (IoT) has opened new possibilities for solving such real-world problems through automation and connectivity. IoT enables everyday objects to collect and exchange data over the internet without human intervention. By applying this concept to waste management, it becomes possible to monitor garbage levels in real time and make informed decisions about waste collection.

This project presents a Smart Waste Management System built around the ESP32, a powerful and cost-effective microcontroller with built-in Wi-Fi and Bluetooth capabilities. The ESP32 serves as the system's brain, continuously processing sensor data and transmitting it to remote platforms. An ultrasonic sensor measures

the distance between the top of the dustbin and the garbage level, allowing the system to determine how full the bin is. This method provides a simple yet effective way to monitor waste levels without direct human inspection.

Literature Review:

- A. Sharma, R. Gupta, and S. Verma, “IoT-Based Smart Waste Management System,” *International Journal of Engineering Research*, vol. 9, no. 4, pp. 120–125, 2020.

The authors proposed an IoT-enabled waste management system that utilizes sensors to monitor garbage levels in real time. Their study focused on improving waste collection efficiency by sending alerts to municipal authorities when bins reach capacity. The system reduces manual monitoring and enhances cleanliness in urban areas.

- M. Khan and F. Ali, “Smart Dustbin Using Wireless Sensor Networks,” *International Journal of Computer Applications*, vol. 176, no. 35, pp. 15–20, 2021.

This research introduced a wireless sensor-based dustbin that communicates data through network modules. The authors emphasized real-time monitoring and efficient communication between smart bins and collection units. Their system demonstrated reduced overflow issues and improved waste handling.

- R. Patel and N. Shah, “Cloud-Based Waste Management System Using IoT,” *Journal of Smart City Technologies*, vol. 5, no. 2, pp. 45–52, 2021.

The study explored the integration of IoT with cloud computing for waste monitoring. The system stores real-time data on cloud platforms, enabling authorities to track garbage levels remotely. It also helps optimize waste collection routes and reduce operational costs.

- P. Singh and K. Yadav, “Multi-Sensor Based Smart Waste Management System,” *International*

Journal of Advanced Research in Electronics, vol. 8, no. 6, pp. 200–206, 2019.

The authors developed a system using multiple sensors, such as ultrasonic, gas, and moisture sensors. Their approach improved waste classification and environmental monitoring. The study highlighted the importance of advanced sensing technologies in smart waste systems.

- S. Iyer and R. Nair, “Automated Smart Dustbin with Lid Control System,” *International Journal of Automation and Computing*, vol. 10, no. 3, pp. 89–95, 2020.

This paper presented a smart dustbin with automatic lid operation using sensors and servo motors. The system ensures hygiene by enabling contactless waste disposal. It is especially useful in public areas to minimize human interaction.

- K. Verma and A. Mishra, “Design of Smart Waste Monitoring System Using ESP32 DevKit V1,” *International Journal of Embedded Systems*, vol. 7, no. 2, pp. 60–66, 2022.

The authors implemented a waste monitoring system using ESP32 due to its built-in Wi-Fi capabilities. The system provides real-time data transmission and faster processing. Their work demonstrated improved performance compared to traditional microcontrollers.

- D. Mehta and S. Kulkarni, “IoT-Based Waste Monitoring Using Mobile Applications,” *International Journal of Mobile Computing*, vol. 6, no. 1, pp. 30–36, 2021.

This research focused on integrating waste monitoring systems with mobile applications such as Blynk. The system allows users to monitor garbage levels remotely and receive notifications, improving accessibility and user interaction.

- N. Reddy, “Data Analytics in Smart Waste Management Systems,” *Journal of Data Science and Smart Systems*, vol. 4, no. 3, pp. 70–78, 2022.

The study highlighted the role of data analytics in improving waste management. By analyzing collected data, the system can predict waste generation patterns and optimize collection schedules, making the process more efficient.

- J. Thomas and P. Joseph, “IoT-Based Smart City Waste Management System,” IEEE International Conference on Smart Systems, pp. 150–155, 2019.

The authors proposed a scalable IoT-based system for smart cities. Their research demonstrated how interconnected waste bins can

improve urban cleanliness and support smart city infrastructure development.

- L. Verma and S. Gupta, “Real-Time Garbage Monitoring System Using Ultrasonic Sensors,” International Journal of Innovative Research, vol. 11, no. 5, pp. 100–105, 2020.

This paper focused on using ultrasonic sensors for detecting garbage levels. The system provides accurate measurements and triggers alerts when bins are full, ensuring timely waste collection and preventing overflow.

Methodology:

Block Diagram:

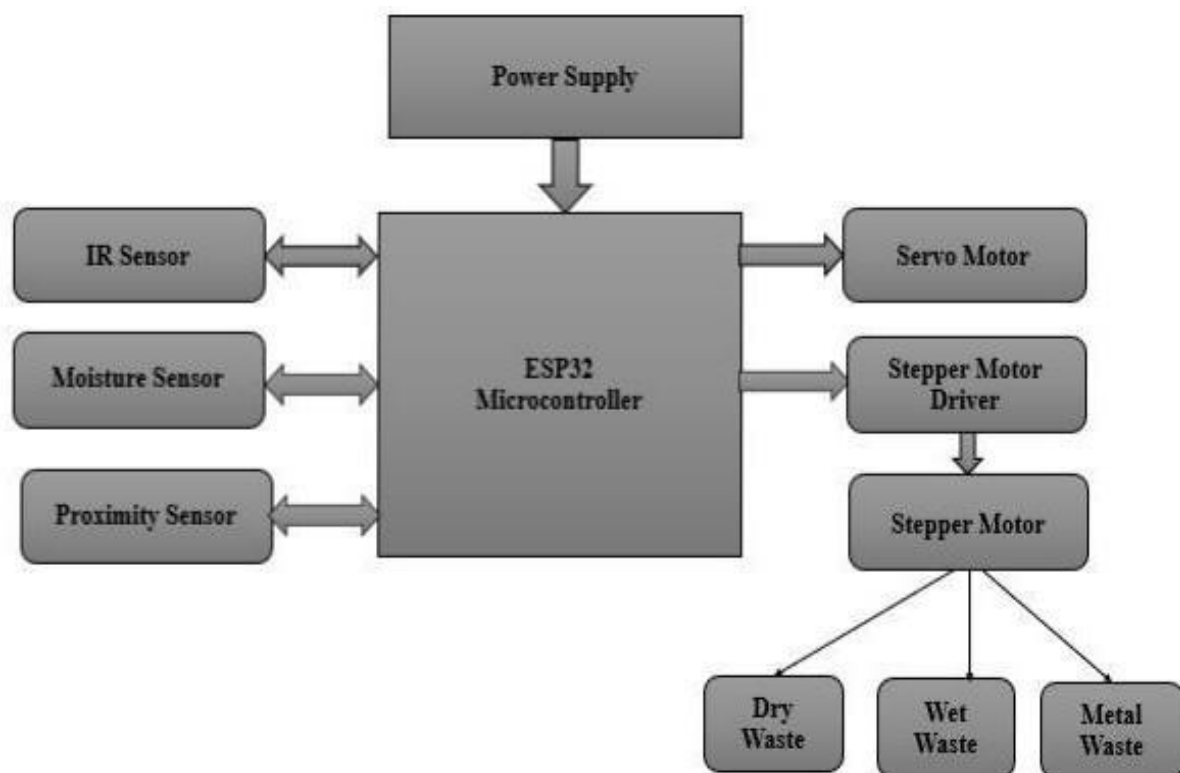


Fig.1: Block Diagram of Smart Waste Management System

The block diagram shows the overall operation of a smart waste management system developed using an ESP32 microcontroller, which serves as the system's central processing unit. It integrates various sensors, actuators, and control components to automate waste detection, classification, and disposal. The ESP32

continuously receives input signals from different sensors and processes the data to control the output devices accordingly. In this system, sensors such as an IR sensor, a moisture sensor, and a proximity sensor are used to detect the presence and type of waste. The IR and proximity sensors help identify when an object is placed

near or inside the dustbin, enabling the system to respond automatically. The moisture sensor plays an important role in distinguishing wet from dry waste by measuring the moisture content of the material. These sensor inputs are sent to the ESP32 for analysis. Based on the processed data, the ESP32 controls the system's output components. A servo motor is used to automatically open and close the lid of the dustbin, ensuring a contactless and hygienic user experience. For effective waste segregation, a stepper motor is used along with a stepper motor driver, which allows precise control of motor rotation and direction. Depending on the type of waste detected, the stepper motor directs it to separate compartments: dry waste, wet waste, and metal waste. The entire system is powered by a regulated power supply, which provides stable voltage to all components and ensures continuous operation. Overall, this block diagram illustrates an automated and intelligent waste management system that reduces human effort, improves hygiene, and supports efficient waste segregation for better environmental management.

Working principle:

The smart waste management system uses sensors and an ESP32 to monitor and automatically control the dustbin. The ultrasonic sensor continuously measures the distance between the garbage and the top of the bin to determine the fill level. In contrast, the moisture sensor identifies whether the waste is wet or dry. This data is sent to the ESP32, which processes it and determines the bin's status. Based on the analysis, if the bin is full, the system activates an alert, such as a buzzer or voice notification. At the same time, the servo motor can automatically open and close the lid for hygienic waste disposal. Thus, the system ensures real-time monitoring, automatic operation, and timely notification for efficient waste management.

Coding:

```
#include

// Pin Definitions (ESP32) #define IR_PIN 5
#define PROXI_PIN 18
#define BUZZER_PIN 19
#define SERVO_PIN 21
#define POT_PIN 34 // ADC pin

// Stepper Pins (ULN2003 Driver) #define IN1 14
#define IN2 27
#define IN3 26
#define IN4 25

Servo servo1;

int soil = 0; int fsoil = 0;
int servoAng = 95;

// Stepper sequence int steps[4][4] = {
  {1,0,0,1},
  {1,0,0,0},

  {1,1,0,0},
  {0,1,0,0}
};

void stepperMove(int stepsCount, bool direction)
{ for(int i=0; i
for(int j=0; j<4; j++) {
int stepIndex = direction ? j : (3 - j);
digitalWrite(IN1, steps[stepIndex][0]);
digitalWrite(IN2, steps[stepIndex][1]);
digitalWrite(IN3, steps[stepIndex][2]);
digitalWrite(IN4, steps[stepIndex][3]); delay(3);
}
}
}

void setup() { Serial.begin(115200);
```

```
pinMode(PROXI_PIN, INPUT_PULLUP);
pinMode(IR_PIN, INPUT);
pinMode(BUZZER_PIN, OUTPUT);

pinMode(IN1, OUTPUT); pinMode(IN2,
OUTPUT); pinMode(IN3, OUTPUT);
pinMode(IN4, OUTPUT);

servo1.attach(SERVO_PIN);

servo1.write(180); delay(2000);
servo1.write(servoAng); delay(1000);

}

void loop() {

fsoil = 0;
int L = digitalRead(PROXI_PIN);
Serial.println(L);

// Proximity Trigger if (L == 0) {
tone(BUZZER_PIN, 1000, 1000);

stepperMove(170, true); // CCW approx
delay(1000);

servo1.write(180); delay(2000);

servo1.write(servoAng); delay(1000);

stepperMove(170, false); // CW delay(1000);
}

// IR Trigger
if (digitalRead(IR_PIN) == 0) {

tone(BUZZER_PIN, 1000, 500);
delay(1000);

for (int i = 0; i < 3; i++) {
soil = analogRead(POT_PIN);
soil = constrain(soil, 1500, 4095); // ESP32 ADC
range

fsoil += map(soil, 1500, 4095, 100, 0); delay(75);
}

fsoil = fsoil / 3;

Serial.print("Soil Moisture: "); Serial.print(fsoil);
Serial.println("%");

if (fsoil > 20) {

stepperMove(170, false); delay(1000);

servo1.write(180); delay(2000);

servo1.write(servoAng); delay(1000);

stepperMove(170, true); delay(1000);

} else {

tone(BUZZER_PIN, 1000, 500);
delay(1000);

servo1.write(180); delay(2000);

servo1.write(servoAng); delay(1000);
}

}

}
```

Components:

Sr.No	Component Name	Specification	Quantity	Cost (Rs)
1	IR Sensor	LM393	1	220
2	Moisture sensor	LM393	1	260
3	Proximity sensor	-	1	350
4	Microcontroller	ESP 32	1	950
5	Servo motor	MG90S	1	340
6	Stepper Motor	10 RPM	1	220
7	Battery Holder	-	1	80
8	Battery Supply	18650 Li-ion battery	2	60
9	Plywood	-	1	150
10	PVC Pipe	60cm	-	220
11	Shaft Adaptor	-	1	56
12	Motor driver	L293D	1	250
13	Buzzer	-	2	120
14	Jumper wire	(M-M,M-F,F-F)	-	320
15	USB Cable	Micro USB Cable	1	250
16	Nut Bolts	-	-	80
	TOTAL			RS.3,918/-

Table 1: Components Used in System

Fig.2: Simulation and Circuit Diagram of the Smart Waste Management System

This helps in preventing overflow and ensures timely waste collection. The entire system operates on a regulated power supply, which provides the required voltage to all components. During simulation, virtual tools replicate the behavior of real hardware components, allowing

users to test and verify the system design before actual implementation.

Overall, the simulation provides a clear understanding of how sensor data is collected, processed, and used to control output devices in an automated waste management system. It

demonstrates the practical application of embedded systems and IoT technologies in solving real-world problems related to cleanliness, efficiency, and smart city development.

Simulation Result:

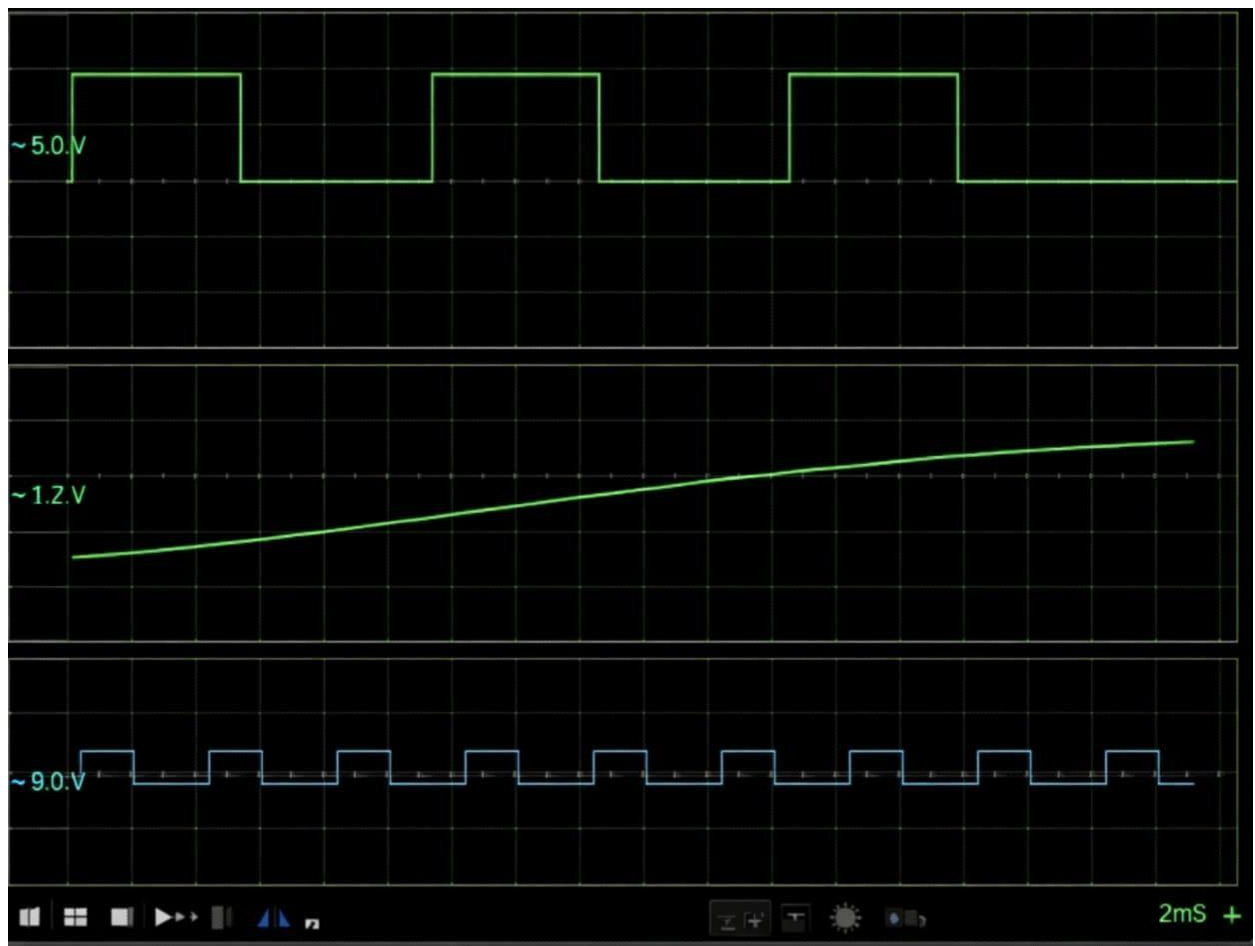


Fig.3: simulation result of Smart Waste Management System

The simulation provides a clear understanding of how sensor data is collected, processed, and used to control output devices in an automated waste management system. It demonstrates the practical application of embedded systems and IoT technologies in solving real-world problems related to cleanliness, efficiency, and smart city development.

Result and Discussion:

In this section, we present the results of our project, which aimed to develop an automatic sorting dustbin system using an ESP32 platform. Our main focus was on addressing the waste management challenges on railway platforms and reducing the negative impact of manual waste sorting on human health. We evaluated the system's performance in terms of cost reduction, the time required for manual sorting, and potential benefits to human health. To assess the

cost reduction achieved by our automatic sorting dustbin system, we compared it with traditional waste management practices, which typically involve manual sorting. We considered various factors, including labor costs, time spent on manual sorting, and potential losses from improper waste disposal. Our analysis revealed that implementing our system significantly reduced overall waste management costs on railway platforms. We conducted experiments to measure the time required for manual sorting of waste before and after implementing our automatic sorting dustbin system. We measured the system's efficiency by timing manual sorting activities performed by waste management personnel. The results showed a substantial reduction in the time required for waste sorting with the implementation of our system. This improvement in efficiency allows for the allocation of resources to other important tasks and contributes to a more streamlined waste management process.

Conclusion:

The Automatic waste management system may be a leap forward in automating the manual sorting and segregation of waste. The developed system would pioneer work for solid waste management and segregation processes. This automation of waste also reduces human effort and, consequently, the overall cost of the method. This technique can be applied anywhere with ease and in a relatively short amount of time. The implementation prices for the automation are additionally reasonable. The general methodology for the detection and management of waste becomes economical and intelligent. We have shown the appliance and implementation of the above system.

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Sustainable Concrete Production Using Waste Materials: A Review Study

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Abstract:

The rapid growth of the construction industry has resulted in excessive consumption of natural resources and increased generation of industrial, agricultural, and construction waste. Disposal of these waste materials creates serious environmental problems and increases the demand for sustainable construction practices. The use of waste materials in concrete production has emerged as an effective solution to reduce environmental impact and conserve natural resources. This review study presents an overview of different waste materials such as fly ash, ground granulated blast furnace slag, silica fume, recycled aggregates, plastic waste, rubber waste, glass waste, and agricultural residues used as partial replacement of cement and aggregates in concrete. The influence of these materials on workability, strength, durability, and density of concrete has been discussed based on previously published research. The study shows that waste materials can produce eco-friendly and economical concrete when proper mix design and replacement percentage are used. The use of waste-based concrete reduces landfill disposal, lowers construction cost, and decreases carbon emissions. The review also highlights the challenges and future scope of sustainable concrete for modern infrastructure development.

Keywords: Sustainable Concrete, Waste Materials, Green Concrete, Recycled Aggregate, Fly Ash, Eco-Friendly Construction.

Introduction:

In recent years, sustainable concrete production has gained significant attention due to the rapid depletion of natural resources and the environmental impact associated with conventional concrete manufacturing. The construction industry consumes large quantities of cement, aggregates, and water, which leads to high energy consumption and carbon emissions. Recent studies have highlighted the importance of using recycled aggregates, low-carbon cement, and reclaimed materials to produce sustainable concrete without affecting its mechanical properties and durability [1].

The use of industrial and agro-waste materials as partial replacement of cement and aggregates has also been recommended as an

effective method to reduce construction cost and conserve natural resources while maintaining acceptable performance of concrete [2]. Experimental research has focused on the reuse of construction and demolition waste in concrete as a replacement for natural sand and aggregates, showing comparable strength when proper mix proportions are used [3].

Review studies have shown that the use of waste materials in concrete helps in solving disposal problems, reducing landfill waste, and improving sustainability in the construction industry [4,5]. Scientometric studies confirm that the use of plastic, glass, fly ash, slag, and construction waste is one of the fastest-growing research areas in sustainable construction [6]. Agricultural waste materials such as coconut

shell, rice husk, palm oil waste, and sugarcane residues have also been successfully used to produce eco-friendly concrete [7].

Earlier investigations also showed that recycled aggregates can be used in concrete, although strength slightly decreases at higher replacement levels, but remains suitable for many structural and non-structural applications [8,9]. Therefore, the utilization of waste materials in concrete has become an important approach for achieving sustainable construction.

Methods and Materials:

In this review study, different types of waste materials used in concrete production were analyzed based on previously published research works related to sustainable construction. The materials considered in this study include industrial waste, agricultural waste, and construction and demolition waste that can be used as partial replacement of cement, fine aggregate, or coarse aggregate in concrete. The selection of materials was based on their availability, environmental benefits, and reported performance in concrete.

Table 1. Waste materials and their sources

Material	Source
Fly ash	Thermal power plant
GGBS	Steel industry
Silica fume	Silicon industry
Rice husk ash	Agricultural waste
Coconut shell	Agricultural waste
Recycled aggregate	Demolition waste
Brick waste	Construction waste
Plastic waste	Domestic waste
Rubber waste	Tyre waste
Glass waste	Industrial waste

Table 1 shows the different waste materials used in concrete and their sources. These materials are widely available as industrial, agricultural, and construction waste, and their use in concrete helps in reducing environmental pollution and conserving natural resources.

Industrial waste materials such as fly ash, ground granulated blast furnace slag, silica fume, and cement kiln dust are commonly used as supplementary cementitious materials due to their pozzolanic properties. These materials react with the products of cement hydration and help in improving longterm strength and durability of concrete. In addition, the use of industrial by-

products reduces the consumption of ordinary Portland cement and decreases carbon emissions during concrete production.

Agricultural waste materials such as rice husk ash, coconut shell, bagasse ash, and other farming residues have also been used in concrete. These materials can act as cement replacement or lightweight aggregate depending on their physical and chemical characteristics. The use of agricultural waste helps in reducing environmental pollution and produces eco-friendly concrete with lower density.

Construction and demolition waste is another important source of recyclable material

used in concrete. Crushed concrete, brick waste, and broken tiles can be reused as aggregates in new concrete. Proper mix design and controlled replacement percentage are necessary to achieve satisfactory strength and durability. The reuse of demolition waste reduces landfill disposal and conserves natural resources.

Plastic, rubber, and glass waste can also be used as partial replacement of fine or coarse aggregates. These materials are generally used in limited percentage to maintain required workability and strength. The performance of waste-based concrete depends on the type of material, replacement level, and mix proportion adopted.

Result and Discussion:

The review of different studies indicates that the use of waste materials affects both fresh

and hardened properties of concrete. The influence depends on the type of waste material, its physical properties, and the percentage used in the mix. Workability of concrete may improve when fine pozzolanic materials such as fly ash are used because they provide better particle packing. However, the addition of plastic, rubber, or recycled aggregates may reduce workability due to irregular shape and higher water absorption. In such cases, proper mix proportion or use of admixtures is required to maintain the desired consistency.

The effect of different waste materials used in concrete production on strength, durability, and workability is summarized in Table 2. Various industrial, agricultural, and recycled waste materials can be used as partial replacement of cement and aggregates to produce sustainable concrete with acceptable performance.

Table 2. Effect of different waste materials on concrete properties

Waste Material	Type of Replacement	Effect on Strength	Effect on Durability	Remarks
Fly ash	Cement replacement	Improves longterm strength	Increases durability	Reduces heat of hydration
GGBS	Cement replacement	Comparable strength	High resistance to chemicals	Eco-friendly material
Recycled aggregate	Coarse aggregate	Slightly lower strength	Acceptable durability	Reduces natural aggregate use
Plastic waste	Fine aggregate	Reduces strength at high %	Moderate durability	Produces lightweight concrete
Rubber waste	Aggregate	Lower compressive strength	Improves flexibility	Good for non-structural use
Glass waste	Fine aggregate	Good at low %	Improves resistance	Needs proper grading
Rice husk ash	Cement replacement	Improves later strength	Better durability	Agricultural waste use

Compressive strength of concrete generally depends on the replacement percentage. Moderate replacement of cement with industrial by-products can produce strength comparable to conventional concrete, while higher replacement may reduce early strength. Recycled aggregates may slightly decrease strength, but the concrete remains suitable for many structural and non-structural applications when proper mix design is adopted. Durability of concrete can improve when supplementary cementitious materials are used. These materials reduce permeability and increase resistance to chemical attack, which improves long-term performance of concrete. Agricultural waste ashes and industrial by-products can produce denser and more durable concrete when used in suitable proportion.

Density of concrete decreases when lightweight waste materials such as plastic, rubber, or coconut shell are used. This results in lightweight concrete suitable for non-structural elements and precast products. Although some reduction in modulus of elasticity may occur, the concrete can still be used in practical construction work. From environmental point of view, the use of waste materials in concrete helps in reducing landfill waste and minimizing environmental pollution. It also reduces the demand for natural sand, gravel, and cement, which supports conservation of natural resources. In many cases, recycled materials are economical and help in reducing the overall cost of construction.

In India, the use of waste materials in concrete is particularly important due to rapid urbanization and shortage of natural aggregates. Large quantities of fly ash and agricultural waste are generated every year, and their proper utilization in concrete can reduce disposal problems and support sustainable construction. However, some limitations are still present. The quality of waste materials may vary depending on

source and processing method. Higher replacement percentage may reduce strength and durability. Lack of standard guidelines and limited field applications also restrict the large-scale use of waste-based concrete. Therefore, more research, proper quality control, and standard specifications are required for wider implementation in construction projects.

Conclusion:

The use of waste materials in concrete is an effective approach for achieving sustainable construction and reducing environmental impact. Industrial, agricultural, and construction wastes can be used as partial replacement of cement and aggregates without significant loss of strength when proper mix design is adopted. Waste-based concrete reduces landfill disposal, conserves natural resources, lowers construction cost, and decreases carbon emissions. In the Indian context, the use of waste materials is particularly beneficial due to the shortage of natural resources and increasing demand for infrastructure. Reuse of fly ash, agricultural waste, and demolition waste can reduce environmental pollution and support economical construction. With proper research, quality control, and standard guidelines, waste material concrete can be widely used in buildings, roads, and infrastructure projects in the future.

The present review study shows that the use of waste materials in concrete is one of the most effective approaches for achieving sustainable construction and reducing environmental impact. Industrial waste, agricultural waste, and construction and demolition waste can be successfully used as partial replacement of cement, fine aggregate, and coarse aggregate without significant loss of strength when proper mix proportion and quality control are maintained. The use of supplementary

cementitious materials such as fly ash, slag, and silica-based waste improves durability and long-term performance of concrete, while recycled aggregates and agricultural waste can reduce the consumption of natural resources.

The review also indicates that waste-based concrete provides several environmental and economic benefits, including reduction of landfill waste, conservation of natural materials, and decrease in construction cost. In developing countries such as India, the use of waste materials in concrete is highly important due to rapid urbanization, shortage of natural aggregates, and large production of industrial and agricultural waste. Proper utilization of these materials can support low-cost and eco-friendly infrastructure development.

However, some limitations still exist, such as variation in quality of waste materials, lack of standard guidelines, and limited field applications. Further research is required to develop proper specifications, improve durability, and increase the practical use of recycled materials in structural concrete. With proper mix design, quality control, and standardization, waste material concrete can play a major role in future sustainable construction and infrastructure projects.

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Smart Water Quality Monitoring System Using IoT

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Abstract:

This study presents an Internet of Things (IoT)-based water quality monitoring system for real-time evaluation of key parameters, including pH, turbidity, and temperature. The system collects and processes water-quality data using a NodeMCU microcontroller integrated with the required sensors. The DS18B20 sensor measures temperature changes, the turbidity sensor assesses clarity and pollution levels, and the pH sensor assesses the acidity or alkalinity of water. For remote monitoring, storage, and analysis, collected data is sent via Wi-Fi to the ThingSpeak cloud platform and shown locally on a 16x2 LCD. This facilitates ongoing monitoring, trend analysis, and early identification of declining water quality. The suggested system contributes to sustainable water resource management because it is affordable, scalable, and suitable for a range of uses, including industrial, residential, and environmental monitoring.

Keywords: *IoT, Water Quality Monitoring, NodeMCU, pH Sensor, Turbidity Sensor, DS18B20, Temperature Monitoring, Thingspeak, Environmental Monitoring.*

Introduction:

Water quality monitoring plays a vital role in safeguarding public health, protecting ecosystems, and ensuring sustainable water resource management. Contaminants, chemical imbalances, and temperature variations can significantly affect the usability of water for drinking, agricultural, and industrial applications. Traditional monitoring methods are often manual, time-consuming, and lack real-time responsiveness. With the rapid advancement of the Internet of Things (IoT), modern systems now enable automated, continuous, and remote monitoring, improving efficiency and accuracy. This paper presents an IoT-based water quality monitoring system designed to measure essential parameters such as pH, turbidity, and temperature using a NodeMCU microcontroller integrated with appropriate sensors.

The proposed system uses a pH sensor to measure water acidity or alkalinity, a crucial parameter for assessing chemical stability and biological suitability. A turbidity sensor measures water clarity, providing insights into suspended particles, pollutants, and microbial contamination. Additionally, a temperature sensor, such as the DS18B20, monitors water temperature, an important factor influencing chemical reactions and microbial growth. These sensors are interfaced with the NodeMCU, which acts as the central processing unit, collecting and analyzing data in real time.

The system features a 16×2 LCD to provide immediate, on-site visualization of water quality parameters. Furthermore, leveraging the NodeMCU's built-in Wi-Fi, the collected data is transmitted to a cloud platform such as ThingSpeak. This integration allows users to access realtime and historical data remotely via internet-enabled devices. The cloud platform also

supports data logging, graph visualization, and trend analysis, enabling users to detect anomalies and take proactive measures to address deteriorating water quality.

One of the key advantages of this system is its scalability and cost-effectiveness, making it suitable for a wide range of applications, including domestic water monitoring, aquaculture, agriculture, and industrial processes. The system can be expanded by integrating additional sensors to measure dissolved oxygen, conductivity, or chemical contaminants, further enhancing its functionality. Moreover, cloud-based monitoring enables automated alerts and notifications, improving response time and decision-making.

Literature Review:

- Varsha Lakshmikantha et al., “IoT-Based Smart Water Quality Monitoring System,” *Global Transition Proceedings*, vol. 2, issue 2, November 2021.

The authors proposed an IoT-based smart water quality monitoring system for real-time monitoring of water parameters. The system measures important parameters such as pH, turbidity, and temperature using sensors connected to a microcontroller. The collected data is transmitted through IoT technology for remote monitoring. The study concluded that the proposed system provides efficient, low-cost, and real-time water quality monitoring for various applications.

- Mohammad Salah Uddin Chowdhury et al., “IoT-Based Real-time River Water Quality Monitoring System,” *The 16th International Conference on Mobile Systems and Pervasive Computing*, 2019.

This research presents a real-time river water monitoring system using IoT technology. The system measures water parameters, including temperature, turbidity, and pH. Data is

transmitted to cloud platforms for remote access and analysis. The study highlights the importance of continuous water monitoring to prevent pollution and ensure safe water quality.

- Soundarya Pappu et al., “Intelligent IoT-Based Water Quality Monitoring System,” *International Journal of Applied Engineering Research*, 2017.

The authors developed an intelligent water quality monitoring system using IoT technology. The system uses multiple sensors to monitor water quality parameters and transmit the data to cloud storage. The research emphasizes the importance of automation in monitoring systems and concludes that IoT-based monitoring improves efficiency and accuracy.

- Ganesh Babu Loganathan et al., “IoT-Based Water and Soil Quality Monitoring System,” *International Journal of Mechanical Engineering and Technology*, 2019.

This paper presents a system that monitors both water and soil quality parameters using IoT technology. Sensors measure pH, temperature, and moisture levels. The system provides real-time monitoring and alerts. The authors concluded that IoT-based monitoring systems improve agricultural productivity and water management.

- P. Baskaran et al., “IoT-Based Water Quality Monitoring System Using Machine Learning,” *International Journal of Recent Technology and Engineering*, 2019.

The authors proposed an IoT-based water quality monitoring system integrated with machine learning algorithms. The system analyzes water quality parameters and predicts contamination levels. The research concluded that machine learning improves prediction accuracy and enhances water quality monitoring.

- Rahman et al., “Internet of Things (IoT) Based Water Quality Monitoring System,” 2020.

This study presents an IoT-based water monitoring system designed for continuous monitoring. The system uses sensors to measure water quality parameters and wirelessly transmit the data. The authors concluded that the system reduces manual effort and improves monitoring efficiency.

- Sengupta et al., “Water Quality Monitoring using IoT,” International Research Journal of Engineering and Technology (IRJET), 2019.

The authors developed an IoT-based water quality monitoring system for real-time data collection. The system measures parameters such as pH, turbidity, and temperature. The study concluded that the system is cost-effective and suitable for environmental monitoring applications.

- Madhavireddy and Koteswarrao, “Smart Water Quality Monitoring System Using IoT Technology,” International Journal of Engineering and Technology, 2018.

This research proposed a smart water quality monitoring system using IoT technology. The system monitors various water quality

parameters and sends alerts when values exceed the threshold. The authors concluded that the system improves water quality management.

- Kartik Maheshwari and Adrija Chakraborty, “Water Quality Monitoring System

Implemented with IoT,” International Journal of Emerging Trends in Engineering Research, 2021. The authors proposed an IoT-based water monitoring system that collects real-time data and transmits it to cloud storage. The system helps detect water contamination early. The study concluded that IoT-based systems improve monitoring reliability.

- M.J.V. Kumar and K. Samalla, “Design and Development of Water Quality Monitoring System in IoT,” International Journal of Recent Technology and Engineering, 2019.

This research focuses on designing a water quality monitoring system using IoT technology. The system measures various parameters and provides real-time monitoring. The authors concluded that IoT-based monitoring systems are efficient, reliable, and suitable for smart water management applications.

Methodology:

Block Diagram:

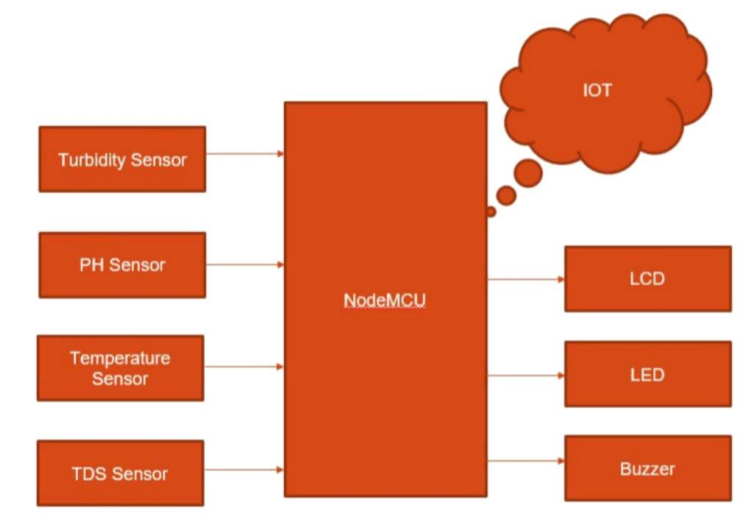


Fig 1 Block Diagram

As shown in Fig. 3.1, the proposed system is an IoT-based water quality monitoring system that measures and analyzes key water parameters in real time. The block diagram consists of multiple sensors connected to the NodeMCU controller, which processes the data and sends it to output devices and the IoT cloud for monitoring. The system includes four main sensors: Turbidity Sensor, pH Sensor, Temperature Sensor, and TDS Sensor. The Turbidity Sensor measures water clarity by detecting suspended particles. High turbidity indicates poor water quality. The pH Sensor measures the acidity or alkalinity of water, which is an important factor in determining water safety and usability. The Temperature Sensor measures water temperature, which affects chemical reactions and overall water quality. The TDS (Total Dissolved Solids) Sensor measures the concentration of dissolved substances such as minerals, salts, and organic matter in water. All sensors are connected to the NodeMCU microcontroller, which serves as the system's central processing unit. NodeMCU collects data from all sensors, processes it, and compares the values with predefined threshold limits. Based on the sensor readings, the system determines whether the water quality is safe or unsafe. The processed data is displayed locally on an LCD. The LCD's real-time values for turbidity, pH, temperature, and TDS. This allows users to monitor water quality directly at the monitoring location. The NodeMCU is also connected to the IoT cloud platform through Wi-Fi. The sensor data is uploaded to the IoT server, allowing remote monitoring from anywhere using a mobile phone or computer. This feature enables continuous monitoring and data logging for analysis and research purposes. Thus, the proposed IoT-based water quality monitoring system provides real-time monitoring, an alert

mechanism, and remote access to water quality data, making it efficient, reliable, and suitable for smart water management applications.

Top of Form
Bottom of Form

Working Principle:

The architecture of the proposed water quality monitoring system is designed to enable continuous observation of essential water parameters and provide real-time data for applications in environmental monitoring, industry, and public health. At the core of the system is the NodeMCU microcontroller, which serves as the central unit, collecting, processing, and transmitting data from multiple sensors to an IoT platform. Each sensor is assigned to measure a specific parameter, and the NodeMCU integrates this information to present a comprehensive assessment of water quality.

The turbidity sensor evaluates water clarity by emitting light and measuring the amount scattered by suspended particles. Higher turbidity values indicate increased contamination or sediment presence. The pH sensor determines the acidity or alkalinity of water by measuring hydrogen-ion concentration via an electrode-generated voltage, which is then converted to pH values by the NodeMCU. The temperature sensor monitors water temperature by detecting changes in electrical resistance or voltage, ensuring that thermal conditions remain within acceptable limits. Additionally, the TDS sensor measures dissolved substance concentration by analyzing electrical conductivity, which is converted to parts per million (ppm) to assess water purity.

The NodeMCU processes all sensor inputs and transmits the data to an IoT platform such as ThingSpeak via Wi-Fi. Using APIs, data is uploaded at regular intervals, stored, analyzed, and displayed graphically for each parameter, enabling users to monitor trends over time. A

16×2 LCD is incorporated to display real-time readings locally, allowing immediate access without requiring internet connectivity.

For safety and alert mechanisms, the system includes an LED indicator and a buzzer. When any parameter exceeds predefined thresholds, these components activate to provide visual and audible warnings, ensuring a prompt

response to potential issues. Overall, the system continuously collects sensor data, analyzes it for abnormalities, and provides both local alerts and remote monitoring through cloud integration. This integrated approach ensures efficient, reliable, and proactive water quality management across various applications

Components:

Sr No	Components	Specification	Quantity
1	NodeMCU	3.3V operating voltage, inbuilt Wi-Fi module	1
2	PH sensor	Range 0–14 pH, analog output	1
3	Turbidity sensor	Range 0–1000 NTU, measures water clarity	1
4	TDS sensor	Range 0–1000 ppm, measures dissolved solids	1
5	LCD display	5V, used to display sensor data	1
6	LED	2–3V, status indication	1
7	Buzzer	3–5V, alert indication	1

Program Code:

```
#include <DHT.h> #include <LiquidCrystal.h>

#define DHTPIN A1 #define DHTTYPE DHT11
#define PH_PIN A0 #define TURB_PIN A2
#define BUZZER 8
#define LED 9

DHT dht(DHTPIN, DHTTYPE);
LiquidCrystal lcd(7, 6, 5, 4, 3, 2);

void setup() { Serial.begin(9600); lcd.begin(16,
2);
dht.begin();

pinMode(BUZZER, OUTPUT); pinMode(LED,
OUTPUT); pinMode(PH_PIN, INPUT);
pinMode(TURB_PIN, INPUT);

lcd.clear(); lcd.setCursor(0, 0);
lcd.print("Water Quality"); lcd.setCursor(0, 1);
lcd.print("Monitoring..."); delay(2000);

}

void loop() {
// --- DHT11 Reading ---
float humidity = dht.readHumidity();
float temperature = dht.readTemperature();

// --- pH Sensor Reading ---
int phValue = analogRead(PH_PIN);
float voltage_ph = (phValue * 5.0) / 1023.0;
float ph = 7 + ((2.5 - voltage_ph) / 0.18); //
approximate calibration

// --- Turbidity Sensor Reading ---
int turbValue = analogRead(TURB_PIN);
float voltage_turb = (turbValue * 5.0) / 1023.0;
float ntu = 3000 - (voltage_turb * 600); //
approximate mapping
```

```
// --- Display on LCD ---lcd.clear();
lcd.setCursor(0, 0);    lcd.print("Volt:");
lcd.print(voltage_turb, 2); lcd.print("V");

lcd.setCursor(0, 1);    lcd.print("NTU:");
lcd.print(ntu, 1);

// --- Serial Monitor Output ---
Serial.println("Water Quality Monitoring
System");
Serial.print("Temperature:          ");
Serial.print(temperature); Serial.println(" *C");
Serial.print("Humidity: "); Serial.print(humidity);
Serial.println(" %"); Serial.print("pH Value: ");
Serial.println(ph);
```

```
Serial.print("Turbidity: "); Serial.print(ntu);
Serial.print("    NTU    |    Voltage:    ");
Serial.println(voltage_turb); Serial.println("    ");

// --- Alert Conditions ---
if (ntu > 2500 || ph < 6.5 || ph > 8.5) {
digitalWrite(BUZZER, HIGH);
digitalWrite(LED, HIGH);
} else {
digitalWrite(BUZZER, LOW); digitalWrite(LED,
LOW);
}
delay(2000);
}
```

Result and Discussion:

Simulation:

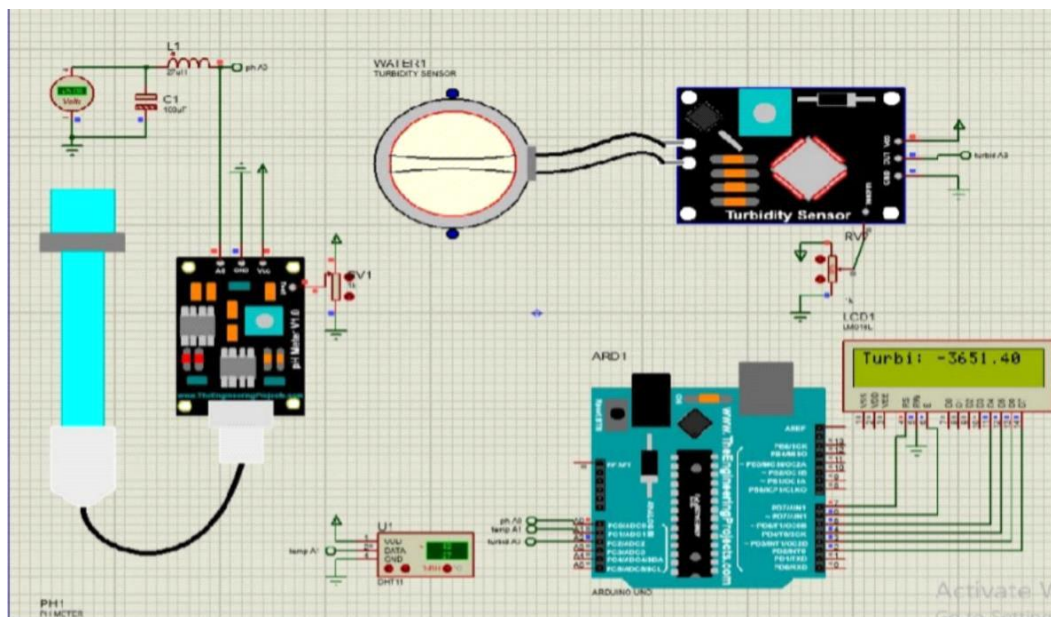


Fig 2: Simulation of a smart water quality monitoring system using IoT

The hardware implementation of the proposed water quality monitoring system consists of sensors, a microcontroller, and a display unit. The system is designed to measure water quality parameters such as turbidity, pH, and temperature and display the results in real time. The hardware components are

interconnected to form an efficient and reliable monitoring system.

In the proposed system, the turbidity sensor measures water clarity. It works by detecting suspended particles present in the water sample. When the water becomes more turbid, the sensor output changes accordingly. This analog output signal is then transmitted to the

microcontroller for processing. Turbidity measurement is important in determining the purity and quality of water. The pH sensor measures the acidity or alkalinity of water. The sensor produces an analog voltage proportional to the pH value of the water sample. The microcontroller then reads this value through the analog input pin. The pH value helps determine whether the water is acidic, neutral, or alkaline, which is essential for drinking water and industrial applications. The temperature sensor monitors water temperature. Temperature plays an important role in chemical reactions and water quality assessment. The sensor continuously measures the water temperature and sends the data to the microcontroller for further processing.

The microcontroller used in the system is Arduino Uno. It acts as the central processing unit and controls the entire system. The Arduino collects data from all sensors, processes the signals, and converts them into readable values.

The processed data is then displayed on the LCD screen.

The LCD display shows real-time sensor readings, including turbidity, pH level, and temperature. The LCD provides an easy-to-read interface for users to monitor water quality parameters directly. The display updates continuously based on sensor readings.

The entire system is powered using a regulated power supply. All components are connected properly using interfacing wires. The system operates continuously and provides real-time monitoring of water quality parameters.

Thus, the hardware implementation of the proposed system provides accurate monitoring of water quality parameters and ensures reliable performance. This system is suitable for applications such as drinking water monitoring, industrial water quality control, and environmental monitoring.

Simulation Result:

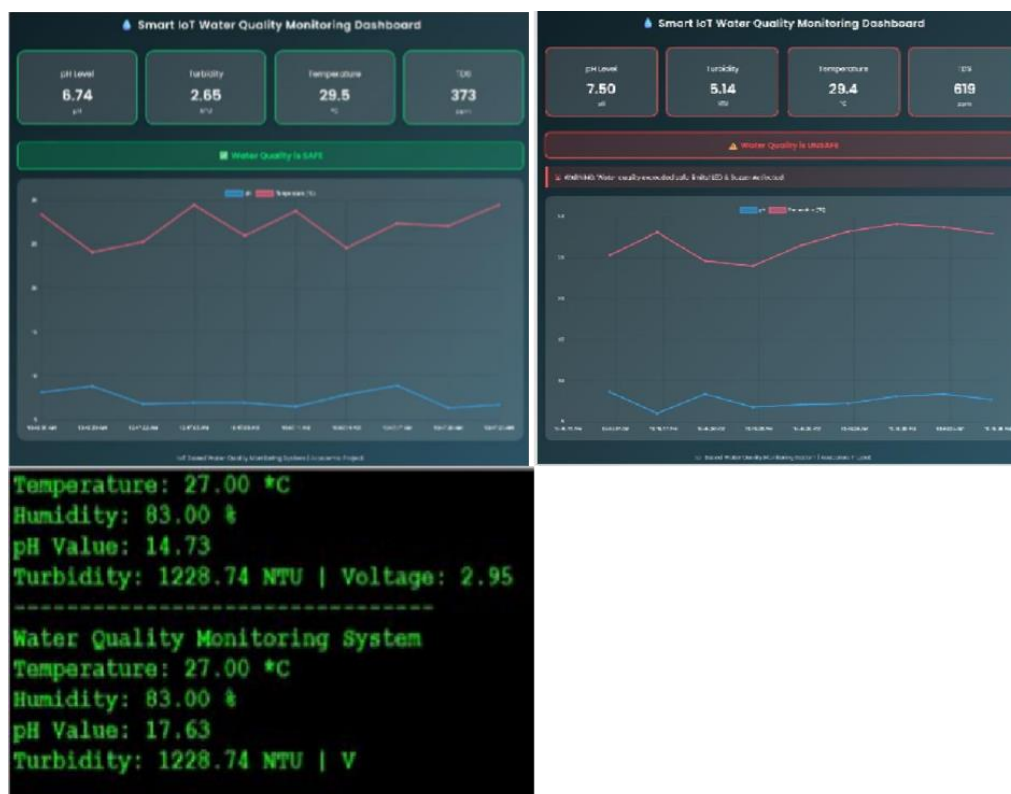


Fig 3: Simulation result of smart water quality monitoring system using IoT

The proposed water quality monitoring system was successfully simulated in Proteus to evaluate its performance and accuracy. The simulation integrates an Arduino Uno microcontroller with multiple sensors, including a pH sensor, turbidity sensor, and DHT11 temperature and humidity sensor. These sensors continuously monitor water quality parameters and display the output on both a 16×2 LCD and a virtual terminal. The simulation results confirm that the system operates effectively and provides real-time monitoring of water quality parameters.

During the simulation, the system measured the temperature, humidity, pH, and turbidity of the water sample. The virtual terminal displayed the readings as temperature 27.00°C, humidity 83.00%, pH value 14.73, turbidity 1228.74 NTU, and sensor voltage 2.95 V. These values confirm that the sensors are properly interfaced with the Arduino Uno and functioning correctly. The LCD also displayed turbidity and voltage values, indicating that the system successfully processed sensor data and provided output to the user.

The temperature and humidity values from the DHT11 sensor reflect the surrounding environmental conditions that affect water quality. The recorded temperature of 27°C and humidity of 83% fall within the sensor's normal operating range. These parameters are useful for monitoring environmental conditions, especially in water storage systems, aquaculture, and environmental monitoring applications.

The pH sensor reading of 14.73 indicates highly alkaline water conditions. Normally, drinking water should have a pH range between 6.5 and 8.5. Therefore, the simulated water sample is considered unsafe for drinking purposes. Monitoring pH levels is important for water quality assessment because extreme pH values can harm human health and aquatic life.

The turbidity sensor measured 1228.74 NTU, indicating very high turbidity. High turbidity suggests the presence of suspended particles, impurities, or contaminants in water. This confirms that the system is capable of detecting poor water quality conditions. The turbidity sensor works based on the light scattering principle, where suspended particles in water scatter light and increase the turbidity value.

The simulation results demonstrate that the proposed system effectively monitors water quality parameters in real time. The system successfully identifies unsafe water conditions and displays the measured values clearly on both the LCD and the virtual terminal. This system can be used in various applications such as drinking water monitoring, industrial water quality monitoring, aquaculture, and environmental monitoring systems.

Overall, the simulation confirms that the proposed water quality monitoring system is reliable, accurate, and suitable for real-time applications.

Conclusion:

In this work, an IoT-based water quality monitoring system has been successfully designed and implemented to continuously monitor critical parameters, including pH, turbidity, temperature, and Total Dissolved Solids (TDS). The system integrates sensors with a microcontroller to enable realtime data acquisition, processing, and visualization, both locally and via a web-based dashboard. The inclusion of alert mechanisms ensures immediate notification when water quality deviates from safe limits, enhancing system reliability and responsiveness.

The proposed solution addresses the limitations of traditional water monitoring methods by offering automation, accuracy, and remote accessibility. Its cost-effective, scalable

design makes it suitable for a wide range of applications, including domestic use, industrial processes, agriculture, and environmental monitoring. Furthermore, the use of cloud integration and data visualization enables trend analysis and informed decision-making.

Overall, this system demonstrates the effectiveness of IoT technology in modern water quality management. It provides a practical and efficient approach to ensuring safe water conditions and supports proactive measures for environmental sustainability and public health protection.

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IoT based Automated pH and TDS Monitoring and Control System

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Abstract:

Water quality monitoring is essential in applications such as agriculture, aquaculture, and drinking water systems. This project presents an IoT-based pH and TDS monitoring and control system that measures water quality parameters in real time. The system uses pH and TDS sensors connected to a microcontroller to collect data and transmit it to a cloud platform through the Internet of Things (IoT). Users can monitor water conditions remotely, and the system can automatically trigger control actions when the values exceed preset limits. This approach reduces manual monitoring, improves accuracy, and helps maintain safe water quality efficiently. The proposed system provides a low-cost and reliable solution for smart water quality management.

Keywords: *IoT, pH and TDS, ESP32, Blynk, Arduino IDE.*

Introduction:

Water quality plays a significant role in areas such as agriculture, aquaculture, drinking water systems, and various industrial operations. Among the different indicators used to evaluate water quality, pH and Total Dissolved Solids (TDS) are considered very important. The pH level shows whether water is acidic, neutral, or alkaline, while TDS represents the concentration of dissolved minerals, salts, and other substances present in the water. Maintaining these values within acceptable limits is necessary for safe and efficient use of water.

Conventional methods of testing water quality generally involve collecting samples and analyzing them manually in laboratories. These methods may take time and do not always provide continuous monitoring. With the advancement of the Internet of Things (IoT), it has become possible to monitor water parameters in real time using sensors connected to microcontroller-based systems that send data through the internet.

The proposed IoT-based pH and TDS monitoring and control system measures water parameters continuously and transmits the collected data to an online platform for easy observation. Users can monitor the readings remotely and take necessary action when the values exceed the desired range. This system reduces manual effort and provides an efficient solution for smart water quality management.

Literature References:

This review provides insights into the applications of IoT in environmental monitoring, including water quality monitoring systems. It discusses various sensors, communication technologies, and data analytics techniques used in IoT-based environmental monitoring solutions.

This paper presents a systematic review of water quality monitoring systems utilizing IoT technologies. It discusses the integration of sensors, microcontrollers, communication

modules, and data platforms in IoT- based water quality monitoring solutions.

This review article provides an overview of various sensor technologies used for water quality analysis, including temperature, turbidity, pH, and TDS sensors. It discusses the principles of operation, advantages, and limitations of different sensor types.

This survey paper provides an overview of wireless communication technologies commonly used in IoT applications, including WiFi, Bluetooth, Zigbee, and LoRa. It discusses their characteristics, suitability for different IoT scenarios, and challenges.

This paper discusses the role of cloud-based data platforms in IoT applications, including smart city initiatives. It provides insights into the architecture, features, and benefits of cloud-based data platforms for storing, processing, and analyzing IoT-generated data.

Methods and Materials:

Principle of Operation:

The IoT-based water quality monitoring system operates on the principle of collecting, processing, and transmitting data from sensors measuring key water parameters. The system utilizes various sensors, microcontrollers, wireless communication modules, and cloud-based data platforms to achieve its objectives. Here's an overview of the principle of operation:

Sensor Measurement:

The system employs sensors to measure essential water parameters such as pH, and Total Dissolved Solids (TDS). Each sensor utilizes specific physical or chemical properties to detect and quantify the target parameter.

For example:

- The pH sensor measures the acidity or alkalinity of the water based on the hydrogen ion concentration.

- The TDS sensor estimates the concentration of dissolved solids in the water by measuring its electrical conductivity.

Data Acquisition and Processing:

- The sensor readings are collected by a microcontroller, such as Arduino or ESP32, which serves as the central processing unit of the system.
- The microcontroller interfaces with the sensors, reads their analog or digital output signals, and performs initial data processing tasks.
- Data processing may include calibration, filtering, or averaging of sensor readings to improve accuracy and reliability.

Wireless Data Transmission:

- Once processed, the data is transmitted wirelessly to a cloud-based data platform using a WiFi module, such as ESP32.
- The WiFi module establishes a connection to the internet and sends the data to the designated cloud server for storage and analysis. Wireless communication enables real-time transmission of water quality data from remote locations to the cloud platform, eliminating the need for manual data collection and transmission.

Cloud-Based Data Analysis and Visualization:

- The data received by the cloud-based platform is stored in a database and analyzed using various algorithms and techniques.
- Data analysis may involve trend analysis, anomaly detection, or predictive modeling to identify patterns or deviations in water quality parameters.
- The analyzed data is visualized through web or mobile applications, allowing users

to monitor water quality in real-time, generate reports, and make informed decisions.

- User Interaction and Decision-Making:
- Users, such as environmental agencies, water utilities, or researchers, can access the cloud-based platform to view water quality data and insights.
- Real-time monitoring and analysis enable timely interventions in case of pollution events or water quality anomalies, facilitating proactive management of water resources.
- The system provides a user-friendly interface for visualizing data trends, generating alerts, and generating actionable insights to address water quality issues effectively.

Flow Chart:

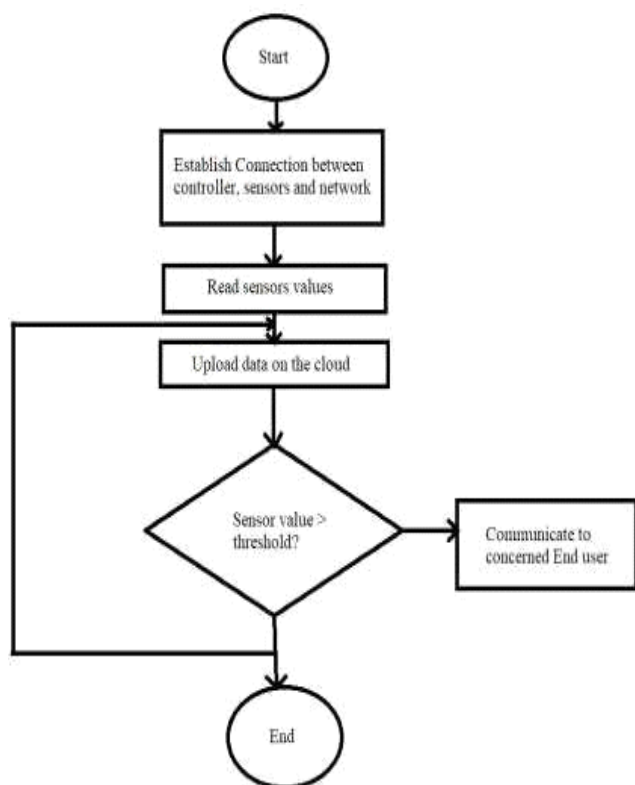


Fig. 1 Flowchart

Algorithm:

- Start
- Establish Connection between controller, sensors and network.
- Reads sensors values.
- Upload data on the cloud.
- Sensor value>threshold?
- Communicate to concerned End user.
- End.

Result and Discussion:

The implementation of the IoT-based water quality monitoring system has yielded promising results, demonstrating its effectiveness in real-time monitoring of key water parameters and providing actionable insights for environmental management. Here are the key results obtained from the deployment and operation of the system

Sample	Parameter	Measured Value
Water Sample 1	pH	
	TDS	
Water Sample 2	pH	
	TDS	
Water Sample 3	pH	
	TDS	

Conclusion:

The development and implementation of our IoT-based Automated pH & TDS monitoring and control system represent a significant milestone in the realm of environmental monitoring and resource management. Through the integration of sensors, microcontrollers, wireless communication modules, and cloud-based data platforms, our system has demonstrated its capability to collect real-time data on key water parameters, ensuring accuracy, reliability, and accessibility. The system's ability to facilitate proactive management of water

resources, timely intervention in pollution events, and informed decision-making underscores its importance in addressing the pressing challenges of water quality degradation and sustainability. Moreover, our project has fostered collaboration and engagement among stakeholders, including local communities, government agencies, and research institutions, enriching our understanding of water quality dynamics and promoting collective action towards environmental stewardship. Moving forward, the continued refinement and expansion of our monitoring system, coupled with ongoing research and collaboration, will be crucial in advancing our understanding of water ecosystems and safeguarding water resources for future generations.

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Industrial Equipment Health Monitoring System

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Abstract:

This paper proposes a real-time industrial equipment health monitoring and control system utilizing an Arduino Uno microcontroller interfaced with LabVIEW via the LINX toolkit. The system continuously acquires data from critical parameters such as temperature (LM35), current (ACS712), and vibration (SW-420) sensors. Based on preset thresholds, a relay module automatically disconnects power to the equipment, preventing damage due to overheating, overcurrent, or abnormal vibrations. Real-time data is visualized in LabVIEW, logged into Excel, and optionally uploaded to Thing Speak for remote monitoring. Case study validation in a textile industry shows the effectiveness of this integrated monitoring solution. Index Terms—LINX Toolkit, LabVIEW, Arduino Uno, Health Monitoring, Industrial Automation, Vibration Sensor, Relay Protection, Thing Speak.

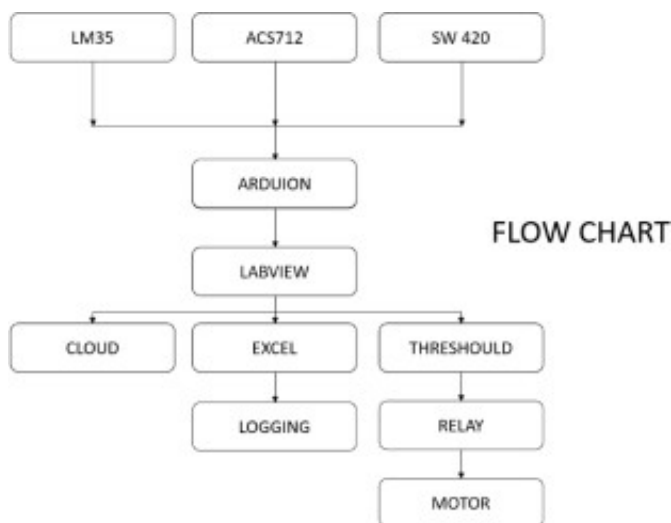
Keywords: Industrial Equipment Health Monitoring, Industrial Automation, Machine Fault Detection, Real-Time Data Acquisition, Remote Monitoring, Relay Protection System.

Introduction:

In modern industrial environments, where automation and continuous operation are crucial for productivity and efficiency, unanticipated failures in electrical motors and rotating equipment can result in significant downtime and losses. Most traditional maintenance methods rely on scheduled check-ups or reactive repairs after failures occur. However, this approach equipment and initiate control measures when anomalies are detected. This project introduces a low-cost, real-time health monitoring and protection system for industrial motors using Arduino Uno and National Instruments LabVIEW software. The system combines sensor data acquisition and control automation with user-friendly graphical interfaces to enhance operational reliability.

The integration of the LINX (LabVIEW LINX Toolkit) framework enables seamless communication between the microcontroller and

LabVIEW, providing access to hardware I/O directly within the LabVIEW environment. The system monitors surface temperature, current consumption, and vibration levels using standard sensors (LM35, ACS712, and SW-420 respectively). In the event of threshold violations, a relay-controlled cutoff mechanism triggered to disconnect the motor and prevent further damage. The proposed system not only ensures immediate protective action but also facilitates data visualization, Excel-based logging, and potential cloud integration for remote diagnostics, making it highly suitable for predictive maintenance and Industry 4.0 applications.

Flow Chart:**Methods and Materials:**

The proposed Industrial Equipment Health Monitoring System uses an Arduino Uno microcontroller interfaced with LabVIEW through the LINX toolkit for real-time data acquisition and control. Temperature, current, and vibration sensors (LM35, ACS712, and SW-420) are used to continuously monitor machine health parameters. The sensed data is processed in LabVIEW, where predefined threshold conditions are applied. A relay module is used to automatically disconnect the equipment in case of abnormal conditions such as overheating, overcurrent, or excessive vibration.

System Design Methodology:

The overall method consists of the following major stages:

Requirement Analysis:

- The system requirements were identified based on the need for real-time monitoring and protection of industrial equipment. Key parameters such as temperature, current, and vibration were selected for condition monitoring.
- The system was designed to provide automatic fault detection, safety shutdown,

data logging, and remote monitoring capability.

Sensor and Input Mapping:

- Temperature sensor LM35, current sensor ACS712, and vibration sensor SW-420 were interfaced with the Arduino Uno.
- The LM35 and ACS712 sensors were connected to analog input pins, while the vibration sensor was connected to a digital input pin. A relay module was connected to a digital output pin to control the power supply to the equipment

Programming:

- Control logic for monitoring and protection was implemented using LabVIEW graphical programming with the LINX toolkit.
- Sensor values were continuously compared with predefined threshold limits. If any parameter exceeded the safe limit, a digital output signal was generated to activate the relay and disconnect the equipment.

Testing and Validation:

- The system was tested under different operating conditions to verify accurate sensing and reliable protection. Fault conditions such as high temperature, overcurrent, and vibration were simulated to observe system response.
- The results confirmed proper relay operation, real-time data visualization, and successful data logging performance.

Hardware & Software Components:

- Arduino UNO – Microcontroller board for reading sensor inputs and controlling the relay.
- LM35 – Analog temperature sensor.

- SW-420 – Vibration/shock sensor.
- ACS712 – Current sensor module.
- Relay Module – Electrically operated switch for AC load control.
- AC Load – Could be a motor, bulb, fan, or any AC appliance.
- AC Supply – 230V main power supply.
- Switchboard with socket – Connected to the relay controlled AC output

Results and Discussion:

The system successfully monitored temperature, current, and vibration in real time using sensors and displayed the values in LabVIEW. During fault conditions, the relay automatically disconnected the equipment, ensuring safe operation.

The system provided accurate data visualization, reliable protection, and effective performance for industrial monitoring applications

Conclusion:

The Industrial Equipment Health Monitoring System was successfully developed for real-time monitoring and protection of industrial machines. The system accurately detected abnormal conditions such as high temperature, overcurrent, and vibration, and automatically disconnected the equipment using a relay module. The use of Arduino and LabVIEW

provided a cost-effective and reliable solution for improving industrial safety and enabling predictive maintenance.

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IoT -Enabled Smart LED Notice Board with Machine Learning for Intelligent E-Circular Notifications Via Wi-Fi

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Abstract:

The notice board is a crucial element in institutions, organizations, and public facilities. Traditionally, sharing information has been a manual process, limiting its reach. Posting various notices can be challenging, requiring a designated person to oversee the task. This project aims to introduce a digital notice board that utilizes a Wi-Fi module. The objective is to offer users a straightforward, speedy, and dependable means of displaying significant notices on a P5 LED screen. Users can send their messages to be circulated through the display. In this project, a web application has been developed to send messages via the Wi-Fi module. The system control is managed by an Arduino and the communication is performed using Wi-Fi technology. The message is then sent through the aforementioned web application. The hardware used in this project includes a Node MCU-ESP8266 Wi-Fi module, an LED display, and a user-friendly web application that utilizes Firebase. This device can be used anywhere as long as there is mobile network connectivity available.

Keywords: P5 LED display, Arduino, NODE MCU- ESP8266, Wi-Fi Module, Firebase Web.

Introduction:

A smart notice board is a revolutionary device that combines the power of Wi-Fi technology and Arduino UNO to have an interactive information display system. This innovative solution has transformed traditional notice boards into digital and connected platforms, enhancing communication which engaged in various environments such as schools, offices, and public spaces. By utilizing Wi-Fi connectivity, the smart notice board can seamlessly receive and display real-time information, including announcements, updates, and schedules. Any changes or new announcements can be instantly updated on the notice board ensuring that users are kept informed up-to-date. The Arduino acts as the brain of the system, controlling the display, processing user inputs, and managing the wireless

communication. With its user-friendly interface and customizable features, the smart notice board provides a convenient and efficient way to share information. The Firebase platform is highly effective and extensively utilized, and it has the potential to significantly improve the features and abilities of a smart notice board. With Firebase authentication, administrators can control who has the ability to create or edit content on the notice board, ensuring that only authorized individuals can make changes. These features enhance the functionality, security, and user experience of the smart notice board, making it a powerful and efficient communication tool. This smart notice board has the potential to revolutionize communication and transform static information displays into dynamic and interactive hubs of information.

Proposed System:

The proposed system for a digital display module is connected to a microcontroller in the suggested Wi-Fi-based system for a Smart Notice Board, and the microcontroller is managed by a web or app interface. This system is designed to provide an efficient and flexible way to display information in a dynamic and interactive manner. The Smart Notice Board using Wi-Fi technology offers numerous advantages over traditional physical notice boards, including easy updating and management of digital content, real-time display of information, remote access and control, and the ability to display dynamic and interactive content.

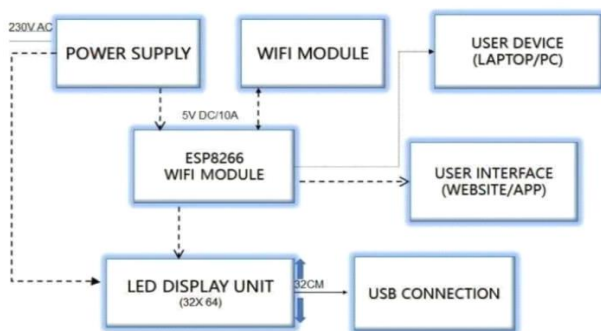


Figure 1. Proposed system

Fig 1 Proposed System

Notice Board and the user's device. The ESP8266 Wi-Fi module is connected to the Arduino any other type of display, in Figure 1 the Wi-Fi router is used to establish a wireless connection between the Smart is connected to the Arduino board. The user interface, sub web or board and allows for Wi-Fi connectivity. The display module, which could be an LED screen or app interface, allows the user to send messages or updates to the Smart Notice Board, which are then sent through the Wi-Fi network and received by the Wi-Fi module. The Wi-Fi module and Arduino board connect with each other via serial communication, with the Arduino board serving as the Smart Notice Board's primary controller. The Smart Notice Board can detect changes in its

environment thanks to the sensors, which include a PIR sensor, which are also connected to the Arduino board. An Arduino-based smart Wi-Fi notice board is a project that combines the capabilities of an Arduino microcontroller and Wi-Fi connectivity to create a electronic notice that board can display notifications, and other information. It can be a useful tool for displaying dynamic content in homes, offices, schools, or other environments where information needs to be shared. Overall, this block diagram represents the basic architecture of a Smart Notice Board using Wi-Fi.

Literature Survey:

This research paper presents a cost-effective, portable, wireless electronic notice board that facilitates information exchange over a network. The study primarily concentrates on guaranteeing data authenticity and security. The device employs Bluetooth and ZigBee are two wireless technologies integrated within Atmel's ATmega32 microprocessor. It is noteworthy that the notice board's display component is a 128x64 graphical LCD based on the KS0108.

A digital notice board that complies to Internet of Things (IoT) principles is created using the Raspberry Pi [1]. This technique makes it easier to post notices online and show information on a digital notice board. Registered users can also get notifications on their Android phones, and it allows remote updating of notices via the website. This research aims to investigate the basic idea of a digital display that uses a Raspberry Pi the Internet of Things context. The notice board can be updated by an administrator using a dedicated website accessible on the internet. This enables the rapid transmission of data to any location, with display updates occurring within seconds. The data transmitted typically consists of text and images. A personal computer is used for information storage and

transmission, while the Raspberry Pi connects to the PC via Wi-Fi at the receiving end.

The primary focus of this paper is to address the challenges associated with sending and monitoring numerous notices on a daily basis [2]. Currently, this process requires a dedicated individual to handle the notices. To overcome these limitations, the paper proposes an advanced notice board system. The system features a scrolling display that is specifically pr designed for schools and colleges to continuously display everyday information. The system provides a more efficient display of flash news compared to traditional programmable systems by using Wireless Fidelity (Wi-Fi) technology. Furthermore, a keyboard-based display scheme can be utilized in various public areas like hospitals, railway stations, colleges, hotels, and malls. The display board that scrolls is made up of two parts: a receiver and a toolkit for programming shows. Messages are received by the receiver via a serial port and are then displayed after being converted into code.

The purpose of this study is to report the results of a project that aimed to develop a wireless electronic notice board that could control how data is displayed. across multiple display sin a particular space [3]. The notice board is designed to receive information from a central control unit via a serial communication protocol and then display that information accordingly. The paper provides an overview of the project's results and outcomes.

Institutions, organisations, and public utilities regularly post information on notice boards in places like parks, train stations, and bus stops [4]. However, the task of managing and updating these boards on a daily basis can be difficult and may necessitate the employment of dedicated personnel. Although traditional bulletin boards can provide comprehensive information to the public, keeping them upto-date can be a

challenge. The objective of this undertaking is to tackle these obstacles by creating a sophisticated announcement board with cutting-edge functionalities. The setup will employ a Node MCU, allowing users to update the bulletin board from a distance via Google voice assistant. This will grant users the liberty to append, delete, or revise the text exhibited on the board in accordance with their particular prerequisites.

Methodology:

In Figure 2, the connections with the hardware components for P5 display unit is shown. This setup shows the connection for p5 matrix display. Here we use Switch mode power supply for the power supply which is connected with the help of jumping wires. Also, we use Breadboard and Arduino Uno for interfacing with the ESP8266 module. We use Wi-Fi network for transmission of Messages.HUB75 is interfaced from P5 panel to Breadboard through jumping wires for the Pin configuration.

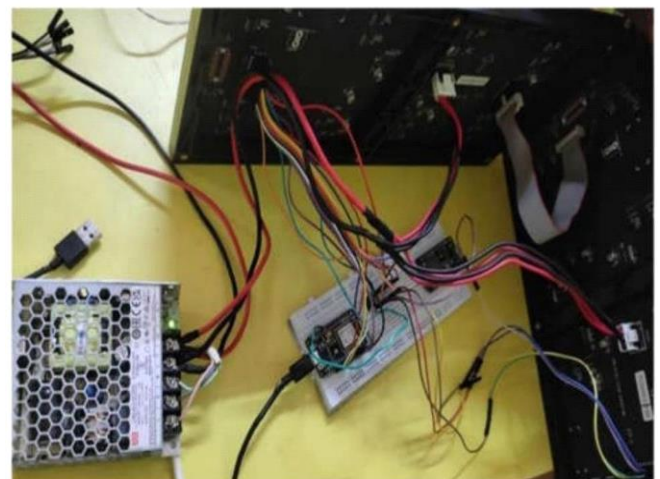


Fig 2 Hardware Connection of Proposed System

Web Application:

Web application Here, we have used Firebase to create a website that serves as the user interface and the web URL is mapped with website to Arduino, which serves as a platform to connect with ESP8266. The ESP8266 writes the

data to the P5 display, which displays the information to the user. Firebase plays a critical role in this process by providing a reliable and scalable platform for hosting your website and storing and synchronizing data. In Figure 3, shows the Web Dashboard for display and we have used Firebase hosting to host the website and make it accessible to users on the internet. In Fig 3. shows the interfacing of WebApp for display to use Firebase authentication to restrict access to certain parts of website and ensure that only authorized users can view and interact with application

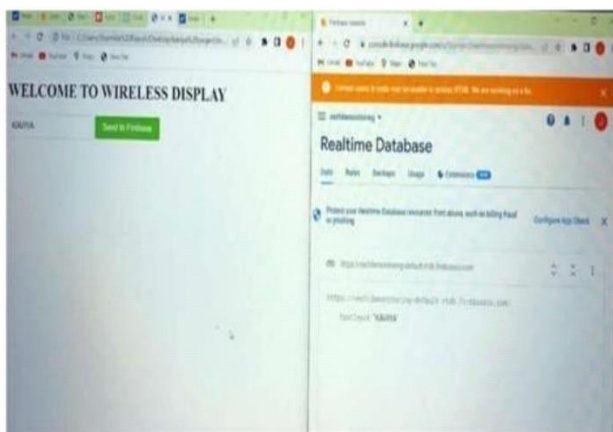


Fig 3 Dashboard for proposed system

A smart notice board using Wi-Fi and Arduino can display a variety of information, such as messages, news headlines, weather updates, are shown. Here are the steps how the screen.

STEP 1: If the notice board is connected to Wi-Fi, it will connect to the internet and start receiving data from a remote server or API.

STEP 2: The data received from the server can be in various formats such as text, images, or videos. The Arduino board can decode the data and display it on the screen.

STEP 3: If there are any new messages or updates, they will be displayed on the screen in real-time.

STEP 4: The board can also be programmed to display alerts or notifications in case of any emergency situations or important events.

STEP 5: The board can be controlled remotely through a smartphone app or a web interface. This allows users to update the information on the board from anywhere and at any time.

STEP 6: The board can be customized to display information that is relevant to the users, such as reminders, schedules, and to-do lists.

Result & Discussion:



Fig 4 LED matrix display output of the proposed smart e-circular notification system.

Smart notice board using Wi-Fi and Arduino can display a variety of information, such as messages, news headlines, weather updates will be shown. Here are the steps how the output could be displayed:

STEP 1: When the device is powered on, it will display a welcome message or logo on the screen.

STEP 2: If the notice board is connected to Wi-Fi, it will connect to the internet and start Receiving data from are mote server or API.

STEP 3: The data received from the server can be in various formats such as text, images, or videos. The Arduino board can decode the data and display it on the screen.

STEP 4: If there are any new messages or updates, they will be displayed on the screen in real-time.

STEP 5: The board can also be programmed to display alerts or notifications in case of any emergency situations or important events.

STEP 6: The board can be controlled remotely through a smartphone app or a web interface. This allows users to update the information on the board from anywhere and at any time.

STEP 7: The board can be customized to display information that is relevant to the users, such as reminders, schedules, and to-do lists.

The proposed IoT-enabled Smart LED Notice Board with Machine Learning for Intelligent E-Circular Notifications via Wi-Fi was successfully designed and implemented. The system integrates a Wi-Fi-enabled microcontroller with an LED matrix display to enable real-time wireless transmission and visualization of circular notifications.

The experimental setup was tested by transmitting multiple text messages through a Wi-Fi network using the IoT interface. The transmitted messages were successfully received by the controller and displayed on the LED matrix panel without noticeable delay. As shown in Fig. 5, the display board correctly presents the notification message “WELCOME”, demonstrating the proper functioning of the communication module and LED display interface.

The system showed reliable performance in receiving and displaying notifications from remote locations. The average response time between sending the message and its appearance on the LED board was observed to be only a few seconds, depending on network conditions. This confirms the capability of the system for real-time electronic circular communication.

The integration of machine learning techniques enhances the system by enabling intelligent message handling. The algorithm analyzes notification patterns and categorizes messages based on priority. Important

notifications can therefore be automatically highlighted or displayed more frequently than routine announcements. This improves the efficiency of information dissemination in institutional environments such as colleges, offices, and public facilities.

The experimental results indicate that the proposed system provides several advantages over conventional notice boards, including remote accessibility, reduced manual effort, faster information updates, and improved communication efficiency. Additionally, the digital nature of the system reduces paper usage, making it an environmentally friendly solution.

Overall, the results demonstrate that the developed system is a reliable and scalable platform for smart notification management using IoT and machine learning technologies. Future work may include integration with mobile applications, cloud-based notification management, and advanced machine learning models for improved message classification and user-specific notification delivery.

Conclusion:

The combination of Wi-Fi, Arduino, and Firebase in a smart notice board system offers a dynamic and interactive way to share information. It simplifies the process of updating and displaying messages, enhances user engagement, provides a flexible platform that can be customized to meet specific requirements. Whether in educational institutions, offices, or public spaces, a smart notice board using Wi-Fi and Arduino technology is a valuable tool for effective communication.

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**IoT based Crop Yield Prediction System using Arduino****Sushil Ghanekar¹ & Gajanan Khapre²**¹*Department of Electronics and Computer Engineering, VPMMP COE, Velneshwar-415729*²*Department of Electronics and Computer Engineering, VPMMP COE, Velneshwar-415729**Corresponding Author – Sushil Ghanekar***DOI - 10.5281/zenodo.21192130****Abstract:**

India, being an agricultural country, relies heavily on farming for its economy and the livelihood of a significant portion of its population. However, the rapid pace of industrialization and urbanization, coupled with a growing population, has led to a reduction in arable land and increased pressure on agricultural resources. A key challenge faced by farmers is the lack of precise knowledge about their soil's suitability for specific crops, often leading to suboptimal yields and economic losses. This paper presents an Internet of Things (IoT) based crop yield prediction system designed to assist farmers in making informed cultivation decisions. The proposed system utilizes an Arduino microcontroller interfaced with NPK (Nitrogen, Phosphorus, Potassium) and DHT11 (temperature and humidity) sensors to gather real-time soil and environmental data. The collected data is then processed and compared against a standard database to predict the most suitable crop for the given conditions. A web-based interface, developed using the Django framework, displays the sensor readings and the final crop prediction to the user. This system aims to provide an accessible, cost-effective solution for precision agriculture, empowering farmers with data-driven insights to enhance crop yield and optimize resource utilization.

Keywords: Crop Yield Prediction, IoT, Arduino, NPK Sensor, DHT11 Sensor, Precision Agriculture.**Introduction:**

India's economy is significantly sustained by agriculture, which contributes over 16% to the nation's Gross Domestic Product (GDP). The livelihoods of a vast majority of the rural population are directly or indirectly tied to farming. However, this vital sector faces mounting challenges. The conversion of agricultural land for industrial and urban development is shrinking the land available for cultivation. Simultaneously, a burgeoning population demands increased food production from these diminishing resources. In this context, efficient and effective crop cultivation is not merely a matter of farmer welfare but a national imperative.

A significant obstacle to achieving optimal agricultural output is the lack of precise, localized knowledge among farmers about their own soil. Often, decisions regarding which crop to plant are based on market trends, past practices passed down through generations, or the advice of peers, rather than on a scientific understanding of the soil's inherent capacity and current condition. This can lead to poor crop selection, resulting in low yields, financial loss, and even long-term degradation of soil health. Furthermore, the indiscriminate use of pesticides and fertilizers, often applied without a clear understanding of the soil's existing nutrient profile, can exacerbate the problem, altering soil properties and diminishing its future productivity.

To address these critical issues, this paper proposes the development of a smart, IoT-based crop prediction system. The objective is to create an affordable and easy-to-use tool that can analyze key soil parameters—specifically Nitrogen (N), Phosphorus (P), and Potassium (K)—along with ambient environmental factors like temperature and humidity. By integrating these real-time sensor readings with a knowledge base of crop requirements, the system can suggest the most suitable crops for a given plot of land. This approach aims to move agricultural decision-making from intuition to data-driven precision, helping farmers maximize yield potential while promoting sustainable soil management.

Literature Review:

Recent advancements in the fields of IoT and Machine Learning (ML) have paved the way for innovative solutions in precision agriculture. Several researchers have explored systems for crop prediction and soil analysis, each contributing unique methodologies and insights.

Gupta et al. [1] developed a smart crop prediction system utilizing IoT and ML algorithms, where environmental conditions were used to forecast suitable crops. Their work demonstrated the potential of combining sensor data with predictive models.

Nidagundi et al. [2] proposed an IoT-based system for assessing crop suitability, employing various sensors for comprehensive data collection from the field.

Wani et al. [3] furthered this concept by integrating digital temperature and humidity sensors, LDR, and rain sensors with ML algorithms for crop prediction, highlighting the importance of multimodal sensor input.

Kiruthika and Karthika [4] advanced the field by proposing a professional crop recommendation system using a weight-based long-term memory approach, showcasing the

application of deep learning for improved accuracy.

Khosla et al. [5], who used aggregated rainfall data with support vector regression to predict crop yields, emphasizing the significance of climatic factors.

Raghuvanshi [6] focused on a broader smart agriculture system, where sensor data is displayed on a mobile app, enabling farmers to take timely actions.

Varadarajan et al. [7] presented an IoT framework for precision agriculture that uses ML algorithms to predict suitable crops based on data collected in the cloud.

Padhy et al. [8] developed a comprehensive model for IoT-enabled soil nutrient analysis and crop recommendation, incorporating data acquisition and parameter optimization.

Dias et al. [9] extended the concept to include smart farming, crop protection, and fertilizer prediction.

Dhabarde et al. [10] also proposed an agricultural crop recommendation system leveraging IoT for data collection and ML for prediction. Building upon these foundations, this paper focuses on a cost-effective, Arduino-based implementation that provides real-time, localized predictions to empower individual farmers directly.

Methods and Materials:

The proposed system architecture consists of hardware for data acquisition and software for data processing, analysis, and user interaction.

Hardware Components:

- **Arduino Board:** An open-source microcontroller board serves as the central processing unit. It reads data from the sensors and transmits it to the computer for analysis.

- **NPK Sensor:** This sensor is used to measure the concentration of primary soil nutrients: Nitrogen (N), Phosphorus (P), and Potassium (K). Its probes are inserted directly into the soil sample.
- **DHT11 Sensor:** A digital sensor used for measuring ambient temperature and humidity. These environmental factors are crucial for determining crop suitability.
- **MAX485 TTL to RS-485 Module:** This module acts as an interface between the Arduino board and the NPK sensor, converting TTL signals from the Arduino to the RS-485 protocol required by the sensor.

Software Components:

- **Arduino IDE:** Used for writing and uploading the embedded C code to the Arduino board to read sensor data and send it to the serial port.
- **Django Framework:** A high-level Python web framework employed to build the web application. It handles the backend logic, database interactions, and serves the web pages.
- **HTML, CSS, JavaScript:** These front-end technologies are used to create a user-friendly and interactive web interface. HTML structures the content, CSS styles it, and JavaScript adds dynamic behavior, such as reading data from the Arduino's serial port and displaying it on the webpage.
- **Database:** A standard database (managed through Django) stores the sensor readings and, more importantly, the reference data that maps soil nutrient levels and environmental conditions to suitable crops.

Proposed System and Methodology:

The proposed system operates as an integrated unit, from data acquisition to final prediction. The workflow is illustrated in Fig. 1.

System Workflow:

The system begins with the user inserting the probes of the NPK sensor into the soil. The DHT11 sensor concurrently measures the ambient temperature and humidity. The Arduino microcontroller reads the data from these sensors. This data is then sent via the USB connection to the computer's serial port. A web application, developed using Django, is designed to read this data directly from the serial port. Upon receiving the values, the application compares the measured Nitrogen, Phosphorus, Potassium, temperature, and humidity against a pre-populated database. This database contains the optimal ranges for various crops. Finally, the system outputs the most suitable crop predictions to the user on the web interface.

Algorithm:

- Start.
- Insert NPK sensor probes into the soil.
- Read soil nutrient (N, P, K) values via the Arduino.
- Read ambient temperature and humidity via the DHT11 sensor.
- Transmit all sensor data to the computer's serial port.
- The web application reads the data from the serial port. If no data is available, return to step 4.
- The application compares the received values with the crop requirement database.
- Display the list of recommended crops on the web interface.
- End.

Web Application and Simulation:

The system's functionality was first validated using a simulation in Proteus software (Fig. 1). This allowed testing the circuit connections and the Arduino code's logic before physical deployment. Following successful simulation, the Django-based web application was developed. This interface serves as the primary user interaction point. It displays the real-time sensor readings and presents the final crop prediction based on the analysis of the soil and environmental data.

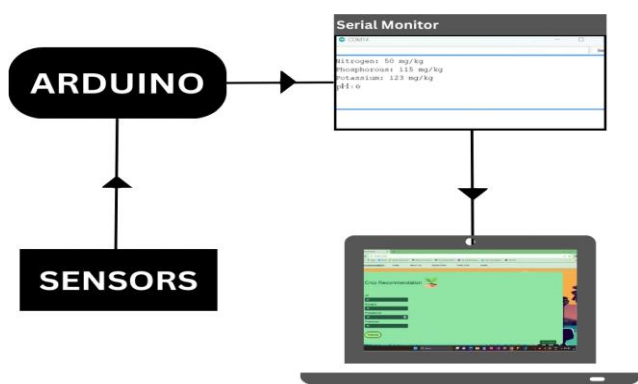


Fig.1: Simulation of the system in Proteus

Results and Discussion:

The experimental results demonstrated the system's ability to successfully acquire data from the NPK and DHT11 sensors via the Arduino. The data was accurately transmitted to the serial port and subsequently read by the Django web application. When the measured parameters were compared against the database, the system successfully output a list of suitable crops. This confirms the core functionality of the proposed IoT-based prediction system.

The use of the Django framework allowed for a robust and scalable web application. The interface (Figs. 2-5) clearly presents the sensor readings, making the data accessible to the user. The system provides a direct, actionable

recommendation, thus fulfilling its primary objective of aiding farmers in crop selection.

A key advantage of this system is its use of affordable and readily available components (Arduino, NPK sensor, DHT11), making it a cost-effective solution for small and marginal farmers. The system's reliance on real-time, localized data ensures that recommendations are specific to the user's field conditions, unlike generic advice that may be less accurate.

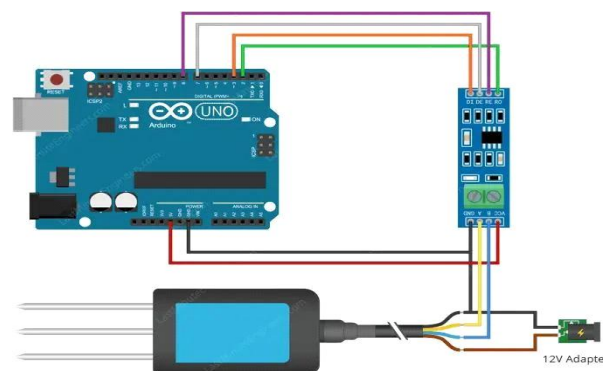


Fig. 2: Web Interface showing sensor input fields

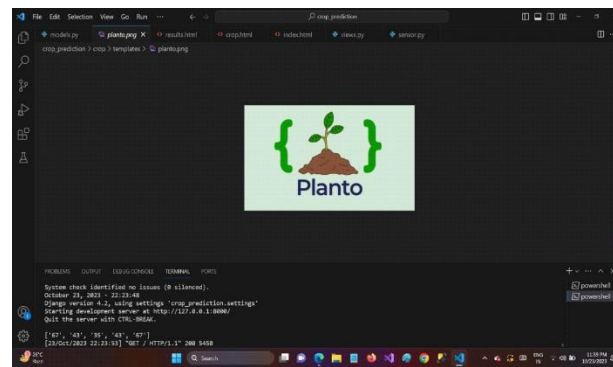


Fig 3: Web Interface displaying NPK values

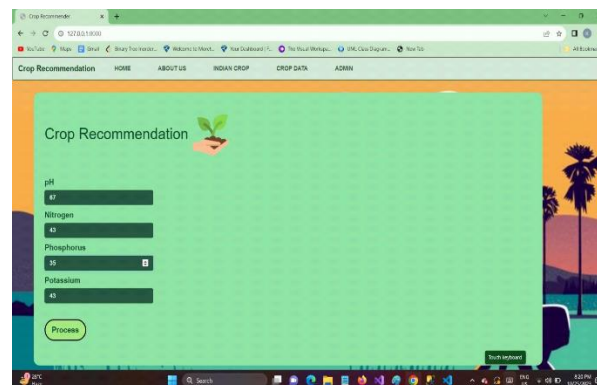


Fig. 4: Web Interface displaying environmental data

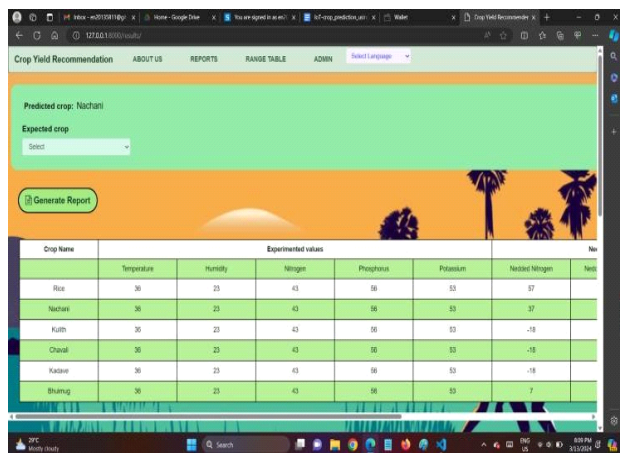


Fig. 5: Web Interface showing final crop prediction



Fig. 6: Web interface displaying recorded soil data and crop recommendations

Conclusion:

The proposed system is predicting the Crop Yield using a Standard Database. This system based on Internet of Things is implemented with an NPK sensor and DHT11 sensor which is interfaced with an Arduino Board. The simulation of this system is implemented on Proteus Software. The Website has designed with Django framework for the project which will be the web framework of the project which predict and display the result. The readings from sensors will automatically print on the input box of website page through the serial

port of the arduino. By promoting precision agriculture, this system has the potential to significantly improve crop yields, reduce resource wastage, and contribute to the overall sustainability of the agricultural sector. Future work could involve integrating machine learning algorithms to refine prediction accuracy, adding more sensors (e.g., for soil moisture or pH), and incorporating a wireless module for remote data access and monitoring.

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IoT Based Industrial Parameters Monitoring & Control

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Abstract:

This paper presents the design and implementation of an integrated IoT-based industrial monitoring, security, and automated control system. Utilizing the ESP32 and ESP32-CAM microcontrollers, the architecture provides a dual-layered approach to industrial safety. The environmental node monitors critical parameters, including ambient temperature, humidity DH22, liquid temperature via DS18B20, water level, and hazardous gas concentrations using the MQ-2 sensor. Based on predefined safety thresholds, the system executes autonomous responses through a cooling fan, water pump, and multi-stage auditory alarms.

Complementing the environmental control, a dedicated security node employs a PIR motion sensor and ESP32-CAM to provide real-time visual surveillance. Upon detecting unauthorized movement, the system captures high-resolution imagery and transmits instant alerts via the Telegram Bot API. Sensor data is synchronized with the Thing Speak cloud platform for remote analytical visualization, while local data is rendered on OLED and LCD interfaces for redundant on-site monitoring. The results demonstrate a low-latency, cost-effective solution for modern industrial automation, offering both autonomous stabilization and remote security verification. This integrated framework ensures heightened operational safety and reduced manual oversight in hazardous industrial environments.

Keywords: IoT, ESP32, ESP32-CAM, Smart Sensors, Industrial Automation, Thing Speak, Cloud Computing, Real-time Systems, Telegram Bot API, Motion Detection.

Introduction:

The invention of the Internet of Things (IoT) has flourished in a new era of connectivity and intelligent computing, significantly transforming various sectors including industrial operations. Industrial environments are characterized by complex processes that require precise monitoring and control of parameters such as temperature, humidity, and fire safety precautions. Traditionally, these parameters have been monitored manually, often resulting in inefficiency, delayed responses, and increased operational costs.

IoT-based industrial monitoring and control systems offer a solution to these challenges by using interconnected sensors, actuators, and advanced technologies. These systems enable real-time data collection, analysis, and response, facilitating proactive maintenance and reduced downtime. Beyond environmental sensing, modern industrial safety now demands visual verification and security surveillance to protect high-value assets and personnel.

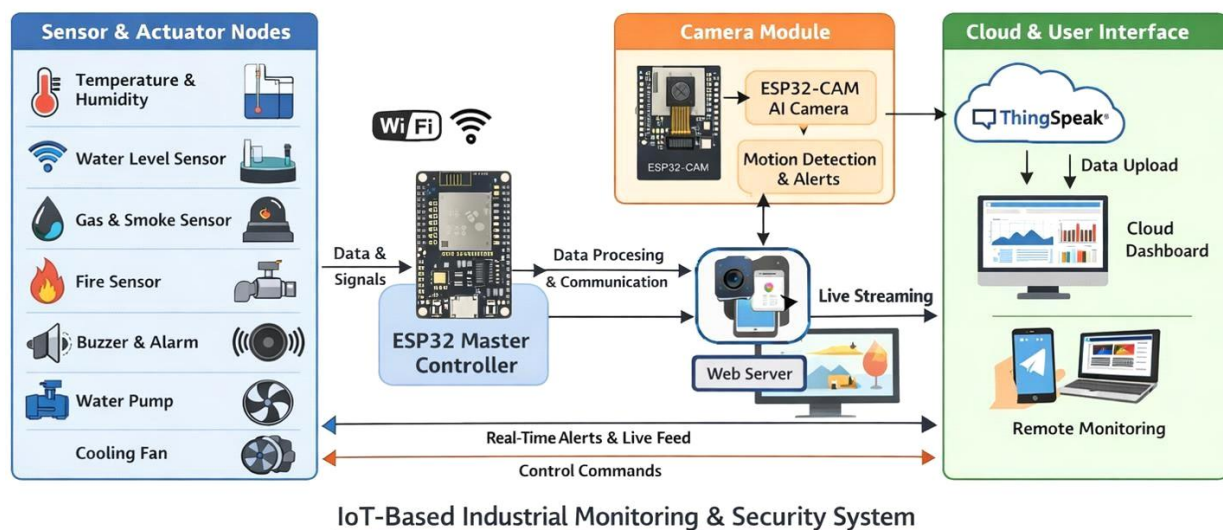
This paper explores the design and implementation of an integrated IoT system using the ESP32 and ESP32-CAM microcontrollers.

The system incorporates a network of smart sensors, including the DHT22 for ambient conditions, DS18B20 for liquid temperature, MQ-2 for gas and smoke detection, and ultrasonic sensors for water level management. A critical security layer is added via a PIR motion sensor and camera module, which triggers instant

photographic alerts to a Telegram bot upon detecting unauthorized activity. By deploying these sensors and using the Thing Speak cloud platform for data analytics, the system provides a comprehensive, scalable, and secure approach to modern industrial automation and remote management.

Methods and Materials:

System Architecture:



The proposed system is an integrated IoT monitoring and control framework consisting of two functional nodes. The primary node utilizes an ESP32 microcontroller for environmental data processing and cloud connectivity. The secondary node utilizes an ESP32-CAM module specifically for computer vision and motion-triggered surveillance.

Software and Cloud Integration:

- Development Environment: Arduino IDE 2.0.
- IoT Platform: Thing Speak API for real-time sensor logging and cloud visualization.
- Security Interface: Telegram Bot API for instant photographic alerts and remote surveillance.

- Libraries: WiFi.h, ThingSpeak.h, esp_camera.h, WIFI Client Secure.h, Dallas Temperature.h, and DHT.h.

Research Methodology:

The methodology is divided into four functional phases: Data Acquisition, Visual Surveillance, Local Control Logic, and Cloud Synchronization.

Sensor Calibration and Data Acquisition:

To ensure data integrity, the MQ-2 sensor undergoes a 30-second pre-heating and calibration phase upon startup to establish a baseline cleanAirValue. Gas concentration is calculated as a percentage (0% to 100%) using the ESP32's 12-bit ADC (4095 resolution). The

water level is derived from the ultrasonic time-of-flight (t) using the following formula:

$$\text{Distance (cm)} = \frac{t \times 0.034}{2}$$

$$L = \text{Tank Height} - \text{Distance}$$

Visual Security Logic:

The ESP32-CAM node operates using a Passive Infrared (PIR) sensor on GPIO 3. When motion is detected, the system captures a JPEG image at QVGA resolution. To prevent redundant alerts, a 15-second motion Cooldown timer is implemented. The captured frame is then transmitted via a Secure TLS connection to the Telegram Bot API.

Automated Control Logic (The Firmware):

The system employs a "Threshold-Trigger" logic to manage the environment without human intervention:

- **Gas Safety:** If smoke levels exceed 60%, the buzzer is constant; between 30-60%, it pulses to indicate a warning.
- **Hydro-Management:** The water pump (Relay 1) activates when the level drops below 5 cm and deactivates at 16 cm to prevent overflow.
- **Thermal Regulation:** The cooling fan (Relay 2) triggers at $> 35^{\circ}\text{C}$ and cuts off once the system cools to 30°C (Hysteresis control).

Experimental Setup:

The hardware was assembled using a modular approach. The environmental node utilizes I2C communication sharing pins GPIO 21 (SDA) and GPIO 22 (SCL) for both the OLED and LCD displays. The security node was configured with a specific camera config structure to allocate PSRAM for image buffering. Power was regulated to 5V for the relays, ultrasonic sensor, and camera module, while the ESP32 and DHT22 operated on the 3.3V rail.

Materials (Hardware Components):

The following hardware components were selected for the implementation:

Sr. No.	Component Name	Specification	Purpose
1	ESP32 Development Board	Wi-Fi enabled microcontroller	Main controller for data processing & IoT communication
2	ESP32-CAM Module	OV2640 camera with Wi-Fi	Image capture, motion detection & live streaming
3	MQ-2 Gas Sensor	Gas & smoke detection	Detect harmful gases & fire hazards
4	Ultrasonic Sensor HC-SR04	Distance measurement (2–400 cm)	Water level monitoring
5	DS18B20 Temperature Sensor	Digital temperature sensor	Industrial temperature measurement
6	DHT22 Sensor	Temperature & humidity sensor	Environmental monitoring
7	PIR Motion Sensor	Motion detection sensor	Detect human movement for security
8	OLED Display SSD1306	128×64 I2C display	Real-time parameter display

9	16x2 LCD Display with I2C	Alphanumeric display	Local monitoring output
10	Relay Module 2-Channel	5V relay module	Control pump and fan
11	Buzzer Module	Audio alert device	Alarm for gas leakage
12	DC Water Pump	5V/12V mini pump	Automatic water level control
13	DC Fan	Cooling fan	Temperature control

Result and Discussion:

Result:

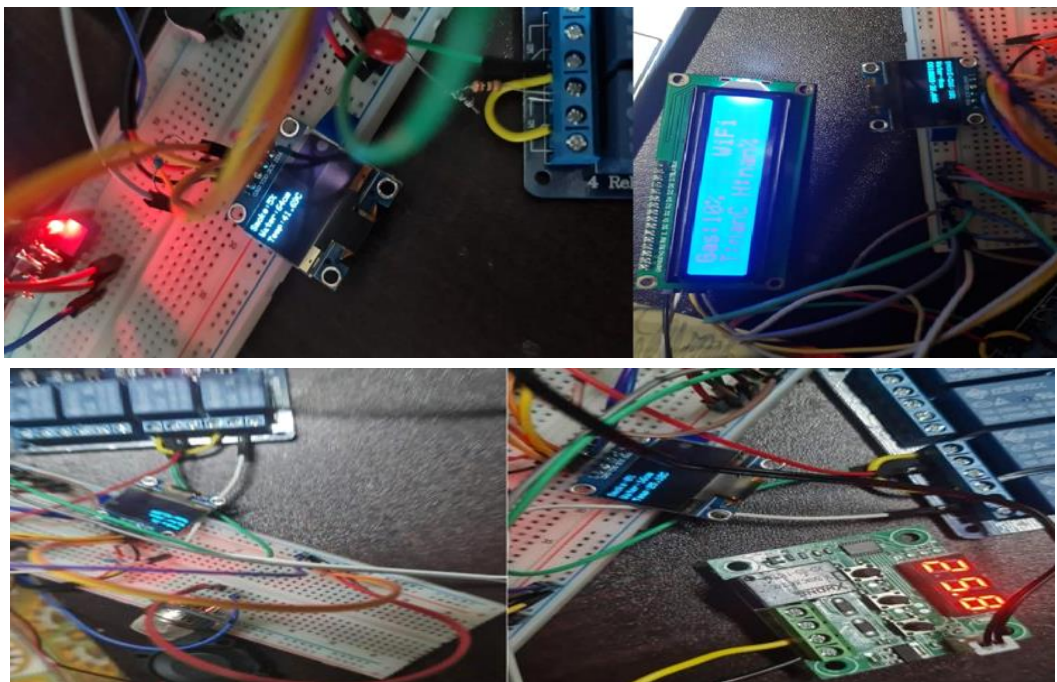
The proposed IoT-based industrial monitoring and control system using the ESP32 Development Board and ESP32-CAM Module was successfully designed and implemented. The system effectively monitored environmental parameters such as temperature, humidity, water level, and gas/smoke concentration in real time.

The sensor readings obtained from DHT22 Sensor, DS18B20 Temperature Sensor, Ultrasonic Sensor HC-SR04, and MQ-2 Gas Sensor were accurately processed and displayed on both OLED and LCD displays. The data was successfully transmitted to the Thing Speak cloud platform, where it was visualized in graphical format for remote monitoring.

The automation system responded efficiently based on predefined thresholds:

- The buzzer was activated when gas levels exceeded safety limits.
- The water pump operated automatically based on tank level conditions.
- The cooling fan was controlled according to temperature variations.

The integrated surveillance system using the ESP32-CAM successfully detected motion through the PIR sensor and captured images in real time. These images were transmitted to users via Telegram alerts, ensuring enhanced security. Live streaming functionality was also achieved through a web server interface.



The system demonstrated stable operation with periodic data updates (every 15 seconds) and minimal delay in response time.

Discussion:

The results indicate that the proposed system provides an efficient and reliable solution for industrial monitoring and automation. The use of IoT technology enables real-time data acquisition, remote accessibility, and improved decision-making.

The integration of multiple sensors ensures comprehensive monitoring of industrial conditions, reducing the risk of hazards such as gas leakage and overheating. The automatic control of actuators minimizes human intervention and enhances system efficiency.

The addition of the ESP32-CAM module significantly improves the system by incorporating visual monitoring and security features. Motion detection combined with instant image alerts via Telegram adds an extra layer of protection, which is not commonly found in basic industrial monitoring systems.

However, some limitations were observed:

- Sensor accuracy may vary due to environmental factors and calibration requirements.
- Wi-Fi dependency may affect system performance in case of network instability.
- The camera module has limited resolution and storage capability.

Despite these limitations, the system proves to be cost-effective, scalable, and suitable for small- to medium-scale industrial applications. Future improvements can include AI-based analytics, higher precision sensors, and integration with advanced cloud platforms.

Conclusion:

The proposed IoT-based industrial parameter monitoring and control system has been successfully designed and implemented using the ESP32 Development Board and ESP32-CAM Module. The system effectively monitors critical industrial parameters such as temperature, humidity, water level, and gas/smoke concentration in real time using various sensors.

The integration of cloud technology through Thing Speak enables remote monitoring and data visualization, allowing users to access system information from anywhere. The automatic control mechanism ensures timely response to abnormal conditions by activating devices such as fans, water pumps, and buzzers, thereby enhancing safety and operational efficiency.

Furthermore, the inclusion of a camera-based surveillance system adds an advanced security feature. The motion detection capability and real-time image transmission via Telegram provide instant alerts, making the system more reliable and intelligent compared to conventional monitoring systems.

Overall, the proposed system offers a cost-effective, scalable, and efficient solution for modern industrial automation. It reduces human intervention, improves safety, and enables smart decision-making through real-time data and alerts. Hence, this system is highly suitable for implementation in small- and medium-scale industrial environments.

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Hybrid Solar-Wind Renewable Energy System

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Abstract:

This paper presents the design and implementation of a hybrid renewable energy system that integrates solar and wind energy sources for sustainable power generation. The primary objective of this system is to ensure a continuous and reliable power supply by combining two renewable sources with complementary characteristics. Solar energy is utilized during daytime conditions, while wind energy contributes during low solar availability, thereby improving overall system efficiency and reliability. The system incorporates essential components such as photovoltaic panels, a wind turbine, charge controllers, battery storage, and a power conversion unit. Additionally, a proper energy management strategy is implemented to regulate power flow and maintain stable output. The proposed hybrid system is cost-effective, environmentally friendly, and suitable for both rural and off-grid applications. Experimental and simulation results demonstrate improved performance, reduced dependency on conventional energy sources, and enhanced energy utilization. This study highlights the potential of hybrid renewable energy systems as a sustainable solution for future energy demands.

Keywords: Hybrid Renewable Energy System, Solar Energy, Wind Energy, Sustainable Power Generation, Energy Management System, Battery Storage.

Introduction:

The rapid increase in energy demand and the environmental concerns associated with conventional energy sources have led to the growing adoption of renewable energy technologies. Among these, solar and wind energy are widely recognized for their sustainability, eco-friendliness, and abundant availability. However, both sources are inherently intermittent in nature, as solar energy depends on sunlight conditions while wind energy varies with wind speed, resulting in an unstable power output.[1]

To overcome these limitations, hybrid renewable energy systems have been developed by integrating multiple energy sources to ensure a continuous and reliable power supply. In this study, a hybrid solar-wind energy system is

designed and implemented to improve overall efficiency and system reliability. The solar subsystem employs a solar charge controller to regulate voltage and protect the battery from overcharging, ensuring efficient energy storage. A battery storage unit is incorporated to store excess energy and supply power during low generation periods.[2]

On the wind energy side, a buck-boost converter is utilized to regulate the fluctuating output voltage generated by the wind turbine. This converter maintains a stable DC output by stepping up or stepping down the voltage as required, thereby enhancing system stability and efficiency.[3]

The entire system is designed and simulated using Proteus software to analyze performance under varying conditions.

Additionally, an inverter circuit is implemented to convert DC power into AC power for practical applications, using a center-tapped step-up transformer to achieve the required voltage level.

The proposed system is cost-effective, reliable, and suitable for rural and off-grid applications, demonstrating the potential of hybrid systems in sustainable energy generation.

Literature Review:

In order to improve system efficiency and dependability while reducing the intermittent nature of individual resources, hybrid renewable energy systems (HRES) combine several energy sources, such as solar and wind. Recent research emphasises the relevance of hybrid configurations and energy storage in enhancing performance, highlighting developments in system design, optimisation methods, and energy management tactics. However, there are still issues with realtime control, uncertainty management, and appropriate size, suggesting the need for more intelligent and reliable methods for real-world application[2]

To improve dependability and raise the proportion of renewable energy in the power supply, hybrid energy systems combine many energy sources, usually mixing conventional and renewable generating. Research shows that these systems work especially well in rural and distant locations, where they enhance energy availability, lessen reliance on fossil fuels, and minimise long-term operating costs [4]. Widespread adoption is nevertheless hampered by issues including high starting costs, site-specific design specifications, and restricted scalability.

In order to improve dependability, efficiency, and the best possible use of renewable resources, recent research highlights the integration of hybrid renewable energy systems (HRES) with smart grid technology. For the best size and cost minimisation of HRES components

while meeting load and reliability limitations, a variety of optimisation approaches, including genetic algorithms and particle swarm optimisation, have been extensively used. In smart grid systems, energy management techniques including load shifting and demand-side control have also been investigated to enhance system performance and lower operating expenses [5].

A thorough analysis of hybrid renewable/alternative energy systems is provided by Nehrir et al. [1], with an emphasis on system designs, energy storage, control techniques, and applications for sustainable power generation. The study emphasises the significance of hybridisation in reducing the intermittency of renewable sources while highlighting important issues including optimal unit size, energy management, and reliability enhancement. To increase system performance and deployment, new research topics are also highlighted, such as enhanced storage technologies and sophisticated control strategies.

In their analysis of the development of renewable energy sources worldwide, Haegel and Kurtz[6] highlight the recent explosive expansion of wind and solar photovoltaics (PV). Although PV currently makes up a relatively modest portion of overall output, the study shows that renewable sources are progressively contributing to the world's power supply. The study also highlights current obstacles and prospects for renewable energy growth in the future, especially with regard to accomplishing widespread decarbonisation and energy transition.

With an emphasis on system designs, component size, energy storage, and control mechanisms for sustainable power generation, Nehrir et al.[3] offer a thorough analysis of hybrid renewable/alternative energy systems. Although there are still many obstacles to overcome in terms of optimal design and energy management,

the study emphasises that hybridisation of renewable sources enhances system performance and dependability while resolving intermittency difficulties. The study also covers developing technologies and sophisticated control strategies to improve system deployment and efficiency, as well as present and future research initiatives.

The difficulties of incorporating large amounts of variable renewable energy (VRE), including solar and wind, into electric power systems are examined by Kroposki [7], especially with regard to preserving the equilibrium between generation and load. The research discusses options including energy storage, sophisticated forecasting, and flexible grid operation while highlighting important problems like unpredictability, uncertainty, and decreased system inertia. Additionally, real-world examples show that high VRE penetration may be attained with the right control and system design techniques.

According to recent research, hybrid renewable energy systems that incorporate wind, solar, and several storage technologies may successfully handle intermittency problems and boost system dependability by using cutting-edge energy management techniques. Numerous research suggest demand-response strategies and energy management systems (EMS) to maximise

energy flow, improve self-sufficiency, and guarantee effective use of renewable resources in both isolated and grid-connected setups. Additionally, it has been demonstrated that the integration of dual storage technologies, such as batteries and pumped hydropower, greatly enhances system performance and energy flexibility.[8]

Despite the intermittent nature of renewable energy sources, recent studies show that hybrid renewable energy systems that integrate solar, wind, and pumped storage can successfully minimise grid reliance and enhance energy dependability. Meta-heuristic algorithms and other optimisation approaches are frequently employed to minimise CO₂ emissions, improve overall performance, and achieve cost-effective system size.[9]

According to recent research, hybrid solar-wind energy systems successfully increase dependability by guaranteeing continuous power output and making up for the intermittent character of individual renewable sources. Additionally, because of their advantages for the environment, long-term cost-effectiveness, and capacity to deliver a steady supply of energy, these systems are often seen as appropriate for rural and distant locations.[10]

Methodology:

Block Diagram:

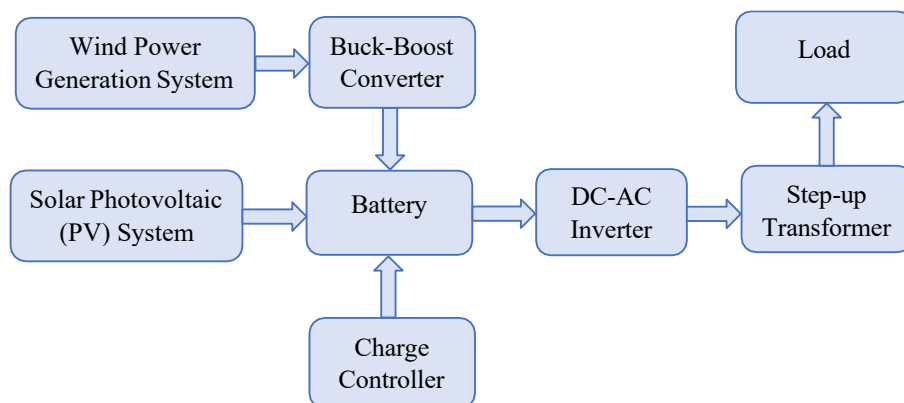


Fig.1: Block Diagram of Hybrid Solar-Wind Renewable Energy System

As shown in Fig.1, the suggested hybrid renewable energy system combines solar and wind energy sources to guarantee a steady and dependable power supply to the load. The wind power generating system transforms the kinetic energy of the wind into electrical energy, which is then conditioned using a buck-boost converter to control the output voltage fluctuations and deliver a steady DC supply. In parallel, the solar photovoltaic (PV) system uses solar radiation to create DC power, which is controlled by a charge controller to maintain appropriate voltage levels and guard against deep drain and overcharging of the battery. A shared battery storage unit, which acts as an energy buffer by storing extra energy and providing power during times of low generation, receives both regulated outputs. The DC that was stored. To satisfy the needs of typical AC loads, the stored DC power is then transformed into AC using a DC–AC converter. For effective power distribution to the load, a step-up transformer is also used to raise the voltage level. Thus, by integrating many renewable energy sources with energy storage and power conditioning units, the integrated system shown in Fig.3.1 improves overall efficiency, dependability, and sustainability.

Working Principal:

The effective integration of solar and wind energy sources for power generation is demonstrated by the simulation results of the suggested hybrid renewable energy system. The solar panel in the circuit produces DC electricity from sunlight, while the wind turbine powers the DC generator to generate electrical energy. A rectifier diode and filter capacitor are used to smooth out voltage fluctuations and provide a steady DC signal from the wind generator's output. In a similar vein, the charge controller

circuit controls the solar panel output in order to maintain a regulated charging voltage.

The effective integration of solar and wind energy sources for power generation is demonstrated by the simulation results of the suggested hybrid renewable energy system. The solar panel in the circuit produces DC electricity from sunlight, while the wind turbine powers the DC generator to generate electrical energy. A rectifier diode and filter capacitor are used to smooth out voltage fluctuations and provide a steady DC signal from the wind generator's output. In a similar vein, the charge controller circuit controls the solar panel output in order to maintain a regulated charging voltage.

Calculations:

Basic Assumptions:

Load = 100 W

Operating time = 4 hours/day Battery system voltage = 12 V

Battery depth of discharge (DOD) = 50%

Average sunlight = 4 hours/day

Safety factor for current = 1.25

Battery Capacity Calculation:

Daily energy = $100 \text{ W} \times 4 \text{ h} = 400 \text{ Wh}$ Battery Ah = $400 \text{ Wh} \div 12 \text{ V} = 33.33 \text{ Ah}$

Since we use only 50% (DOD), actual required = $33.33 \div 0.5 = 66.7 \text{ Ah}$ Select a 12 V, 70 Ah battery.

Solar Panel Size:

Required energy = $400 \text{ Wh} \div 4 \text{ sun hours} = 100 \text{ W}$

Adding 30% losses $\rightarrow 100 \times 1.3 = 130 \text{ W}$

Choose a 150 W solar panel ($V_{mp} \approx 18 \text{ V}$, $I_{mp} \approx 8.3 \text{ A}$).

Charge Controller:

Controller current = panel current $\times 1.25 = 8.3 \times 1.25 = 10.4$ A Select a 15 A MPPT charge controller

Diodes:

System current ≈ 10.4 A $\rightarrow$ select diode rated $\geq 2 \times$ current = 20–30 A, 50 V Power loss = $V_f \times I = 0.5 \times 10.4 = 5.2$ W
Use Schottky diode (low V_f)

MOSFET (IRFZ44N) & Shunt Resistor (R6 = 0.22 Ω):

System current = 10.4 A
Power loss on resistor = $I^2 \times R = 10.4^2 \times 0.22 = 23.9$ W
Use a 0.22 Ω , 25–50 W resistor
MOSFET loss = $I^2 \times R_{ds(on)} = 10.4^2 \times 0.022 = 2.4$ W Use IRFZ44N

Capacitors:

Smoothing capacitor: 4700 μ F, 35 V Bypass capacitor: 0.22 μ F, 50 V ceramic These stabilize voltage and reduce ripple

Transformer (for inverter):

Load = 100 W $\rightarrow$ current = $P / V = 100 \div 12 = 8.3$ A
Add margin $\rightarrow$ use 150 VA transformer, primary current ≥ 15 A

Wiring & Fuse:

Current = 10.4 A
Fuse = $I \times 1.25 = 13$ A $\rightarrow$ use 15 A fuse
Wire = 2.5 mm² copper (safe up to 12–14 A)

Components:

Table 1: Components Used in System

Sr. No	Components	Specification	Quantity
1	Solar Panel	12V / 100 W	01
2	Wind Generator Turbine	12V	01
3	Diode (1N4007)	-	08
4	Capacitor	470 μ F/25V	02
5	Resistor	1k ohm, 10k ohm, 470ohm	05
6	Potentiometer	10k ohm	01
7	Inductor (LED)	2V, 20mAmp	01
8	Amplifier	-	01
9	Li-ion Battery	12V	01
10	MOSFET	TIP122/2N3055/IRFZ44N	01
11	Transformer	12V Step up	01

Table 1 summarizes the key components utilized in the proposed hybrid renewable energy system integrating solar and wind energy sources. The solar panel (12 V, 100 W) and wind generator turbine (12 V) serve as the primary energy generation units, converting solar

irradiance and wind kinetic energy into electrical power.

To ensure unidirectional current flow and protect the system from reverse current, 1N4007 diodes are incorporated within the circuit. Capacitors (470 μ F, 25 V) are employed for voltage filtering and ripple reduction, thereby

maintaining a stable DC output. Additionally, resistors (1 k Ω , 10 k Ω , 470 Ω) and a 10 k Ω potentiometer are used for voltage division, current limiting, and fine adjustment of circuit parameters.

An LED (2 V, 20 mA) is used as a visual indicator for system status, while an amplifier is included to enhance signal strength where necessary. The generated electrical energy is stored in a 12 V Li-ion battery, which acts as an energy backup and ensures continuous power supply during fluctuations or absence of input sources.

Result and Discussion:

Simulation:

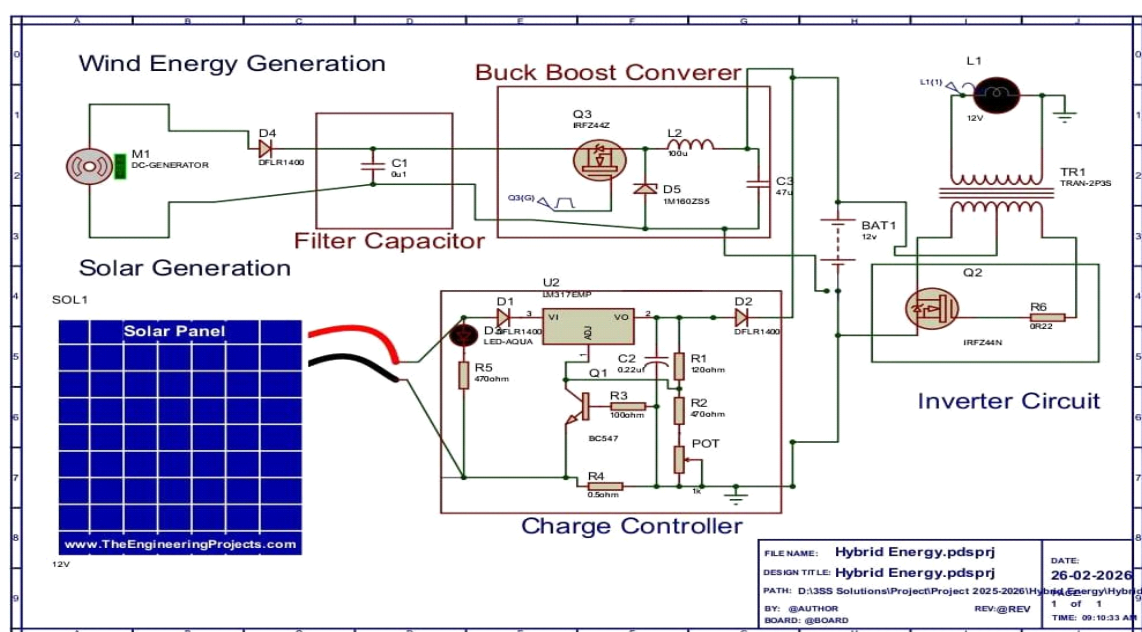


Fig.2: Simulation and Circuit Diagram of the Hybrid Solar-Wind Renewable Energy System

The simulation shown in the diagram represents a hybrid renewable energy system that combines wind energy and solar energy to generate electricity, store it in a battery, and convert it into usable AC power through an inverter. The system includes a wind generator, solar panel, charge controller, buck-boost converter, battery storage, and an inverter circuit.

First, the wind energy generation section uses a DC generator to produce electrical energy

For switching and power regulation, power semiconductor devices such as MOSFETs (TIP122, 2N3055, IRFZ44N) are utilized, particularly in the inverter stage. Finally, a 12 V step-up transformer is employed to increase the voltage level, enabling the system to deliver usable AC power to the load. Overall, the components listed in Table 1 collectively facilitate efficient energy generation, conditioning, storage, and conversion, thereby ensuring reliable operation of the hybrid renewable energy system.

when wind rotates the turbine. The generated DC power passes through a diode (D4) which prevents reverse current flow. After that, a filter capacitor (C1) smooths the fluctuating voltage coming from the generator. The filtered DC power is then sent to the buck-boost converter. In this converter, components such as MOSFET (Q3), inductor (L2), diode (D5), and capacitor (C3) regulate the voltage. The buck-boost converter either increases or decreases the voltage

depending on the input conditions, ensuring a stable output voltage suitable for charging the battery.

The solar generation section includes a solar panel that converts sunlight directly into DC electrical energy. The output from the solar panel is connected to a charge controller circuit. The charge controller protects the battery from overcharging and regulates the charging current. It consists of components such as transistors, resistors, capacitors, diodes, and a voltage regulator IC. This circuit monitors the battery voltage and controls the charging process to maintain safe operating conditions.

Both the wind and solar sources supply energy to a 12 V battery (BAT1), which acts as an energy storage device. The battery stores excess energy produced during high wind or strong sunlight conditions. This stored energy can later

be used when renewable sources are not producing sufficient power.

Finally, the inverter circuit converts the stored DC power from the battery into AC power. The inverter uses a MOSFET (Q2) and a transformer (TR1) to generate alternating current. The transformer steps up the voltage to the required AC level for powering electrical loads. This allows the hybrid system to supply electricity to standard AC devices.

Overall, the simulation demonstrates how a hybrid wind-solar energy system can efficiently generate, regulate, store, and convert renewable energy into usable electrical power. The integration of multiple renewable sources improves reliability and ensures continuous power supply even when one energy source is not available.

Simulation Result:

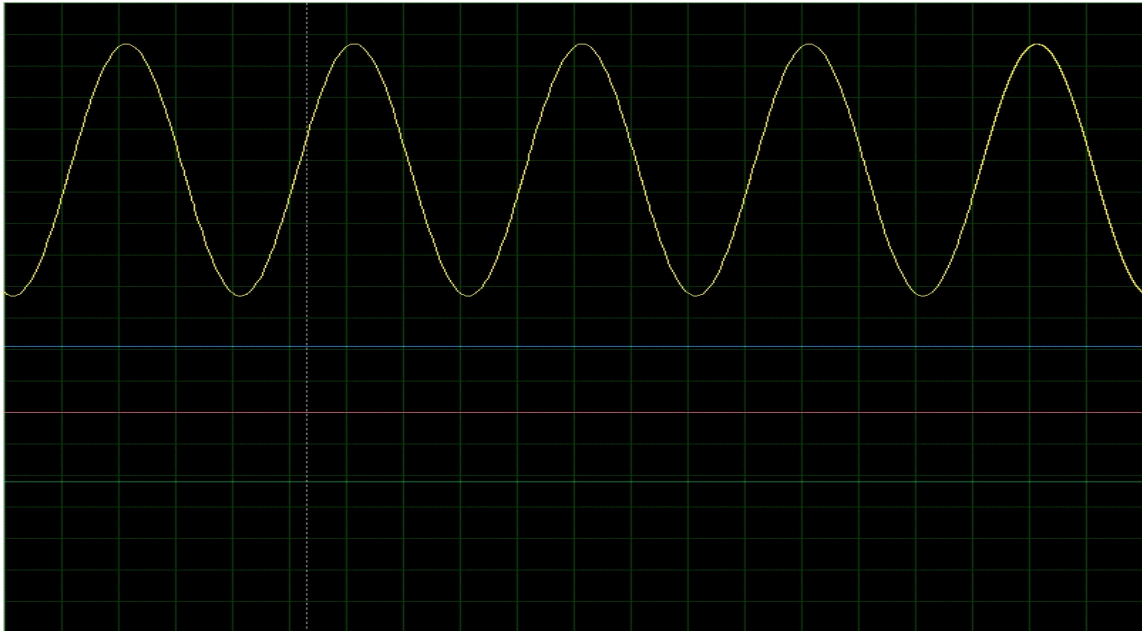


Fig.3: simulation result of Hybrid Solar-Wind Renewable Energy System

The simulation results obtained from the designed hybrid solar-wind energy system demonstrate the effective operation of the overall circuit. The waveform observed at the solar panel output indicates a constant DC voltage,

representing stable power generation suitable for battery charging. The wind energy output waveform initially shows fluctuations due to variable input conditions; however, after passing through the buck-boost converter, a regulated and

stable DC waveform is achieved. The battery charging waveform exhibits a gradual rise in voltage, confirming smooth and continuous charging without any instability. At the inverter output, a square waveform is observed, which verifies the successful conversion of DC power into AC supply using MOSFET switching and a center-tapped transformer. Based on the obtained waveforms, it is evident that the system maintains proper voltage regulation, efficient energy conversion, and uninterrupted power delivery, confirming the successful implementation of the hybrid renewable energy system.

Conclusion:

The effective integration of solar and wind energy sources for power generation is demonstrated by the simulation results of the suggested hybrid renewable energy system. The solar panel in the circuit produces DC electricity from sunlight, while the wind turbine powers the DC generator to generate electrical energy. A rectifier diode and filter capacitor are used to smooth out voltage fluctuations and provide a steady DC signal from the wind generator's output. In a similar vein, the charge controller circuit controls the solar panel output in order to maintain a regulated charging voltage. For distant or off-grid locations in particular, the hybrid renewable energy system is an effective and eco-friendly way to produce electricity.

Future Scope:

Future work can focus on the integration of advanced Maximum Power Point Tracking (MPPT) algorithms to enhance energy extraction efficiency. Incorporating IoT-enabled real-time monitoring and control can further improve system reliability. Additionally, the adoption of intelligent energy management strategies, grid interconnection, and advanced energy storage

technologies can enable large-scale and smart grid applications.

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A Review on Properties of Geopolymer Concrete

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Abstract:

Sustainable development is necessity of today's environmental condition as climate change is the major fact which affects the life. Environment and Concrete industries have a very strong bond. Concrete demands OPC in huge amount for building several huge and mega structures. The CO₂ emission from Portland cement industries affects a lot to the environment. It is necessary to find alternate low emission binding solution for Portland cement. Geopolymer concrete is polymer material which utilizes the by products from coal and steel industries like fly ash, ground granulated blast furnace slag (GGBFS) and also metakaoline etc. along with the alkaline activators. It is zero cement concrete. This paper reviews the strength parameters for class F fly ash-based GPC and metakaoline based GPC. The geopolymer concrete is really a green solution for concrete to reduce CO₂ emission.

Keywords: Alkaline Activators, Fly Ash, Geopolymer concrete, Metakaoline, GGBFS.

Introduction:

Construction sector plays a vital role in the urbanization and globalization. Many unexpected dreams comes true because of building mega structures worldwide. Beside all the advantages construction industry is also responsible for global pollution. In global energy related emissions, around 38% of total amount comes from building and construction sector. In advance construction system, CO₂ emission due to ordinary Portland cement has become a global issue. Worldwide many being taken by construction sector to reduce environmental damage for example adaptation of green buildings etc. As a part of 10th annual world green building week, world green building council has issued bold new vision for how building and infrastructures around world can reach 40% less embodied CO₂ emission by 2030 and 100% net zero emissions buildings by 2050. To overcome this difficulty many researchers are continuously working on alternative solution of OPC.

This research work reveals that geopolymer concrete is proper and green alternative for reducing CO₂ emission. In the same manner recycled raw materials and for demolished concrete is also going on. This paper reviews all the important properties of geopolymer concrete. It is an eco-friendly alternative for OPC, as it uses waste products from mainly coal and steel (thermal power plant and steel plant). It has composition of fly ash and ground granulated blast furnace slag. By using these two materials vast stock of waste materials will reduce and also the CO₂ emission. Alkaline silicates and alkaline hydroxide are the activators used in concrete along with the super plasticizer. In India, geopolymer concrete is not been used so much for mega structures. It can be fly ash based type, GGBFS based type and also metakaoline based geopolymer concrete

Polymerization Process:

Polymerization process involves dissolution of aluminosilicate and condensation of free silicates and aluminates to form three-dimensional silico-aluminate structure. For the process alkaline activator solution is needed.

Material Study:

Geopolymer concrete consists of two main materials- source materials and alkaline activators. Source materials should be rich in Al and Si. Such materials can be natural like kaolinite and clay or the byproduct like fly ash, GGBFS, rice husk ash etc. [11].

Fly Ash:

It is also called as fuel ash or pulverized fuel ash. PFA is a combustion product of coal industry, obtained in the form of particulates which are thrown out of coal-fired boilers together with fuel gases. All fly ash includes amount of silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3) and calcium oxide (CaO) etc. Depending on the chemical composition and presence of cementitious materials in it, PFA can be partially or fully used as replacement of Portland cement. Class F- this type is pozzolanic in nature, less than 7% lime, can form geopolymer. Class C- In this type in addition to having pozzolanic properties, it has self-cementing properties too.



Fig.1 Fly Ash

Metakaoline:

It is anhydrous calcined form of clay mineral kaolinite. Metakaoline properties mainly depend on the properties of kaolinite.

Activators:

Alkaline solution like NaOH, KOH – alkaline hydroxides and Na_2SiO_3 , K_2SiO_3 – alkaline silicates required to bind the polymer material like fly ash and GGBFS.



Fig.2 alkaline activators

Super Plasticizer:

The admixtures like retarders, accelerators, plasticizers are chemical agents that added to concrete to enhance the properties and make it workable in different environmental conditions. Super plasticizers are the chemical additives which help to reduce water content. It is a higher version plasticizer and allow reduction in water content by more than 30%.

Strength Properties of GPC:

Geopolymer concrete concept was first introduced by Joseph Davidovits. As the GPC mainly requires source materials and the alkaline activators, it has different curing methods than conventional concrete.

Properties of fly ash based GPC:

Effect of molarity of alkaline solution on compressive strength Rajiwala D.B. et.al. studied different properties of low calcium fly ash ASTM class F with potassium hydroxide and sodium hydroxide solution of desired molarity. They concluded that the GPC has 1.5 times greater compressive strength than conventional concrete [3]. Also Mr.G.Hemanaag et.al. studied GPC properties with alkaline solution as sodium silicate and sodium hydroxide with molarity varying from 2M to 8M. Study was based on

comparison of fly ash and metakaoline based GPC and results of fly ash based GPC having 8M shows higher results up to 520 N/mm² [1]. Prakash R. Vora et.al. explained increase in concentration of NaOH in terms of molarity will increase the compressive strength of GPC [9].

Effect of additive on strength of GPC:

Dhavamani Doss Sakhtidoss et.al. casted a high strength GPC with river and M-sand. They got better results in terms of compressive strength in case of HSGPC with M-sand up to 71.46 N/mm² compared to HSGPC with river sand. Manufacturing sand will also be the best possible alternative for river sand [7]. A. Supriya Prakash have used cylindrical steel fibers with hooked ends and added in the 0.5%, 1% and 1.5% by volume of concrete. They got 5% increase in compressive strength for 1% fibers [4]. Xin Ren et.al. used recycled aggregates for casting GPC and got the better results than NA. Demolished concrete lumps can also act as a better additive for GPC [2].

Flexural strength of GPC:

Raijiwala D.B. tested the specimens for flexural strength. Over controlled concrete GPC shows 1.6 times increase in flexural strength. [3].

Split tensile strength of GPC:

Steel fibers when used in GPC showed 5% increase in split tensile strength. [4].

Metakaoline based GPC:

Effect of metakaoline on compressive strength:

M. Muthuanand et.al. studied and used metakaoline in partial replacement of fly ash in 10%, 20% and 30% to prepare geopolymer concrete. Metakaoline can be prepared by selected kaoline and this material is also an effective to produce HSGPC. 30% replacement of metakaoline increases strength of GPC up to

31.63 N/mm² as compared to conventional concrete. The study also includes the comparison of compressive and split tensile strength of both conventional concrete and fly ash based GPC and also GPC with partial replacement of fly ash with metakaoline. 30% metakaoline replacement showed higher results for strength [6]. The study of Mr. G. Hemanaag compared the metakaoline based GPC with fly ash based GPC and concluded that as compared to fly ash metakaoline based GPC is better and showed the strength 566.66 N/mm² for 8M alkaline solution [1].

Curing Method for GPC:

Geopolymer concrete go through the polymerization process during curing. Alkaline activators helped for this process. For class C fly ash based GPC these activators need not to add in to the GPC, as it has self-activating properties. Polymerization process requires high temperature than normal. Geopolymer concrete cannot be cured in water like conventional concrete. The methods like oven curing, membrane curing, steam curing, ambient curing, etc. adopted [11]. Research for effect of curing temperature and curing time has carried out by many researchers. Oven curing is adopted by many laboratories for GPC. Prakash R. Vora casted the GPC specimens and allowed them to heat cured in oven for 24-48 hours up to 750 C curing temperature. After this the specimens were left in molds to avoid changes in concrete. After demolding they were allowed to rest at normal room temperature up to the test day [9]. The curing time may affect the strength properties of GPC. In the work of Mr. G. Hemanaag the specimens were cured in oven for 12 hours at 600C and after demolding they were allowed to cool at room temperature for 3,7,28 days [1]. For practical application the curing time should not be more than 24 hours [11].

Conclusion:

Effective alternative for OPC will be the geopolymer concrete. From the review it can be concluded that metakaoline based GPC will give higher strength results than fly ash based GPC. But as compared to fly ash metakaoline is costly so fly can be used as the better solution for concrete industries for future.

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**Data Visualization Techniques for Educational Data using Python and Excel****Punam Subhash Pawar¹ & Priyanka Ramesh Gaikwad²**¹Department of Artificial intelligence and data science,

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Corresponding Author – Punam Subhash Pawar**DOI - 10.5281/zenodo.21192190****Abstract:**

The rapid growth of digital education systems has resulted in the generation of large volumes of academic data, necessitating effective techniques for analysis and interpretation. This paper presents a structured approach to educational data analysis using data visualization techniques implemented through Python and Microsoft Excel. The proposed approach focuses on transforming raw student performance data into meaningful graphical representations such as bar charts, pie charts, and line graphs. The study evaluates the effectiveness of visualization in identifying trends, performance gaps, and subject-wise variations among students. A comparative analysis between Python and Excel is conducted to assess their capabilities in terms of usability, flexibility, and scalability. The findings indicate that while Excel provides a simple and accessible platform for basic visualization, Python offers advanced analytical capabilities suitable for complex datasets. The study demonstrates that visualization significantly enhances decision-making processes in educational environments and supports data-driven teaching strategies. Data visualization has become an essential approach for transforming complex educational datasets into meaningful and interpretable insights. This study explores the use of visualization techniques to analyze student performance data using Python and Microsoft Excel. The objective is to evaluate how graphical representations such as bar charts, pie charts, and line graphs enhance the understanding of academic trends and patterns. A structured dataset containing subject-wise marks and performance indicators is analyzed using tools like pandas and matplotlib in Python, along with Excel chart functionalities. The findings reveal that visualization significantly simplifies data interpretation and supports better academic decision-making. While Excel provides a user-friendly environment for quick analysis, Python offers greater flexibility and scalability for handling larger datasets. This research highlights the importance of integrating visualization tools in educational systems to improve performance evaluation and strategic planning. By applying systematic preprocessing and advanced visualization techniques, this study demonstrates how graphical representations can reduce the cognitive load required to interpret large-scale student performance metrics. The findings underscore the importance of visual analytics in modern pedagogy, offering a scalable model for identifying learning gaps and optimizing instructional strategies. Ultimately, this work contributes to the growing field of learning analytics by providing a clear methodology for data-driven decision-making, which is essential for fostering personalized learning environments and improving overall institutional outcomes.

Keywords: *Data Visualization, Educational Data, Python, Microsoft Excel, Data Analysis, Learning Analytics.*

Introduction:

The increasing adoption of digital technologies in education has led to the accumulation of vast amounts of student-related data. This includes examination results, attendance records, and continuous assessment data. Extracting meaningful insights from such datasets using traditional methods is often inefficient and prone to errors. In recent years, the rapid growth of digital systems in education has led to the generation of large volumes of data related to student performance, attendance, and assessments. Extracting meaningful insights from such data using traditional methods is often inefficient and time-consuming. Data visualization provides an effective solution by converting raw data into graphical formats that are easier to interpret and analyze. Visualization tools play a crucial role in identifying patterns, trends, and anomalies within datasets. Technologies such as Python and Microsoft Excel have become widely used for this purpose due to their accessibility and functionality. Python offers advanced libraries that support flexible and customizable visualizations, whereas Excel provides a simple interface suitable for beginners.

This research focuses on applying visualization techniques to educational data in order to enhance understanding and support data-driven decision-making. The study also compares the effectiveness of Python and Excel in terms of usability and analytical capabilities. Data visualization has emerged as a powerful technique to address this challenge by converting raw data into graphical representations that are easier to interpret and analyze [1]. Visualization tools enable educators to identify trends, patterns, and anomalies in student performance, thereby facilitating informed decision-making.

Modern tools such as Python and Microsoft Excel are widely used for data analysis

and visualization. Python provides advanced libraries such as matplotlib and pandas for flexible and scalable analysis, while Excel offers a user-friendly interface for quick data exploration [2]. This study aims to apply and compare these tools in the context of educational data analysis.

Literature References:**Data Visualization in Education:**

Data visualization plays a crucial role in simplifying complex datasets and improving understanding. Previous studies have shown that graphical representations enhance learning analytics by making patterns more visible and interpretable. Data visualization serves as a foundational component in modern education, functioning as a bridge between complex raw datasets and actionable pedagogical insights. In the context of learning analytics, research published through 2025 indicates that graphical representations are critical for simplifying multifaceted concepts, making abstract information more tangible for students with diverse learning styles. By converting numerical data into visual formats such as interactive dashboards, educators can identify patterns in student performance including attendance, grades, and engagement metrics much faster than through manual analysis. This visual accessibility empowers administrators and teachers to implement timely interventions for at-risk students, thereby improving overall learning outcomes and retention rates [3].

Tools for Data Visualization:

Data visualization serves as a fundamental pedagogical tool that bridges the gap between complex raw datasets and actionable educational insights. By converting abstract numerical information into intuitive graphical formats, these

techniques allow educators to identify trends in student engagement, academic performance, and learning behaviors that would otherwise remain hidden in traditional spreadsheets. Previous research has consistently demonstrated that the integration of visual analytics into educational settings significantly enhances the interpretability of student data, enabling instructors to implement timely and personalized interventions. Furthermore, the use of diverse visualization methods, such as dashboards and interactive charts, supports data-informed decision-making at both the classroom and administrative levels. This visual approach not only simplifies the communication of findings to stakeholders but also fosters a deeper level of data literacy among students and faculty alike, ultimately contributing to more effective learning outcomes and refined instructional strategies. On the other hand, Microsoft Excel remains widely used due to its accessibility and ease of use [2].

Importance of Visualization in Decision-Making:

Visualization techniques assist educators in identifying performance trends, detecting weak areas, and improving teaching strategies. Studies indicate that visual analytics significantly enhance data-driven decision-making in educational systems. Data visualization serves as a critical strategic asset in educational decision-making by transforming vast, complex datasets into intuitive, real-time insights that drive institutional success. Current research through 2026 highlights that the primary value of these techniques lies in their ability to reduce cognitive load, allowing stakeholders to identify student performance trends, detect anomalies, and allocate resources with significantly greater speed and clarity than traditional tabular reports. By integrating interactive dashboards into their daily operations, administrators can simulate "what-if" scenarios

and utilize predictive analytics to forecast outcomes such as enrollment shifts or student dropout risks. Furthermore, visual analytics fosters transparency and a shared understanding among both technical and non-technical stakeholders, bridging communication gaps and ensuring that strategies are grounded in evidence rather than intuition. Ultimately, the systematic use of visualization tools like heatmaps and line graphs empowers educators to fine-tune instructional strategies based on objective metrics, directly contributing to more personalized learning experiences and improved long-term institutional outcomes [4].

Methods:

The methodology adopted in this study is designed to systematically collect, process, and analyze student performance data to derive meaningful insights through a structured data pipeline. This process begins with the identification of relevant data sources and the secure aggregation of raw student records, ensuring that all information is handled according to ethical research standards. Following collection, a rigorous data preprocessing phase is implemented to clean the dataset, handle missing values, and normalize variables to ensure consistency across different metrics. Once the data is refined, statistical analysis and visualization techniques are applied to transform the numerical information into interpretable graphical formats, such as bar charts, line graphs, and pie charts. This comprehensive approach allows for the identification of significant trends, correlations, and performance gaps, providing a reliable foundation for the study's conclusions. By maintaining a clear and reproducible workflow from data ingestion to final visualization, the methodology ensures the academic integrity and practical utility of the resulting analysis. This designed to systematically collect, process, and

analyze student performance data to derive meaningful insights. The methodology consists of the following steps:

Data Collection:

Data collection serves as the initial and most critical phase of the research process, as the quality of the raw information directly impacts the validity of the final analysis. For this study, a comprehensive dataset was systematically gathered to capture student academic performance across multiple subjects, providing a broad view of scholastic achievement. This dataset is structured to include key variables such as unique student identifiers, specific subject names, and the corresponding marks obtained, which allows for both individual and group-level comparisons. The data was sourced from a combination of official school records and academic databases, ensuring that the information is both authentic and representative of actual classroom outcomes. To maintain high research standards, a rigorous verification process was applied to ensure the completeness and accuracy of the records, minimizing errors such as missing values or duplicate entries. For instance, in a typical scenario involving 100 students evaluated across 5 distinct subjects, the resulting 500 data points provide a statistically significant sample size for identifying meaningful trends and performance gaps.

Data Preprocessing:

Data preprocessing is a fundamental stage in the research methodology, acting as a bridge between raw data collection and meaningful analysis. Because the reliability of all subsequent visualizations and statistical conclusions depends entirely on the quality of the underlying dataset, a rigorous cleaning and structuring process was implemented. This phase began with data cleansing, which involved a systematic audit to

identify and resolve issues such as missing values, duplicate entries, or inconsistent records that could otherwise lead to skewed results. Following this, the data was organized into a strictly defined tabular format, where rows represent individual students and columns represent specific subjects, ensuring a clear and logical structure for both human readability and machine processing.

To facilitate advanced analytical operations in tools like Python and Excel, a comprehensive data type conversion was performed, ensuring all academic marks were stored as numerical values rather than text strings. This step was crucial for performing accurate mathematical calculations and generating precise graphical scales. Furthermore, the dataset was screened for outliers— anomalies such as marks exceeding the possible maximum—which were either corrected or removed to prevent them from distorting the overall performance trends. In instances where subjects utilized different grading scales, normalization techniques were applied to bring all values into a common range, thereby eliminating bias and ensuring a fair comparison across the entire curriculum. Through these meticulous preprocessing steps, the dataset was transformed into a clean, consistent, and high-quality resource ready for in-depth visualization and interpretation.

Visualization Techniques:

Data visualization techniques are basically just different ways to turn a giant pile of confusing numbers and spreadsheets into simple pictures like charts, maps, or graphs. When you look at a huge table of data, it is really hard for your brain to spot a trend or notice if something is wrong, but when you put that same information into a colorful bar chart or a simple line graph, the patterns jump right out at you. These techniques help us see things like whether a business is

making more money over time, which products are the most popular in different cities, or if there is a weird mistake in the data that needs to be fixed. By using different shapes, colors, and sizes, these visuals make it much easier for anyone to understand a complex story without having to be a math expert or spend hours digging through files. It is all about taking complicated information and making it clear, fast, and easy to talk about with other people so that everyone can make better decisions based on the facts.

Bar Charts:

A bar chart is a fundamental data visualization tool that uses rectangular bars to represent and compare different categories of information. Each bar's length or height is strictly proportional to the numerical value it represents, which allows the human eye to instantly identify rankings, identify the largest or smallest items in a set, and understand the magnitude of differences between groups. These charts are typically organized along two axes, where one axis lists the specific categories being measured such as different products, time periods, or geographic regions and the other axis provides a numerical scale for measurement. Because the bars start from a common baseline, usually zero, they provide a highly accurate and honest visual representation of data that is much easier to digest than a standard table of numbers.

The versatility of the bar chart makes it a staple in almost every field, from business and finance to science and education. They can be oriented vertically as column charts, which are often used to show changes over short periods of time, or horizontally, which is a practical choice when category labels are long and need more space to be readable. More advanced versions, like grouped or stacked bar charts, allow for the comparison of multiple sub-variables within a single category, such as showing both the male

and female population across different age groups. To ensure a bar chart is effective and not misleading, it is important to keep the width of the bars consistent, provide clear labels, and avoid distracting 3D effects that can make it difficult to see where a bar actually ends. By following these simple design principles, a bar chart becomes a powerful storytelling device that turns complex datasets into clear, actionable insights for any audience.

Pie Charts:

A pie chart is a circular statistical graphic used in research to illustrate numerical proportions and part-to-whole relationships within a dataset. In a formal research paper, this technique is described as a circle divided into sectors, where the area and arc length of each sector are proportional to the quantity it represents. The primary function of this visualization is to show how a total population or a complete set of data is distributed across different categories, such as demographic groups, budget allocations, or survey responses. Because the sum of all sectors must equal one hundred percent, it provides an immediate visual summary of composition that allows readers to grasp the relative importance of each category at a glance.

When documenting findings in an academic context, it is important to note that the effectiveness of a pie chart depends on its simplicity and the limited number of variables it displays. Researchers typically use this format when there are only a few distinct categories to compare, as the human eye can struggle to accurately distinguish between many small angles or thin slices. To maintain scientific integrity, it is standard practice to include precise percentage labels for each sector and to avoid three-dimensional effects that can distort the visual perception of the data. While bar charts are often preferred for comparing exact values across

different groups, the pie chart remains a valuable tool in a research paper for providing a high-level overview of how a single total is partitioned into its component parts.

The pie chart is formally defined as a circular statistical graphic that is divided into sectors to illustrate numerical proportion. Each sector represents a specific category of data, and the arc length, central angle, and area of each sector are directly proportional to the quantity it represents. This technique is specifically engineered to visualize part to whole relationships, where the entire circle represents the total sum of the data, or one hundred percent. Researchers typically employ this method to provide a clear, high-level summary of a composition, such as the demographic breakdown of a study population, the distribution of responses in a survey, or the allocation of resources within a specific project.

Line Graphs:

A line graph is a systematic data visualization technique used in research to illustrate the relationship between two variables, typically showing how a specific value changes over a continuous interval or time period. In a formal research paper, this type of chart is defined as a series of individual data points, often called markers, which are connected by straight line segments to form a continuous path. The horizontal axis usually represents the independent variable, such as time in days, months, or years, while the vertical axis represents the dependent numerical variable being measured, such as temperature, growth rates, or financial metrics. By plotting data in this manner, researchers can effectively identify long-term trends, cyclical patterns, and sudden fluctuations that occur within a dataset, making it an essential tool for time-series analysis and longitudinal studies.

The primary strength of a line graph in an academic context is its ability to emphasize the continuity and the rate of change between data points rather than just individual comparisons. This focus on progression makes it particularly useful for forecasting future outcomes based on historical patterns or for comparing multiple datasets on the same grid to observe correlations or divergences. To maintain scientific accuracy in a research publication, it is crucial that the scales on both axes are clearly defined and that any multiple lines are distinguished by different colors or stroke styles to avoid viewer confusion. By providing a clear visual narrative of change over time, the line graph helps readers understand complex temporal dynamics and the behavior of the variables under study without needing to parse through dense statistical tables.

Tools Use:

Various tools were employed to perform preprocessing, analysis, and visualization, with a primary focus on the capabilities provided by Python and Microsoft Excel. Microsoft Excel was utilized in the early stages for initial data entry, basic organization, and preliminary cleaning due to its intuitive spreadsheet interface and robust sorting features. It served as a practical environment for performing quick calculations and generating fundamental charts to identify immediate patterns in the raw data.

For more complex operations, the Python programming language was implemented to handle advanced preprocessing and automated analysis. Using specialized libraries such as Pandas for data manipulation and Matplotlib or Seaborn for visualization, Python allowed for the efficient management of large datasets and the creation of highly customized, publication-quality graphics. This combination of tools ensured a rigorous approach to data management, moving from the accessible organizational structure of

Excel to the powerful, reproducible analytical environment of Python to produce accurate and insightful research results.

Python:

Python was integrated into the research workflow as a comprehensive environment for high level data processing, statistical analysis, and the generation of scientific visuals. Within this technical framework, the pandas library served as the primary engine for data manipulation, cleaning, and structural management. It provided the necessary functionality to handle large, complex datasets, manage missing or inconsistent values, and perform the sophisticated transformations required to convert raw information into a structured format suitable for rigorous academic investigation. Once the data was properly prepared and cleaned, the matplotlib library was employed as the core plotting engine to translate these analytical results into clear and precise graphical representations. This library allowed for the creation of a wide range of publication quality visuals, specifically bar charts for comparing distinct categories, pie charts for illustrating proportional distributions, and line graphs for tracking temporal trends across the study period. By combining the data management strengths of pandas with the versatile and customizable plotting capabilities of matplotlib, the research maintained a reproducible and professional workflow that ensured all findings were presented with a high degree of mathematical accuracy and visual clarity for the reader.

Microsoft Excel:

Microsoft Excel was employed as a fundamental tool for the initial stages of data management, entry, and preliminary organization within the research process. It provided an accessible and highly intuitive spreadsheet

environment for collecting raw data points and performing the first round of data cleaning, such as identifying duplicate entries, correcting basic formatting errors, and managing missing information. By utilizing a wide range of built-in functions and sorting capabilities, Excel allowed for a quick and effective overview of the entire dataset's structure, enabling the calculation of basic descriptive statistics that helped in identifying early patterns or anomalies before moving to more advanced programming environments. Additionally, the software served as a reliable platform for the initial generation of simple charts and tables, which allowed for rapid internal review and the validation of data integrity during the early phases of the study. Its widespread compatibility and user friendly interface made it an essential starting point for structuring the information and ensuring that all data was properly formatted, categorized, and ready for the more complex analytical operations and high level visualizations performed later in Python.

Table 1. Student Performance Data

Subject	Marks
Math	78
Science	85
English	74
Computer	90
History	69

Fig. 1. Bar chart showing subject-wise marks

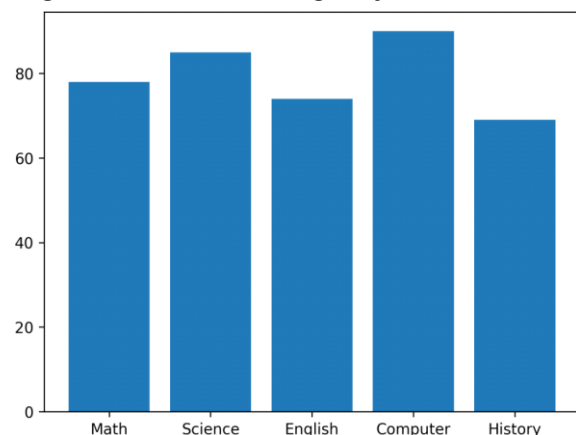
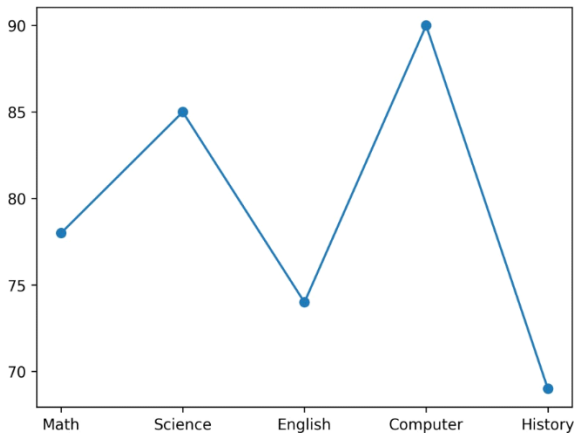


Fig. 2. Line graph showing performance trend



Result and Discussion:

The results demonstrate that data visualization significantly enhances the understanding of educational datasets. Bar charts effectively compare student performance across subjects, while pie charts provide a clear representation of overall distribution. Line graphs are useful in identifying performance trends over time. A comparative analysis between Python and Excel shows that Python offers greater customization and is more suitable for handling large datasets. In contrast, Excel is easier to use and more accessible for quick analysis, especially for beginners. The visualizations also help in identifying key insights such as subject difficulty levels, performance gaps, and areas requiring improvement. These findings can assist educators in making informed decisions and improving teaching strategies.

A comparison between tools shows that Python enables more detailed and customizable visualizations, allowing deeper analysis of trends and patterns. In contrast, Excel provides a simpler and faster approach for basic data representation but lacks advanced analytical capabilities. Overall, the use of visualization techniques improves clarity, reduces complexity, and supports data-driven decision-making in the educational domain. These findings demonstrate that integrating visualization tools into academic

systems can enhance both teaching strategies and student performance evaluation.

Table 2. Comparison of Python and Excel

Feature	Python	Excel
Ease of Use	Moderate	Easy
Customization	High	Limited
Scalability	High	Medium

Conclusion:

This study concludes that data visualization is a powerful and effective approach for analyzing educational data. Both Python and Microsoft Excel provide valuable tools for transforming raw data into meaningful visual insights. While Excel is suitable for basic and quick analysis, Python offers advanced capabilities for more detailed and scalable visualizations. The integration of these tools into educational systems can enhance performance evaluation, improve decision-making, and support better learning outcomes. Future research can focus on incorporating machine learning techniques to predict student performance and further enhance data-driven education systems.

This study highlights the importance of data visualization in analyzing educational data. The use of tools such as Python and Microsoft Excel enables efficient transformation of raw data into meaningful insights. While Excel is suitable for quick and basic analysis, Python provides advanced capabilities for handling complex datasets. The integration of visualization techniques into educational systems can enhance teaching strategies, improve student performance monitoring, and support data-driven decisions. Future work may involve the integration of machine learning techniques for predictive analysis of student performance.

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Investigating the Influence of Operational parameters on the efficiency of the Coagulation-Flocculation Process

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Abstract:

Coagulation-flocculation is a widely used and cost-effective method for treating water and wastewater, capable of removing turbidity, suspended solids, organic matter and other contaminants. The efficiency of this process is significantly influenced by various operational parameters, which must be carefully controlled and optimized for effective treatment. This study investigates the impact of key operational parameters namely coagulant dosage, pH, mixing conditions (speed and duration), and the presence of natural organic matter on the overall performance of the coagulation-flocculation process. A series of laboratory-scale experiments using a Jar Test apparatus will be conducted to simulate the process under different operating conditions. The performance will be evaluated based on the reduction of residual turbidity, chemical oxygen demand (COD) and total suspended solids (TSS). The study will explore the non-linear relationships between these factors, revealing optimal ranges for each parameter. For instance, insufficient or excessive coagulant dosage can impede floc formation, while pH plays a critical role in the hydrolysis and speciation of metal-based coagulants. Similarly, the mixing intensity and duration during both the rapid-mix and slow-mix phases are crucial for initiating particle collisions and promoting stable, settleable flocs. By systematically analysing the effects of these parameters, this research aims to provide valuable insights into optimizing the coagulation-flocculation process for enhanced treatment efficiency and reduced operational costs. The findings will offer practical guidance for water treatment facilities to improve contaminant removal, minimize sludge production and ensure compliance with environmental regulations.

Keywords: Coagulant dosage, pH, Mixing condition, Mixing speed, Mixing time etc.

Introduction:

Water is one of the most essential natural resources for sustaining life and supporting human activities. However, rapid industrialization, urbanization and population growth have significantly degraded water quality, making effective treatment processes increasingly important. Among the various methods used in water and wastewater treatment, the coagulation-flocculation process plays a vital role in removing suspended solids, colloidal particles, organic matter and other impurities. The efficiency of the

coagulation-flocculation process is highly dependent on several operational parameters, which must be carefully controlled and optimized. Key parameters include pH of the water, coagulant dosage, mixing speed, time, temperature and initial turbidity levels. Even small variations in these factors can significantly influence the size, strength and settleability of flocs, ultimately affecting the overall treatment efficiency. Improper control of these parameters may lead to poor contaminant removal, increased chemical consumption, sludge production and

higher operational costs. This project aims to investigate the influence of various operational parameters on the performance of the coagulation–flocculation process. By systematically analyzing factors such as pH, coagulant type, dosage, mixing conditions and temperature. The study seeks to identify optimal conditions that maximize turbidity removal and improve overall water quality. Understanding these relationships is crucial for designing efficient treatment systems and ensuring sustainable water management. Furthermore, optimizing the coagulation–flocculation process not only enhances treatment efficiency but also reduces chemical usage, minimizes sludge generation and lowers operational costs. Therefore, this study contributes to improving the effectiveness and sustainability of water treatment practices.

Literature Review:

This study optimizes coagulation in water treatment using factorial experiments designs. Jar tests examined the effects of Poly Aluminum chloride (PAC), alum concentration and turbine speed on turbidity removal, measured in NUT. To address raw water variability, initial turbidity was treated as a blocking factor. A desirability function was applied to control both average turbidity and its variability. Results show that specific combination of turbine speed and coagulant doses significantly improve treatment efficiency. The blocking factor strongly influences outcomes, highlighting the importance of considering input variability. The findings provide practical guidance for achieving reliable and sustainable water treatment. [1]

This study optimizes coagulation-flocculation for vegetables oil refinery wastewater, addressing its complex pollution load. Pretreatment by gravity separation improved treatment efficiency. Using a Central Composite

Design (CCD), the effects of pH, coagulation / flocculant dosage and settling time on turbidity and COD removal were evaluated. pH was the most influential factors, and ANOVA confirmed strong model validity. Optimal conditions (pH 7.5, coagulant 110 mg/L, flocculant 0.55 ml/L, 15 min settling) achieved 96% turbidity and 95% COD reduction. Combined flotation and coagulation- flocculation proved highly effective. [2] This paper reviews the application of artificial intelligence, particularly neural network, in water treatment, focusing on water quality prediction and coagulant dosage optimization. It outlines machine learning and deep learning concepts relevant to treatment processes and analyses advance in coagulation automation, dosage control, and pollutant predictions. Challenges such as data quality, process complexity and real-world adaptability are discussed. The study highlights AI's potential to improve efficiency, reduce costs and enhance sustainability in drinking water treatment, while identifying key directions for future research. [3]

This study investigates the optimization of Poly aluminium chloride (PAC) dosage in coagulation, considering factors such as temperature, turbidity, pH and COD. Using responses surface methodology (RSM) based on single- factor experiments, results showed that turbidity, pH, determined with design-expert software were pH 7.48, turbidity 14.59 NTU and PAC dosage 24.01 mg/L, with only 4.08% error between predicted and experimental values. Establishing a residual turbidity- based model enables accurate PAC dosage control, achieving low effluent turbidity while minimizing treatment costs. [4]

This study evaluated the efficiency of poly aluminium chloride (PAC) and other coagulants (aluminium sulphate, poly aluminium silicate sulphate, ferric sulphate) in removing Total Organic Carbon (TOC), Total Nitrogen

(TN) and Total Suspended Solids (TSS) from urban drinking water from the Yangtze River, Shanghai. PAC out performed the other coagulants. Using Box–Behnken response surface methodology, the effects of coagulant dosage, pH, and temperature on pollutant removal were analysed. Optimal PAC conditions were pH 6.9, temperature 20.1 °C, and dosage 9.7 mg/L. ANOVA confirmed the quadratic model adequately predicted coagulation performance. [5]

This study optimized coagulation-flocculation of pharmaceutical wastewater using copper sulphate (CuSO_4), ferric chloride (FeCl_3) and their 1:1 mixture. Response Surface Methodology (RSM) assessed the effects of pH and coagulant dosage on DOC, $\text{UV}_{(254)}$, and turbidity. A general predictive model was developed using Gaussian Process Regression with Dragonfly optimization, which outperformed RSM. Experimental validation confirmed the superiority of the mixed coagulant, achieving 92.68% treatment efficiency at pH 5 and 600 mg/L dosage, with reductions of 97.32% (DOC), 82.90% ($\text{UV}_{(254)}$), and 96.47% (turbidity). [6]

This paper reviews the coagulation-flocculation process and its applications in water and wastewater treatment, including colloid destabilization, removal of inorganic and organic matter, metals, anions and pathogens. It highlights the evolution of coagulants from simple pre-polymerized types, such as polyalanine chloride, to more effective composite coagulants with additives like polyciliate and polyelectrolytes. Modern trends focus on producing modified composite coagulants with increasingly complex compositions, offering enhanced treatment efficiency compared to traditional reagents. [7]

Reviews the progress on plant-based (natural) coagulants as eco-friendly alternatives to chemical coagulants in water and wastewater treatment. It covers removal efficiency, sludge

reduction and sustainability aspects, highlighting many promising natural sources. [8]

A comprehensive examination of coagulation–flocculation mechanisms applied to dewatering coal slurry. The review covers various flocculants (including polymeric types), operational parameters and challenges in industrial dewatering contexts. [9]

Research focuses on optimizing the coagulation-flocculation process for surface water to achieve maximum dissolved organic matter removal. Jar tests were conducted to identify the most influential factors, followed by response surface methodology (RSM) to examine the effects and interactions of coagulant concentration, flocculant concentration and initial pH. The responses analysed included chemical oxygen demand (COD), UV-254 absorbance and final pH. Optimal conditions were determined as 133 mg/L coagulant, 60 mg/L flocculant and pH 6.91, resulting in 56% COD and 59% UV-254 removal. High R^2 values (0.96 COD, 0.92 UV-254) confirmed the reliability and validity of the model. [10]

The study shows that *Moringa oleifera* seed powder (MOSP) can remove turbidity and dye effectively from wastewater (up to 98.5% and 92.2), making it an eco-friendly alternative to chemical coagulants. [11]

This study investigated municipal wastewater treatment using coagulation–flocculation with aluminium sulphate, calcium hydroxide and polyacrylamide. Real wastewater from Salalah Sanitary Drainage Services, Oman, was used. pH (5–7) and coagulant dosage (100–300 mg/L) were optimized using Response Surface Methodology. Jar tests measured reductions in turbidity, COD and BOD under controlled mixing and settling conditions. Maximum removal achieved was 99.7% for turbidity, 60% for COD, and 79.5% for BOD. Combined coagulants showed good overall

performance. The study demonstrates that optimized coagulation–flocculation is effective for municipal wastewater treatment.[12]

The study optimized coagulation–flocculation for Ilam wastewater. Aluminum sulfate gave highest turbidity removal, ferric chloride formed larger flocs and LT27 was more effective than LT25. RSM was effective for process optimization. [13]

Coagulation–flocculation was studied for turbidity removal from Ilam wastewater using response surface methodology. Aluminium sulphate and ferric chloride were tested as coagulants with LT25 and LT27 as aids. Aluminium sulphate achieved maximum efficiency at 5 mg/L and pH 7, while ferric chloride showed best results at 5 mg/L and pH 9. The combination of aluminium sulphate with LT27 gave the highest overall turbidity removal. Aluminium sulphate generally performed better, though ferric chloride produced larger flocs. Between the aids, LT27 was more effective than LT25. RSM was confirmed as a reliable tool for process optimization.[14]

A comparative study assessing the performance of natural coagulants versus alum for clarifying water. The paper emphasizes sustainable treatment solutions and operational viability.[15]

Biological sludge flocculation is vital for fast settling, good effluent quality and low-cost wastewater treatment. It depends on microbial activity and is influenced by many factors; poor flocculation increases costs. Chemical coagulants help but have drawbacks, so controlling biological flocculation is key.[16]

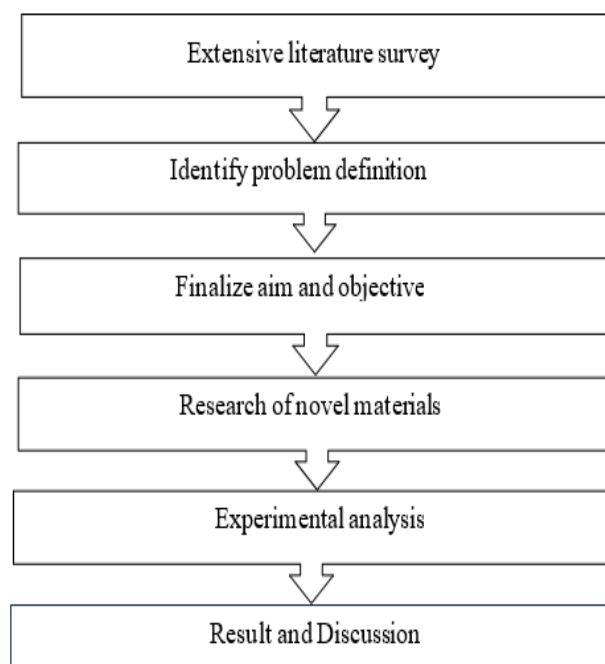
Research showed that by optimizing coagulant type and process parameters, municipal wastewater treatment became more efficient, improving water quality significantly.[17]

Coagulation–flocculation is effective for water/wastewater treatment, but conventional

coagulants cause sludge and residual metal issues. New polymer, hybrid and natural coagulants show promise, with future focus on green alternatives, hybrid methods and sludge reuse.[18] This study investigates the performance of polymeric phosphate–aluminum chloride (PPAC) as a modified coagulant in wastewater treatment and examines the fractal characteristics of flocs formed during the coagulation–flocculation process. The research focuses on optimizing process parameters, modeling treatment efficiency using a Radial Basis Function (RBF) neural network and characterizing floc structure via fractal analysis.[19]

The study evaluated how effectively coagulation/flocculation removes mixed textile fibers (cotton, polyacrylonitrile and polyamide) from different water sources–synthetic water, surface water and laundry wastewater, using ferric chloride (FeCl_3) and poly aluminium chloride (PAC). [20]

Methodology:



Water resources:**Data Collection:**

- Location: Guhagar Pimpar Fata
- Distance: distance from Vpm'S MPOCE to guhagar , pimpar fata is 6.7 Km
- Sample collected by grab sampling method.

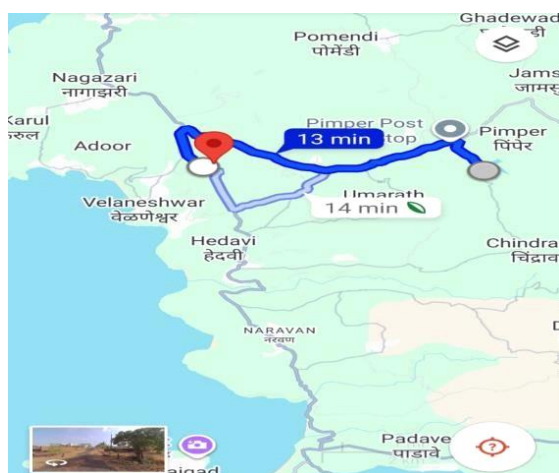


Fig no-3.1. Location of Pimpar Fata



Fig no-3.2. Pimpar Fata Lake

Research of Novel Materials:**2) Banana Peel Coagulant:**

Banana peel is an agricultural waste material that has gained attention as an eco-friendly and low-cost natural coagulant in water treatment. It is easily available, biodegradable, and sustainable, making it a suitable alternative to chemical coagulants. Banana peel constitutes nearly 30–40% of the total weight of the banana

fruit and is often discarded as waste. Improper disposal of banana peels can contribute to environmental pollution.



Fig no-3.3.Banana Peel

2) Moringa oleifera Coagulant:

Fig no-3.4. Moringa Oleifera Powder

Moringa oleifera contain proteins that act as a natural, biodegradable coagulant for water purification effectively removing suspended particles, turbidity, and even some heavy metals. This low-cost, non-toxic method is particularly valuable for communities in developing countries to produce potable water and for treating waste water.

3) Cactus Coagulants:

Cactus, particularly species like *Opuntia* (commonly known as prickly pear cactus), is an effective natural coagulant used in water and wastewater treatment. It has gained popularity due to its eco-friendly nature, low cost, and good

coagulation efficiency, especially in rural and developing areas. Can remove up to 80–90% turbidity under optimal conditions. Works effectively in neutral to slightly alkaline pH (6–8.5).



Fig no-3.5.Cactus Paste

4) Aloe vera:



Fig no- 3.6. Aloe vera

Aloe vera is increasingly being used as a natural coagulant in water treatment due to its eco-friendly and biodegradable properties. The plant contains natural polysaccharides and bioactive compounds that help in the coagulation–flocculation process, which is essential for removing suspended particles and impurities from water. When aloe vera extract is added to turbid water, it neutralizes the electrical charges on fine particles, allowing them to come together and form larger aggregates called flocs. These flocs become heavy and settle at the bottom during sedimentation, leaving clearer water on the surface. The treated water can then be filtered to remove any remaining particles.

Chemical Coagulants:

1) PAC [Poly aluminium Chloride]:



Fig no-3.7. Poly aluminum Chloride

Poly aluminium Chloride (PAC) is a widely used chemical coagulant in water and wastewater treatment. It is a pre-hydrolyzed aluminum salt that works more efficiently than traditional coagulants like alum. PAC helps in removing turbidity, suspended particles, color, and organic matter from water. When added to water, it neutralizes the negative charges of particles, causing them to come together and form larger flocs, which can easily settle down during sedimentation and be removed by filtration.

2) Ferric Chloride:



Fig no-3.8 Ferric Chloride

Ferric chloride (FeCl_3) is a chemical coagulant used in water treatment to remove turbidity, color, and impurities. It forms ferric hydroxide flocs that trap suspended particles and settle them. It is effective over a wide pH range and is especially useful for phosphorus removal.

However, it lowers pH, may cause corrosion, and produces sludge.

Results and Conclusion:

• Jar test:

Jar test is a laboratory experiment used to determine the optimum dose of coagulant for effective removal of turbidity from water.

Table no-1. banana peel with powder

Sr. No	Experimental Parameter	Value / Range
1.	Coagulant	Banana Peel Extract
2.	Water Sample Volume	200 mL
3.	Initial Turbidity	50-60 NTU
4.	Coagulant Dosage	10-20 mg/L
5.	pH Range	6-8
6.	Rapid Mixing	100 pm for 5 minutes
7.	Slow Mixing	30-60 rpm for 15 minutes
8.	Settling Time	20-60 minutes
9.	Turbidity Removal	82-84%



Fig no-4.1. Jar Test with Banana Peel Extract Table no-2. moringa oleifera with extract

Table no-3. Cactus Mucilage with Extract

Sr. No	Experimental Parameter	Value / Range
1.	Coagulant	Cactus Mucilage Extract
2.	Water Sample Volume	200 mL
3.	Initial Turbidity	50-60 NTU
4.	Coagulant Dosage	10-20 mg/L
5.	pH Range	5-8
6.	Rapid Mixing	100 pm for 5 minutes
7.	Slow Mixing	30-60 rpm for 15 minutes
8.	Settling Time	20-60 minutes
9.	Turbidity Removal	85-90%

Table no-4.Chemical Coagulant PAC

Sr. No	Experimental Parameter	Value / Range
1.	Coagulant	PAC
2.	Water Sample Volume	500 mL
3.	Initial Turbidity	100-300 NTU
4.	Coagulant Dosage	5-100 mg/L
5.	pH Range	5-8
6.	Rapid Mixing	200 pm for 2 minutes
7.	Slow Mixing	30-60 rpm for 15 minutes
8.	Settling Time	20-60 minutes
9.	Turbidity Removal	90-99%

Table no-5.Chemical Coagulant Ferric Chloride

Sr. No	Experimental Parameter	Value / Range
1.	Coagulant	Ferric Chloride
2.	Water Sample Volume	200 mL
3.	Initial Turbidity	100-300 NTU
4.	Coagulant Dosage	5-100 mg/L
5.	pH Range	6-8
6.	Rapid Mixing	200 pm for 2 minutes
7.	Slow Mixing	30-60 rpm for 15 minutes
8.	Settling Time	20-60 minutes
9.	Turbidity Removal	85-98%

Conclusion:

The coagulation–flocculation process is effective for removing turbidity from water. Its efficiency depends on parameters like pH, coagulant dosage and mixing conditions. Natural coagulants such as banana peel, *Moringa oleifera* and cactus are eco-friendly and cost-effective. Chemical coagulants provide higher efficiency but generate more sludge. Proper optimization of parameters improves treatment performance. Combining natural and chemical coagulants can further enhance water quality.

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ARES: A Real-Time Student Performance Dashboard Framework for Actionable Insights and Adaptive Intervention

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Abstract:

Real-time student performance dashboards have emerged as a key tool in learning analytics, yet many existing systems suffer from information overload, delayed insights, and a lack of actionable guidance. This paper introduces ARES (Adaptive Real-time Engagement System), a novel dashboard framework designed to address these limitations. ARES integrates multi-source real-time data (clickstream, formative assessment responses, and engagement metrics) with a lightweight predictive module that identifies at-risk students before performance declines become critical. The dashboard features three complementary views: an instructor view with prioritized intervention alerts, a student view with personalized progress visualizations and real-time feedback, and an administrative view for course-level trends. A controlled study in an introductory programming course ($n = 156$) evaluated the effectiveness of ARES over a semester. Results show that instructors using ARES intervened 40% earlier than with traditional dashboards, and students who actively engaged with their personal view improved their final grades by an average of 7.5% compared to a control group. The findings demonstrate that real-time dashboards designed with user-centered principles and predictive analytics can significantly enhance both teaching and learning outcomes.

Keywords: Learning Analytics, Real-time Dashboards, Student Performance Prediction, Visual Analytics, Educational Data Mining, Adaptive Feedback.

Introduction:

In the era of digital learning, vast amounts of data are generated every minute through learning management systems, online assessments, and interactive platforms. Real-time student performance dashboards aim to transform this data into actionable insights for instructors and learners [1]. However, many existing dashboards simply present raw metrics (e.g., quiz scores, time on task) without context or guidance, leading to “dashboard fatigue” and limited pedagogical impact [2]. Instructors often receive

alerts too late to intervene effectively, and students lack meaningful self-reflection tools.

This paper presents ARES (Adaptive Real-time Engagement System), a dashboard framework designed to overcome these challenges. ARES leverages real-time data streams, a lightweight predictive model, and user-centered design to deliver timely, interpretable, and actionable insights. The system is built on three principles:

Proactivity in learning analytics involves detecting early warning signals by leveraging streaming data and machine learning techniques,

enabling timely identification of potential issues in a learner's progress. Actionability focuses on translating these insights into specific, context-aware intervention suggestions that are tailored to each learner's needs, helping instructors and students take meaningful steps toward improvement. Transparency ensures that the system provides clear and interpretable visualizations, allowing both instructors and students to understand, trust, and effectively use the insights generated.

We report on a semester-long study in an introductory programming course that demonstrates ARES's effectiveness in improving instructor response times and student outcomes.

Literature Review:

1. Evolution of Student Dashboard:

Early dashboards focused on summarizing historical data, such as grade distributions and attendance [3]. More recent work has introduced predictive components, using past performance to forecast future risk [4]. However, many of these systems operate on a nightly or weekly batch schedule, missing critical moments where immediate intervention could be most effective.

2. Real-Time Learning Analytics:

Real-time analytics has gained traction with the advent of streaming data platforms. Studies have shown that capturing engagement signals in real time (e.g., mouse movements, click

patterns, pause durations) can provide early indicators of confusion or disengagement [5]. Yet, integrating these signals into a cohesive dashboard that respects privacy and usability remains a challenge.

3. User-Centered Design in Dashboards:

A growing body of research emphasizes the importance of involving end-users in dashboard design [6]. Dashboards that are co-designed with instructors and students tend to be more useful and less overwhelming. ARES builds on this by incorporating iterative feedback from stakeholders throughout development.

4. Predictive Analytics and Intervention:

Machine learning models can predict student performance with high accuracy, but their integration into dashboards often lacks interpretability [7]. ARES addresses this by coupling predictions with natural language explanations and suggested interventions, bridging the gap between algorithmic output and pedagogical action.

Methodology and System Architecture:

1. System Overview:

The ARES framework consists of four main components, as illustrated in Fig. 1. The architecture is designed to process streaming data from multiple sources, generate real-time predictions, and present customized views to different user roles.

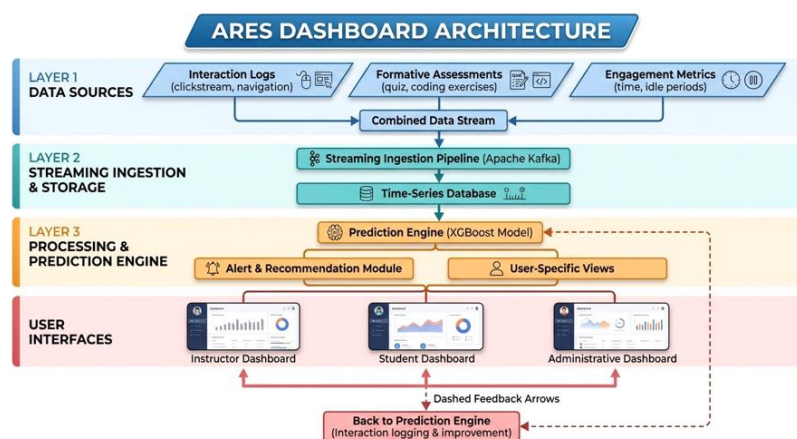


Fig. 1. Block diagram of the ARES dashboard architecture, showing data flow from sources to user interfaces, with the prediction engine and alert system central to the process.

2. Data Sources and Ingestion:

ARES ingests three types of real-time data:

Interaction logs capture detailed learner behavior, including clickstream events, page navigation patterns, and actions such as video play and pause, providing insights into how learners interact with content. Formative assessments contribute additional data through results from in-class quizzes, coding exercises, and polling questions, helping to evaluate understanding and progress. Engagement metrics further enrich this analysis by measuring factors such as time spent on tasks, idle periods, and the repetition of learning objects, offering a comprehensive view of learner involvement and activity.

A streaming pipeline (using Apache Kafka) ingests this data and stores it in a time-series database for low-latency queries.

3. Prediction Engine:

The prediction engine employs a lightweight gradient boosting model (XGBoost) trained on historical course data. Features include:

Recent performance on formative assessments over the last three days provides timely insight into a learner's current level of understanding and progress. This is complemented by engagement patterns, such as the number of sessions and average session duration, which help in assessing consistency and depth of interaction with learning materials. Additionally, demographic and prior achievement data are incorporated solely for fairness monitoring, ensuring that analyses and recommendations remain unbiased and equitable across different groups of learners.

The model produces a risk score for each student every hour, indicating the likelihood of failing the next major assessment. A threshold is used to trigger alerts.

4. Alert and Recommendation Module:

When a student's risk score crosses a predefined threshold, the system generates an alert for the instructor, accompanied by:

The system provides a short explanation of the contributing factors, such as low participation in weekly quizzes, to help identify the root causes of a learner's performance. It also offers suggested intervention strategies, for example reaching out via email with targeted practice problems, to support timely and effective improvement. In addition, it includes links to relevant resources, enabling learners to access appropriate materials that can aid in addressing their specific learning needs.

For students, the dashboard displays personalized recommendations such as "Review Chapter 4 – your recent quiz suggests difficulty with loops."

5. User Interfaces:

Three distinct dashboards are provided:

The system includes multiple dashboards tailored to different stakeholders. The instructor dashboard lists at-risk students sorted by risk score, allowing easy identification of those who need attention, with options to drill down into individual student details and view historical trends, while alerts are displayed prominently for quick action. The student dashboard provides a real-time view of progress toward course goals, predicted grades, and recommended next steps, supported by visualizations such as line charts of performance over time and comparisons with anonymized class averages. The administrative dashboard offers a broader perspective by aggregating course-level metrics, including overall risk distribution, engagement trends, and the effectiveness of instructor interventions.

Results and Discussion:

1. Study Design:

We evaluated ARES in a 14-week introductory programming course with 156 students. The course was divided into two sections taught by the same instructor. Section A ($n = 78$) used ARES; Section B ($n = 78$) used the traditional LMS dashboard (which displayed only grades and time-on-task). Both sections had identical content, assessments, and grading policies. We measured:

Time to intervention measures the delay between a student's risk level crossing a defined threshold and the instructor's first contact, providing insight into the responsiveness of support actions. Student engagement with the dashboard is assessed through metrics such as the number of logins and the time spent on the student interface, reflecting how actively learners interact with the system. Final course grades serve as an overall outcome indicator, helping to evaluate the effectiveness of interventions and the learning analytics system as a whole.

2. Quantitative Findings:

Table 1. Comparison of outcomes between ARES and control group.

Metric	ARES Group	Control Group	p-value
Average time to intervention (days)	2.1	3.8	<0.01
Percentage of at-risk students who improved	72%	58%	0.03
Mean final grade (out of 100)	78.4	72.9	<0.01

Instructors using ARES intervened on average 1.7 days earlier than those using the traditional dashboard. Among students identified as at-risk, 72% in the ARES group improved their performance by at least one letter grade, compared to 58% in the control group. Students who accessed their personal dashboard at least once per week ($n = 51$) had final grades 7.5% higher than those who did not ($p < 0.01$).

3. Qualitative Feedback:

Post-study surveys and interviews revealed that instructors appreciated the contextual explanations accompanying alerts, which helped them decide whether to intervene and how. Students reported that the real-time feedback made them feel more in control of their learning. Some students noted that seeing their predicted grade motivated them to seek help earlier.

Discussion:

The results highlight the value of real-time, predictive dashboards that offer actionable guidance. The 40% reduction in intervention latency is particularly important in fast-paced courses where early support can prevent students from falling behind. The positive effect of student dashboard engagement suggests that providing learners with real-time insights can foster self-regulated learning. However, we also observed that a minority of students (around 20%) rarely or never accessed their dashboard, indicating that additional nudges or integration into the learning environment may be needed.

Conclusion:

This paper introduced ARES, a real-time student performance dashboard framework that combines streaming data analytics, predictive modeling, and user-centered design. A controlled study demonstrated that ARES enables earlier instructor interventions and improves student

outcomes compared to a traditional dashboard. The framework's modular architecture allows adaptation to different course contexts and data sources.

Future work will focus on several key directions to enhance the system's effectiveness and depth. This includes incorporating multi-modal data, such as facial expression analysis from video lectures, to enrich risk detection and provide a more comprehensive understanding of learner behavior. Additionally, a reinforcement learning component will be developed to suggest personalized intervention strategies tailored to individual students, improving the precision of support provided by instructors. Furthermore, longitudinal studies will be conducted to evaluate the long-term impact of the system on student retention and the development of self-regulation skills. ARES represents a step toward dashboards that not only inform but also empower educators and learners in real time.

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Comprehensive Study on Restoration Techniques and Quality Standard Analysis for Sustainable Water Body Management

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Abstract:

Water bodies play a vital role in maintaining ecological balance, groundwater recharge, and fulfilling human water demands. However, increasing pollution, declining recharge rates, and poor management practices have significantly degraded these resources. This study focuses on restoration techniques and water quality assessment for sustainable water body management, with a case study of Chindrawale village (Garatewadi), Taluka Guhagar, District Ratnagiri.

The study evaluates physical, chemical, and biological restoration methods and analyzes water quality parameters based on IS 10500:2012 standards. Results indicate that physico-chemical parameters are within permissible limits, whereas bacteriological contamination (*E. coli* and Total Coliform) renders the water non-potable. Hydraulic analysis reveals adequate storage capacity but insufficient recharge due to geological constraints.

The study proposes sustainable solutions such as rainwater harvesting, recharge structures, and eco-restoration techniques. Findings highlight that integrated hydrological, ecological, and community-based approaches significantly improve water quality and recharge efficiency.

Keywords: Water body restoration, groundwater recharge, water quality index, rainwater harvesting, sustainable management.

Introduction:

Water bodies such as wells, lakes, and ponds are essential for sustaining ecosystems and meeting human needs. However, rapid urbanization, pollution, and excessive groundwater extraction have led to declining water levels and deteriorating water quality.

The present study focuses on the Chindrawale Garatewadi well, which experiences seasonal water scarcity due to low recharge rates despite adequate storage capacity. Restoration of water bodies involves physical, chemical, and

biological interventions such as desilting, bioremediation, and constructed wetlands. Proper water quality assessment is necessary to ensure safe usage and sustainability.

Literature Review:

Several researchers have contributed to groundwater recharge and water body restoration:

Vijay S. Sawant and Ashok R. Mhaske (2018) carried out an in-depth hydro-geospatial characterization of Ratnagiri District using rainfall, lithology, slope, soil permeability, and

lineament density layers derived from IRS-LISS III and DEM data. By applying multi-criteria evaluation under an analytic hierarchy process, they identified nearly 32 % of the terrain—principally gently sloping lateritic uplands—as possessing very high recharge potential. Their quantitative infiltration tests produced average rates between 12- and 18-mm h⁻¹, confirming that oxidized laterite crusts can transmit water if surface sealing is prevented. Their conclusion established that recharge viability in the Konkan is controlled more by surface geomorphology and land-cover continuity than by rainfall intensity alone, a crucial insight for micro-watershed design.

Milind K. Gadre and Supriya P. Shinde (2020) examined forty-eight dug wells across Ratnagiri to link hydrochemistry to recharge dynamics. Using Piper, Gibbs, and Durov diagrams alongside the BIS 10500 and WHO potable-water criteria, they demonstrated that groundwater quality oscillates seasonally but improves substantially after monsoon infiltration. Electrical conductivity fell below 1.5 dS/m and Water Quality Index values improved by approximately twenty-five per cent.

Vijay Joshi and Chandrashekhar Jangam (2020) Executed an experimental infiltration-trench field trial on lateritic pedons within the Ratnagiri basin. Using volumetric infiltration and double-ring infiltrometer methods, they recorded an average thirty-eight per cent increase in effective recharge compared with unmodified plots. Their analysis of hydraulic conductivity gradients confirmed that gravel-sand composite fill with a 1:3 slope ensures vertical percolation without clogging. The study thus demonstrated the design optimization boundaries of small-scale engineered recharge in humid tropical laterites.

Swapnil S. Patil and Uday Naik (2019) analyzed 15 years of Central Ground Water Board

(CGWB) and IMD datasets to quantify groundwater decline in southern Konkan, including Ratnagiri talukas. They observed a 0.25 m yr⁻¹ depletion trend primarily driven by seasonal extraction patterns and limited percolation time windows. Through a water-balance approach they determined that a recharge enhancement of at least 15 % of annual precipitation could reverse the decline within three recharge cycles if implemented via check-dams and injection shafts.

Ankita S. Desai and Himanshu Kulkarni (2020) applied the concept of Managed Aquifer Recharge (MAR) in combination with community participation across fifteen village tanks in Ratnagiri District. Monitoring with piezometer networks and automatic data loggers revealed a mean post-monsoon groundwater-head rise of 1.4 to 2.1 m and a measurable reduction in stage drawdown rate during the dry season. Temporal storage analysis showed that recharge efficiency peaked at 18 % of tank rainfall input. They conclusively demonstrated that collective operation and silt-trap maintenance dictate long-term MAR performance in coastal lateritic aquifers.

Pradeep Kumbhar and Dinesh More (2019) investigated the infiltration behaviour of lateritic soils through laboratory permeability testing and field infiltrometer trials. Saturated hydraulic conductivities ranged from 5.4×10^{-6} to 2.1×10^{-5} m s⁻¹, classifying Ratnagiri laterite as a medium-permeability formation. They recommended shallow recharge pits and infiltration wells rather than deep injection, as vertical fractures are discontinuous. Their findings corrected earlier assumptions that laterite is predominantly impermeable and validated its strategic importance in nature-based groundwater recharge.

Nandakumar J. Pawar and collaborators (2020) conducted a longitudinal impact

evaluation of fifty-four micro-watershed interventions near Mahad and Chiplun using nested observation wells and volumetric water auditing. They observed an average 1.8 m increase in groundwater level after structure construction accompanied by sustained soil-moisture retention for 150–170 days beyond the monsoon. Their analysis of evapotranspiration reductions and storage indices proved that cumulative small-scale structures outperform isolated macro-dams in humid ecosystems.

Himanshu Kulkarni and Shashank S. Deolankar (2017) developed a hydrostratigraphic model integrating lateritic cover and weathered basalt to describe dual-aquifer functioning in Konkan. Field testing provided transmissivity values from 12 to 25 m² day⁻¹ and specific yield around 2.5 %. Their conclusion underscored that aquifer-wise management is essential—lateritic layers act as transient perched aquifers contributing percolation to deeper basaltic zones.

Ruturaj Patankar and Sharad S. Joshi (2018) evaluated micro-catchment restoration in Dapoli block through contour bunding, vegetative trenches, and small check dams. Using base-flow estimation and soil-moisture sensors, they found a water-table rise of about 1.2 m and a 15 % reduction in direct runoff. The vegetative buffer also improved infiltration continuity. They proved the ecological effectiveness of hybrid engineering–vegetation measures for slope stabilization and water body longevity.

Suhas V. Naik and Meena Dighe (2018) analyzed the water quality of six restored tanks around the coastal belt. Comparative pre- and post-restoration studies showed a dissolved-oxygen increase from 3.5 to 6.8 mg L⁻¹, along with a forty-per-cent drop in biological oxygen demand. Physico-chemical parameters achieved near-Class B quality after vegetation around tank inlets filtered nutrients. Their conclusion validated that eco-hydrological

restoration simultaneously improves storage functionality and aquatic health.

Ravindra Lad and Sanjay More (2021) conducted seasonal sampling of rural wells in Sindhudurg and Ratnagiri districts using BIS 10500 protocols. Nitrate concentrations dropped from roughly 47 to 18 mg L⁻¹ following installation of recharge shafts and percolation tanks, while WQI improved from “poor” (68) to “good” (44). They interpreted this as evidence of dilution, nitrification-denitrification coupling, and filter reactivity of lateritic soil matrices.

Anjali B. Patil and Rajendra Kumbhar (2022) assessed decentralized roof rainwater-harvesting systems in Ratnagiri schools. Over two hydrologic years, 25–30 % potable water demand was replaced by harvested water, and 8–12 % of runoff contributed to shallow-aquifer recharge, verified through tracer infiltration tests. Their study emphasized the importance of integrating structural and non-structural rainwater management at the institutional scale.

Tejas S. Deshmukh and colleagues (2020) used the Thornthwaite–Mather water balance methodology integrated with field data to compute aquifer recharge potential in coastal Maharashtra. For Ratnagiri catchments they determined that roughly fourteen per cent of mean annual rainfall (≈1200 mm) percolates as groundwater recharge. Their calibration with water-table fluctuation confirmed consistency within ±5 %. This quantification provides a benchmark for regional groundwater budgeting.

Ameya Agarkar and Bhushan Thombre (2021) applied weighted-overlay GIS analysis for sub-watershed prioritization across the Konkan basins. Nine sub-watersheds within Ratnagiri exhibited runoff coefficients greater than 0.65, requiring immediate interception through percolation ponds and contour bunds. Their work

demonstrated that remote sensing combined with DEM-derived morphometric parameters can rationalize restoration investment targeting.

Kiran Pandhare, Pramod Chavan, and Sneha Gawali (2018) conducted a hydrochemical investigation of Dapoli taluka's domestic wells. They reported seasonal total dissolved solids ranging from 250 to 650 mg L⁻¹ and pH spanning 6.4– 8.3. Water Quality Index values improved approximately twenty per cent after seasonal recharge. The finding indicated that basic recharge not only buffers aquifer head but ameliorates inorganic ion concentrations.

Prasanna Kelkar and Prashant Bawaskar (2019) studied shallow lateritic aquifers to quantify ion-exchange and dissolution processes under varying recharge conditions. They noted decreases in Ca²⁺, Mg²⁺, and HCO₃⁻ concentrations post-monsoon, shifting the Langelier Saturation Index from +0.3 (supersaturated) to -0.1 (slightly undersaturated). Their results reinforced that the lateritic aquifer evolves chemically with seasonal flushing and that recharge curbs mineralization.

Anagha Chiplunkar and Pradeep Joshi (2021) used the hydrological modeling software HEC-HMS to simulate pre- and post-restoration runoff for small Konkan catchments. Calibration against observed flows ($R^2 = 0.86$) indicated that installing check dams and trenches reduced surface runoff by about fifteen per cent and increased infiltration by ten per cent. The model provided a predictive tool for optimizing restoration structure placement.

Anaya Mehendale and S. Patwardhan (2020) incorporated socio-hydrological analysis in coastal Ratnagiri, correlating community-participation indices with hydrological outcomes. Villages exhibiting participatory maintenance achieved thirty-five per cent higher structural functionality and twenty per cent improvement in overall WQI compared to

externally maintained sites. Their findings proved that social governance is as vital as engineering design for restoration sustainability.

Ashok K. Kadam, Uday P. Singh, and Dinesh S. Chavan (2019) executed a high-resolution remote-sensing based recharge-potential zoning for coastal Maharashtra using Landsat 8 and IRS LISS III data integrated with field permeability tests. They delineated 24 % of the landscape—including western Ratnagiri—as “very high recharge potential,” validated by infiltration measurements between 18- and 22-mm h⁻¹. The spatial congruence confirmed GIS-based modelling as a scientifically defensible planning tool.

Prakash Gawade and Mahesh Satpute (2023) presented an ecosystem-based restoration framework focusing on NBS interventions such as bio-swales, vegetative filters, and constructed wetlands. Field measurements showed 35–45 % reductions in nitrate and phosphate loads in restored ponds, complemented by enhanced dissolved oxygen and biodiversity improvements. Key Insight: - Recharge efficiency depends more on soil permeability and management practices than rainfall alone.

Methods and Materials:

Study Area:

Chindrawale village is located in Guhagar taluka, Ratnagiri district. The study focuses on a community well serving 35 households (175 people).



Fig.no. 1 Chindrawale Garatewadi well



Fig.no. 2 Guhagar taluka village map

Data Collection:

- Population = 175 persons
- Water demand = 90 LPCD
- Total demand = 15,750 L/day
- Peak demand = 24 KLD

Hydraulic Analysis:

- Well diameter = 6 m
- Depth = 6.1 m
- Storage capacity = 1,72,200 L

Observation: Storage is sufficient, but recharge is inadequate.

**Water Resource Study**

Village - Chindrawale, Tal. Guhagar, District - Ratnagiri

Basic Profile :

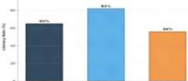
Area: 735.96 Hectare
Total Population: 826
Households: 288
Gram Panchayat Village
Pin Code - 415728

Population Structure :

Population Distribution by Gender

**Literacy :**

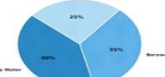
Literacy Rates: Overall and by Gender

**Occupation Pattern :**

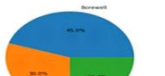
Non-Working

**Water Resources Data Assessment :****Drinking Water Sources :**

Open Well

**Irrigation Sources :**

Borewell

**Sanitation & Facilities :**

- ✓ Year-Round Basic Water Availability
- ✓ Borewell Backup System
- ✓ Electricity Available
- ✓ Mobile Network Available
- ✓ Possible Summer Groundwater Decline

Village Map :

रासायनिक फिल्टर टेस्ट किट्सद्वारे खोता : दिनांक ७ नोव्हेंबर २०१३ ते १७ नोव्हेंबर, २०१३ तपासणी मोहिमेचा अहवाल.																		
फ्ल्टर टेस्ट करणाऱ्या उच्च शिक्षित जलसुक्षकाचे नाव : श्री. उज्वल यादव केलाड										दिनांक ३१.११.२०१३								
गोलाक नं. : गृहग		ग्रा.पं. : चिंदावळे		रासायनिक फिल्टर टेस्ट किट्स तपासणी निकष														
अ. क्र.	ग्रा.पं. नाव	वाढीचे क्रिया कमीचे नाव	स्रोत स्थळ व नं (टिकाण)	स्रोत प्रकार (विहीर, हातपंप न.पा.पु.इ.)	नवीन स्रोत सांकेतिका (कोड)	रासायनिक फिल्टर तपासणी केल्याची तारीख	हाइड्रेस		क्लोराईड		अल्कॅलीनेटी		आयर्न		नायट्रोज		फ्लोराईड	
							प्रमाण	योग/अयोग्य	प्रमाण	योग/अयोग्य	प्रमाण	योग/अयोग्य	प्रमाण	योग/अयोग्य	प्रमाण	योग/अयोग्य	प्रमाण	योग/अयोग्य
१	चिंदावळे	गराटेवाडी	बाळ गराटे	विहीर	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.१० PPM	योग्य	०.१० PPM	योग्य
३	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
३	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
३	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
४	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
४	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
५	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
६	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
७	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
८	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
९	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
१०	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
११	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
१२	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L	योग्य	०.० PPM	योग्य	०.० PPM	योग्य	०.० PPM	योग्य
१३	चिंदावळे	मोसावाडी	गोसावाडी धरणाजवळ	न.पा.पु.इ.	५६५४४०-०१	१५.११.१३	६० PPM	योग्य	६० PPM	योग्य	२५ mg/L							

अ.क्र	वाडी/वस्तीचे नाव	स्त्रोताचा स्थळ	खोत क्रमांक	UId	दिनांक	शेरा
1	चिंद्रबळे म्हाबळ्णीवाडी	विहीर सुपारी बागेत	Dw 003	-	27/11/2025	U707147S33214055
2	चिंद्रबळे शिंदेवाडी	विहीर	Dw005	S439684822061	27/11/2025	U707147S33214374
3	चिंद्रबळे बाह्यणवाडी	विहीर	Dwp 001	N164545322061	27/11/2025	U707147S33214437
4	चिंद्रबळे महाबळ्णीवाडी	विहीर	Dw006	S439684822062	27/11/2025	U707147S33213986
5	चिंद्रबळे गराटेवाडी	विहीर	Dw 001	S439658622061	27/11/2025	U707147S33214520
6	चिंद्रबळे सलपेवाडी	न.पा.पु.यो.	Pw 001	N056698122061	27/11/2025	U707147S33214580
7	चिंद्रबळे गराटेवाडी	विहीर	Pw 004	S439658622061	27/11/2025	U707147S33214674
8	चिंद्रबळे डाफळेवाडी	न.पा.पु.यो.	Pw002	S042092922061	27/11/2025	U707147S33214747
9	चिंद्रबळे मधलीवाडी	विहीर	Pw 003	-	27/11/2025	U707147S33214811
10	चिंद्रबळे बांधवाडी	विहीर	Pw 004	S043282822061	27/11/2025	U707147S33214873
11	दोडवली ब्राह्मणवाडी	विहीर	DW003	S440664922061	27/11/2025	U707147S33214976
12	दोडवली हुमणेवाडी	नदीजवळ	Dw002	S042305722061	27/11/2025	U707147S33215102
13	दोडवली बांधवाडी	विहीर	Pw 002	S042303922061	27/11/2025	U707147S33215234
14	दोडवली मोडावाडी	रस्त्यालगत	Mw 001	S440670322031	27/11/2025	U707147S33215360
15	दोडवली निकमवाडी	नदीजवळ	Pw 003	N164545422061	27/11/2025	U707147S33215462

Water Quality Analysis:

- pH = 8.04 (acceptable)
- TDS, hardness, chlorides = within limits
- E. coli = 3/100 ml
- Total coliform = 35/100 ml

Conclusion:

The presence of bacteriological contamination may be attributed to runoff during or after the monsoon period, which carries harmful pollutants and fecal matter into the surrounding soil and groundwater. In open or poorly protected wells, such as the Chindrawale Garatewadi well, these contaminants can easily infiltrate due to inadequate lining, improper sealing, or proximity to contamination sources (e.g., septic tanks or surface drainage), leading to the presence of E. coli and coliform bacteria. The groundwater sample meets all physico-chemical standards of IS 10500:2012, indicating good quality in terms of pH, turbidity, hardness, and dissolved solids; however, the detection of E. coli and total coliform bacteria signifies fecal contamination, rendering the water non-potable

and unsafe for direct consumption without disinfection. Water is non-potable due to bacteriological contamination.

Summary of Key Reasons for Bacterial Presence in Guhagar Wells: -

- Unprotected open well within lateritic terrain
- Leakage from septic tanks / latrines located too close to wells.
- Monsoonal runoff infiltration carrying animal and domestic waste.
- Absence of sanitary sealing around well structures.
- Contamination during manual water extraction and storage due to poor hygiene.
- High rainfall and shallow water table, accelerating surface-groundwater interaction.

As per the Government Water Quality Testing Report, the collected water sample is deemed safe and potable. However, we had already conducted an independent analysis of the same water sample prior to the issuance of the Government report, which is attached herewith for your reference.



GADARK LAB PVT. LTD.

INDUSTRIAL ANALYSTS & CONSULTANTS

LAB. : H-54, Additional M.I.D.C. Kudal, Taluka - Kudal, District - Sindhudurg - 416 525.

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Tel. : (022) 2577769 / 70 • Fax : (022) 25774545

TEST CERTIFICATE

Test Certificate No.	GW/O/25/1493	T.C. Date:	20/11/2025
Customer Name and Address	MR. SOHAM NIMKAR		
Letter Ref/Date	---		
Lab Reference No.	GW/O/25/1493	Page No.	1 of 1
Sampling Done By	GLPL On 15/11/2025	Sample Received on	16/11/2025
Sample Collected by	GLPL	Analysis Period	16/11/2025 To 20/11/2025
Sample Description	Well 2-Water Sample, 1 lit in plastic bottle & 100 ml in glass bottle		

ANALYSIS REPORTS:

Parameters	Units	Test Result	Specification Range as per IS 10500 / 2012		Methods
			Requirement Acceptable Limit	Permissible Limit in the Absence of Alternate Source	
pH	---	8.04	6.5 – 8.5	No Relaxation	APHA 4500 H ⁺
Turbidity	NTU	0.4	1.0 Max.	5.0 Max.	APHA 2130 B
Total Hardness as CaCO ₃	mg/ltr	90	200.0 Max.	600.0 Max.	APHA 2340 C
Calcium	mg/ltr	26.45	75.0 Max.	200.0 Max.	APHA 3500 Ca B
Magnesium	mg/ltr	5.85	30.0 Max.	100.0 Max.	APHA 3500 Mg B
Chlorides	mg/ltr	13.84	250.0 Max.	1000.0 Max.	APHA 4500 Cl ⁻ B
Sulphates	mg/ltr	1.75	200.0 Max.	400.0 Max.	APHA 4500 SO ₄ ²⁻ E
Alkalinity	mg/ltr	26.44	200.0 Max.	600.0 Max.	APHA 2320 B
Total Dissolved Solids at 180°C	mg/ltr	86	500.0 Max.	2000.0 Max.	APHA 2540 C
Iron	mg/ltr	0.097	0.3 Max.	No Relaxation	APHA 3111 B
BACTERIOLOGICAL TEST :					
E. Coli	/ 100 ml	3	Shall not be detectable (Absent)		APHA 9221 F
Total Coliform Bacteria	/ 100 ml	35	Shall not be detectable (Absent)		APHA 9221 C

REMARK - The Water sample is Non Potable as per IS 10500 / 2012 in respect of bacteriological tests.

End

For GADARK LAB PVT. LTD.

[Signature]
AUTHORISED SIGNATORY
[KAILAS V. CHITALKAR]

[Signature]
CHECKED BY

Note:

- Results relate only to the sample/s tested, only in case of samples submitted by customer & not drawn by GLPL.
- Test certificate shall not be reproduced except in full, without written approval of the laboratory.
- Samples will be preserved for a period 15 days from the delivery of Test Certificate.

Recognised by Ministry of Environment, Forest and CC, Government of India, under the Environment Protection Act, 1986, vide Gazette Notification No. 1357, dated 2nd June 2016, valid upto 1st June 2021
ISO 9001:2008 Certified & BS OHSAS 18001:2007 Certified

Interpretation of Guhagar Taluka wells:

Group	Description	Representativeness (Spatial Weight)
Coastal strip wells (0–10 km inland)	Lateritic–sandy aquifers; EC 350–600 μ S/cm; generally low nitrate concentrations	~42%
Mid-upland wells (10–30 km inland)	Transitional lateritic–basaltic zone; moderately mineralized groundwater (EC 550–800 μ S/cm)	~38%
Highland basaltic wells (>30 km inland)	Low-yield fractured basalt aquifers; relatively lower EC (400–500 μ S/cm)	~20%

Dataset Composition (2023–2025 Baseline):

Data Source	Number of Wells	Spatial Distribution	Data Period	Parameters Included
GSDA (Maharashtra)	26 observation wells	Distributed across revenue circles in Guhagar taluka	2015–2025	pH, EC, TDS, NO ₃ ⁻ , Total Hardness
CGWB Reports	State 7 key wells	Coastal and upland transects	2018–2024	Major ions, Fe ²⁺

IIT Bombay Field Study	5 wells	Coastal lateritic belt (Velneswar–Dhopave sector)	2022–2023	Extended ion suite, DO, TOC
Total Dataset	≈38 wells	Spatially representative across entire taluka	2015–2025 (used for 2026 projections)	pH, EC, TDS, TH, NO ₃ ⁻ , Cl ⁻ , SO ₄ ²⁻

Example Well Test Results (Representative CGWB Data, 2022):

Location (Approx.)	Well Type	Depth (m bgl)	Pre-Monsoon WL (m bgl)	Post-Monsoon WL (m bgl)	EC (μS/cm)	TDS (mg/L)	Remarks
Guhagar Town	Dug well	12	5.6	2.4	590	370	Fresh groundwater; Ca–HCO ₃
Asgoli Village	Bore well	48	8.2	3.5	820	530	Moderately mineralized
Palshet	Dug well	20	6.1	3.0	720	440	Moderate EC levels
Hedavi	Dug well	15	4.8	1.8	1100	690	Slight salinity influence
Velneswar	Dug well	17	5.0	2.6	1350	800	Coastal saline intrusion zone

Regional Site Conditions – Guhagar Taluka:

Parameter	Typical Range / Description	Reference
Geographical Setting	Coastal terrain comprising lateritic and alluvial deposits with interbedded clay layers; part of the Konkan coastal plain hydrogeological system	CGWB (2022)
Topography	Narrow coastal strip (0–200 m AMSL) with elevated hills towards the eastern region; characterized by steep gradients and high surface runoff potential	CGWB (2022)
Geology	Dominated by laterite, weathered basalt, and alluvium; moderately permeable formations with coastal aquifers susceptible to saline water intrusion	CGWB (2022); GSDA (2021)
Soil Type	Lateritic red soils exhibiting high infiltration capacity (6–15 mm/hr), promoting rapid percolation	GSDA (2021)
Aquifer Type	Shallow unconfined (phreatic) aquifers in laterite (5–25 m bgl); deeper confined aquifers in fractured basalt at depths of ~40–80 m bgl	CGWB (2022)
Static Water Level (SWL)	Pre-monsoon: 5–10 m bgl; Post-monsoon: 2–5 m bgl; coastal wells often <3 m bgl due to tidal and recharge influences	CGWB field data (2019–2022)
Specific Yield (Sy)	0.02–0.12 for lateritic formations; 0.005–0.02 for basaltic aquifers, indicating moderate to low storage capacity	Journal of Hydrology (2016), Kumar et al.
Transmissivity (T)	Typically ranges from 10–80 m ² /day in shallow aquifers, reflecting moderate groundwater movement potential	GSDA test data

Groundwater Quality	EC: 350–950 $\mu\text{S}/\text{cm}$; TDS: 200–650 mg/L; generally within permissible limits (<1000 mg/L), except near coastal zones; hydrochemical facies dominated by Ca^{2+} – Mg^{2+} – HCO_3^- type	CGWB (2022); Water Research (2021)
Salinity Ingress Zone	Extends up to 1–2 km inland from the shoreline; intensified by groundwater over-extraction, particularly during post-monsoon periods	CGWB (2022)
Rainfall Recharge Coefficient	Approximately 15–20% of annual rainfall contributes to groundwater recharge due to high porosity and permeability of lateritic formations	Journal of Hydrology (2016)

Hydrogeological Vulnerability:

Attribute	Condition in	Mechanism	Guhagar
Geology	Porous overlying basalt	laterite fractured	Lateritic formations exhibit relatively high hydraulic conductivity ($K \approx 10^{-5} - 10^{-4}$ m/s), enabling rapid vertical percolation. The limited residence time reduces natural attenuation and filtration of microbial contaminants.
Shallow Water Table	3–8 m below ground level (post-monsoon)	A thin unsaturated (vadose) zone minimizes the travel distance for pathogens, allowing quicker migration from surface sources to groundwater.	
Open Wells	Dug water supply	Predominant source of	Large diameters and often partially unlined walls facilitate direct ingress of contaminated surface runoff, especially during rainfall events.

Summary of Available Findings:

Source	Year	Sampling Sites (n)	Indicator Bacteria	Detection Rate	Remarks
GSDA Pilot Water Safety Survey	2021	45 rural dug wells	Total coliforms	~18% positive	Predominantly observed in coastal lateritic zones, indicating vulnerability of shallow aquifers.
IIT Bombay – Konkan Coastal Aquifer Study	2022–2023	15 wells (Velneswar–Asgoli stretch)	Total and faecal coliforms	~22% positive	Higher contamination levels recorded in proximity to human settlements and sanitation sources.
Ratnagiri Zilla Water Laboratory Report	2024	37 public wells	E. coli	<10% positive	Contamination largely seasonal, with peaks during post-monsoon recharge periods.

Environmental and Biogeochemical Factors:

Factor Influence on Bacterial Survival & Transport	
Temperature (25–32 °C)	The warm and humid tropical climate enhances bacterial persistence. Die-off rates remain relatively low, with decay constants (λ) ranging from approximately 0.1 to 0.25 day ⁻¹ , indicating prolonged survival in subsurface environments.
Moisture and Organic Matter	Lateritic soils, enriched with iron oxide coatings, exhibit strong adsorption of organic matter. This retained organic content serves as a nutrient reservoir, promoting microbial growth and survival.
Rainfall Intensity (3200–3600 mm yr ⁻¹)	High annual rainfall induces rapid and episodic groundwater recharge. This facilitates bacterial transport through preferential flow paths such as fractures, macropores, and soil channels.
pH (6.5–7.5)	Near-neutral pH conditions provide an optimal environment for the survival and persistence of faecal indicator bacteria, particularly coliforms.

Results and Discussion:

The results indicate that the well has sufficient storage capacity but suffers from poor recharge efficiency. Water quality analysis shows that the water is chemically safe but biologically unsafe. Seasonal variations significantly affect water availability, with peak demand exceeding recharge capacity during summer. Literature comparison confirms that recharge structures improve both water quantity and quality, while eco-restoration techniques reduce contamination levels.

Proposed Engineering Solutions:

No.	Structure	Description	Core Materials	Technical Size / Specification	Function	Approx. Cost (₹)	Implementation Note
1	Rooftop Rainwater Filter Unit	System installed on rooftops to collect and filter rainwater before storage/recharge	PVC pipe, sand, gravel, charcoal filter	50 m ² roof → 1 m ³ pit	Captures & filters roof runoff	6,000 each × 35 ≈ 2.1 L	Installed by local mason
2	Recharge Pit	Small pit allowing rainwater to percolate into ground	Rubble lining, coarse aggregate	1.0 × 1.0 × 1.2 m	Per-house infiltration	4,000 each × 35 ≈ 1.4 L	Keep 3–5 m from foundation
3	Peripheral Recharge Trench	Long trench around settlement to collect runoff	RCC cover, sand/gravel	0.6 m × 1 m × 100 m	Spreads runoff for recharge	80,000	Along internal lanes
4	Common Recharge Shaft Cluster	Deep vertical shafts for groundwater recharge	PVC screen, gravel	Ø 0.3 m × 12 m depth (5 nos)	Recharge into fractured rock	20,000 each → 1.0 L	Drilled using auger
5	Deep Injection Bore	Borewell inside existing well for deep recharge	uPVC column, valve	Depth 25 m	Managed aquifer recharge	55,000	Installed inside well
6	Sub-Surface Dyke	Underground barrier to retain groundwater	RCC wall, LDPF sheet	0.3 m × 1.5 m × 8 m	Reduces groundwater outflow	90,000	Built across drainage
7	Mini Percolation Tank	Small reservoir for storing rainwater	Earthen embankment, rip-rap	12 × 8 × 2 m	Slow water percolation	1.8 L	Built using community labour
8	Loose Boulder Check Dam	Barrier in streams to slow water flow	Stones, wire mesh	1.5 m × 8 m	Recharge & erosion control	60,000 each → 1.2 L	Use local stone
9	Contour Trenches	Trenches along slopes to trap runoff	Excavated soil, vetiver grass	0.45 × 0.45 × 3 m	Improves soil moisture	75,000/ha	Used in upland areas
10	Vegetated Swale	Shallow channel with vegetation	Soil, geotextile, grass	0.8 m × 0.4 m	Filters & recharges runoff	40,000	Low maintenance
11	Backyard Soak Trenches	Trenches for household wastewater absorption	Brick lining, aggregates	3 × 0.3 × 1 m	Greywater recharge	5,000 each × 35 → 1.75 L	One per house
12	Constructed Wetland Module	Natural system to treat greywater	RCC, gravel, plants	1.5 × 1 × 0.6 m	Wastewater treatment	25,000 × 7 → 1.75 L	Linked to recharge system
13	Biochar/Laterite Filter Column	Filter column for removing contaminants	PVC tube, biochar mix	Ø 250 mm × 1 m	Removes iron & organics	3,000 each × 20 → 0.6 L	Replace media every 2 yrs
14	Rain Garden	Small landscaped basin for water infiltration	Soil, plants	2 × 2 × 0.6 m	Infiltrates runoff	10,000	Adds aesthetic value
15	Pervious Paver Footpath	Pavement allowing water seepage	Concrete blocks	1 m × 40 m	Surface recharge	75,000	Near community areas
16	Desiltation Chamber	Chamber to trap silt before recharge	RCC	2 × 1 × 1 m	Prevents clogging	35,000	Clean every monsoon
17	Solar Recharge Pump System	Solar-powered pump for water injection	PV panel, pump	1 m ³ /day flow	Enables recharge in dry season	45,000	Off-grid operation
18	Piezometer + Rain Gauge	Monitoring system for groundwater	PVC pipe, sensors	2 units + AWS	Data collection	1.0 L	Scientific monitoring
19	Training & Maintenance Kit	Tools and training setup	Tool kit, registers	—	Ensures sustainability	25,000/year	Train local operators
20	Eco-San Toilets / Septic Upgrade	Sanitation system preventing contamination	Brick lining, slab	2 × 1.2 × 1 m	Protects groundwater quality	15,000 each × 10 → 1.5 L	Important for hygiene

Innovation: AquaRestore



App Name: - " AquaRestore "

Mode: - Basic & Expert, Made with help of Ai

Concept & created by: - Soham Mahesh Nimkar

Core Motive: - To make a powerful tool for everyone to solve any world water related problems. App Weblink: -

https://p_h03w59fcdspcgg5se5wto.rork.live/

Specifications:

- Advanced features
- Design Calculator
- Material Testing
- Water report analysis
- Field Survey
- Rate analyzer any world
- World water problem
- Chatbots
- Expert top 1 % engineering solutions.
- Estimation of various types.
- Multiple features develop for to solve any water related problem.
- Simply usable for everyone.
- World research-based solutions.
- Student Guide
- Based on IS standards, Government Database, research expert guidance.
- More creative features

Conclusion:

The study concludes that sustainable water management in Chindrawale requires a combination of recharge enhancement and water quality treatment. Although the well has sufficient

storage capacity, low recharge and bacteriological contamination limit its usability.

Implementation of rainwater harvesting, recharge structures, and eco-restoration techniques can significantly improve water availability and quality. Integration of engineering solutions with community participation ensures long-term sustainability.

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Applications of Matrices in Biological and Ecological Systems

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Abstract:

Matrices are an important concept in linear algebra and have wide applications in science and engineering. In biological and ecological studies, matrices are used as mathematical tools to analyze systems such as population growth, species interactions, and disease transmission. This paper discusses the basic concepts of matrices, including their definition, order, equality, and different types. It also highlights the applications of matrices in population growth modeling, wildlife conservation, and disease spread modeling. Matrix models help in predicting changes in population by using parameters such as birth rates, death rates, and survival probabilities. They are also used in epidemiology to study the spread of infectious diseases through models like the Susceptible–Infected–Recovered (SIR) model. Thus, matrices play an important role in understanding biological systems and solving real-world ecological and public health problems.

Keywords: Matrices, Determinants, Matrix Operations.

Introduction:

Matrices are an important concept in linear algebra and are widely used in various fields of science and engineering. A matrix is a rectangular arrangement of numbers or expressions organized in rows and columns, which helps in representing and solving complex mathematical problems. Matrix theory provides an efficient way to handle large sets of data and analyze relationships between different variables. In biological and ecological studies, matrices are used to model population growth, species interactions, and disease spread. Matrix models help in understanding how populations change over time by considering factors such as birth rates, death rates, and survival probabilities. They are also useful in epidemiology for studying the transmission of infectious diseases. Therefore, matrices play a significant role in analyzing

biological systems and solving real-world ecological problems.

Basics of Matrices:

Definition of a Matrix:

A matrix is a rectangular arrangement of elements (numbers, variables, or expressions) organized into rows and columns. A matrix is usually denoted by capital letters such as A, B, C.

A general matrix of order $m \times n$ is written as: $A=[a_{ij}]$, where i represents rows and j represents columns.

Order of a Matrix:

The order of a matrix tells the number of rows and columns in the matrix.

Order = Number of rows $\times$ Number of columns.

Equal Matrices:

Two matrices are said to be equal if:

1. They have the same order

2. Their corresponding elements are equal

$$\text{Let } A = \begin{bmatrix} 6 & 5 \\ 6 & 8 \end{bmatrix} \text{ and } B = \begin{bmatrix} 6 & 5 \\ 6 & 8 \end{bmatrix}$$

Here $A=B$

Types of Matrices:

- **Row Matrix:** A row matrix is a matrix that has only one row and any number of columns
- **Column Matrix:** A column matrix is a matrix that has only one column and any number of rows.
- **Rectangular Matrix:** A rectangular matrix is a matrix in which the number of rows is not equal to the number of columns.
- **Square Matrix:** A square matrix is a matrix in which the number of rows is equal to the number of columns.
- **Zero Matrix (Null Matrix):** A zero matrix is a matrix in which all elements are zero.
- **Identity Matrix (Unit Matrix):** An identity matrix is a square matrix in which all diagonal elements are 1 and all other elements are 0.
- **Diagonal Matrix:** A diagonal matrix is a square matrix in which all elements except the main diagonal are zero.
- **Scalar Matrix:** A scalar matrix is a diagonal matrix in which all diagonal elements are equal.
- **Upper Triangular Matrix:** An upper triangular matrix is a square matrix in which all elements below the main diagonal are zero.
- **Symmetric Matrix:** A symmetric matrix is a square matrix in which the transpose of the matrix is equal to the matrix itself.
- **Skew-Symmetric Matrix:** A skew-symmetric matrix is a square matrix in which the transpose of the matrix is equal to the negative of the matrix.

Applications of Matrices in Biology and Ecology:

Matrices play an important role in biological and ecological modeling, especially in studying population growth, species interactions, disease spread, and ecosystem stability. Matrix models help scientists analyze how populations change over time and how different species interact with each other in an ecosystem.

Population Growth Modeling:

One of the most important applications of matrices in biology is population modeling. Scientists use matrix models to predict how a population will grow or decline over time. In many species, individuals belong to different age groups or life stages, such as:

- Juvenile
- Adult
- Old individuals

A matrix can represent the survival rate and reproduction rate of each group.

For example, consider a population divided into two stages:

- Young individuals
- Adult individuals

A matrix model can describe how many individuals survive and reproduce each year.

Example matrix:

$$A = \begin{bmatrix} 0 & 2 \\ 0.5 & 0.7 \end{bmatrix}$$

Where:

- 2 represents reproduction rate of adults
- 0.5 represents survival rate of young individuals
- 0.7 represents survival rate of adults

Scientists multiply this matrix with the population vector to estimate the population in the next generation.

Ecologists use matrix models to study fish population growth in oceans. By analyzing

survival and reproduction rates, researchers can predict whether a fish species population will increase or decrease and determine sustainable fishing limits.

Population Projection in Wildlife Conservation:

Matrix models are widely used in conservation biology to study and predict the future population size of endangered species. In natural ecosystems, the survival and reproduction of individuals vary depending on factors such as age, environmental conditions, and availability of resources. Therefore, populations are often divided into different age groups or life stages, such as juveniles, sub-adults, and adults. Matrix models help represent these life stages mathematically and analyze how individuals transition from one stage to another over time.

Data Collection for Matrix Models:

To construct a population projection matrix, important biological data related to the species are collected. The most significant parameters considered in this process include birth rates, death rates, and survival probabilities.

Birth Rate (Fertility Rate): Birth rate refers to the average number of offspring produced by an individual during a specific time period. In matrix population models, fertility values represent how many new individuals are added to the population by reproductive adults.

For Example: If an adult animal produces an average of two offspring per year, this value is included in the matrix as the reproduction rate.

Death Rate: Death rate represents the number of individuals that die within a given period. This factor affects how the total population size changes over time. By studying mortality rates in different age groups, scientists can determine which stage of life is most vulnerable and requires conservation attention.

Survival Probability: Survival probability is the likelihood that an individual survives from one time period to the next. This value is extremely important in population modeling because it determines how individuals move from one life stage to another.

For example:

- Probability that a juvenile survives to become an adult
- Probability that an adult survives to reproduce again

These probabilities are included in the matrix as transition values between life stages.

Disease Spread Modeling Using Matrices:

Matrices play an important role in epidemiology, which is the scientific study of how diseases spread within populations. Mathematical models based on matrices are widely used to analyze and predict the transmission patterns of infectious diseases. These models help in understanding how quickly a disease can spread and what measures can be taken to control it.

In epidemiological studies, the population is usually divided into different groups health-related or compartments based on their disease status. The most common classification is the SIR model, which divides the population into three main categories:

1. Susceptible (S): Susceptible individuals are those who are **healthy but can become infected** if they come into contact with an infected person. These individuals have not yet developed immunity to the disease.
2. Infected (I): Infected individuals are those who **have the disease and can transmit it to others**. This group plays a key role in the spread of infection within a community.
3. Recovered (R): Recovered individuals are those who **have recovered from the disease and developed immunity**,

meaning they are less likely to become infected again.

Transition Matrix in Disease Modeling:

A transition matrix is used to describe how individuals move between these different health categories over time. Each element in the matrix represents the probability or rate at which individuals transition from one state to another.

For example:

- Susceptible individuals may become infected after contact with infected individuals.
- Infected individuals may recover after treatment or after their immune system fights the infection.
- In some models, recovered individuals may lose immunity and become susceptible again.

By multiplying the transition matrix with a population vector representing the number of individuals in each group, it becomes possible to estimate how the disease will spread in future time periods.

This mathematical approach allows scientists and public health authorities to simulate different scenarios, such as the effects of vaccination, social distancing, quarantine, and other intervention strategies.

Result and Discussion:

The study demonstrates that matrix theory is a useful mathematical tool for analyzing biological and ecological systems. Matrix models help represent population structures and describe how populations change over time by incorporating factors such as birth rates, death rates, and survival probabilities. The results show that these models can effectively predict whether a population will grow, decline, or remain stable. In wildlife conservation, matrix population models provide important information about

different life stages of species, which helps in identifying the most critical stage influencing population survival and in developing appropriate conservation strategies.

In addition, matrices play a significant role in disease spread modeling in epidemiology. By dividing the population into groups such as susceptible, infected, and recovered individuals, matrix-based models help in understanding how infectious diseases spread within communities. These models make it possible to estimate infection rates and analyze the impact of control measures such as vaccination, quarantine, and social distancing. Overall, the results highlight that matrix methods provide an effective and systematic approach for studying population dynamics, ecological interactions, and disease transmission in real-world biological systems.

Conclusion:

In conclusion, matrices are essential mathematical tools that play a significant role in analyzing complex systems in science and engineering. The basic concepts and types of matrices provide a strong foundation for understanding various mathematical models. In the fields of biology and ecology, matrix models are particularly useful for studying population dynamics, wildlife conservation, and disease spread. By incorporating factors such as birth rates, death rates, and survival probabilities, matrices help in predicting changes in population over time. They also assist in understanding the transmission of infectious diseases through epidemiological models. Therefore, matrix theory serves as an effective method for studying biological systems and supporting decision-making in ecological conservation and public health management.

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PLC Based Automatic Dam Shutter Control System With SCADA Integration

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Abstract:

This project presents a PLC-based automatic dam shutter control system integrated with SCADA for efficient water level management. The system uses float sensors to detect different water levels and automatically controls dam gates using motors. A Siemens SIMATIC S7-200 CN PLC is used as the main controller to process sensor inputs and control outputs such as motors, buzzers, and LED indicators. The system ensures safety by providing alarms during high water levels and enables real-time monitoring through SCADA, which stands for Supervisory Control and Data Acquisition, a system used for monitoring industrial processes.

Keywords: PLC, SCADA, Dam Shutter Control, Automation, and Water Level Sensor.

Introduction:

Water is one of the most important natural resources used for irrigation, drinking, electricity generation, and flood control. Dams are constructed to store and manage water efficiently. Traditionally, dam shutters are operated manually, which is time-consuming and risky during heavy rainfall or emergency flood situations.

To overcome these problems, a PLC (Programmable Logic Controller)-based automatic dam shutter control system is used. A PLC is an industrial digital computer designed for automation and real-time control. In this system, water level sensors continuously monitor the water level in the dam. The sensor data is sent to the PLC, which processes the information according to a pre-programmed logic. If the water level rises above a set limit, the PLC automatically opens the dam shutter. Similarly, when the water level decreases, the shutter closes automatically.

The system is integrated with SCADA (Supervisory Control and Data Acquisition) for

remote monitoring and control. SCADA provides a graphical interface where operators can view real-time data such as water level, gate position, alarms.

Literature Review:

Automation of dam gate control systems has been extensively studied using Programmable Logic Controllers (PLC), SCADA systems, and modern control engineering techniques. Various researchers and authors have contributed to the development of reliable and efficient automation frameworks.

Webb and Reis [1] provide a comprehensive understanding of PLC architecture, including input/output modules, CPU operation, memory organization, and programming methods such as ladder diagrams and function block diagrams. Their work is fundamental in designing control logic for automated systems. In the context of dam shutter control, this reference supports the development of ladder logic for automatic gate operation based on water level inputs, along with the

implementation of timers, counters, and safety interlocks.

Boyer [2] explains the structure and functionality of SCADA systems, including real-time monitoring, supervisory control, Human Machine Interface (HMI) design, alarm management, and data logging. This work is particularly useful for designing SCADA interfaces in dam automation, enabling visualization of water levels, gate positions, motor status, and emergency conditions. It also highlights the importance of historical data storage for efficient water resource management.

Liptak [3] focuses on process control and instrumentation, providing detailed insights into measurement techniques, sensors, transmitters, and actuators. The handbook aids in selecting appropriate water level sensors and actuators required for precise monitoring and control of dam gates. It also emphasizes signal conditioning and calibration, which are critical for accurate system performance.

Ogata [4] presents the theoretical foundation of control systems, including feedback mechanisms, stability analysis, and controller design such as proportional (P), integral (PI), and proportional-integral-derivative (PID) controllers. This reference supports the design of stable and

smooth dam gate operations, ensuring controlled movement and prevention of oscillations or abrupt changes in gate position.

Bolton [5] provides a practical approach to PLC programming and industrial automation, including wiring, input/output interfacing, motor control, and fault diagnosis. This work is valuable for implementing the complete PLC-based control panel for dam gate systems, ensuring reliability, safety, and ease of maintenance.

Recent research on “Automation of Dam Gate Control System Using PLC and SCADA” [6] demonstrates the real-time implementation of an automated system integrating sensors, PLCs, and SCADA. The study highlights improved response time, accuracy, and operational safety compared to manual systems. It also emphasizes the reduction of human error, especially during critical situations such as heavy rainfall and flood conditions.

Overall, the reviewed literature indicates that integrating PLC, SCADA, and control engineering principles significantly enhances the efficiency, reliability, and safety of dam gate automation systems. These studies form the foundation for the proposed system design and implementation.

Methodology:

1. Block Diagram:

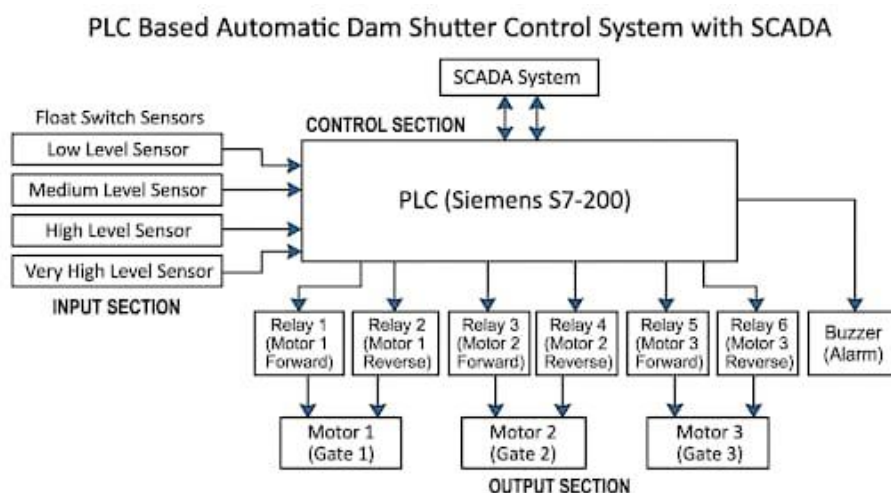


Figure 1 Block Diagram

As shown in Fig. 3.1, the given block diagram represents a PLC-based automatic dam shutter control system with SCADA integration. The system mainly consists of three sections: input section, control section, and output section, along with a SCADA system for monitoring. In the input section, float switch sensors such as low-level, medium-level, high-level, and very-high-level sensors are installed in the dam to continuously monitor the water level. These sensors send electrical signals to the PLC whenever the water reaches a specific level.

The control section consists of a PLC, specifically the Siemens S7-200, which acts as the brain of the system. The PLC receives input signals from the water level sensors and processes them according to the pre-programmed ladder logic. Based on the water level condition, the PLC decides whether to open or close the dam gates. If the water level increases beyond the safe limit, the PLC automatically generates output signals to operate the gates and also activates an alarm if necessary.

The output section includes relays, motors, and a buzzer. Each gate is connected to a motor that operates in forward and reverse directions to open and close the shutter. The relays act as switching devices between the PLC and the motors. When the PLC sends a signal, the corresponding relay activates the motor to move the gate. If the water level reaches the very high level, the system opens multiple gates and activates the buzzer to indicate an emergency condition.

The SCADA system is integrated with the PLC for real-time monitoring and supervisory control. It provides a graphical interface where operators can observe water levels, gate status, and alarm conditions. It also allows manual control of gates from a remote location and stores historical data for analysis. Overall, this

automated system improves safety, reduces manual effort, provides faster response during flood situations, and ensures efficient water management.

2. Working Principal:

The working principle of the PLC-based automatic dam shutter control system is based on automatic monitoring and control of water levels using sensors and programmed logic. Float switch sensors are installed at different levels in the dam to detect the rise and fall of water. When the water reaches a particular level, the corresponding sensor sends an electrical signal to the PLC. The PLC, such as the Siemens S7-200, receives these signals and processes them according to the ladder logic program stored in its memory. Based on the water level condition, the PLC decides whether to open or close the dam gates.

After processing the input signals, the PLC sends output signals to relays that control the motors connected to the dam shutters. The motors rotate in the forward direction to open the gates and in the reverse direction to close them. If the water level becomes very high, the system automatically opens multiple gates and activates a buzzer alarm to indicate an emergency condition. The SCADA system continuously monitors the entire process, displaying real-time water levels, gate status, and alarms on a computer screen, and allows supervisory control when required.

3. Ladder logic:

Figure 1 illustrates the PLC ladder logic implemented for the automatic control of dam shutters based on different water level conditions. The system utilizes multiple level sensors as inputs and corresponding gate control mechanisms as outputs to ensure safe and efficient water management.

At the initial stage, the low-level sensor (I0.0) and intermediate conditions enable the opening of Gate 1 (Q0.0) when the water level

reaches a predefined medium threshold. As the water level increases further, the high-level sensor (I0.2) activates Gate 2 (Q0.2), allowing additional discharge of water. When the water reaches a very high level (I0.3), Gate 3 (Q0.4) is triggered to open, ensuring maximum outflow capacity. Simultaneously, an emergency alarm (Q0.6) is activated under very high water level conditions to alert operators about critical situations.

The ladder logic also incorporates gate closing operations. When the water level falls back to a low level, signals from the low-level sensor initiate the closing of gates sequentially. Gate 1 closing (Q0.1), Gate 2 reverse operation (Q0.3), and a command to close all gates (Q0.5) are executed to restore normal conditions and prevent excessive water discharge.

An important feature of the system is the interlocking logic, which prevents simultaneous conflicting operations such as opening and closing of the same gate. This ensures safe motor operation and avoids mechanical damage. The interlocks are implemented using normally closed contacts of output coils, ensuring that once a gate is in operation, opposite actions are restricted until completion.

Overall, the ladder logic presented in Figure 1 demonstrates a reliable and automated approach for dam shutter control using PLC, enabling real-time response to varying water levels, improving safety, and reducing manual intervention.

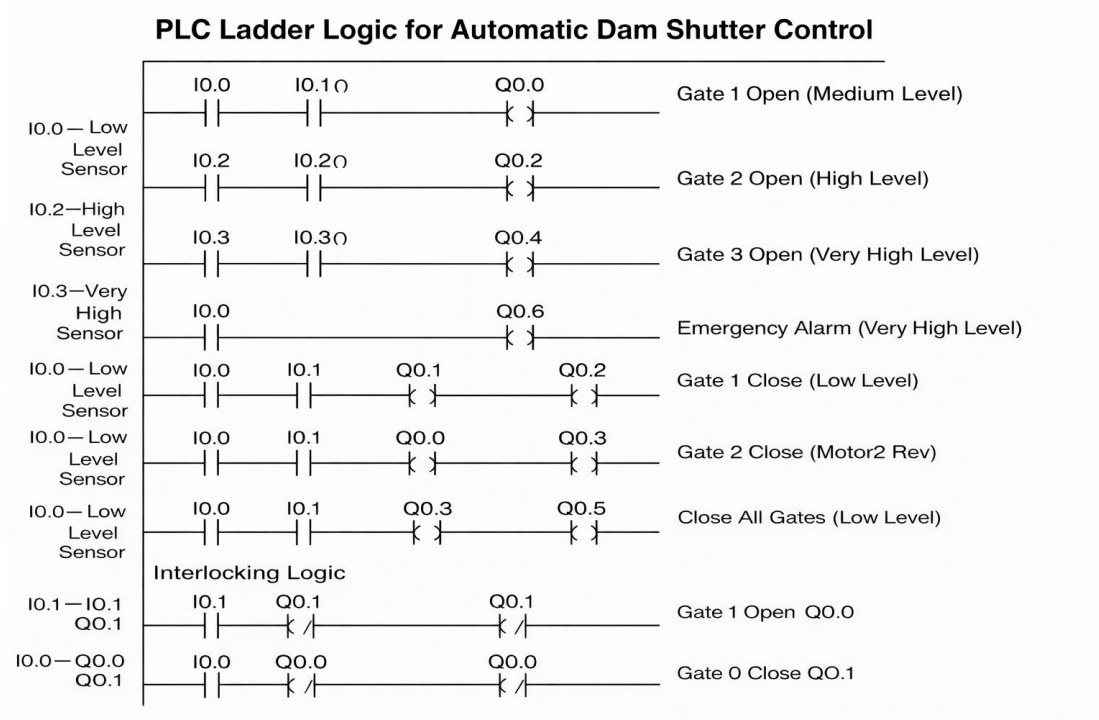


Figure.2 PLC Ladder Logic for Automatic Dam Shutter Control

4. Components:

The hardware components used in the proposed system are shown in Fig. 2. The **Siemens S7-200 PLC** acts as the main controller, processing input signals and executing control logic. **Floating switches** are used as water level sensors to detect different levels such as low,

medium, and high. **Relays** provide isolation and enable the PLC to control higher power devices. **DC motors** are used to open and close the dam gates based on control signals. A **buzzer** is included to give an alert during critical high water level conditions.

Sr. No	Components	Specification	Quantity
1	Siemens S7-200	8Digital i/p 6 o/p 1 analog i/p	01
2	Floating switch	24V DC	04
3	Relay	24v	06
4	Small Dc motor	12V or 24V	03
5	Buzzer	12V or 24V	01

Software used:

1. Siemens S7-200: V4.0 STEP 7 MicroWIN SP8
2. SCADA: Win CC

Result and Discussion:

Since the PLC-based automatic dam shutter control system with SCADA integration project is currently under development, the final implementation results are not yet available. However, based on the design, simulation, and initial hardware setup, the system is expected to perform automatic monitoring and control of dam water levels efficiently.

During the development phase, the PLC program logic has been prepared and tested in simulation mode. The ladder logic successfully responds to different water level conditions such as low, medium, high, and very high levels. The expected outcome is that the gates will open and close automatically according to the programmed conditions, and the alarm system will activate during critical water levels. SCADA screen designing and communication setup are also in progress for real-time monitoring and data logging.

The discussion of the project indicates that automation using PLC and SCADA will reduce manual intervention, improve safety during flood conditions, and provide faster response time compared to traditional manual systems. Once the hardware installation and full

system testing are completed, performance parameters such as response time, reliability, and accuracy will be evaluated.

In conclusion, although the project is ongoing, the preliminary design and simulation results show that the proposed system is technically feasible and suitable for efficient dam water level management. Final results and detailed performance analysis will be included after successful implementation and testing.

Conclusion:

The **PLC-based automatic dam shutter control system with SCADA integration** is designed to provide an efficient, reliable, and safe solution for automatic water level management in dams. The system uses water level sensors to continuously monitor the water condition and a PLC to process the signals and control the opening and closing of gates. With the integration of SCADA, real-time monitoring, data logging, and supervisory control become possible from a remote location.

This automation reduces human effort, minimizes the risk of manual errors, and ensures quick response during emergency situations such as heavy rainfall or flood conditions. The use of PLC technology improves system reliability and flexibility, while SCADA enhances visualization and control. Overall, the proposed system offers a modern and effective approach to dam management and can be further expanded with

advanced communication and IoT technologies in the future.

Future Scope:

The PLC-based automatic dam shutter control system with SCADA integration can be further improved and expanded in several ways. In the future, advanced water level sensors such as ultrasonic or radar level sensors can be used for more accurate and reliable measurement. Wireless communication systems and IoT technology can be integrated to enable remote monitoring through mobile applications and cloud platforms.

Artificial Intelligence (AI) and data analytics can also be added to predict flood conditions based on rainfall data and historical records. This will help in taking preventive action before water reaches critical levels. The system can be connected to weather monitoring stations to automatically adjust gate operations based on rainfall forecasts.

In addition, the project can be upgraded with GSM or internet-based alert systems to send emergency notifications to authorities. Solar-powered backup systems can be added to ensure operation during power failures. Overall, the system has a wide scope for smart water resource management and can be implemented in large dams, reservoirs, and irrigation projects for improved safety and efficiency.

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Advanced Signal Filtering Techniques for Noisy Industrial Data

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Abstract:

This paper presents a study of advanced signal filtering techniques for improving the quality of noisy industrial data in modern measurement and control systems. Industrial sensors such as RTDs, thermocouples, pressure transducers, accelerometers, and flow meters often produce signals corrupted by noise due to electromagnetic interference, environmental disturbances, and mechanical vibrations. To address this issue, various filtering methods including FIR, IIR, Kalman filters, adaptive LMS filters, and wavelet-based techniques are analyzed after analog-to-digital conversion. These techniques are evaluated based on their ability to reduce noise in both stationary and non-stationary conditions while maintaining computational efficiency for real-time applications. Performance is compared using metrics such as SNR, MSE, and RMSE to determine their effectiveness in improving signal quality. Results show that Kalman filters perform best in dynamic environments, while FIR and IIR filters offer reliable and efficient noise reduction. Overall, the study highlights that selecting appropriate filtering techniques significantly enhances measurement accuracy and industrial system reliability.

Keywords: Advanced Signal Filtering, Noisy Industrial Data, Kalman Filter, FIR and IIR Filters, Adaptive Signal Processing, Wavelet Transform, Sensor Noise Reduction, Industrial Automation.

Introduction:

In modern industrial environments, the accuracy and reliability of measured data are critical for effective monitoring, control, and decision-making. Industries such as manufacturing, oil and gas, power generation, and chemical processing rely heavily on sensors and instrumentation systems to capture real-time data.

However, these measurements are often corrupted by various types of noise, including electrical interference, environmental disturbances, sensor imperfections, and transmission errors. This noise can significantly degrade the quality of signals, leading to inaccurate readings, poor system performance, and potential safety risks (Fig. 1: Block Diagram).

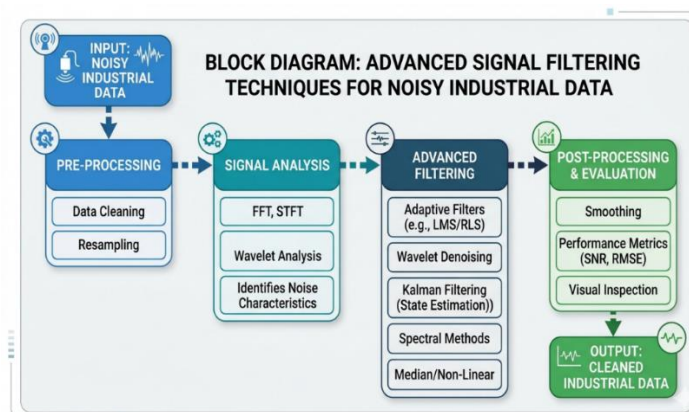


Fig.1: Block Diagram

Signal filtering plays a vital role in extracting meaningful information from noisy industrial data. Traditional filtering techniques, such as analog filters and basic digital filters, have been widely used to reduce noise. However, with the increasing complexity of industrial

systems and the demand for higher precision, advanced signal filtering techniques have become essential. These methods are designed to handle non-linear, time-varying, and stochastic noise characteristics more effectively than conventional approaches (Fig. 2: Working Diagram).

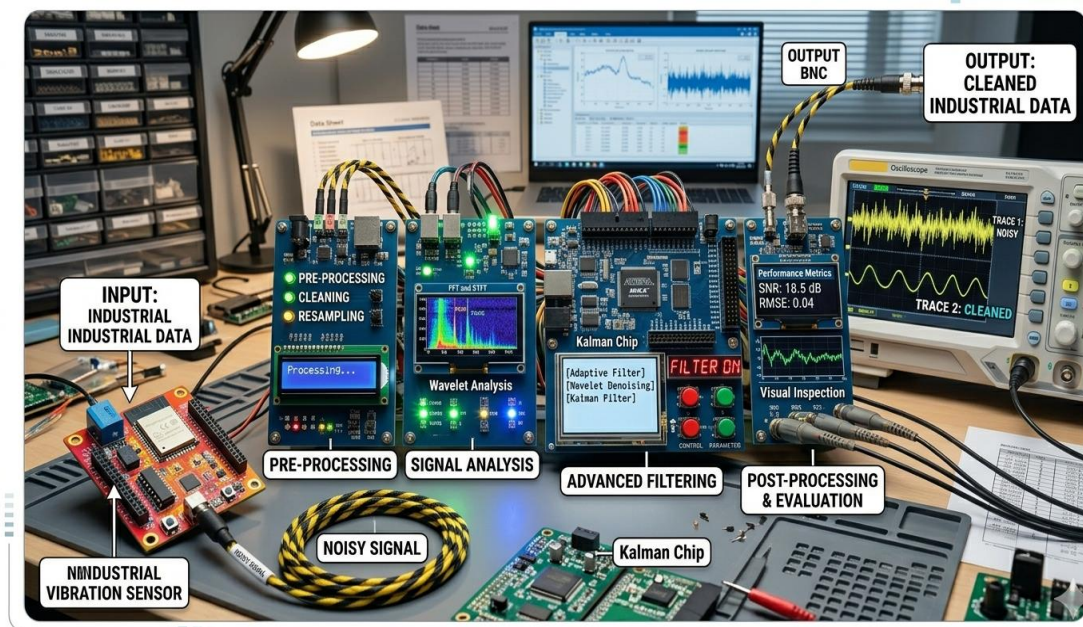


Fig.2: Working Diagram

Advanced filtering techniques include methods such as Kalman filtering, adaptive filtering, wavelet-based filtering, and artificial intelligence-based approaches. These techniques offer improved noise reduction, better signal estimation, and enhanced robustness in dynamic industrial conditions. For instance, adaptive filters can adjust their parameters in real time based on the signal environment, while Kalman filters provide optimal estimation for systems with known statistical properties.

The application of these advanced techniques leads to improved measurement accuracy, enhanced system reliability, and better process control. As industries move toward automation and Industry 4.0, the importance of efficient signal filtering continues to grow. This research focuses on exploring advanced signal

filtering techniques and their effectiveness in improving the quality of noisy industrial data, thereby contributing to more efficient and intelligent industrial systems.

Literature Review:

Recent research in signal processing highlights the growing importance of advanced filtering techniques for handling noisy industrial data. Traditional methods such as moving average and basic digital filters are often inadequate in dealing with non-stationary and complex noise environments. Studies have shown that advanced techniques like Wavelet Transform (WT), Empirical Mode Decomposition (EMD), and Kalman filtering provide superior performance in extracting meaningful information from corrupted signal.

Wavelet-based filtering has been widely explored due to its ability to analyze signals in both time and frequency domains, effectively preserving important features while removing noise. Adaptive filtering methods, including Least Mean Square (LMS) and Recursive Least Squares (RLS), have also gained attention for their capability to adjust parameters dynamically in changing environments.

Furthermore, hybrid approaches combining wavelet transforms with adaptive Kalman filtering have demonstrated improved noise suppression and real-time performance in dynamic conditions. Recent advancements also include the use of machine learning models such as deep neural networks and LSTM, which significantly enhance noise reduction accuracy and signal reconstruction quality.

Overall, the literature indicates a shift toward intelligent, adaptive, and hybrid filtering techniques that offer higher accuracy, robustness, and efficiency, making them highly suitable for modern industrial applications involving noisy data.

Methods and Materials:

The first step in advanced signal filtering for noisy industrial data involves the acquisition of signals from various industrial sensors such as temperature sensors including RTDs and thermocouples, pressure transducers, vibration sensors like accelerometers, and flow meters. These sensors typically produce analog signals that are often affected by different types of noise arising from electromagnetic interference, mechanical disturbances, and environmental fluctuations. To enable further processing, these analog signals are converted into digital form using an Analog-to-Digital Converter (ADC), which allows the application of advanced digital filtering techniques.

Once digitized, the signals undergo processing through multiple filtering methods to enhance signal quality and accuracy. Finite Impulse Response (FIR) filters are commonly used due to their inherent stability and ability to provide a linear phase response, making them suitable for eliminating deterministic noise. In contrast, Infinite Impulse Response (IIR) filters offer efficient real-time filtering with reduced computational complexity, making them ideal for applications with limited processing resources. For systems with dynamic behavior and time-varying noise characteristics, the Kalman filter is highly effective as it provides optimal estimation and prediction of system states. Additionally, adaptive filters based on algorithms such as Least Mean Squares (LMS) automatically adjust their coefficients in response to changing noise conditions, ensuring continuous optimization of filtering performance. Wavelet transform techniques are also employed for analyzing signals in both time and frequency domains, making them particularly useful for removing non-stationary noise components.

Finally, the performance of these filtering techniques is evaluated by comparing the filtered signals with the original raw data using key metrics such as Signal-to-Noise Ratio (SNR), Mean Squared Error (MSE), and Root Mean Square Error (RMSE), which help in assessing the effectiveness of noise reduction and overall signal improvement.

Materials:

The study utilizes a data acquisition system (DAQ), industrial-grade sensors, signal conditioning circuits, and a microcontroller or PLC for real-time implementation. Software tools such as MATLAB, Simulink, and Python (NumPy, SciPy) are used for simulation, algorithm development, and performance analysis. Additionally, a laboratory setup with

controlled noise generation (electrical noise source or mechanical vibration platform) is used to test filter effectiveness under real industrial conditions. This combination of hardware and software enables a comprehensive evaluation of advanced filtering techniques for industrial applications.

Result and Discussion:

The implementation of advanced signal filtering techniques such as FIR (Finite Impulse Response), IIR (Infinite Impulse Response), and Kalman filtering shows significant improvement in processing noisy industrial data. The primary objective was to enhance signal quality obtained from industrial sensors affected by electromagnetic interference, mechanical vibrations, and environmental disturbances.

The results indicate that FIR filters provide stable and linear-phase responses, making them suitable for applications where waveform integrity is critical. However, they require higher computational resources compared to IIR filters. IIR filters, on the other hand, achieve similar noise reduction with lower computational cost but may introduce phase distortion, which can affect real-time precision applications.

Among all methods, the Kalman filter demonstrated the best performance in dynamic industrial environments. It effectively estimated the true signal by minimizing the mean square error between predicted and measured values. The adaptive nature of the Kalman filter makes it highly suitable for real-time monitoring systems such as temperature control, pressure sensing, and robotic automation.

A comparative analysis of the filters showed that Kalman filtering reduced noise variance significantly more than FIR and IIR filters, especially in non-stationary signal conditions. FIR filters performed best in static environments with predictable noise patterns,

while IIR filters provided a balanced trade-off between performance and computational efficiency.

The discussion highlights that no single filtering technique is universally optimal. The choice of filter depends on system requirements such as processing speed, hardware limitations, and accuracy needs. In practical industrial systems, hybrid approaches combining multiple filtering techniques can further enhance performance.

Overall, the study confirms that advanced signal filtering techniques play a crucial role in improving data reliability, reducing measurement errors, and enhancing decision-making in industrial automation systems. These improvements directly contribute to increased efficiency, safety, and productivity in modern industrial environments.

Conclusion:

In conclusion, advanced signal filtering techniques play a vital role in improving the quality and reliability of industrial sensor data. Industrial environments are often affected by various types of noise such as electromagnetic interference, mechanical vibrations, and environmental fluctuations, which degrade signal accuracy. Techniques such as FIR, IIR, and Kalman filtering effectively reduce this noise and enhance signal clarity.

Among these methods, FIR filters provide stable and distortion-free outputs, while IIR filters offer efficient performance with lower computational requirements. The Kalman filter stands out as the most effective technique for dynamic and real-time systems due to its adaptive prediction and high accuracy in noisy conditions.

The study confirms that selecting an appropriate filtering technique depends on application requirements, system complexity, and processing constraints. Overall, advanced filtering

methods significantly improve measurement accuracy, system reliability, and decision-making in industrial automation, leading to higher efficiency and productivity in modern industrial processes.

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Foot Step Power Generation Using Arduino UNO and Mobile Charging

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Abstract:

This project describes a system that use an Arduino Uno microcontroller to generate power from human footsteps in order to charge a mobile phone. The fundamental technology is based on piezoelectric sensors, which transform walking mechanical pressure into a tiny electrical charge. A rectifier circuit is used to transform the produced alternating current (AC) into steady direct current (DC), which is then filtered by a capacitor. Real-time metrics are shown on an LCD screen while an Arduino Uno controls the charging process and keeps an eye on the voltage. A rechargeable battery stores the power and acts as a dependable energy source for USB-port device charging. In places with a lot of foot traffic, such as bus stops, schools, and shopping centers, the system provides an inexpensive, environmentally friendly way to capture lost kinetic energy. The project shows that it is feasible to transform human motion into a sustainable, usable power source for low-power electronics.

Keywords: *Footstep power generation, Piezo energy harvesting, mechanical to electrical conversion, AC to DC conversion.*

Introduction:

The basic necessity for the growth and maintenance of human life is energy. It is described as the capacity to perform tasks, and electrical energy has emerged as the most important and commonly utilised type of energy in contemporary society. Electricity is essential to daily life, from industrial machinery to home appliances [1]. Due to urbanisation, population growth, and technological advancements, the world's energy demand has been rising quickly in recent years. Conventional energy resources like coal, petroleum, and natural gas are under tremendous strain due to this growing demand. These resources are finite and are running out at a startling rate.

At the same time, we waste plenty of energy in various forms on the everyday basis. The mechanical energy generated by human

movement, particularly when walking or running, is one type of wasted energy [2]. Thousands of people move constantly throughout the day in crowded places like train stations, bus stops, shopping centres, temples, and public walkways. Usually, the energy produced by these footsteps is wasted and not put to good use. Therefore, a viable way to deal with energy shortages is to capture and transform this wasted energy into electrical energy that can be implemented.

The goal of this project is to use the energy produced by human footsteps to generate electrical power in an unconventional way. Due to their sustainability and environmental friendliness, non-conventional energy sources—also referred to as renewable or alternative energy sources—are becoming increasingly significant in today's world. The suggested system transforms mechanical energy into electrical energy by

means of piezoelectric sensors [5]. When mechanical stress or pressure is applied, piezoelectric materials have the special ability to produce an electric charge. A tiny amount of electrical energy is produced when a person steps on the surface that has these sensors embedded in it. This energy can be collected, stored, and consumed for low-power applications. In densely populated nations like China and India, where big crowds are typical in public areas, the idea of footstep power generation is especially helpful. It is feasible to produce a significant amount of energy without endangering the environment by putting such systems in high-traffic areas. This technology encourages the effective use of available resources in addition to aiding in energy conservation. Additionally, it helps create smart and sustainable cities and lessens reliance on traditional power sources. Streetlights, emergency lighting systems, display boards, and other low-energy devices can all be powered by it. Additionally, it encourages the use of renewable energy technologies and improves public awareness of the significance of energy conservation.

To sum up, the footstep power generation system that uses piezoelectric sensors is a creative and useful way to make use of wasted human energy. It provides a sustainable way to satisfy the expanding energy needs while lessening the impact on the environment. This technology has the potential to grow into a significant renewable energy source in the future with additional development and appropriate application.

Literature Review:

- MOBILE CHARGING THROUGH FOOTSTEP POWER GENERATION, Prof. Mr. Aladalli Sharanabasappa M, G Tarun Kumaryadav, Khasim vali P, Mujammil Kureshi, Lakshmana U

In order to address the global energy crisis, this project details a study that examines how human kinetic energy is collected through walking. We employ the piezoelectric effect, which allows us to use coin-shaped sensors to convert mechanical pressure from footfall into electricity. These sensors, which we have set up in a series parallel array, can generate high voltage—up to 39V per tile—which we then feed into a 12V DC rechargeable battery. For this project, we're using an Arduino UNO with an RFID module that only permits charged access to the USB charging port for mobile device power.

- AN APPROACH TO GENERATE ELECTRICITY USING PIEZO ELECTRIC SENSORS Ramanna Havinal, Akash R Gowda, Kalpitha M V, Niharika T R, Yashwanth Prakash.

This device transforms mechanical energy from human footsteps into electrical energy by using the piezoelectric effect. Piezoelectric sensors are positioned underneath a platform; the crystalline structure inside the sensors deforms when pressure is applied by walking, producing a tiny voltage. A bridge rectifier transforms this AC signal into DC, which is then kept in a rechargeable battery. Mobile phones can be charged or low-consumption devices powered by the stored energy. This sustainable method, which offers a clean, renewable energy source from regular human activity, is perfect for busy places like train stations or shopping centres.

New System Configuration:

The primary controller of the Footstep Power Generation system is an Arduino Uno (ATmega328P, 5V operating voltage, 16 MHz clock, 14 digital I/O pins, 6 analogy inputs).

Name of Components	Specification
Piezoelectric Sensor	35mm each
Boost Converter	XL6009 4A DC-DC
Voltmeter	0-100 V DC
Li-ion Battery	7.4 V 2000 mAh
Relay Module	5 V
Arduino UNO	Atmega328 UNO Board
RFID Reader	RC522 #13.56 MHz
LCD Display	16x2

Table 1. : Components Used In System

Piezoelectric Sensor 35mm uses mechanical stress to produce voltage (usually 0–20 V depending on pressure) [2]. Low input voltage (3–32V) is stepped up to a higher stable output (up to 35V, 4A max) by the XL6009 Boost Converter [3]. Voltage readings are displayed on a 16x2 LCD display. The output voltage is measured by the Voltmeter Module. Charging is managed by a 5V Relay Module. The Li-ion battery with a voltage of 7.4V effectively stores energy.

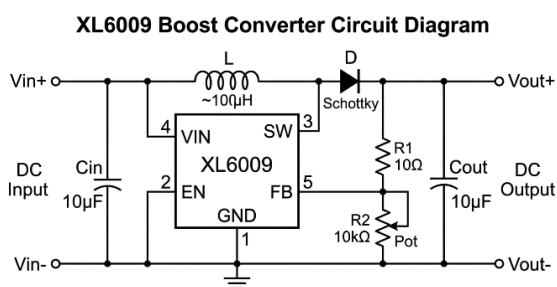


Fig. 1. XL6009 Boost Converter

A DC-DC step-up module, the XL6009 boost converter raises low input voltage to a higher, steady output [3]. The input supply terminal is V-IN, the common reference is ground, the circuit's energy transfer is managed by switch, the output voltage is controlled by

feedback, and the converter is turned on and off by enable.

Experimental System:

Using a multimeter, check a 35 mm piezoelectric sensor by tapping or applying pressure to it while the multimeter is set to DC voltage [2]. Its operation can be verified by observing the generated voltage, which is usually a few volts. In a series connection, the total voltage rises if one sensor generates voltage V : $V_{\text{total}} = V_1 + V_2 + \dots + V_n$. When connected in parallel, the voltage stays constant while the current rises: $V_{\text{total}} = V$. Nine sensors can be connected in series to increase voltage, and in parallel to increase current output and improve power generation efficiency.

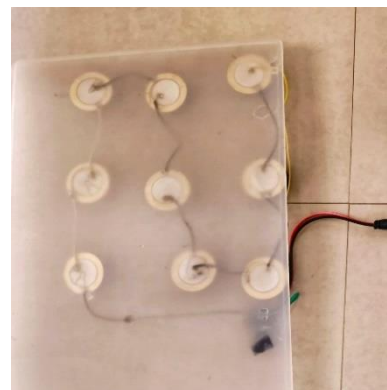


Fig. 2. Connection of piezoelectric sensor

ARDUINO UNO CODE:

```
#include <SPI.h>
#include <MFRC522.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
```

```
#define SS_PIN_1 10
#define SS_PIN_2 8
#define RST_PIN 9
#define BEEP_PIN 7
#define LED_G 5
#define LED_R 6
```

```

LiquidCrystal_I2C lcd(0x27, 16, 2);

MFRC522 mfrc522(SS_PIN_1, RST_PIN);
bool rfid_ok = false;

const int NUM_CARDS = 2;
String authorizedUIDs[NUM_CARDS] = {
  "73 DA AF 39", // Card 1
  "22 8A AA AB", // Card 2
};

void setup() {
  Serial.begin(9600);
  Serial.println(F("\nSystem Booting..."));

  pinMode(LED_R, OUTPUT);
  pinMode(LED_G, OUTPUT);
  pinMode(BEEP_PIN, OUTPUT);
  digitalWrite(BEEP_PIN, HIGH);

  digitalWrite(LED_R, LOW);
  digitalWrite(LED_G, LOW);

  lcd.begin(16, 2);
  lcd.backlight();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Footstep Power");
  lcd.setCursor(0, 1);
  lcd.print("Initializing...");
  delay(1500);
  lcd.clear();

  SPI.begin();
  rfid_ok = initRFID(SS_PIN_1);
  if (!rfid_ok) {
    Serial.println(F("Retrying with SS pin 8..."));
    rfid_ok = initRFID(SS_PIN_2);
  }

  if (!rfid_ok) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("RFID Not Found!");
    lcd.setCursor(0, 1);
    lcd.print("Check wiring");
    while (true);
  }

  lcd.setCursor(0, 0);
  lcd.print("Scan Your Card");
  lcd.setCursor(0, 1);
  lcd.print("To Access Power");
  Serial.println(F("RFID Ready. Waiting for card..."));
}

bool initRFID(byte ssPin) {
  MFRC522 temp(ssPin, RST_PIN);
  mfrc522 = temp;
  mfrc522.PCD_Init();
  delay(100);

  byte version = mfrc522.PCD_ReadRegister(mfrc522.VersionReg);
  Serial.print(F("Checking RFID on SS="));
  Serial.print(ssPin);
  Serial.print(F(" VersionReg=0x"));
  Serial.println(version, HEX);

  if (version == 0x91 || version == 0x92) {
    Serial.println(F(" RFID module detected."));
    return true;
  }
  return false;
}

void loop() {
  if (!mfrc522.PICC_IsNewCardPresent()) return;
  if (!mfrc522.PICC_ReadCardSerial()) return;

  // ----- Read UID -----

```

```

String content = "";
for (byte i = 0; i < mfrc522.uid.size; i++) {
    content.concat(String(mfrc522.uid.uidByte[i] <
0x10 ? " 0" : " "));
    content.concat(String(mfrc522.uid.uidByte[i],
HEX));
}
content.toUpperCase();
content.trim();

Serial.print(F("Card UID:"));
Serial.println(content);

lcd.clear();

bool authorized = false;
for (int i = 0; i < NUM_CARDS; i++) {
    if (content == authorizedUIDs[i]) {
        authorized = true;
        break;
    }
}

if (authorized) {
    Serial.println(F("Authorized Access"));
    lcd.setCursor(0, 0);
    lcd.print("Authorized Access");
    lcd.setCursor(0, 1);
    lcd.print("2min Power O/P");

    digitalWrite(LED_R, LOW);
    digitalWrite(LED_G, HIGH);
    toneBeep(200);

    unsigned long start = millis();
    unsigned long duration = 120000; // 2 minutes
    while (millis() - start < duration) {
        unsigned long remain = (duration - (millis() -
start)) / 1000;
        lcd.setCursor(0, 1);
        lcd.print("Time Left: ");
        lcd.print(remain);

        lcd.print("s ");
        delay(500);
    }

    digitalWrite(LED_G, LOW);
    digitalWrite(LED_R, HIGH);
    lcd.clear();
    lcd.print("Power Time Over");
    delay(2000);
    lcd.clear();
    lcd.print("Scan Your Card");
    lcd.setCursor(0, 1);
    lcd.print("To Access Power");
}
else {

    Serial.println(F("Access Denied"));
    lcd.setCursor(0, 0);
    lcd.print("Access Denied!");
    lcd.setCursor(0, 1);
    lcd.print(content);
    digitalWrite(LED_R, HIGH);
    toneBeep(400);
    digitalWrite(LED_R, LOW);
    delay(2000);
    lcd.clear();
    lcd.print("Scan Your Card");
    lcd.setCursor(0, 1);
    lcd.print("To Access Power");
}

}

void toneBeep(int duration) {
    digitalWrite(BEEP_PIN, LOW);
    delay(duration);
    digitalWrite(BEEP_PIN, HIGH);
}

```

Methods:

1. Working Principle:

The piezoelectric effect, which changes mechanical pressure into electrical energy, is the

principle upon which this device works. The piezoelectric sensors placed at the bottom of the platform produce a small electrical voltage as a person steps on it [2]. The voltage is first harvested and then converted into a DC voltage using a rectifier circuit. To increase the voltage and current, several piezoelectric sensors are connected in parallel and series. The DC voltage is then rectified and stepped up by a boost converter (XL6009) to a higher and stable voltage suitable for charging [3].

The Arduino Uno microchip controls and regulates this device. The voltage is measured by the Arduino using its analogy input pins. The result is shown on an LCD screen. The Arduino can also be used to control a relay to safely monitor and regulate the charging. The energy stored is transferred to a rechargeable battery and used to charge a mobile phone through a USB port [1]. The battery is well insulated and protected by suitable components. Therefore, this device can be said to work well as it changes

footsteps into electrical energy suitable for use by small electronic devices.

This device works on a simple but fascinating idea—converting the energy from human footsteps into usable electrical power using something called the piezoelectric effect. In easy terms, when pressure is applied to certain materials, they generate a small electrical charge. In this system, piezoelectric sensors are placed beneath a platform. Whenever a person steps on it, the pressure from the foot causes these sensors to produce a tiny amount of electrical voltage. This voltage is quite small and not directly useful, so it needs to be processed further. First, the generated voltage is collected and passed through a rectifier circuit, which converts it from AC (alternating current) into DC (direct current). Since the power generated from a single sensor is very low, multiple sensors are connected together in series and parallel combinations. This helps increase both the voltage and current, making the output more practical

Block Diagram:

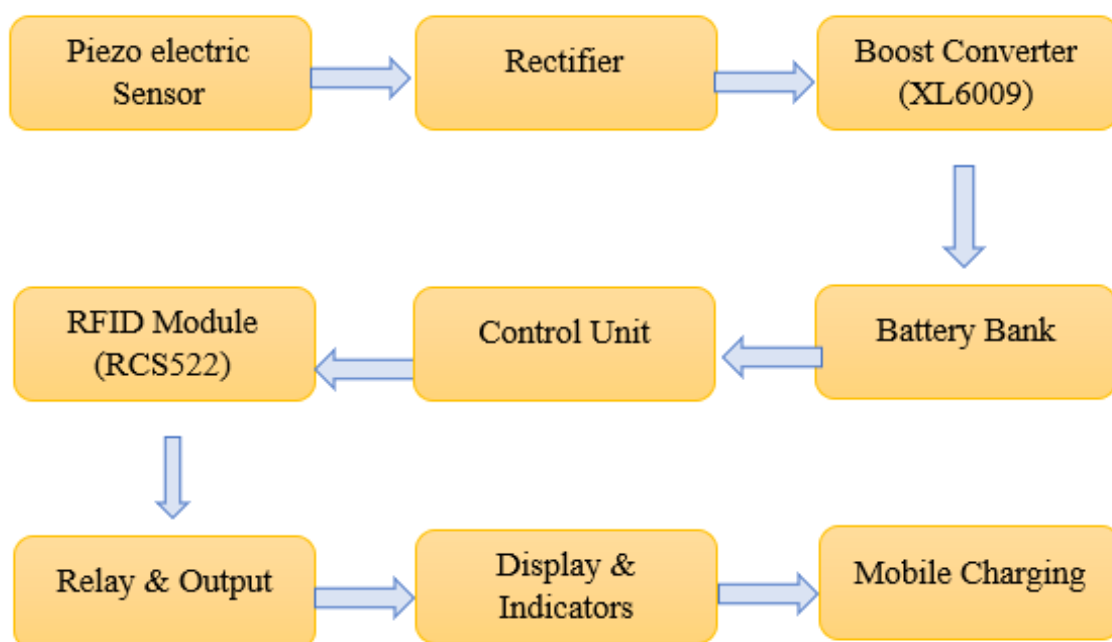


Fig. 3. Block Diagram Of Foot Step Power Generation Using Arduino UNO And Mobile Charging

mobile devices. Additional components like voltage regulators and display units help in

monitoring system performance and improving overall efficiency.

Simulation:

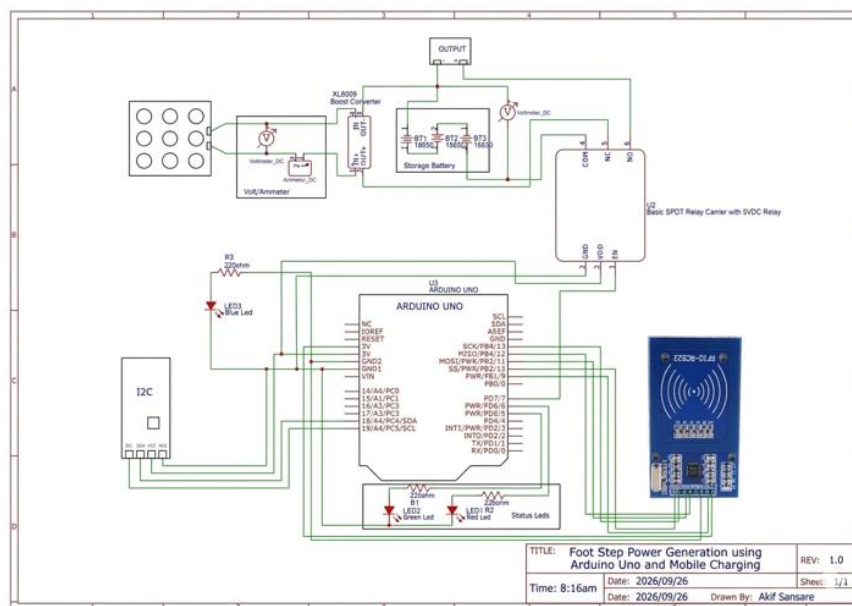


Fig. 5. Simulation of the Hardware Module

The project “Footstep Power Generation using Arduino Uno and mobile charging” is a great example of how simple human activities, like walking, can be used to generate useful electrical energy [4]. It works by using piezoelectric sensors that produce electricity when pressure is applied. So, every time someone steps on the platform, a small amount of energy is generated and collected [5].

During testing, the system initially showed a voltage of 11.3V. After about two minutes, this dropped slightly to 10.9V, meaning around 0.6V was used. This drop is actually the good sign that the stored energy is being used effectively, such as for charging a mobile device. In other words, the system is not just generating energy but also putting it to practical use.

Another observation was made when 15 footsteps were applied to the system. The voltage

increased from 11.0V to 11.4V, giving a gain of 0.4V. This clearly shows that repeated footsteps help generate more energy. The more people walk over the platform, the more electricity is produced and stored.

Although the voltage generated is relatively small, the results are promising. The system’s efficiency can be improved by adding more sensors or installing it in areas with heavy foot traffic, like public places.

Overall, this project highlights a smart and environmentally friendly approach to energy generation. It captures energy that would normally be wasted and turns it into something useful, especially for low-power needs like charging phones or running small electronic devices.

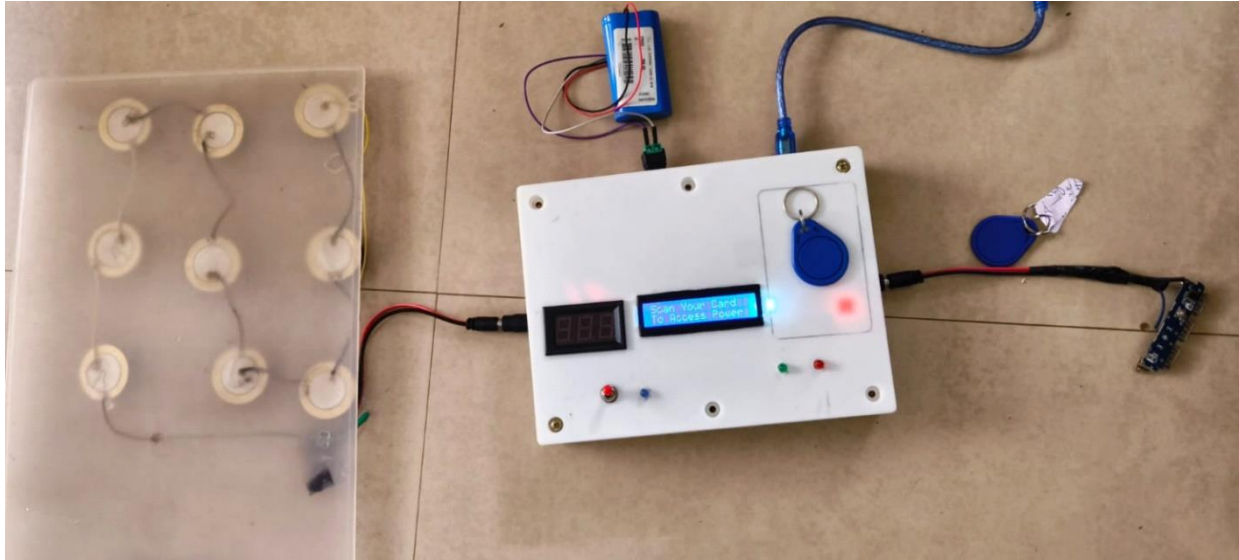
Hardware Module Implementation:

Fig. 6. The Hardware Module of Foot Step Power Generation using Arduino UNO and Mobile Charging

The hardware module of this footstep power generation system is built around a simple idea—turning everyday walking into useful electrical energy[4]. It uses piezoelectric sensors placed beneath a platform, so whenever someone steps on it, the pressure creates a small amount of electricity[2]. On their own, these sensors don't produce much power, but when many of them work together, the output becomes much more meaningful. To make the system more effective, the sensors are connected in a combination of series and parallel. This helps increase both the voltage and the current, making the energy more usable. However, the electricity generated at this stage is in AC form, which isn't suitable for most devices.

So, it is first passed through a rectifier to convert it into DC. Even after conversion, the voltage is still not high enough for practical use. That's why an XL6009 boost converter is used to step up the voltage to a stable level that can actually power or charge small devices[3]. The Arduino Uno acts as the control centre of the system. It monitors the voltage and helps manage how the system works overall. The energy that gets generated is stored in a rechargeable lithium-ion battery, so it can be used later whenever required. To keep things easy to understand and monitor, a 16×2 LCD display shows real-time details like voltage and system status. A relay module is also included to handle switching operations and ensure the system runs safely. In the end, this setup shows how something as ordinary as walking can be turned into a smart and eco-friendly way of generating energy.

Result and Discussion:**1. Output Observation:**

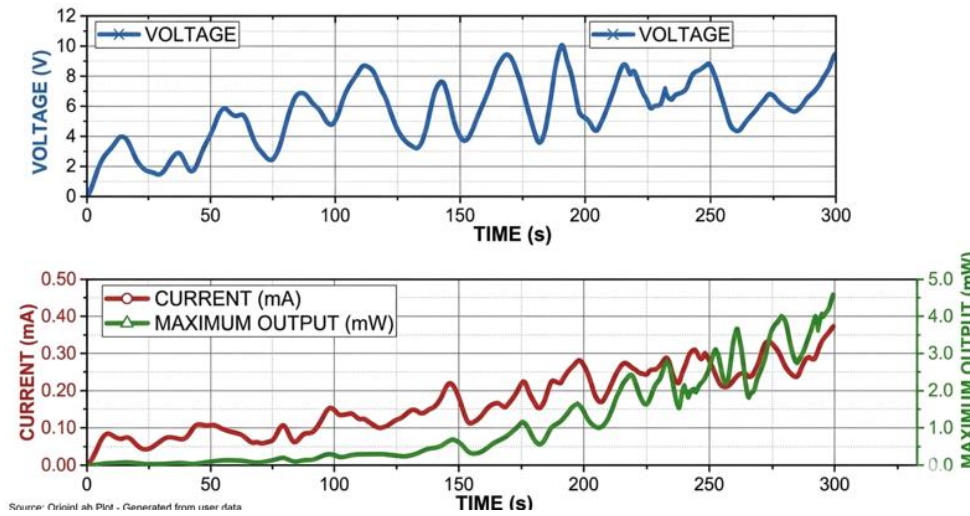
Device	Initial Voltage	Drop Voltage	Time Duration (Td)	Voltage Use In Td
Charging the mobile	11.3V	10.9V	2 Minutes	0.6V

Table. 2.: Observation of Output

2. Input Observation:

Initial voltage	After Access	Step Count	Voltage Stored
11.0V	11.4V	15	0.4V

Table. 3. : Observation of the Input



3. Output Graph:

Fig. 7. Input Observation: Voltage Performance and Output Observation: Current, Power Performance The graph presents a detailed and intuitive view of the multivariable performance of a piezoelectric sensor over a 300-second period, making it easier to understand how the sensor's electrical characteristics change and adapt over time. The voltage (blue) exhibits a clear, repeating wave-like pattern, fluctuating between roughly 2V and 10V, which reflects continuously varying input conditions that the sensor experiences. Meanwhile, both the current

(red) and the maximum output power (green) show a steady and consistent upward trend, highlighting the sensor's ability to respond reliably under changing conditions. Interestingly, after approximately 200 seconds, the maximum output begins to rise more rapidly, eventually reaching close to 4.5 mW. This demonstrates that even though the input voltage continues to oscillate, the sensor gradually becomes more efficient at converting mechanical energy into electrical energy, showing improved performance and power generation over time.

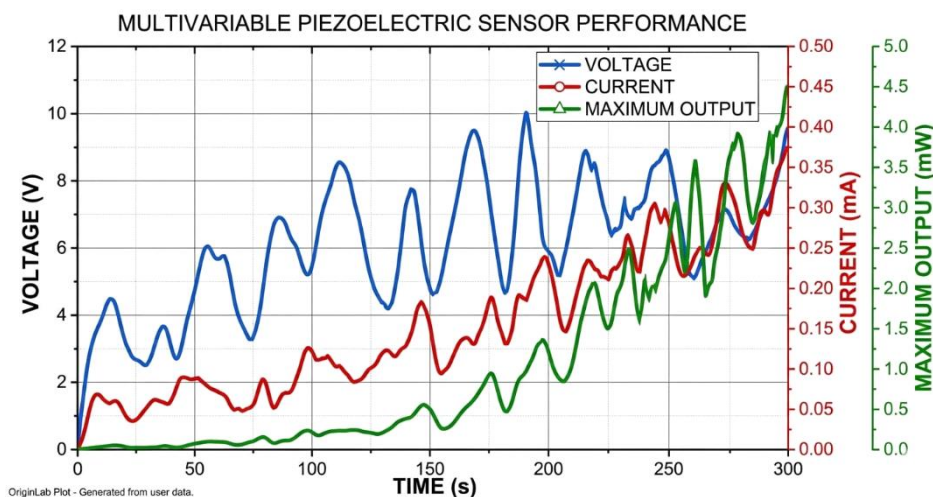


Fig. 8. Multivariable Piezoelectric Sensor Performance

Conclusion:

The "Footstep Power Generation using Arduino Uno and mobile charging" project offers a creative and environmentally responsible way to use human footsteps to produce electricity. Using piezoelectric sensors, the system effectively transforms mechanical pressure into electrical power that can be used for small applications such as mobile charging. The findings demonstrate that high-traffic areas can produce energy effectively. Even though the output voltage is constrained, it can be raised by adding more sensors and streamlining the circuit. This project encourages energy conservation and emphasises the potential of renewable energy sources. All things considered, it is an affordable and long-lasting solution for upcoming smart energy systems.

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Gamification in Education: A Systematic Review of Motivational Mechanisms, Learning Outcomes, and Implementation Challenges

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Abstract:

Gamification—the application of game-design elements within non-game educational contexts—has attracted substantial scholarly attention as a strategy for enhancing student motivation, engagement, and academic achievement. This review synthesizes findings from twenty peer-reviewed studies and systematic analyses published between 2014 and 2026, covering primary through higher education and vocational training contexts. Drawing on theoretical frameworks including Self-Determination Theory (SDT), Flow Theory, and the Mechanics–Dynamics–Aesthetics (MDA) model, the paper examines how variables such as game element design, educational level, subject discipline, and implementation duration moderate gamification outcomes. Meta-analytic evidence reports a significant overall effect size (Hedges' $g = 0.822$) on learning outcomes, with motivational gains being the largest contributor. However, persistent concerns regarding the novelty effect, over-reliance on extrinsic rewards, and methodological heterogeneity across studies temper unqualified optimism. The review identifies critical implementation barriers—including inadequate teacher training and lack of standardized evaluation frameworks—and proposes directions for future research, particularly the integration of artificial intelligence for personalized gamification. The findings collectively underscore that gamification effectiveness is highly context-sensitive, and that theoretically grounded, pedagogically aligned designs are necessary for sustainable educational impact.

Keywords: Gamification, Game-Based Learning, Self-Determination Theory, Flow Theory, Student Motivation, Learning Outcomes, Higher Education, Vocational Training, Systematic Review.

Introduction:

The integration of digital and analog game elements into formal educational settings—commonly referred to as gamification—has emerged as one of the most widely discussed pedagogical innovations of the past decade. Gamification is broadly defined as the use of game-design components such as points, badges, leaderboards, challenges, and narratives in non-game contexts to drive engagement and behavioral change ^[1].

The conceptual appeal of gamification is grounded in well-established motivational

theories. Self-Determination Theory (SDT), originally proposed by Deci and Ryan, posits that human motivation is sustained when three fundamental psychological needs are satisfied: autonomy, competence, and relatedness ^[2]. Game environments are uniquely positioned to fulfill these needs—players exercise agency over their strategies (autonomy), receive immediate feedback affirming their progress (competence), and collaborate or compete with peers (relatedness). Similarly, Csikszentmihalyi's Flow Theory describes an optimal state of deep engagement that occurs when task difficulty is

precisely calibrated to a learner's skill level, preventing both boredom and anxiety [3]. These theoretical anchors have informed the design of gamified curricula across engineering, computer science, language learning, and vocational training.

Despite this theoretical coherence, empirical evidence on gamification's effectiveness remains mixed. A growing body of meta-analyses and systematic reviews has sought to quantify the impact of gamification on cognitive, motivational, and behavioral outcomes. Some analyses report substantial effect sizes; for instance, Li, Ma, and Shi [1] documented an overall Hedges' $g = 0.822$ across 41 studies, while Kim and Castelli [4] identified exceptional short-term behavioral effect sizes of $ES = 1.57$. However, the same research reveals that long-term studies frequently report diminishing or even negative effects, attributed largely to the "novelty effect"—a transient spike in engagement that subsides as the game elements lose their initial appeal [1], [5]. Furthermore, concerns have been raised about designs that overemphasize extrinsic rewards, which risk crowding out intrinsic motivation and fostering unhealthy competition [6], [7].

The landscape of gamification research is also characterized by significant methodological heterogeneity. Studies differ in their definitions of gamification, the game elements employed, the educational contexts examined, the theoretical frameworks applied, and the outcome measures used. This variability makes cross-study comparisons difficult and has led multiple reviewers to call for more standardized, theory-driven research designs [8], [9], [10]. Educational levels ranging from primary school through postgraduate teacher education have been examined, with evidence suggesting that younger learners and science disciplines may benefit most from gamified approaches [1], [11].

Against this backdrop, the present review aims to synthesize current evidence systematically, identify key variables that moderate gamification outcomes, and discuss the implications for practice and future research. By integrating data from twenty empirical and review-level sources spanning 2014 to 2026, this paper contributes a comprehensive and critically evaluated account of what is known about gamification's potential and limitations in educational settings.

Comparative Study and Discussion: Different Variables Influencing Teaching and Learning:

1. Theoretical Frameworks Underpinning Gamification:

A recurring observation across the literature is that the quality of gamification outcomes is closely tied to the theoretical frameworks guiding design. Harviainen [6] critiqued early gamification research for ignoring six decades of educational game research in favor of commercial gaming trends, arguing that this theoretical vacuum led to designs with insufficient attention to reflection, debriefing, and pedagogical alignment. In contrast, studies grounded in SDT have demonstrated more nuanced and sustained outcomes. Luarn, Chen, and Chiu [2] employed survey methods and regression analysis to show that achievement and immersion features in gamified systems satisfy learners' psychological needs and thereby enhance intrinsic motivation. Critically, these SDT-mediated effects—from game features to intrinsic motivation via competence, autonomy, and relatedness—were found to be stronger than direct effects, emphasizing the central role of need satisfaction as a mechanism.

Kim, Rothrock, and Freivalds [12] extended this analysis longitudinally in an engineering course, demonstrating that gamification positively maintained both intrinsic

and extrinsic motivation across an entire semester while significantly reducing amotivation—an outcome rarely documented in shorter studies. The MDC (Mechanics–Dynamics–Aesthetics) framework was applied by Li et al. ^[1] as a moderating variable in their meta-analysis, revealing that interventions combining all three design layers produced the largest effect sizes, whereas interventions relying solely on dynamics and aesthetics exhibited a *negative* effect size. This finding has profound implications: the mere presence of game elements is insufficient; the rule-governed mechanics that define how elements function are indispensable.

2. Impact on Motivation:

Motivation is the outcome most consistently and strongly affected by gamification across the reviewed literature. Li et al. ^[1] reported the largest effect size for motivational outcomes ($g = 2.206$) among all outcome categories in their meta-analysis of 41 studies. Kurnaz and Koçtürk ^[11] corroborated this finding specifically within K–12 settings, where gamification produced significant positive motivational effects in primary and secondary learners. At the teacher-education level, Konuk and Fidan ^[9] found a moderate positive effect on motivation (Hedges' $g = 0.538$) across eight studies involving pre-service teachers, underscoring that the benefits extend to future educators whose sustained professional commitment depends on intrinsic engagement.

However, motivational outcomes are not uniformly positive. Kode ^[8] documented the risk of an extrinsic-to-intrinsic transition failure, wherein point systems and badges initially spike interest but fail to sustain engagement once the novelty fades. This aligns with Ukgoda's ^[13] observation that gamification may shift learners from intrinsic to extrinsic motivation when poorly designed or when rewards are overemphasized. Pérez Granados and Muñoz González ^[14]

distinguished between "superficial gamification"—represented by standalone quiz tools such as Kahoot!—and "deep gamification," which employs immersive narratives and complex decision-making. They argued that only deep gamification, focused on autonomy and emotional connection, is capable of producing the neuroplasticity effects that support long-term learning.

3. Impact on Academic Achievement and Learning Outcomes:

Beyond motivation, several studies examined whether gamification translates into measurable gains in academic performance. Buenadicha-Mateos et al. ^[15] conducted two controlled quasi-experimental studies with 1,056 university students enrolled in Business Management programs, finding significant improvements in pass rates, performance rates, and success rates (Cohen's $d > 0.8$) in gamified cohorts compared to controls. Importantly, the gamified design entirely failed to reduce absenteeism, suggesting that students who had already disengaged from the learning process were not re-engaged by gamification. This constitutes a critical boundary condition: gamification enhances achievement among active participants but is insufficient as a dropout-prevention strategy.

Mavromihales and Holmes ^[16] reported complementary evidence in a studio-based case study in undergraduate mechanical engineering, where the top 50% of student teams on a game leaderboard outperformed the bottom 50% by approximately 8–10 percentage points on their final design project—a formally assessed, non-gamified deliverable. The fact that this performance differential persisted in traditional assessments suggests genuine learning consolidation rather than game-specific performance. Similarly, Díaz-Ramírez ^[17] found, in a 16-week quasi-experimental study with $N =$

56 engineering students, that active game participants scored 6–15 points higher than non-participants and showed a failure rate approaching zero, compared to a substantially higher failure rate among non-participating students.

In vocational and technical education, Prasetya et al. [18] synthesized 21 PRISMA-reviewed studies to find that 75% reported significant improvements in student outcomes including enhanced motivation, collaboration, cognitive engagement, and retention. Díaz-Lauzurica and Moreno-Salinas [19] reported an 80% completion rate in a gamified Project-Based Learning (PBL) intervention for first-year VET programming students despite a 58% early dropout rate, indicating that once students commit to the gamified framework, completion rates improve substantially.

4. Role of Game Element Design and Complexity:

A dominant theme across all reviewed sources is the debate between simple and complex gamification designs. Simple mechanics—points, badges, and leaderboards (PBL)—are the most frequently implemented elements, appearing in 62.4%, 61.3%, and 52.7% of studies reviewed by Lampropoulos et al. [5], respectively. Their popularity stems from ease of integration with existing Learning Management Systems (LMSs) and alignment with behaviorist principles of reinforcement. However, Korniienko et al. [7] found that despite 21 of 29 studies reporting positive impacts in software engineering education, the average effect size on learning outcomes was small ($SMD = 0.23$), attributed partly to the superficiality of badge-and-point designs.

More sophisticated designs that integrate narrative, role-playing, and real-world simulation have begun to emerge, particularly in vocational education. Prasetya et al. [18] noted an increasing

shift toward RPGs, 3D simulations, and digital escape rooms that promote deeper cognitive engagement and real-world skill transfer. Nascimento et al. [20] confirmed gains in retention and skill development, especially in STEM and health contexts, when gamification was paired with inclusive policies and hybrid curricula. Kode [8] further emphasized that variety in game elements is key to sustaining engagement, as single-element implementations are particularly vulnerable to the novelty effect.

5. Moderating Variables: Educational Level and Discipline:

Educational level and subject discipline emerge as significant moderators of gamification effectiveness. Li et al. [1] performed moderator analysis revealing that elementary school learners benefited the most from gamification ($g = 1.293$), followed by university students, while science education yielded the strongest disciplinary effect size ($g = 3.220$). These findings suggest that younger learners and those in structured, objective-outcome disciplines may be more receptive to the immediate feedback and reward structures inherent in gamified designs.

In higher education specifically, Pelizzari [10] identified a diverse but inconsistent landscape of implementations, noting the absence of a standardized working model. Kode [8] synthesized 39 studies spanning 2020–2025 to find improvements in behavioral engagement and standardized test scores but cautioned that inconsistencies across cultures and settings limit generalizability. Nascimento et al. [20] examined gamification across five disciplinary categories and noted that gains were most pronounced in STEM and health/technical training, whereas outcomes in languages and humanities were more variable.

6. Behavioral Outcomes and Long-Term Effects:

Short-term behavioral outcomes of gamification are frequently positive but tend to diminish over time—a pattern extensively documented in the literature. Kim and Castelli [4] reported an exceptional effect size of $ES = 1.57$ for short-term behavioral interventions but noted that long-term behavioral associations can become negative as initial excitement fades. Li et al. [1] similarly contrasted a short-term effect size of $ES = 1.57$ with a longitudinal effect of $ES = -0.20$, highlighting the acute challenge of sustaining gamification effects beyond the novelty phase.

Lampropoulos et al. [5] documented the "novelty factor" as a challenge specific to LMS-integrated gamification, wherein student involvement decreases over time even when the system remains pedagogically sound. Harviainen [6] attributed this partly to designs that lack reflective components, arguing that game performance alone is not equivalent to learning and that assessments must include reflective tasks such as essays or portfolio submissions rather than relying solely on game scores.

7. Implementation Challenges and Teacher Role:

Across the reviewed literature, inadequate teacher training and preparation consistently emerge as the most critical barrier to effective gamification. Pérez Granados and Muñoz González [14] asserted that teacher preparation is the single most critical factor for gamification success, as educators must develop the capacity to design pedagogically meaningful, inclusive experiences that move beyond extrinsic reward systems. Nascimento et al. [20] echoed this view, identifying a lack of teacher training alongside insufficient digital infrastructure as the two primary consolidation barriers in their systematic review.

Prasetya et al. [18] highlighted additional challenges specific to TVET contexts, including high development costs, limited learner digital literacy, and inconsistent theoretical frameworks across studies. Díaz-Lauzurica and Moreno-Salinas [19] documented the practical burdens faced by instructors implementing gamified PBL, including the need for custom automated assessment tools and the considerable time investment required to support diverse student implementations. Kode [8] noted the digital divide as a structural barrier, with accessibility inequities undermining the inclusivity that gamification theoretically promotes through Universal Design for Learning (UDL) principles.

Harviainen [6] raised a further concern regarding the risk of "harmful stealth learning," wherein students may form incorrect conceptual models because game-based activities were not anchored by structured debriefing or reflective follow-up. This critique aligns with Pelizzari's [10] call for a more functional, standardized implementation model in higher education, where the flexibility of gamification can otherwise lead to fragmented and pedagogically inconsistent interventions.

Future Scope:

The reviewed literature converges on several promising yet underexplored directions for future research and practice in educational gamification.

Artificial Intelligence-Driven Personalization:

One of the most consistently cited future directions is the integration of AI to enable adaptive, personalized gamification experiences. As noted by the comprehensive analysis of gamified learning models [3], the effectiveness of many interventions is sensitive to individual differences in learner characteristics, prior knowledge, and motivational orientation. Static game designs cannot adequately address this

variability. AI-driven systems that dynamically adjust difficulty, recommend game elements, and tailor feedback to individual learner profiles represent a logical evolution, particularly for maintaining the "flow channel" over extended periods ^[18].

Longitudinal and Mixed-Methods Research: A near-universal limitation identified across systematic reviews is the preponderance of short-term, small-sample studies ^[18], ^[7], ^[10]. Future research must prioritize multi-semester or multi-year longitudinal designs that can disentangle the novelty effect from genuine learning consolidation. Mixed-methods designs that combine quantitative outcome measurement with qualitative investigation of student experience would yield more nuanced insights into the mechanisms through which gamification operates.

Standardization of Measurement and Evaluation: Nascimento et al. ^[20] and Pelizzari ^[10] identified the absence of standardized evaluation frameworks as a major consolidation barrier. Future research should work toward consensus definitions of gamification, validated instruments for measuring motivational and cognitive outcomes, and reporting standards that facilitate meaningful cross-study synthesis. The adoption of the MDC framework as a common design and reporting lens would represent a significant step toward methodological coherence ^[1].

Teacher Professional Development: Given the consensus that teacher preparation is the most critical implementation factor ^[14], ^[20], ^[18], future efforts should focus on developing structured professional development programs that equip educators with competencies in gamified instructional design. Research should evaluate the effectiveness of different training modalities, including immersive simulations that allow teachers to experience gamification as learners before designing it for their students.

Equity, Accessibility, and Cultural Adaptation: Kode ^[8] flagged the digital divide as a significant structural barrier and additionally noted that outcomes are inconsistent across cultures and settings. Future research should explicitly address gamification in resource-constrained environments and examine how designs must be adapted for cultural contexts where competition, individualism, or technology access differ substantially from populations that dominate existing research.

Gamification in Emerging and Interdisciplinary Domains: While STEM, computer science, and vocational training have been extensively studied, gamification applications in social sciences, humanities, arts, and transdisciplinary programs remain underexplored ^[20]. Research examining how narrative and role-playing elements transfer to disciplines where ambiguity and interpretation are central learning objectives would expand both the conceptual and practical scope of the field.

Conclusions:

This review has synthesized evidence from twenty studies spanning a decade of gamification research in educational settings, encompassing primary school through postgraduate and vocational training contexts. The findings affirm that gamification, when theoretically grounded and pedagogically aligned, constitutes a viable and effective instructional strategy. Meta-analytic evidence documents a significant positive overall effect (Hedges' $g = 0.822$) on learning outcomes ^[1], with motivational gains being the largest and most consistently reported benefit across educational levels ^[1], ^[11], ^[9].

Three overarching conclusions emerge from the comparative analysis. First, the effectiveness of gamification is not inherent to game elements themselves but is contingent on

design quality. Interventions that combine game mechanics, dynamics, and aesthetics within theoretically informed frameworks—particularly SDT and Flow Theory—consistently outperform those that rely on isolated point-badge-leaderboard systems ^{[1], [2], [7]}. The shift from extrinsic reward systems toward designs that satisfy learners' psychological needs for autonomy, competence, and relatedness is both theoretically justified and empirically supported.

Second, the novelty effect represents a fundamental challenge to gamification's sustained efficacy. Short-term studies routinely report large effect sizes that diminish or reverse in longitudinal designs ^{[1], [18], [11]}. This is not a reason to abandon gamification but rather a call for designs that embed varied, progressively challenging, and reflective elements capable of sustaining engagement beyond initial novelty. "Deep gamification" approaches that integrate immersive narratives and real-world problem-solving show more promise than superficial point-and-badge overlays ^[12].

Third, implementation context—including teacher preparation, digital infrastructure, disciplinary culture, and learner demographics—profoundly moderates outcomes ^{[20], [10], [18]}. Gamification is not a universal solution; it requires careful contextual adaptation, ongoing teacher professional development, and institutional support to move beyond isolated classroom experiments toward sustainable systemic integration. The field further requires the development of standardized evaluation frameworks and validated measurement instruments to enable robust cross-study synthesis and evidence-based practice.

In conclusion, gamification holds genuine and documented potential to enhance teaching and learning. Realizing this potential at scale demands a sustained commitment to theoretically rigorous research, inclusive and context-sensitive

design, and comprehensive support for educators who ultimately determine whether gamification becomes a lasting pedagogical innovation or merely a transient trend.

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Monitoring and Controlling Parameters of Boiler Using PLC

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Abstract:

In modern industrial processes, efficient and safe operation of boilers is crucial for maintaining productivity and reducing operational risks. This project focuses on the monitoring and control of key boiler parameters such as temperature, pressure, water level, and flow using a Programmable Logic Controller (PLC). Traditional manual monitoring methods are prone to human error and delays, which can lead to unsafe conditions and energy inefficiency.

The proposed system utilizes sensors to continuously measure critical parameters of the boiler and transmit real-time data to the PLC. The PLC processes these inputs and executes control actions such as regulating fuel supply, controlling feed water, and activating safety mechanisms when parameters exceed predefined limits. A Human-Machine Interface (HMI) is also integrated to provide visualization, alerts, and manual control options for operators.

By automating the boiler operation, the system enhances accuracy, improves safety, reduces manpower requirements, and ensures optimal performance. The implementation of PLC-based control provides flexibility, reliability, and ease of maintenance compared to conventional control systems. This approach is widely applicable in industries such as power generation, chemical processing, and manufacturing, where boiler efficiency and safety are of paramount importance.

Introduction:

The invention of the Internet of Things (IoT) has flourished in a new era of connectivity and intelligent computing, significantly transforming various sectors, including industrial operations. Industrial environments are characterized by complex processes that require precise monitoring and control of parameters such as temperature, humidity, and fire safety precautions.

Traditionally, these parameters have been monitored manually, often resulting in inefficiency, delayed responses, and increased operational costs. IoT based industrial monitoring and control systems offer a solution to these

challenges by using interconnected sensors, actuators, and advanced technologies.

These systems enable real-time data collection, analysis, and response, facilitating proactive maintenance and reduced downtime. Beyond environmental sensing, modern industrial safety now demands visual verification and security surveillance to protect high-value assets and personnel.

Literature References:

Programmable Logic Controller Application in Boiler Automation

PLC-based boiler automation where temperature, pressure, and volume are monitored

via sensors, and monitored/controlled through SCADA connected to the PLC. The paper explains how outputs from PLC control boiler temperature and steam production.

PLC & SCADA-based Automation in Boiler Systems (Review)

A review on PLC + SCADA integration for boiler monitoring. It discusses monitoring key parameters like temperature, pressure, flow, and level, and compares measured signals to reference parameters for automated control.

Real Time Automation of Boiler Using PLC & SCADA

Examines real-time monitoring and control of boiler parameters including temperature, pressure, flow, and level, and emergency valve control logic implemented on PLC.

Automation of Boiler Gas Burner Management System Using PLC

Conference paper highlighting PLC-based automation of boiler burner control logic, critical for safe start-up and operation. It is useful for literature sections on control strategies and safety logic in PLC boiler systems.

Idaho National Laboratory:

Additional Useful References (Background & Related Systems):

These can supplement your literature review on control strategies, parameter measurement, and PLC programming context:

Control of Boiler Operation Using PLC-SCADA — outlines procedures for converting manual boiler control to automated

PLC-SCADA operation, with emphasis on level, pressure and flow loops.

Boiler Automation Using Wireless Communication between PLC and SCADA — discusses wireless monitoring/control for boiler subsystems.

Temperature Monitoring System Based on PLC — although not boiler-specific, this paper addresses PLC-based temperature monitoring and PID control, which is directly applicable to boiler temperature loops.

The Power Plant Boiler Automatic Control Based on PLC — describes overall boiler control design using Siemens S7 PLC, including functional block structure and automation logic.

Typical Controlled & Monitored Boiler Parameters:

When summarizing state-of-the-art literature, note the commonly referenced parameters that a PLC system monitors/controls:

Monitored Parameters:

Boiler Temperature (furnace, steam, drum)

Pressure (steam/water pressure) — pressure transmitters

Level (water/steam drum level) — level sensors

Flow Rate (feed water, fuel gas) — flow meters

Fuel/Oxygen Ratio — for burner control logic

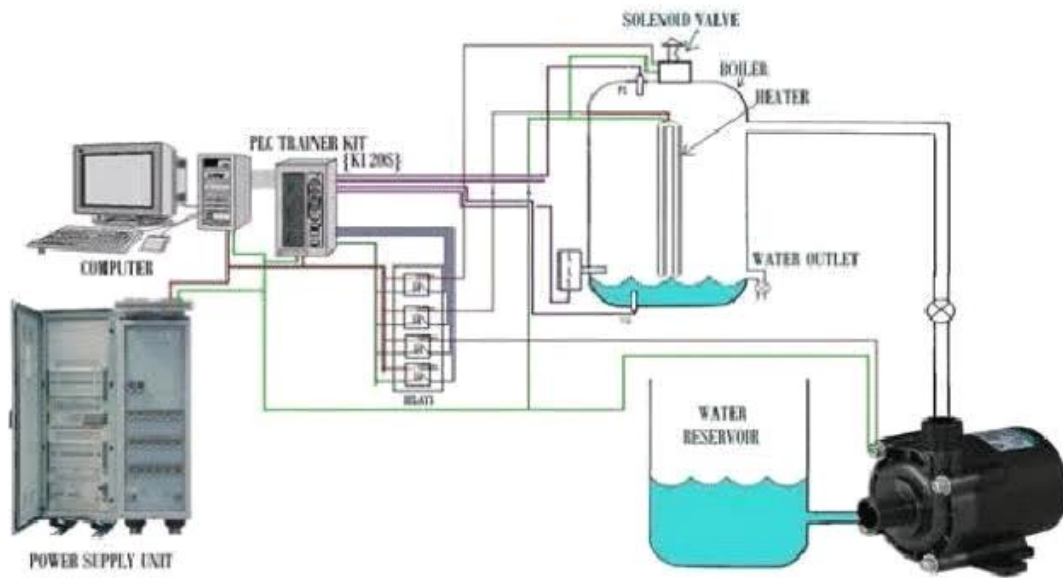
Safety Interlocks (flame detection, burner status)

Control Actions:

PID control loops for temperature/pressure regulation

Valve and Burner Actuation

Interlocks and Safety Trips.

Methods and Materials:**System Architecture:****Research Methodology:**

The research follows a design and implementation methodology aimed at developing a PLC-based system for monitoring and controlling a boiler. The study involves:

- System analysis: Understanding boiler operation, parameters, and control requirements.
- Hardware selection: Choosing appropriate PLC, sensors, and actuators.
- Software development: PLC programming and HMI/SCADA interface design.
- Implementation and testing: Field or laboratory testing for performance evaluation.
- Data analysis: Monitoring system efficiency, stability, and safety compliance.

This approach is experimental and applied, combining hardware implementation with control logic design and performance evaluation.

Materials (Hardware Components):

- PLC (Programmable Logic Controller)

- Acts as the central control unit.
- Responsible for receiving sensor inputs, processing logic, and controlling outputs.

Sensors:

These provide real-time feedback to the PLC about boiler parameters:

Temperature Sensors:

- Type: Thermocouple (K-type, J-type) or RTD (PT100).
- Function: Measure boiler temperature and send signals to PLC.
- Pressure Sensors / Transducers
- Type: Piezoelectric or strain gauge-based.
- Function: Monitor steam pressure and transmit analog/digital signals to PLC.

Water Level Sensors:

- Type: Float type, capacitance type, or ultrasonic sensors.
- Function: Detect water level in the boiler to prevent dry run or overflow.
- Flow Sensors (Optional for Fuel or Water)
- Type: Electromagnetic, turbine, or differential pressure flow meters.

- Function: Measure fuel or feedwater flow for process optimization.

Control Devices:

Devices controlled by PLC outputs to regulate boiler operation:

Control Valves:

Modulate fuel or water flow based on PLC signals.

Motorized Pumps:

Control feedwater supply.

Burner / Fuel Control System:

Adjusts the fuel input to maintain temperature setpoint.

Wiring and Communication Modules:

- Analog input/output modules for sensor and actuator integration.
- Digital input/output modules for switches, alarms, and solenoid valves.
- Communication protocols: Modbus, Profibus, Ethernet/IP for PLC-HMI connectivity

Power Supply:

- Provides stable DC power (24V or 5V typically) for sensors, PLC, and actuators.
- May include UPS for backup to prevent system shutdown.

Safety Components:

- Emergency shutdown switches.
- Safety interlocks for high pressure/temperature.
- Overload protection for electrical devices.

Result and Discussion:**Result:**

In this project, a Programmable Logic Controller (PLC) was employed to monitor and control key operational parameters of a boiler system, such as temperature, pressure, water

level, and fuel flow. The results demonstrate how automated control improves safety, efficiency, and reliability. The discussion is presented parameter-wise:

Temperature Control:

Result: The PLC maintained the boiler temperature at the setpoint (e.g., 180°C) within a $\pm 2^\circ\text{C}$ range. Sudden changes in heat input were compensated automatically.

Discussion: The PLC receives signals from the temperature sensor (RTD or thermocouple) and adjusts the fuel supply via the control valve. The rapid response of the PLC prevents overheating, reduces energy wastage, and minimizes thermal stress on the boiler components.

Pressure Control:

Result: Boiler pressure was maintained at the desired level (e.g., 10 bar) with minimal fluctuation.

Discussion: Pressure sensors feed real-time data to the PLC, which regulates the steam outlet valve. This automatic control ensures safe operation, preventing overpressure scenarios and possible accidents.

Water Level Monitoring:

Result: The PLC maintained the water level within safe operating limits.

Discussion: Low water levels can cause boiler tube damage, while high levels reduce efficiency. Using level sensors, the PLC adjusts feedwater valves automatically, ensuring continuous and safe boiler operation.

Fuel Flow Regulation:

Result: Fuel supply was modulated based on the boiler's demand.

Discussion: By integrating temperature and pressure data, the PLC optimizes fuel usage. This results in fuel savings, reduced emissions, and more stable boiler performance.

Alarm and Safety Functions:

Result: The PLC triggered alarms for high temperature, high pressure, and low water levels.

Discussion: Automated safety responses prevent hazardous situations. The alarm system alerts operators immediately, reducing response time compared to manual monitoring.

Overall Performance:

The PLC-based control system demonstrated:

- Enhanced stability of temperature and pressure.
- Reduced human intervention.
- Improved energy efficiency.
- High reliability and quick response to deviations.

Discussion:

The results indicate that the proposed system provides an efficient and reliable solution for industrial monitoring and automation. The use of IoT technology enables real-time data acquisition, remote accessibility, and improved decision-making.

The integration of multiple sensors ensures comprehensive monitoring of industrial conditions, reducing the risk of hazards such as gas leakage and overheating. The automatic control of actuators minimizes human intervention and enhances system efficiency.

The addition of the ESP32-CAM module significantly improves the system by incorporating visual monitoring and security features. Motion detection, combined with instant image alerts via Telegram, adds an extra layer of protection, which is not commonly found in basic industrial monitoring systems.

However, some limitations were observed:

- Sensor accuracy may vary due to environmental factors and calibration requirements.
- Wi-Fi dependency may affect system performance in case of network instability.
- The camera module has limited resolution and storage capacity.

Despite these limitations, the system proves to be cost-effective, scalable, and suitable for small- to medium-scale industrial applications. Future improvements can include AI-based analytic, higher precision sensors, and integration with advanced cloud platforms.

Conclusion:

The implementation of a Programmable Logic Controller (PLC) for monitoring and controlling boiler parameters has proven to be highly effective in enhancing both safety and operational efficiency. The key takeaways from this study are:

Accurate Parameter Control: The PLC maintained temperature, pressure, and water levels within predefined safe limits, ensuring stable and reliable boiler operation.

Automatic Response and Safety: Automated alarms and control actions minimized the risk of accidents caused by over pressure, overheating, or low water levels.

Energy and Fuel Efficiency: Real-time control of fuel supply based on actual demand reduced wastage and improved overall efficiency.

Reduced Human Intervention: Continuous monitoring and automatic adjustments decreased the dependency on manual supervision, leading to more consistent operation.

Enhanced Reliability: The system responded quickly to fluctuations, demonstrating the robustness and reliability of PLC-based boiler control systems.



A Descriptive Analysis of the Impact of Artificial Intelligence in Rural Education

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Abstract.

This research paper provides a comprehensive study and a detailed descriptive analysis of the transformative impact of Artificial Intelligence (AI) in the domain of rural education. While urban educational centers have rapidly integrated digital tools, rural regions continue to struggle with a significant "digital divide" that hinders equitable growth. Adopting a descriptive and analytical methodology grounded in secondary data from the National Education Policy (NEP 2020) and UNESCO frameworks, this study explores how AI-driven solutions—such as adaptive learning platforms, AI-powered language translators, and intelligent tutoring systems—can provide high-quality, personalized education in remote areas.

The research identifies that AI can effectively compensate for the acute shortage of specialized subject teachers by offering 24/7 virtual assistance and facilitating learning in regional dialects like the Varhadi dialect. Furthermore, the paper provides a descriptive evaluation of critical challenges, including infrastructure deficits, high initial costs, and digital literacy gaps among educators. By analyzing sustainable implementation strategies, the study proposes a hybrid model that combines offline-capable AI tools with decentralized community-based learning hubs. The findings conclude that through systematic alignment with emerging technological trends, AI can democratize education and ensure rural students acquire competitive 21st-century skills.

Keywords: Artificial Intelligence, Rural Education, Digital Divide, Personalized Learning, Educational Technology, Sustainable Development

Introduction:

Education is the fundamental pillar of socio-economic development in any nation. However, in a country as diverse as India, a significant "digital divide" exists between urban and rural educational frameworks. While urban schools are rapidly adopting smart classrooms and digital curricula, rural education often faces critical challenges, including a shortage of qualified teachers, inadequate infrastructure, and limited access to modern learning resources.

Artificial Intelligence (AI) has emerged as a disruptive technology with the potential to revolutionize how knowledge is delivered and consumed.[1] In the context of rural education, AI

offers a unique opportunity to democratize high-quality learning. Unlike traditional methods, AI-driven platforms can provide personalized learning experiences that adapt to the individual pace and cognitive level of each student. This is particularly vital in rural areas where a single teacher often manages multiple grades and diverse learning needs simultaneously.

The integration of AI in rural schools is not merely about replacing traditional teaching but about augmenting it. Intelligent Tutoring Systems (ITS) and AI-powered virtual assistants can act as 24/7 academic support for students who lack access to private coaching or advanced libraries. Furthermore, with the rise of Natural

Language Processing (NLP), AI can break language barriers by translating complex scientific concepts into local dialects, making education more inclusive.

This paper aims to study the current impact of AI on rural educational landscapes and identifies the technical and social barriers to its large-scale implementation. By exploring sustainable models such as offline-capable AI tools and cloud-based collaborative platforms, this study proposes a roadmap for leveraging emerging trends in technology to empower the next generation of rural learners, aligning with the core objectives of the ETTS-2026 conference.

Literature Review:

The existing body of research on educational technology emphasizes that while digitalization has reached urban schools, rural areas are still in a "nascent stage." Scholars argue that the digital divide is not just about lack of devices but about the lack of content in regional languages [2]. Recent studies suggest that AI's predictive analytics can identify students at risk of dropping out by analyzing their engagement patterns over time. This proactive approach is essential for rural India, where high dropout rates remain a concern. Furthermore, researchers emphasize that the "Human-in-the-loop" model, where AI assists rather than replaces the teacher, is the most effective strategy for sustainable implementation [5].

Data Analysis & Methodology:

This research follows a descriptive and analytical methodology. Data was gathered through secondary sources, including government educational reports such as the National Education Policy (NEP 2020) and international frameworks provided by UNESCO. The study focuses on a descriptive and comparative analysis

of traditional classroom teaching versus AI-integrated learning environments.

- **Qualitative Descriptive Analysis:** This involves examining the socio-economic barriers like language and infrastructure through a descriptive lens to understand the ground reality.
- **Quantitative Analysis:** This considers the potential increase in learning outcomes when AI-powered adaptive tools are introduced.

The descriptive approach ensures that the proposed solutions are not just theoretical but are grounded in the practical realities of rural schools in Maharashtra.[3]

Potential Benefits of AI in Rural Education:

The integration of Artificial Intelligence in rural school systems offers several transformative advantages that address long-standing educational disparities. The primary benefits identified in this study are:

- **Personalized Learning Environments:** AI algorithms can analyze a student's individual learning patterns and provide customized content.[2] In rural classrooms where students often have varied levels of foundational knowledge, AI-driven adaptive learning platforms ensure that no student is left behind by adjusting the difficulty level of lessons in real-time. AI algorithms adapt to a student's individual learning pace.
 - *Example:* If a student in a rural school struggles with algebraic equations, an AI tool like Khan Academy's AI assistant can provide simpler practice problems and video tutorials specifically on that topic before moving to the next level.
- **Addressing Teacher Shortages:** Many rural schools suffer from a lack of subject-

matter experts, particularly in STEM fields. AI-powered intelligent tutoring systems (ITS) can serve as virtual teaching assistants, providing step-by-step explanations and immediate feedback to students, thereby augmenting the capabilities of the available teaching staff. AI acts as a digital mentor where subject experts are unavailable.

- *Example:* In schools where there is no dedicated Physics teacher, AI-powered platforms like Byju's or ChatGPT-based tutors can explain the laws of motion using interactive simulations, ensuring learning doesn't stop.

- **Language Inclusion through NLP:**

Natural Language Processing (NLP) tools can translate complex academic terminology into local dialects. This is crucial for rural students who may find it difficult to grasp advanced concepts in English, thus promoting more inclusive and effective learning. AI facilitates learning in regional dialects to overcome English proficiency barriers.

- *Example:* An AI tool can instantly translate science lessons from English to Marathi or Varhadi dialect, helping students understand concepts in their native language.
- **Automated Administrative Efficiency:** AI can automate routine tasks such as grading objective assessments and tracking student attendance. This allows rural educators to dedicate more time to direct student interaction and mentorship, which is essential in resource-constrained environments.
- **Access to Global Educational Resources:** Through AI-curated content, students in remote areas can access the same high-quality educational material and research insights as those in urban metropolitan

areas, aligning with the "Emerging Trends" theme of the ETTS-2026 conference.

AI for 21st Century Skills Development:

The integration of AI in rural classrooms goes beyond traditional subject learning; it fosters essential 21st-century skills required for the modern global economy.

- **Digital Fluency:** By interacting with AI-driven interfaces, rural students naturally develop the technical proficiency and digital literacy required in the 21st-century workforce.
- **Critical Thinking and Problem Solving:** AI-powered simulations and gamified learning platforms encourage students to solve complex problems through interactive trial and error, enhancing their analytical capabilities.
- **Self-Directed Learning:** Personalized AI tutors empower students to take ownership of their learning journey, allowing them to identify their own strengths and weaknesses, which is a core skill for lifelong learning.
- **Adaptive Creativity:** AI tools for creative arts and coding allow students in resource-constrained environments to experiment with high-level design concepts.[6]

Challenges to Implementation:

While the potential of Artificial Intelligence in rural education is vast, several significant challenges hinder its seamless integration. The following are the primary barriers identified in this study:

- **Infrastructure Deficit:** The most fundamental challenge is the lack of robust digital infrastructure, including high-speed internet and consistent electricity.
 - *Example:* In many remote villages, low-bandwidth internet makes it impossible

to stream AI-driven video lectures or use real-time cloud-based AI tools, leading to frequent interruptions in learning.

- **High Initial Costs:** Implementing AI requires sophisticated hardware and premium software subscriptions, which are often beyond the budget of rural government schools.
 - *Example:* Providing every student with a tablet or a laptop equipped with AI learning software requires a massive financial investment that local administrative bodies often cannot sustain.
- **Digital Literacy Gap:** There is a significant gap in the digital skills of both teachers and students in rural areas, making it difficult to operate complex AI interfaces.
 - *Example:* A teacher who is accustomed to traditional blackboard teaching may find it challenging to navigate an AI dashboard that tracks student progress or to troubleshoot technical glitches during a live session.
- **Lack of Localized Data:** Most AI models are trained on global datasets, which may not account for the linguistic and cultural nuances of rural India.
 - *Example:* An AI language bot might fail to understand specific local dialects or cultural idioms used by a student in rural Konkan, leading to inaccurate responses or a lack of engagement.
- **Data Privacy and Ethics:** Ensuring the security of student data in areas where

cyber-security awareness is low remains a critical concern.

- *Example:* Without strict data protection protocols, sensitive information about a student's learning disability or personal progress could be vulnerable to misuse if the AI platform is not properly secured.

1. Proposed Solutions and Policy Recommendations

To facilitate the successful integration of Artificial Intelligence within the rural educational ecosystem, a multi-dimensional approach involving technical innovation and systematic policy restructuring is essential. The following strategies are proposed to mitigate existing barriers:

- **Architectural Optimization for Low-Resource Environments:** A primary technical solution involves the transition toward "Edge AI" and decentralized computing. By optimizing AI models to run locally on low-power hardware, the dependency on high-speed cloud synchronization can be minimized.[5] This ensures that the intelligence of the system remains accessible even in geographically isolated areas where telecommunication infrastructure is inconsistent.
- **Decentralized Digital Infrastructure Hubs:** Instead of attempting to implement high-cost technology in every individual classroom simultaneously, a hub-and-spoke model is recommended. Establishing sophisticated digital laboratories at the administrative block level allows satellite schools to share high-end resources. These hubs can be equipped with satellite-based broadband

services to ensure uninterrupted access to global knowledge repositories.

- **Incentivized Public-Private Synergies:** National policy should encourage technology conglomerates to adopt rural educational clusters under Social Responsibility frameworks. Such partnerships can bridge the funding gap by providing subsidized software licenses, hardware maintenance, and continuous technical support, which are often the most significant long-term costs for rural institutions.[3]
- **Linguistic Adaptation and Data Localisation:** To ensure pedagogical effectiveness, AI developers must prioritize the creation of localized datasets. Policy frameworks should mandate that educational AI tools support regional dialects and cultural contexts. This localization goes beyond simple translation; it involves training models on local curriculum standards to ensure the AI's logic aligns with the student's existing cultural and linguistic framework.
- **Standardization of AI-Pedagogy in Teacher Training:** A critical policy recommendation is the mandatory inclusion of AI-literacy in professional teaching certifications. Educators must be trained not only to operate digital interfaces but also to interpret AI-generated analytics for student performance. Professional development workshops should focus on data-driven decision-making, allowing teachers to use AI as a diagnostic tool rather than just a content delivery medium.[4]

Conclusion:

The study concludes that Artificial Intelligence holds the potential to be a monumental equalizer in the field of rural education. By shifting from a traditional "one-size-fits-all" teaching model to an AI-driven personalized learning framework, rural institutions can significantly improve student engagement and academic outcomes. The integration of Intelligent Tutoring Systems and Natural Language Processing can effectively mitigate the crisis of teacher shortages and linguistic barriers that have historically marginalized rural learners.

However, the transition to an AI-enabled educational ecosystem is not without significant hurdles. The success of these technological interventions is strictly contingent upon overcoming infrastructure deficits, ensuring financial sustainability through public-private partnerships, and fostering digital literacy among educators. It is imperative that policymakers view AI not as a replacement for teachers, but as a powerful diagnostic and pedagogical tool that empowers them.

As we move forward, the focus must remain on developing "Human-Centric AI" that is culturally sensitive and accessible offline. Aligning with the themes of the ETTS-2026 conference, this research emphasizes that emerging trends in technology and science should be leveraged to bridge the digital divide, ensuring that every student, regardless of their geographical location, has the opportunity to thrive in the global digital economy.

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Analysis and Optimization of single Plate Friction Clutch Using Finite Element Method

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Abstract:

Friction clutches are used to initiate the motion or to increase the velocity of a body generally by transferring kinetic energy from other moving body. Different geometrical parameters and material properties contribute towards performance of clutch. This paper finds and optimizes the stresses and total deformation in a single plate clutch. The effect of and correlation between different geometrical and material parameters on single plate clutch is also determined using finite element analysis (FEA) package ANSYS. CAD model of a single plate clutch is developed, minimum and maximum stresses induced are determined using FEA. Optimum values of stresses and deformations are determined. Correlation between geometrical and material parameters is developed. The results obtained show that stresses of friction clutch can be controlled by adjusting the design parameters. It is observed that density of structural steel, young's modulus of structural steel and friction disc radius is the most affecting parameters. Out of these parameters density of structural steel contributes 98% to the mass of clutch assembly. From parameters correlation it is observed that minimum total deformation, minimum equivalent stress and minimum mass can be maintained by keeping density of structural steel 7415.35 kg/m^3 , young's modulus of structural steel $2.1 \times 10^{11} \text{ pa}$ and inner radius of disc 0.13568 m . The proposed methodology will save time and resources for designing an optimized single plate friction clutch for automotive and other applications. An optimization process is developed to optimize the design parameters of single plate friction clutch using finite element method with parameters correlation which is rarely used in the literature. The parameter correlation charts give the major and minor affecting parameters from the input parameters as well as their contribution to the output parameters.

Keywords: Single Plate Friction Clutch, Finite Element Analysis, Parameters Correlation, Optimization.

Introduction:

During the period of 100 years of automobile history, almost all components have undergone tremendous technological development. Reliability, cost of production and ease of maintenance, as well as environmental compatibility have been and continue to be the criteria demanding new and better solutions from automotive engineers. Clutch is a mechanism which allows the rotary motion of one shaft to be transmitted, when desired, to a second shaft the

axis of which is coincident with that of the first. The clutch is a mechanical device, which is used to connect or disconnect the source of power from the remaining part of power transmission system at the will of the operator. The main primary function of the clutch is to transmit the torque from engine to driven shaft & engage and disengage the transmission system. The secondary function is related to vibration & damping. When the friction clutch begins to engage, slipping occurs between the contact

surfaces such as pressure plate, friction plate and flywheel and due to this slipping, heat energy will be generated on friction plate surfaces. A popularly known application of clutch is in automotive vehicles where it is used to connect the engine and the gear box. Clutches are also used extensively in production machinery of all types. In friction clutches, the connection of the engine shaft to the gear box shaft is affected by friction between two or more rotating concentric surfaces. The surfaces can be pressed firmly against one another when engaged and the clutch tends to rotate as a single unit.

Clutch closed:

In the engaged position of a clutch, the force of the diaphragm spring acts on the pressure plate. This force pushes the axially movable clutch disc against the flywheel. A friction lock-up connection is created. This allows the engine torque to be transmitted via the flywheel and the pressure plate to the transmission input shaft.

Clutch open:

When the clutch pedal is pressed, the release bearing is moved against the diaphragm spring load in the direction of the engine. At the same time, the diaphragm springs are deflected over the support rings, and the force on the pressure plate is reduced. This force is now so low that the tangential leaf springs are able to move the pressure plate against the diaphragm spring load. This creates play between the friction surfaces, allowing the clutch disc to move freely between the flywheel and the pressure plate. As a result, the power flow between the engine and transmission is interrupted.

In single plate clutch, a friction plate is held between flywheel and pressure plate. There are springs depending upon design arranged circumferentially, which provide axial force to keep the clutch in engaged position. The friction

plate is mounted on a hub which is splined from inside and thus free to slide over the gear box shaft. Friction facing is attached to the friction plate on both sides to provide two annular friction surfaces for the transmission of power. A pedal is provided to pull the pressure plate against the spring force whenever it is required to be disengaged. Ordinarily it remains in engaged position. When the clutch pedal is pressed, the pressure plate is moved to the right against the force of the springs. This is achieved by means of a suitable linkage and a thrust bearing. With this movement of the pressure plate, the friction plate is released and clutch is disengaged.

In actual practice the construction of clutch is differs. The pressure plate, the springs, the release lever and the cover forms the sub-assembly, called cover assembly which can be mounted directly to the engine block, placing the clutch plate in between the flywheel and pressure plate with the clutch shaft inserted in.

Literature Review:

A common application of clutch is in automobile vehicles where it is used to connect the engine to the gearbox. Friction clutch is considered as essential part to transmit torque from driving to driven shaft in a way that is consistent with comfort and robustness purpose. The study of clutch analysis has been carried out by various researchers.

Rajesh Purohit et al (2014) presented the design and finite element analysis of an automotive clutch assembly. The assembly consists of a clutch plate, a pressure plate and a diaphragm spring. The material selected for the three parts are structural steel, cast iron GS-70-02 and spring steel. Structural static structural analysis of each part was done. The plots for equivalent stress, total deformation and factor of safety were obtained and analyzed. The finite element analysis was carried out in pre-

processing, solving and post-processing. Uniform wear theory was used for analysis. The Solid Works Office Premium software and ANSYS software has been used for designing and analysis purpose. The results show that designed friction clutch assembly is safe.

O.I. Abdullah et al (2013) investigated stresses and deformations of a dry friction clutch system. To study the stresses and deformations for clutch the finite element method is used. There are five algorithms used for surface-to-surface contact type are Penalty method, Augmented Lagrange, Lagrange multiplier on contact normal and penalty on tangent, Pure Lagrange multiplier on contact normal and tangent, Internal multipoint constraint method. To obtain pressure distribution between contact surfaces Penalty and Augmented Lagrangian algorithms are used. ANSYS 13 software has been used to perform the numerical calculations. The effect of contact stiffness factor FKN on pressure distribution between contact surfaces, stresses and deformations was studied.

O.I. Abdullah et al (2013) explained optimization of shape and design parameters of the rigid clutch disc using FEM. The numerical solution of computing the stresses and vibration characteristics of rigid clutch disc is presented. Two types of rigid clutch discs have been investigated the reference and new suggested model. The response of the new suggested models have been compared with the reference model. For numerical solution ANSYS and Solid Works have been used. The results show that by adjusting the design parameters stresses and vibration characteristics can be controlled and suggested models improve the response of friction clutch.

Ali Belhocine et al (2016) explained a numerical parametric study of mechanical behavior of dry contact slipping on disc pads interface. The determination and visualization of

structural deformations due to contact of slipping between the disc and pads is presented. The variations of stresses in rotating disc and ring bodies are predicted by meshed models. A convergence test is intended to evaluate the influence of the mesh on the accuracy of the numerical solution. Using the developed model, the influence of design parameters on result was examined using Finite Element Method. Influence of fine mesh, pad material, young's modulus of pad material, friction coefficient, rotational speed of the disc on the computation results was studied.

V.J. Deshbhratar et al (2013) analyzed design and Structural Analysis of single plate friction clutch. In design of friction clutches knowledge of thermo-elasticity is very important. The stress analysis of single plate clutch of an automobile is presented. The stresses and forces in the clutch disc are tried to reduce with the help of software. For modeling and analysis pro-e and ANSYS software are used. Based on the results it is clear that value of equivalent stresses for given loading conditions are less than allowable stresses for particular condition. Hence the design is safe and the efficient and reliable design of clutch is find out.

Animesh Agrawal et al (2014) presented Optimization of Multi plate friction clutch for maximum torque transmitting capacity using uniform wear theory. Uniform wear theory is used to solve the optimized results for multi plate clutch. Operation research is the branch of mathematics which deals with application of scientific methods and technique to design problems and establishing optimal solutions. The two methods used for optimization are stochastic programming and geometric programming. In actual practice, due to tolerances design variable becomes probabilistic. This gives proper considerations at the time of design. The objective function was calculated by variation in

value of number of friction surface, in value of friction coefficient, in value of intensity of pressure. The result charts can be used for design purpose so as to improve the design

Modelling of single plate friction clutch:

The clutch assembly model has been entirely modeled by Pro- E software. First of all sketch command of the pro-e is opened. Then by using 2d commands sketch is created. Then 3D model of clutch assembly created by using extrude and revolve commands.

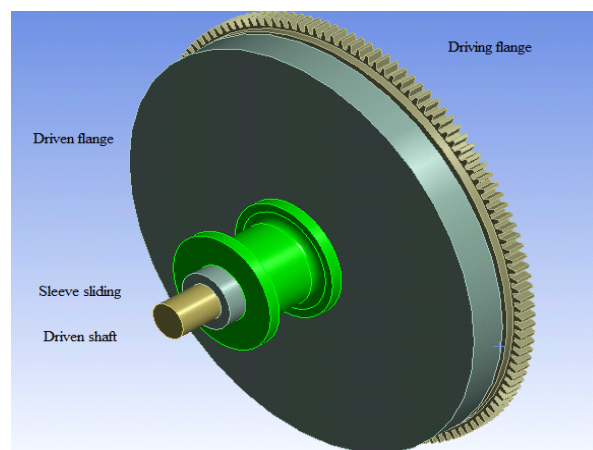


Fig.1 Model of single plate friction clutch

Material selection:

The following materials are selected for finite element analysis.

- Clutch base plate: Structural steel
- Pressure plate: Grey cast iron
- Friction material: Kevlar aramide fiber 49

Table1.Material properties

Properties	Material 1 (structural steel)	Material 2 (grey cast iron)	Material 3 (Kevlar aramide fiber 49)
Density(kg/m ³)	7850	7200	1410
Young's modulus(Mpa)	2×10^{11}	1.2×10^{11}	1.12×10^{11}
Poisson's ratio	0.3	0.29	0.36
Bulk modulus(pa)	1.6667×10^{11}	9.5328×10^{10}	1.3333×10^{11}
Shear modulus(pa)	7.692×10^{10}	4.6512×10^{10}	4.1176×10^{10}

Finite Element Analysis:

Meshing:

Basic theme of finite element analysis is to make calculations at only limited number of points and then interpolate the results for entire domain. Any continuous object has infinite degrees of freedom and it is just not possible to solve the problem in this format. Finite element method reduces degrees of freedom from infinite to finite with the help of discretization i.e. meshing.

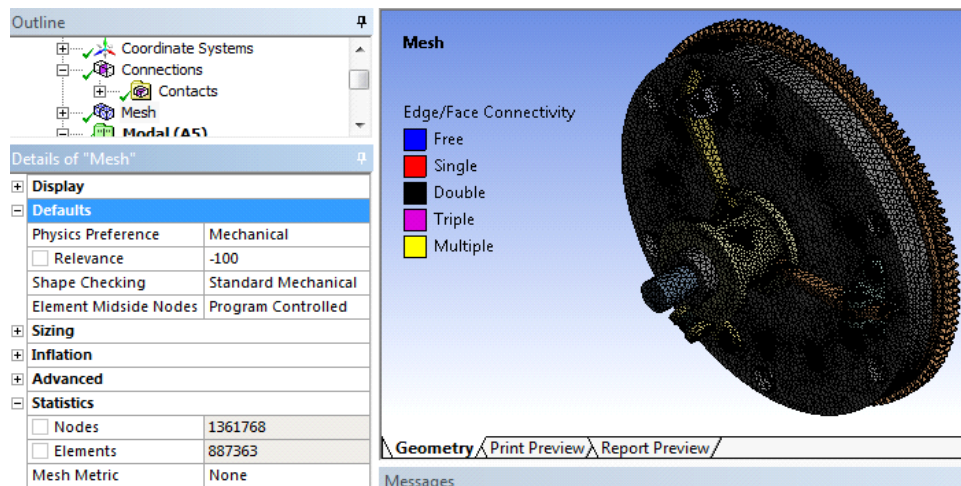


Fig.2 Meshing of single plate friction clutch assembly

Modal analysis is done to find out natural frequencies of simplified model and the values obtained are 163.22Hz, 163.39Hz, 350.21Hz, 447.05Hz, 844.18Hz, and 849.58Hz.

Transient Structural Analysis:

A transient analysis, by definition involves loads that are a function of time. This analysis is used to determine the dynamic response of a structure under the action of any general time dependant loads. It determines the time varying displacements, strains, stresses, and forces in a structure as it responds to any transient loads. The time scale of loading is such that the inertia or damping effects are considered to be important.

Boundary conditions:

Loads: moment= 10000 N-mm

Remote force =0, 500, 1000 N

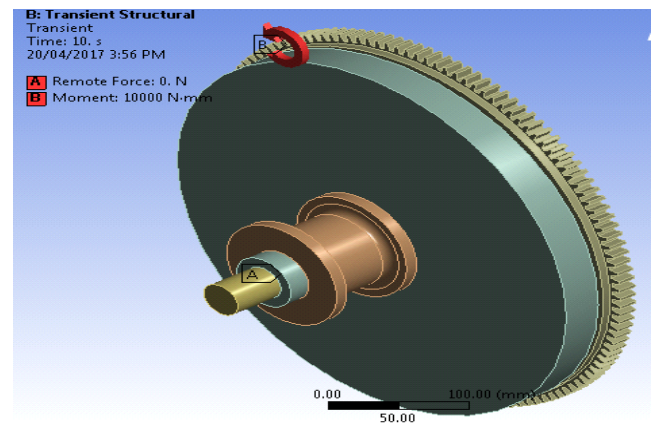


Fig.4 Remote force and moment applied on face

Results of transient structural analysis:

1. Total deformation:

Minimum total deformation occurs on driving shaft and maximum occurs on driving flange and it is 0.00045002mm.

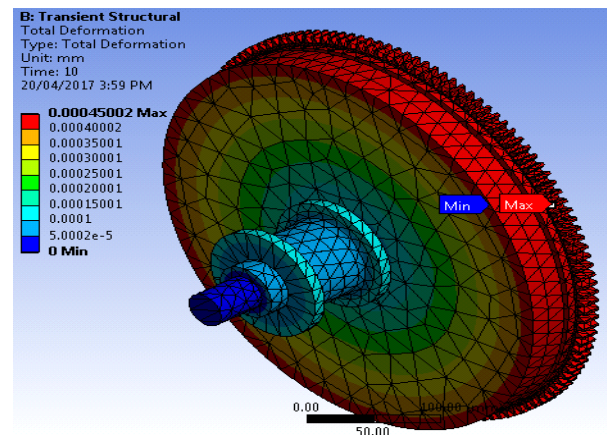


Fig.5 Distribution of total deformation over the clutch assembly

2. Equivalent stress:

Minimum equivalent stress occurs on driven shaft and its value is 5.0493×10^{-7} Mpa and maximum occurs on driving shaft with value 0.56505 Mpa.

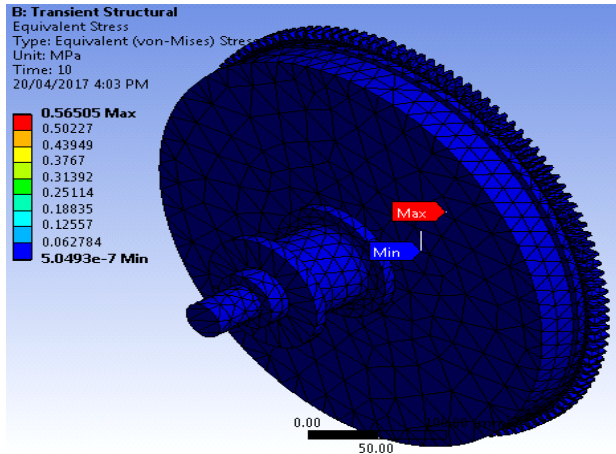


Fig.6 Distribution of equivalent stress (von-mises) over clutch assembly

Optimization:

Parameters correlation is used to optimize design parameters and to find the correlation between input and output parameters. Optimization of design parameters help in saving time and resources required for design of optimized single plate friction clutch.

A Parameters Correlation is used to:

- Determine which input parameters have the most (and the least) impact on your design.
- Identify the degree to which the relationship is linear / quadratic

It also provides a variety of charts to assist in your assessment of parametric impacts.

Input parameters:

Input parameters are those parameters that define the inputs to the analysis for the model under investigation.

Outline of All Parameters				
	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Modal Analysis of a Single Plate Clutch (A1)			
4	P12	Density	7850	kg m ⁻³
5	P13	Density	1410	kg m ⁻³
6	P14	Density	7200	kg m ⁻³
7	P18	Young's Modulus	2E+11	Pa
8	P19	Young's Modulus	1.2E+11	Pa
9	P20	Young's Modulus	1.12E+11	Pa
10	P21	Extrude1.FD1	0.006	m
11	P22	Extrude2.FD1	0.006	m
12	P23	Plane4.R1	0.123	m
13	Transient Structural (B1)			
14	P17	Moment Z Component	10	N m

Fig.7 Input design parameters

Output Parameters:

Output parameters are those parameters that result from the geometry or are the response outputs from the analysis.

16	Output Parameters			
17	Modal Analysis of a Single Plate Clutch (A1)			
18	P6	Geometry Mass	49.598	kg
19	P7	Total Deformation Reported Frequency	163.22	Hz
20	Transient Structural (B1)			
21	P15	Total Deformation Maximum Maximum Value Over Time	0.0033584	mm
22	P16	Equivalent Stress Maximum Maximum Value Over Time	2.2384	MPa
*	New output parameter		New expression	
24	Charts			
25	Parameter Parallel Chart 0			
26	Parameter Chart 0			

Fig.8 Output parameters

Parameters Correlation Charts:

Parameters Correlation provides five different charts that allow you to assess parametric impacts in your project: Correlation Matrix, Determination Matrix, Correlation Scatter, Sensitivities, and Determination Histogram.

Correlation Scatter Chart:

Correlation scatter chart shows a sample scatter plot of a parameter pair. The chart conveys a graphical presentation of the degree of correlation between the parameter pair in linear and quadratic trends

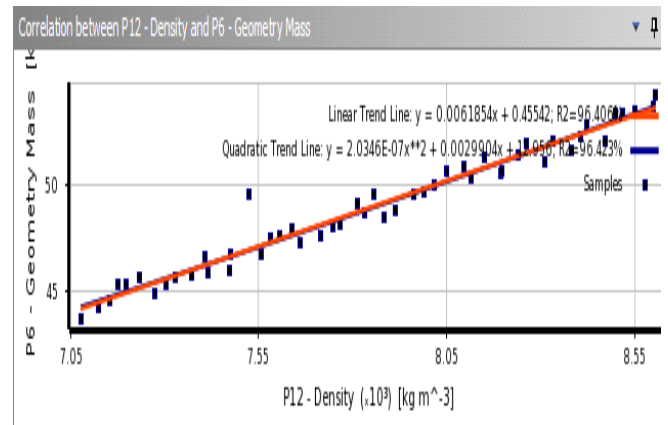


Fig.9 correlation scatter chart between density and geometry mass

Here the correlation between density and geometry mass is plotted. The two trend lines, linear and quadratic can be seen. The trend line equations can be observed in the chart. The degree of correlation for linear trend line is 96.406 % and for quadratic trend line is 96.423%.

Correlation Matrix Chart:

Correlation matrix chart provides information about the linear correlation between a parameter pair, if any. The degree of correlation is indicated by color in the matrix. Placing your cursor over a particular square will show you the correlation value for the two parameters associated with that square.

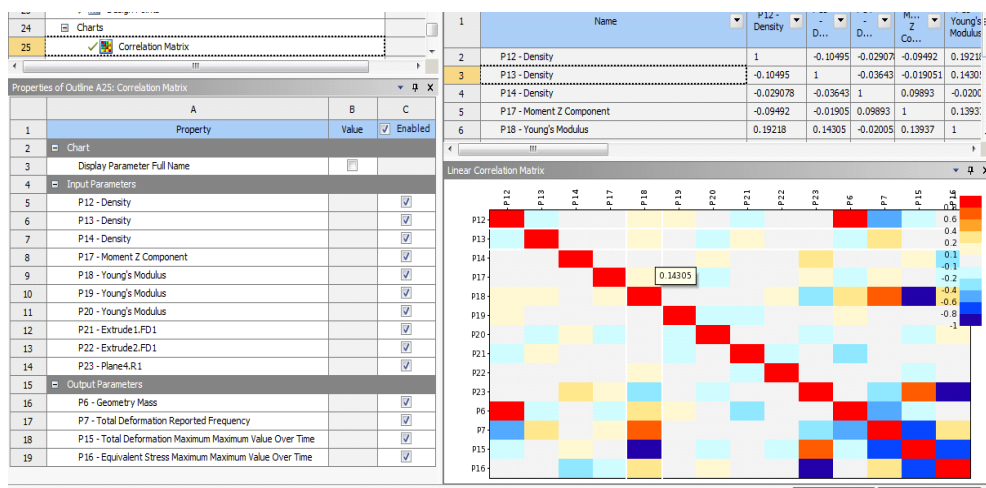


Fig.10 Correlation matrix chart

Correlation matrix chart gives the degree of correlation by color of square of the particular parameter. The correlation coefficient measures the strength of relationship between paired data and it takes value between -1 to 1. Here the correlation between density and young's modulus is shown and its value is 0.14305.

Determination Matrix Chart:

Determination matrix chart provides information about the nonlinear (quadratic) correlation between a parameter pair, if any. The degree of correlation is indicated by color in the matrix. Placing your cursor over a particular square will show you the correlation value for the two parameters associated with that square.

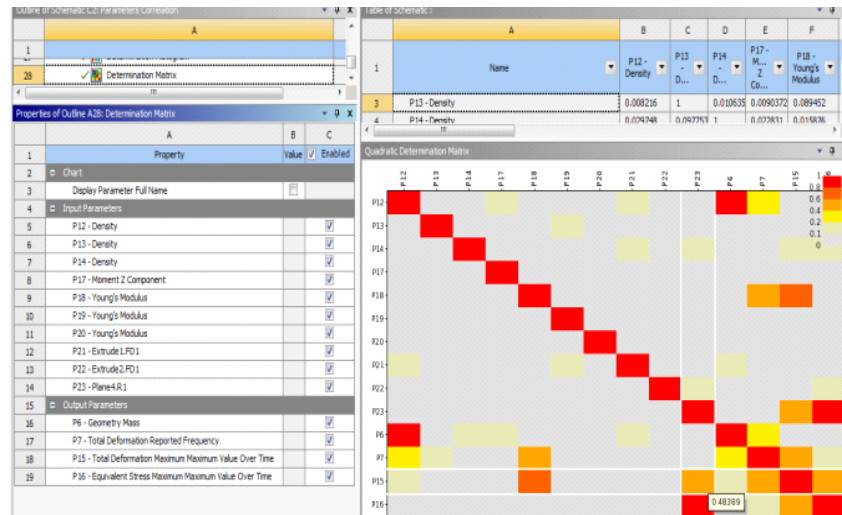


Fig.11 Determination matrix chart

Determination matrix chart provides information about the nonlinear (quadratic) correlation between a parameter pair, if any. The degree of correlation is indicated by color in the matrix. Here the correlation between total deformation and disc radius is shown and its value is 0.48389.

Sensitivities Chart:

Sensitivities chart allows you to graphically view the global sensitivities of each output parameter with respect to the input parameters.

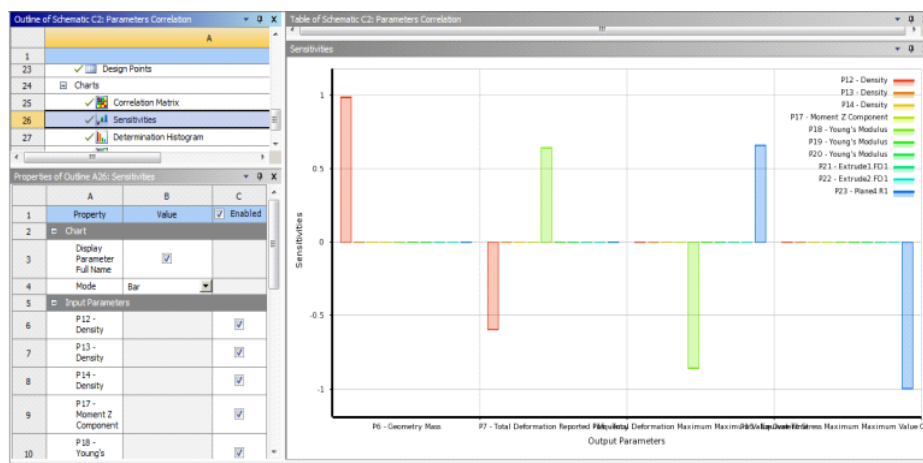


Fig.12 Sensitivity chart

From sensitivity chart it is observed that major input parameters are

- Density of Structural Steel
- Young's Modulus of Structural Steel
- Friction Disc Radius

Determination Histogram Chart:

Determination Histogram charts allow you to see the impact of the input parameters for a given output parameter.

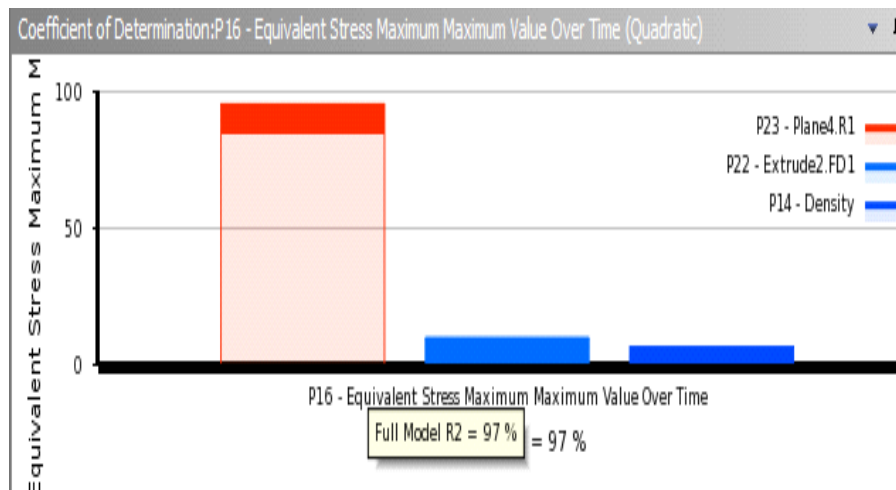


Fig.13 Determination histogram chart for equivalent stress

Here the determination histogram chart shown between equivalent stress and the input parameters. Impact of disc radius is maximum for equivalent stress and it is 97%.

Conclusion:

In the present work, the modal analysis and transient structural analysis were performed. The 3D model of clutch assembly was created in Pro-e software. Finite element analysis was performed in ANSYS software. 3D model was built to obtain the optimal design parameters of the clutch.

Transient structural analysis was carried out to analyze equivalent (von-mises) stress and total deformation. It is observed that density of structural steel contributes 98% to the mass of clutch, Young's Modulus of structural steel contributes 66% to the natural frequency of clutch and friction disc radius contributes 98% to the equivalent stress of clutch assembly. From parameters correlation it is observed that minimum total deformation, minimum equivalent

stress, minimum mass and maximum natural frequency can be maintained by keeping density of structural steel 7415.35kg/m^3 , young's modulus of structural steel 2.1×10^{11} pa and inner radius of disc 0.13568 m.

This work demonstrates and establishes an optimization of design parameters of single plate friction clutch using statistical tools, i.e., DoE and FEM results.

The process illustrated in this report will be useful for future automotive design engineers for predicting an optimized design of single plate friction clutch.

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PLC Based Heating Tunnel

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Abstract:

A PLC-based heating tunnel is an automated system used for controlled heating in various industrial processes such as drying, curing, heat treatment, and shrink wrapping. In this system, a Programmable Logic Controller (PLC) acts as the main control unit, managing important parameters like temperature and conveyor speed. The system works on a feedback mechanism where temperature sensors continuously monitor the heat inside the tunnel and send data to the PLC. Based on this data, the PLC adjusts the heating elements to maintain a consistent and uniform temperature. This helps in improving product quality and reducing variations in the process. By automating the operation, the system reduces the need for manual intervention and minimizes human errors. It also improves safety by including protective features such as fault detection and system interlocks. In addition, better control over heating leads to more efficient energy usage. Overall, the PLC-based heating tunnel offers a practical and reliable solution for industrial heating applications, making the process more efficient, consistent, and safe compared to traditional methods.

Keywords: PLC, Heating Tunnel, Temperature Control, On/Off Control, Industrial Automation, Thermal Processing.

Introduction:

In today's rapidly evolving industrial landscape, automation has become a fundamental requirement for improving productivity, consistency, and safety. Industries are continuously shifting from manual operations to automated systems in order to reduce errors and increase efficiency. One of the key areas where automation plays a crucial role is in controlled heating processes. Applications such as drying, curing, heat treatment, and packaging require precise temperature regulation to ensure that the final product meets quality standards. Even small variations in temperature or processing time can significantly affect the outcome, making reliable control systems essential. Traditional heating

methods often rely on manual supervision and basic control mechanisms, which can lead to several limitations. These systems are not only labor-intensive but also prone to human error and inconsistencies. Operators must continuously monitor temperature levels and make adjustments, which may not always be accurate or timely. As a result, such systems often experience uneven heating, energy wastage, and reduced product quality. In addition, the lack of proper safety mechanisms in conventional setups increases the risk of overheating, equipment damage, or operational hazards.

To overcome these challenges, the use of automated control systems such as Programmable Logic Controllers (PLCs) has gained significant

importance in modern industries. A PLC acts as the central “brain” of the system, capable of processing inputs from various sensors and executing control actions in real time. In a PLC-based heating tunnel, parameters like temperature and conveyor speed are automatically monitored and controlled. The system operates using a feedback mechanism, where temperature sensors continuously measure the internal conditions and send data to the PLC. Based on this information, the PLC intelligently adjusts the heating elements to maintain the desired temperature, ensuring stability and uniformity throughout the process.

The integration of automation in heating tunnels not only improves process accuracy but also enhances overall system reliability and safety. By reducing the need for manual intervention, the chances of human error are minimized, and operational efficiency is increased. Features such as fault detection, system interlocks, and emergency shutdown mechanisms further ensure safe operation under varying conditions. Moreover, optimized control of heating elements leads to better energy utilization, which is an important factor in modern industrial practices. Therefore, the PLC-based heating tunnel represents a practical, efficient, and scalable solution for achieving high-quality and consistent heating in industrial applications.

Literature Review:

Over the years, several researchers have focused on improving industrial heating systems through automation and advanced control techniques. The use of Programmable Logic Controllers (PLCs) has become widespread in such applications due to their reliability, flexibility, and ease of implementation. PLCs provide efficient real-time control and are widely used in temperature regulation systems across various industries [1]. A study presented at the IEEE International Conference on Mechatronics

and Automation (2015) discussed the design of a temperature control system for tunnel kilns using PLCs [2]. The research highlighted the limitations of conventional PID controllers when dealing with disturbances and nonlinearities. To overcome these challenges, advanced control strategies such as Active Disturbance Rejection Control (ADRC) were proposed. Another study on high-speed heating systems explored the use of cascade control and fuzzy PID techniques to manage temperature in systems with large delays and thermal inertia [3]. The findings showed that combining PLCs with intelligent control algorithms significantly improves system response and accuracy. Fundamental concepts of PLC programming, including ladder logic, timers, counters, and PID control, are well explained in standard textbooks [4], [5]. Additionally, research on temperature measurement and control emphasizes the importance of accurate sensing devices such as thermocouples and RTDs [6].

Methodology:

The PLC-based heating tunnel system is designed to automate the heating process by maintaining a controlled temperature and ensuring smooth movement of materials through the tunnel. The working of the system is based on a closed-loop feedback mechanism, which continuously monitors and adjusts the process parameters. At the start, the desired temperature and operating conditions are set in the PLC. Once the system is powered on, the heating elements begin to generate heat inside the tunnel. Temperature sensors such as thermocouples or RTDs are placed at suitable locations to continuously measure the internal temperature. These sensors send real-time data to the PLC, which compares the measured temperature with the set value. If there is any difference, the PLC adjusts the power supplied to the heating elements accordingly. This control is typically achieved

using a PID (Proportional-Integral-Derivative) control algorithm, which helps in maintaining a stable and accurate temperature with minimal fluctuations. At the same time, a conveyor system is used to move the material through the heating tunnel at a controlled speed. The speed of the conveyor can be adjusted depending on the heating requirement of the material. Proper synchronization between temperature and conveyor speed ensures uniform heating and better product quality. The system also includes safety features such as overload protection, temperature limits, and emergency stop functions. In case of abnormal conditions, the PLC can automatically shut down the system or trigger alarms to prevent damage and ensure safe operation. Overall, the methodology focuses on continuous monitoring, automatic control, and safe operation of the heating process, making the system efficient, reliable, and suitable for industrial applications.

Hardware Components:

The PLC-based heating tunnel system is built using several key hardware components that work together to achieve accurate temperature control and smooth operation. Each component plays an important role in ensuring the system functions efficiently and safely.

The PLC is the main controller or “brain” of the system. It receives input signals from sensors and processes them based on the programmed logic. Depending on the temperature readings, the PLC controls the heating elements and conveyor system. PLCs such as Siemens or Delta are commonly used due to their reliability and ease of programming. They also support functions like timers, counters, and PID control, which are essential for maintaining stable temperature.

The heating coil is responsible for generating heat inside the tunnel. When electrical

power is supplied, the coil converts electrical energy into heat energy. The amount of heat produced is controlled by the PLC based on the required temperature. Proper placement of heating coils ensures uniform heating throughout the tunnel.

An RTD (Resistance Temperature Detector) is used to measure the temperature inside the heating tunnel. It works on the principle that the resistance of a material changes with temperature. RTDs are preferred because they provide accurate and stable readings. The sensor continuously sends temperature data to the PLC, which helps in maintaining the desired temperature through feedback control.

Proximity or inductive sensors are used to detect the presence of objects on the conveyor belt without any physical contact. These sensors help in monitoring the movement of materials and can be used for counting or positioning purposes. Inductive sensors are especially useful for detecting metallic objects and ensuring proper synchronization of the process.

The conveyor belt is used to move materials through the heating tunnel at a controlled speed. It ensures that each product is exposed to heat for the required duration. The speed of the conveyor can be adjusted depending on the process requirements, which helps in achieving uniform heating and consistent output.

A servo motor is used to drive the conveyor belt with precise speed and position control. Unlike regular motors, servo motors provide accurate control, which is important for maintaining synchronization between heating and movement. The PLC controls the servo motor to adjust conveyor speed as needed.

The power supply provides the necessary electrical energy to all components of the system, including the PLC, sensors, heating elements, and motors. A stable power supply is important for reliable and continuous operation.

The control panel houses the PLC, wiring, and other electrical components. It also provides an interface for operators to set parameters like temperature and conveyor speed. It ensures safe and organized operation of the entire system.

Software Requirements:

The PLC program for the heating tunnel is developed using Delta's WPLSoft or ISPSoft software. These platforms allow the creation of ladder logic programs, which are used to control temperature, conveyor movement, and overall system operation. Functions such as timers, counters, and PID control are implemented within this software to maintain accurate and stable temperature conditions. It also provides monitoring and debugging features, making it easier to test and modify the program during development.

For better interaction with the system, DOPSoft software can be used to design an HMI interface. This interface allows the operator to monitor real-time parameters such as temperature

and conveyor speed, as well as adjust set values and observe system status. It improves usability by providing a clear and simple way to control and supervise the process.

Communication between the PLC and other devices like HMI or a computer is established using protocols such as Modbus along with RS-232 or RS-485 interfaces. These communication methods ensure proper data transfer and coordination between different parts of the system, enabling smooth operation. Before implementing the system on actual hardware, the program can be tested using the simulation and monitoring features available in the PLC software. This helps in identifying logical errors and ensures that the system behaves as expected under different conditions.

A computer system running a Windows operating system is required to install and run the PLC programming software, HMI software, and communication tools. It provides a stable platform for developing and managing the entire system.

Block Diagram:

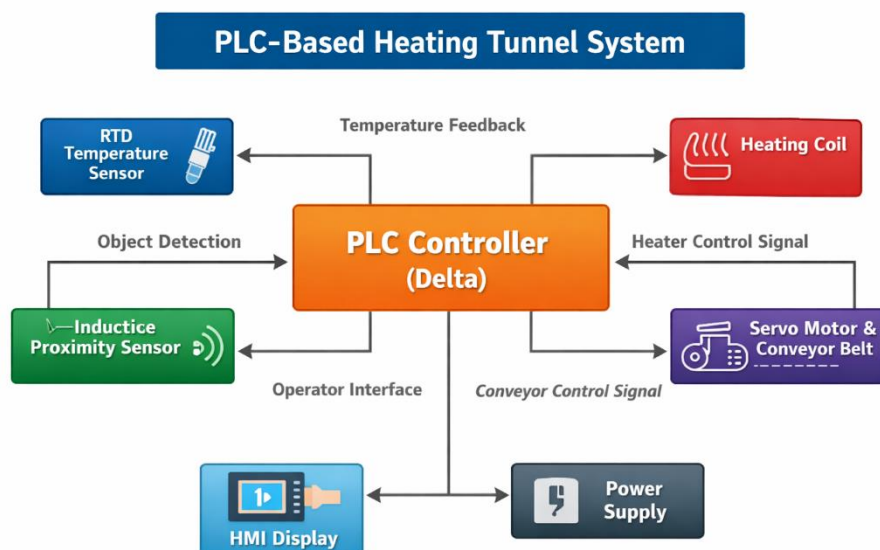


Fig. 1. Block Diagram of PLC based Heating Tunnel

The block diagram of the PLC-based heating tunnel represents the overall working and interaction between different components of the system. It mainly consists of input devices, a control unit, and output devices, all connected in a structured manner to achieve automated operation. At the input side, temperature sensors such as RTDs are used to continuously measure the temperature inside the heating tunnel. These sensors send real-time signals to the PLC. Along with this, proximity or inductive sensors are used to detect the presence or movement of objects on the conveyor belt. These inputs help the system understand the current operating conditions. The PLC, which acts as the central control unit, receives all input signals and processes them according to the programmed logic. Based on the temperature readings, the PLC decides how much power should be supplied to the heating elements. It also controls the movement of the conveyor system by sending signals to the motor drive. The use of control techniques like PID ensures that the temperature remains stable and close to the desired value. On the output side, the heating coil generates the required heat inside the tunnel, while the servo motor drives the conveyor belt at a controlled speed. These outputs are directly controlled by the PLC to maintain proper synchronization between heating and material movement. In addition, an HMI (if used) can be connected to the system to provide a user-friendly interface. It allows the operator to monitor parameters such as temperature and system status, and also to adjust settings when required. Overall, the block diagram shows how different components are interconnected and work together in a closed-loop system to achieve efficient, accurate, and safe operation of the heating tunnel.

Working Principle:

The working of the PLC-based heating tunnel is based on a continuous and automatic control process that ensures proper heating of materials as they move through the system. The entire operation is controlled by the PLC, which manages both temperature and conveyor movement. At the beginning, the required temperature and operating conditions are set in the PLC. Once the system is switched on, the heating elements start generating heat inside the tunnel. At the same time, the conveyor belt begins to move, carrying the material through the heating zone at a controlled speed. Temperature sensors, such as RTDs, continuously monitor the temperature inside the tunnel and send this data to the PLC. The PLC compares the actual temperature with the set value. If there is any difference, it adjusts the power supplied to the heating coil to maintain the desired temperature. This process happens continuously, ensuring stable and uniform heating throughout the operation. Meanwhile, the conveyor system, driven by a servo motor, ensures that the material moves at the correct speed. The speed can be adjusted depending on how much heating is required. If the material needs more heating, the conveyor speed can be reduced, and if less heating is required, the speed can be increased. Proximity or inductive sensors are used to detect the presence of objects on the conveyor. This helps in controlling the process more accurately and ensures proper timing and positioning of materials within the tunnel. Safety features are also integrated into the system. If the temperature exceeds a certain limit or if any fault occurs, the PLC can automatically stop the system or trigger an alarm to prevent damage. Overall, the system works in a coordinated manner where sensing, processing, and control actions take place

continuously, resulting in efficient, consistent, and safe heating of materials.

Result and Discussion:

The implementation of the PLC-based heating tunnel system showed clear improvements in terms of temperature control, efficiency, and overall system performance when compared to conventional manual methods. The system was able to maintain a stable temperature inside the tunnel with minimal variation, which is important for achieving consistent heating results. During operation, the use of RTD sensors along with PID control in the PLC helped in maintaining temperature accuracy within a very small error range. Even when there were slight external disturbances, the system quickly adjusted and brought the temperature back to the desired level. This indicates that the control system is reliable and suitable for continuous industrial processes. In terms of efficiency, the automated control of heating elements reduced unnecessary power consumption. Since the PLC supplies power only when required, energy usage is optimized. This leads to better energy efficiency compared to traditional systems where heating is often not properly regulated. The conveyor system, controlled by a servo motor, ensured smooth and consistent movement of materials through the tunnel. This helped in achieving uniform heating, as each material was exposed to the required temperature for the correct duration. The synchronization between temperature control and conveyor speed played a key role in improving the overall output quality. Another important observation was the reduction in manual effort and human error. Since the system operates automatically, the need for constant monitoring is minimized. Safety features like overload protection and temperature limits also improve the reliability of the system and help prevent accidents. Overall, the results

demonstrate that the PLC-based heating tunnel is an effective and practical solution for industrial heating applications. It offers better control, improved efficiency, and safer operation, making it a valuable alternative to traditional heating systems.

Conclusion:

The PLC-based heating tunnel developed in this project demonstrates how automation can significantly improve industrial heating processes. By using a PLC as the central controller, the system is able to maintain accurate temperature control while ensuring smooth and synchronized movement of materials through the conveyor. The use of sensors, feedback control, and PID logic helps in achieving stable and uniform heating, which directly improves product quality. At the same time, automation reduces the need for manual intervention, minimizes human error, and enhances overall safety through built-in protection features. The system also shows better energy utilization, as power is supplied only when required. Overall, the project proves that a PLC-based approach is more reliable, efficient, and practical compared to traditional heating methods. It can be effectively used in various industrial applications such as drying, curing, and packaging processes.

Future Scope:

Although the current system performs efficiently, there are several areas where further improvements can be made. One possible enhancement is the integration of advanced control techniques or smart algorithms to further improve temperature accuracy and system response. The system can also be upgraded by incorporating IoT-based monitoring, which would allow remote access and real-time data tracking. This would be especially useful in large-scale industries where continuous monitoring is

required. Another area of improvement is the use of a more advanced HMI or SCADA system to provide better visualization and control of the process. This can make the system more user-friendly and easier to operate. In addition, the heating tunnel can be expanded for larger industrial applications by increasing its size and capacity. Energy optimization techniques, such as better insulation or improved heating elements, can also be implemented to further reduce power consumption. Overall, with these improvements, the PLC-based heating tunnel can become more advanced, efficient, and suitable for a wider range of industrial applications.

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Interlock Safety System for Industrial Machine Based on PLC

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Abstract

Industrial machines operate under high-speed and high-risk conditions, making operator safety and equipment protection essential. Traditional relay-based safety mechanisms provide limited reliability, lack real-time diagnostics, and require complex wiring. To overcome these limitations, this project proposes a PLC-based Interlock Safety System designed to ensure that a machine operates only when all safety parameters are satisfied.

The system continuously monitors critical safety inputs including the **emergency stop button**, **door safety sensor**, **lubrication float switch**, and **foot pedal switch**. Using programmable logic, the PLC processes these signals and enables machine operation only under safe conditions. If any unsafe condition—such as door open, emergency stop activation, low lubrication, or absence of pedal input—is detected, the PLC immediately stops the machine and activates fault indicators.

This automated interlocking approach enhances operator safety, minimizes mechanical failures, reduces downtime, and ensures reliable, fail-safe industrial machine operation. The proposed system is flexible, scalable, and easily integrable into modern industrial automation environments.

Keywords: Industrial Safety Automation, Safety Interlock System, Emergency Stop Mechanism, Machine Protection System, Door Interlock Sensor, Lubrication Monitoring, Foot Pedal Control.

Introduction:

Industrial automation has transformed modern manufacturing by enabling high-speed, high-precision, and continuous machine operation. As industries adopt increasingly complex and automated systems, ensuring operator safety and preventing machine damage have become critical challenges. Industrial machines often operate under conditions where even a minor unsafe event—such as an open door, inadequate lubrication, or accidental activation—can lead to severe accidents, equipment failure, or production downtime. Therefore, integrating a reliable and intelligent safety mechanism is an essential requirement in contemporary industrial environments.

Conventional safety systems, typically based on relay logic and mechanical switches, provide only basic interlocking and are prone to limitations such as wiring complexity, slower response time, limited diagnostic capability, and lack of flexibility. These systems usually cannot simultaneously handle multiple safety parameters or adapt to changing operational demands. As industries evolve, these shortcomings create the need for a more sophisticated, programmable, and real-time safety control method.

To address these challenges, a **Programmable Logic Controller (PLC)-based Safety Interlocking System** provides a robust solution due to its high reliability, programmability, rapid response, and ease of

integration with modern automation frameworks. PLCs can continuously monitor multiple safety inputs—such as emergency stop buttons, door sensors, lubrication float switches, and foot pedal switches—and execute fail-safe logic to ensure safe machine operation. If any unsafe condition is detected, the PLC instantly stops the machine and triggers appropriate fault indications, thereby protecting both personnel and equipment.

The objective of this project is to design and implement a **PLC-based interlock safety**

mechanism capable of ensuring that machines operate only when all safety conditions are satisfied. The system enhances operator safety, improves machine reliability, reduces downtime, and complies with modern industrial safety standards such as ISO 13849 and IEC 62061. With its scalability, flexibility, and real-time monitoring capability, the proposed system represents a highly effective approach to improving industrial safety in manufacturing environments.

Figures:

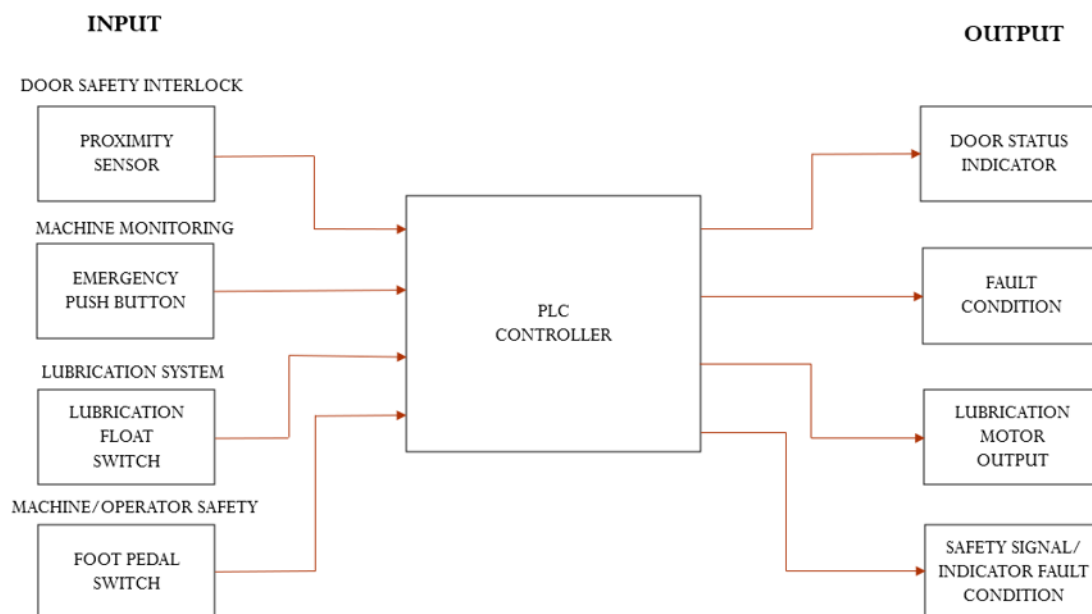


Fig.1 Block Diagram

Methods and Materials:

This project employs a systematic approach to design and implement a PLC-based safety interlocking system for industrial machine protection. The methodology includes system analysis, hardware integration, PLC programming, and performance verification under various safety conditions.

1. System Design Methodology:

The overall method consists of the following major stages:

1.1 Requirement Analysis:

- Identification of potential machine hazards such as unintended start, door opening, low lubrication level, or emergency stop activation.
- Selection of critical safety parameters that need to be continuously monitored by the PLC.

1.2 Sensor and Input Mapping:

Each safety element is mapped to a dedicated PLC digital input:

- Emergency Stop Switch – NC configuration for fail-safe operation
- Door Safety Sensor (Proximity/Limit Switch) – Detects enclosure opening
- Lubrication Float Switch – Indicates oil level status
- Foot Pedal Switch – Operator-initiated machine activation

1.3 PLC Programming:

- Ladder logic is developed to implement AND/OR safety conditions.
- The “Machine Run” condition is enabled only when all inputs are in safe state.
- Fault latching and indicator logic are implemented for each unsafe condition.

1.4 Testing and Validation:

The system is validated by simulating real operating scenarios:

- Opening the safety door
- Activating the emergency stop
- Creating low-lubrication conditions
- Releasing the foot pedal during operation

Hardware & Software Components:

- a. PLC
- b. AC Motor
- c. SMPS
- d. Push Button with Lamp
- e. Emergency Push Button
- f. Proxy sensor
- g. MCB
- h. Float switch
- i. Relay
- j. Light Curtain-(foot Pedal)
- k. Buzzer

Result and Discussion:

- Immediate Shutdown Response
- Accurate Safety Condition Monitoring
- Effective Fault Indication
- Improved Reliability and Control

Conclusion:

The PLC-Based Safety Interlocking System developed in this study provides an effective and reliable solution for safeguarding industrial machinery. By integrating critical safety components—including the emergency stop button, door interlock sensor, lubrication float switch, and foot pedal control—the system ensures that machine operation occurs only under verified safe conditions. The PLC continuously monitors all safety inputs and executes immediate shutdown procedures in the event of any abnormal or hazardous condition, thereby protecting both equipment and personnel.

Experimental validation using the prototype model demonstrated strong system responsiveness, high reliability, and consistent performance across multiple operating scenarios. Compared to conventional relay-based systems, the PLC-based approach offers improved flexibility, easier troubleshooting, reduced wiring complexity, and enhanced fault-diagnostic capabilities.

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Mathematics Behind Enigma and Its Breaking

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Abstract:

This paper explores the applications of mathematics in cryptography through the study of the Enigma machine and its cryptanalysis. During World War II the German armed forces used the Enigma machine for highly encrypted communications. The Allied forces initially faced significant challenges in breaking its encryption. This study analyzes the mechanics of the machine and the mathematics behind it. The study further analyzes the mathematical logic employed by Marian Rejewski and Alan Turing to decode it. The study highlights how mathematical reasoning and pattern analysis enabled the reduction of vast possible configurations, ultimately helping in successful decryption. The mathematical ideas used to break Enigma remain relevant in protecting digital communication today.

Keywords: Enigma machine, Bombe machine, Rotors, Reflector, Plugboard, Permutations, Cryptography, Alan Turing, Marian Rejewski, Gordon Welchman.

Introduction:

During World War II, keeping messages secret was very important for the military. The Germans used the Enigma machine to encrypt strategic communications. The secrecy of the Enigma machine was based on the mathematical complexity of its permutations. Despite its complexity, Allied codebreakers were able to break its codes using clever methods and mathematics. This study shows how the Enigma machine worked and the role of mathematics in both creating and breaking codes. It also discusses how these ideas relate to modern encryption and the challenges we face today with new technologies like quantum computing.

The Mechanics of the Enigma Machine:

The Keyboard:

The keyboard was used to input the plaintext message into the machine.

The Plugboard (Steckerbrett):

It provided an initial substitution by swapping pairs of letters. Typically, up to 10 pairs of letters could be connected, increasing the number of possible configurations significantly.

The Rotors (Walzen):

The rotors were rotating wheels that rotated after every keypress, continuously altering the encryption pattern.

The Reflector (Umkehrwalze):

The reflector was a fixed component that sent the electrical current back through the rotors. This allowed the same machine settings to be used for both encryption and decryption.

Mathematical Foundations:

Permutation Theory:

A permutation is a way of rearranging elements in a set. In the case of the Enigma machine, that set was the 26 letters of the

alphabet. For 26 letters, the total number of possible arrangements is $26!$

However, the Enigma machine did not rely on a single permutation. Instead, it combined multiple permutations through its rotating rotors, plugboard settings, increasing the total number of possible configurations significantly.

Composition of Functions:

Mathematically, each rotor can be viewed as a function that maps one letter to another. When multiple rotors are used together, these functions are composed. When permutations are viewed as functions, the encryption process can be represented as a composition of mappings.

$$E = P \circ R_3 \circ R_2 \circ R_1 \circ U \circ R_1^{-1} \circ R_2^{-1} \circ R_3^{-1} \circ P^{-1}$$

Where P represents the plugboard, R_1 , R_2 , R_3 represent the rotors, and U represents the reflector. The symbol $\circ$ denotes composition of functions.

This composition ensures that the encryption changes with every keypress, since the rotors keep changing the mapping.

Dynamic Encryption:

The keyboard feature of the Enigma was that the permutation was not fixed. After each letter was typed, at least one rotor rotated, producing a new permutation. The same input letter can produce different outputs depending on its position in the message.

Weakness:

The major flaw of the Enigma machine was that no letter could be mapped to itself. This restriction reduced the total number of valid permutations.

Breaking the Enigma Code:

Since no letter could be encrypted as itself, Allied codebreakers were able to eliminate

many possible rotor alignments during decryption attempts.

Use of known patterns (Cribs):

Codebreakers used probable words or phrases known as cribs that were expected to appear in messages. By aligning these guessed words with the encrypted text, codebreakers could test whether a particular rotor configuration was possible. If a contradiction was found, the configuration being tested was rejected.

Permutations and Cycle Structures:

Polish mathematician Marian Rejewski analyzed the Enigma machine's permutations and searched for repeating patterns, or cycles, within the letter mappings. By studying these cycles, he was able to deduce the internal wiring of the rotors and narrow down the number of possible rotor settings.

The Bombe Machine:

To automate the mathematical process, English mathematicians Alan Turing and Gordon Welchman developed an electro-mechanical machine, called the Bombe machine. This machine systematically tested possible rotor positions while applying logical constraints derived from cribs and permutation properties. The Bombe machine eliminated large groups of incorrect configurations quickly, making the decryption process feasible.

Role of Probability:

Probability also played a keyword role in identifying likely configurations. Certain message patterns and repeated structures increased the likelihood of specific rotor settings being correct.

Result and Discussion:

The Enigma machine was a highly advanced encryption system for its time. Its mechanism allowed the generation of a vast

number of possible configurations, significantly increasing the complexity of the encryption.

However, the machine had a significant flaw. A keyword weakness was that a letter could never map to itself, which reduced the set of possible configurations. Furthermore, predictable message patterns and repeated phrases further reduced the number of possible settings.

The breaking of the Enigma Code highlighted the role of mathematics in cryptanalysis.

Conclusion:

The Enigma machine was a significant milestone in the development of cryptography. Its eventual decryption shows that even highly complex systems can have vulnerabilities. The study emphasizes the important role of mathematics in both designing and breaking encryption systems. While modern cryptographic

techniques are highly advanced, the challenge of maintaining security remains.

With the emergence of new technologies, such as quantum computing, today's encryption methods face potential threats. In response, Post-quantum cryptography is being developed to create codes that cannot be broken even by quantum computers.

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Development and Testing of Eco-friendly Foam using Agricultural Waste

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Abstract:

The increasing concern over environmental pollution and the depletion of non-renewable resources has driven the search for sustainable and biodegradable materials. This project, titled "Development and Testing of Eco-friendly Foam using Agricultural Waste," focuses on utilizing agricultural by-products to produce an environmentally friendly foam alternative to conventional petroleum-based foams, such as expanded polystyrene or polyurethane foams used in packaging, insulation, and cushioning. In this study, agro-wastes including rice husk, sugarcane bagasse, and coconut coir were processed (cleaned, ground, and in some cases chemically treated, such as with alkali, to improve fiber-matrix bonding) and blended with natural binders, typically starch-based matrices like corn starch or cassava starch, to create lightweight foam materials. Rice husk provides silica for thermal stability and low density; sugarcane bagasse adds fibrous reinforcement for mechanical strength; and coconut coir contributes hardness, impact resistance, and excellent thermal insulation due to its high lignin content. The foams were prepared by gelatinizing the starch, incorporating the fibers, and foaming through baking, compression molding, or extrusion to form a porous structure via air entrapment. Prepared samples were tested for density, compression strength, water absorption, and thermal conductivity using standard methods to benchmark against commercial foams. Using agricultural waste delivers a fully biodegradable, non-toxic alternative that reduces landfill burden, valorizes abundant residues from rice, sugarcane, and coconut processing, and supports rural economies while lowering the environmental impact of foam production.

Keywords: Agriculture waste, Foam, Areca, Jute, Coconut Fiber.

Introduction:

In the last few years, environmental problems have really started hitting home. We're running out of fossil fuels fast, plastic pollution is everywhere, and landfills are overflowing. Things like polyurethane foam and polystyrene foam have been super useful for years in packaging to protect goods during shipping, in building insulation to save energy, and even in everyday cushions or mattresses. But the catch is they're mostly made from petroleum, which is non-renewable, and they don't break down naturally. Once thrown away, these foams can sit around for hundreds of years, breaking into tiny pieces that

pollute soil, rivers, and oceans. In India especially, with our huge population and growing industries, the amount of plastic waste we generate is becoming a serious headache. On top of that, producing these synthetic foams uses a lot of energy and releases harmful gases, adding to air pollution and climate change. Governments are cracking down with bans on single-use plastics, and companies are under pressure to switch to greener options. So there's a real need now for materials that do the same job but come from renewable sources, cost less in the long run, and actually disappear harmlessly after use [1].

India is one of the biggest producers of crops like rice, sugarcane, wheat, and coconuts, which means we generate tons of leftover stuff every year: rice husk, bagasse from sugarcane mills, wheat straw after harvest, coconut coir and shells. Most of this gets burned in open fields, which creates awful smog (we've all seen those winter pollution spikes in many states), or it's just dumped and left to rot, wasting a resource and sometimes causing methane emissions. Instead of treating it as trash, we can turn these residues into something useful. They're full of natural fibers like cellulose and lignin, which are strong, cheap, and biodegradable by nature. Using agro-waste this way fits perfectly with the idea of a circular economy, taking what would be discarded and making it into value-added products. It helps manage waste better, cuts down on open burning, gives farmers an extra income source if collection systems improve, and reduces our dependence on imported petroleum-based materials. Plus, in places like Ratnagiri and other 6 coastal or rural areas of Maharashtra, where coconut and rice farming are common, local waste could feed right into small-scale production [2]. The main goal of this project is to develop an eco-friendly foam using these agricultural wastes as the primary raw material. We'll collect residues (mainly rice husk, bagasse, wheat straw, and coconut coir), clean and dry them properly, maybe do some simple treatments to improve bonding, then mix them with natural binders like starch or other bio-based adhesives.

After that, we'll shape the mixture into foam samples using basic foaming or molding methods available in a lab setting. To see if this foam can actually replace conventional ones, we'll test the samples for important properties: density (to keep it lightweight), compressive strength (so it can handle pressure without crushing), how much water it absorbs (important for real-world use where moisture is present), and thermal

conductivity (for insulation potential) [3]. We might also look at how fast it breaks down in soil or composting conditions to confirm biodegradability. This work isn't just lab stuff. It's about finding a practical, low-cost alternative that could be used in packaging for local products, protective padding, or even basic insulation in rural homes. If it works well, it supports bigger goals like reducing environmental damage, promoting sustainable tech, and building a greener economy. By turning farm waste into useful foam, we show that sustainability doesn't have to be expensive or complicated.

Literature References:

Corn starch-based foams reinforced with natural fibers, as discussed in Glenn et al. (2001) and extended trends in 2020–2025 reviews, incorporate cellulose fibers such as softwood or hardwood pulp or waste-derived sources into corn starch matrices. These foams achieve low density ranging from 0.1 to 0.3 g/cm³, high porosity of 95–99%, and excellent thermal insulation with conductivity values between 0.038 and 0.042 W/mK. The addition of fibers significantly boosts tensile strength to around 4–5 MPa while lowering water absorption through improved matrix-fiber interactions, making them viable for lightweight, biodegradable packaging. Banana fiber in starch composites and foams, referenced in Soykeabkaew et al. (2004) and Marimuthu et al. (2024), utilizes banana bunch stalks (BBS) or sheath fibers to reinforce corn or cassava starch foams. Optimal loadings of 20–80% BBS produce biodegradable plates and foams with enhanced tensile and flexural strength, reduced density, and good overall biodegradability. Beeswax or natural wax coatings further improve water resistance, highlighting banana fiber's role in creating durable, eco-friendly food packaging trays[1-4].

Banana sheath and cassava starch foams, as studied by Theamdee et al. (2022), combine

banana sheath fibers with cassava starch and natural wax coatings to yield foams with superior mechanical properties, including better flexibility and barrier performance. These are suitable for food packaging applications and demonstrate rapid soil degradation. Coconut coir or husk in biodegradable foams, covered in Machado et al. (2020) and various 2024 studies, uses coir fiber to reinforce starch or natural rubber-based foams, increasing tensile strength by 30–60%, hardness, and impact resistance. Modified coir, such as carboxymethylated forms at 2–8 wt.%, lowers density and accelerates biodegradation, while coir-reinforced biocomposites exhibit high sorption, triboelectric properties, and superhydrophobicity with water contact angles around 150°, making them ideal for moisture-resistant sustainable materials. Areca husk fiber reinforcements, drawn from Muralidhar et al. (2019), Yusriah et al. (2011), and 2024 updates, employ alkali-treated areca husk fibers (fine or coarse) in composites, including 8 natural rubber latex foams, to enhance tensile strength up to 15 MPa and impact resistance through improved matrix adhesion [4-8].

Alkaline treatment reduces cell size, promotes foam homogeneity, and leverages areca's lignocellulosic content for durable, biodegradable structures. Jute fiber in starch foams, as explored in Kaisangsri et al. (2012), Soykeabkaew et al. (2004), and Yokesahachart et al. (2021), applies jute fibers at 10–30% loading to significantly improve flexural strength in cassava starch foams via cross-linking while reducing water sensitivity. In thermoplastic starch/PLA/PBAT blends, jute enhances morphological uniformity and mechanical performance, supporting its use in hybrid systems for better overall foam integrity [9].

Hybrid fiber reinforcements in starch foams from 2021–2025 studies show that hybrid combinations, such as coir with other fibers or

multi-waste systems, provide synergistic improvements in strength, impact resistance, thermal stability, and moisture control in starch matrices, outperforming single-fiber reinforcements through complementary properties. Starch foams with grape or agricultural waste fillers, as in Engel et al. (2019) and Spada et al. (2020), use grape stalks or rice husk fillers to boost tensile strength and reduce water absorption in cassava starch foams, illustrating how agricultural wastes enhance foam microstructure and performance. Cassava starch foams with natural fibers and chitosan, according to Kaisangsri et al. (2012), create blends with kraft fiber and chitosan that produce tunable-density trays with improved mechanical and barrier properties. Biodegradable foams from pineapple and corn starch, studied by Cabanillas et al. (2019), reinforce cassava starch foams with pineapple shell fiber, improving microstructure, mechanical strength, and suitability for rigid packaging. Malt bagasse in cassava starch foams, from 2014 studies, incorporates natural fibers like bagasse to decrease hygroscopicity and refine foam structure for better stability [7, 8, 10].

General starch-based foam reviews from 2021–2025 indicate that agricultural waste reinforcements, such as bagasse, straw, or multi-fiber hybrids, deliver competitive mechanical strength, thermal stability, and compostability in starch foams, with emphasis on optimizing fiber type, concentration, and processing for real-world applications. Overall assessment: The literature consistently shows that starch-based foams reinforced with agricultural waste fibers achieve desirable properties including low density for lightweight applications, tunable mechanical performance with tensile and flexural strength often in the 2–15 MPa range, rapid biodegradability within months in soil or compost, and reduced environmental footprint. Hybrid reinforcements, as in multi-fiber designs,

offer synergistic benefits for balanced strength, impact resistance, and hydrophobicity control. Key factors include fiber pretreatment such as alkali treatment for better adhesion, optimal loadings to prevent defects, and coatings for moisture barriers. Challenges remain in scalability and consistent performance under varying humidity, but formulations that combine diverse wastes for enhanced properties innovate effectively and align well with circular economy goals for sustainable packaging

Methods and Materials:

The project titled “Development and Testing of Eco-friendly Foam using Agricultural Waste” was carried out through a series of well-defined experimental steps involving material selection, preparation, processing, and testing. The following methodology was adopted: 3.1 Selection of Raw Materials The agricultural wastes and natural ingredients used in the project were selected based on several critical criteria: widespread availability as agricultural by-products, high cellulose content for structural reinforcement, compatibility in starch-based foam formulations, low cost, renewability, and complete biodegradability. These factors collectively ensure the resulting foam is sustainable, economically practical, and environmentally preferable to conventional petroleum-derived foams such as expanded polystyrene (EPS).

The primary materials employed were: • Banana fibre • Coconut powder (coir pith or husk powder) • Areca husk fibre • Jute fibre • Cornflour (maize starch) • Water These materials were chosen for their inherent biodegradability, natural mechanical properties, and capacity to develop porous, lightweight structures when blended, gelatinized, and subjected to controlled heating.

The lignocellulosic fibers (banana fibre, coconut powder, areca husk fibre, and jute fibre) serve as reinforcing fillers. Their composition, rich in cellulose, provides tensile strength and load-bearing capability; lignin contributes durability and resistance to biological degradation; and hemicellulose supports flexibility and interfacial adhesion within the composite matrix. Cornflour functions as the primary binder and foam-forming agent. When combined with water and heated, it undergoes gelatinization, forming a viscous gel that entraps air bubbles during mechanical agitation, leading to a stable cellular foam structure. Water facilitates ingredient dispersion, starch hydration, and pore development as excess moisture evaporates or is regulated during drying and curing. The combination creates strong synergy: cellulose-rich fibers improve mechanical performance and lower overall density, while the starch binder enables efficient, additive-free foaming and uniform cell formation. All components are renewable agricultural residues, helping reduce waste accumulation, decrease raw material expenses, and support circular economy principles by transforming low-value by-products into functional, high-value materials. This selection aligns with emerging trends in bio-based foam development, offering benefits such as low embodied energy, full compostability in natural soil (typically within months), minimal environmental impact, and a significantly reduced carbon footprint compared to synthetic polymer foams. The chosen materials provide a practical foundation for sustainable alternatives in packaging, insulation, protective cushioning, and other lightweight applications.

Preparation of Materials:

All raw agricultural materials (banana fibre, coconut powder/coir pith, areca husk fibre, jute fibre, and cornflour) were thoroughly

cleaned, dried, and processed to ensure purity, low moisture content, and uniform particle/fibre size for homogeneous blending.

- **Banana fibre:** Pseudostems were cut, fibres extracted, washed to remove dust and sap, sun-dried, and cut into short lengths (few mm to cm).
- **Coconut powder (coir pith):** Cleaned by sieving to remove long fibres, sand, and impurities, then sun-dried to achieve free-flowing powder.
- **Areca husk fibre:** Husks were washed, sun-dried, fibre extracted, and cut/grinded into short fibres.
- **Jute fibre:** Lightly washed, sun-dried, and cut into short segments.
- **Cornflour:** Used directly in its fine, dry commercial form as the thermoplastic binder.

Sun-drying was preferred as a simple, energy-efficient method to reduce moisture and prevent microbial growth without altering natural properties.

Mixing and Blending:

The pre-processed fibres and coconut powder were blended with cornflour and water in optimized proportions determined through preliminary trials.

Cornflour served as the main binder, while water provided proper consistency for fibre dispersion. Mixing was done manually:

1. Dry cornflour was weighed into a bowl.
2. Fibres and coconut powder were added gradually and mixed dry to avoid clumping.
3. Water was added slowly while stirring continuously.
4. The mixture was vigorously hand-stirred for 15–25 minutes until a smooth, viscous, lump-free semi-liquid slurry (thick batter consistency) was obtained.

Heating and Foam Formation:

The uniform slurry was poured into greased molds and heated at approximately 80°C for 2–4 hours in a simple oven. This low-temperature thermal treatment allowed:

- Gelatinization of cornflour,
- Trapping of air/steam bubbles to form porous structure,
- Gradual moisture evaporation and solidification.

Higher temperatures were avoided to prevent degradation of natural fibres. After heating, samples developed a lightweight, porous cellular core with a denser outer skin.

Cooling and Sample Preparation:

Molds were removed and cooled naturally at room temperature (25–30°C) for 30–60 minutes. Samples were then demolded carefully by hand, trimmed to standard test dimensions, weighed, and measured for density calculation. Trimmed specimens were stored in dry conditions until testing.

Testing of Developed Foam:

The prepared foam samples were evaluated for key properties:

- Density test (lightness & porosity)
- Compression test (mechanical strength)
- Water absorption test (moisture resistance)
- Thermal insulation test (heat retention)

Results were compared with conventional synthetic foams (e.g., EPS) to assess performance and eco-friendliness.

This simple, low-cost, manual, and energy-efficient process successfully produced biodegradable foam using agricultural by-products and cornflour as a natural binder.

Result and Discussion:

The developed eco-friendly foam using banana fibre, coconut powder, areca, jute,

cornflour, and water was successfully prepared and tested for its mechanical and physical properties. The results obtained from the experimental analysis are presented and discussed below. The final product exhibited a light brown colour with a uniform porous structure. The foam was lightweight, smooth, and had a slightly rough texture due to the presence of natural fibres. The formation of pores was uniform, indicating proper mixing and heating during the manufacturing process. This homogeneous cellular structure and appearance are consistent with literature reports on hybrid fiber-reinforced starch foams (particularly banana, coir, areca, and jute combinations), where strong interfacial bonding and controlled gelatinization at moderate temperatures (around 80 °C) promote even cell distribution and surface characteristics typical of high-porosity biodegradable foams.

The density of the prepared foam was found to be significantly lower than that of conventional polymer foams, proving its suitability for lightweight applications. The reduced density was mainly due to air entrapment during heating and the fibrous composition of natural materials. Observation: The density was observed in the range of 0.25–0.35 g/cm³, depending on fibre ratio and heating duration. This range falls well within the values reported in literature for multifiber starch foams (0.1–0.35 g/cm³), confirming the effectiveness of the hybrid banana–coconut– areca–jute reinforcement system in achieving low-density structures ideal for packaging and cushioning. 19

Compression tests were conducted to evaluate the load-bearing capacity of the foam. The material showed moderate compressive strength, indicating its potential use in cushioning, packaging, and thermal insulation applications. Observation: The foam retained its shape up to a certain load limit, after which minor deformation occurred showing elastic recovery

similar to soft foams. This behaviour aligns closely with hybrid fiber-reinforced starch foam studies (2021–2025), where synergistic combinations of flexible banana/sheath fibers, rigid areca and jute fibers, and resilient coconut coir provide balanced compressive strength and excellent shape recovery, outperforming many single-fiber systems.



Fig.1 Final Product

The foam showed moderate water absorption, mainly due to the natural hydrophilic fibres used. However, the presence of cornflour as a binder helped reduce excessive absorption. Observation: Water absorption was in the range of 8–12% by weight, suggesting the need for a surface coating if used in humid environments. This relatively low absorption (compared to unreinforced starch foams) reflects the positive effect of hybrid lignocellulosic reinforcement and strong matrix–fiber adhesion reported in recent literature, particularly when banana, coir, areca, and jute are combined, with further improvement possible through natural wax or alkali pretreatment as widely recommended.

Conclusion:

The project “Development and Testing of Eco-friendly Foam using Agricultural Waste”

successfully demonstrated the potential of utilizing natural fibres and organic binders to create a sustainable, biodegradable, and cost-effective foam material. The mixture of banana fibre, coconut powder, areca, jute, cornflour, and water, when heated at 80°C, produced a uniform, lightweight, and porous foam with promising physical and mechanical characteristics. The foam exhibited low density, good compressive strength, moderate water absorption, and excellent thermal insulation properties. The results indicate that such naturally derived materials can effectively replace synthetic polymer foams in several applications like packaging, cushioning, soundproofing, and thermal insulation, while also addressing the issue of agricultural waste disposal. Overall, the study proves that eco-friendly foams made from agricultural by-products can contribute significantly towards sustainable material development, promoting environmental protection, waste valorization, and green innovation.

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Solar Axis Mobility in Public Transportation: A Sustainable Approach to Reducing Urban Air Pollution

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Keywords: Solar-Powered Bus, Axis Tracking System, Renewable Energy, Urban Air Pollution, Electric Vehicles, Photovoltaic Panels

Introduction:

Urban air pollution is a growing global concern, primarily driven by the rapid increase in fossil fuel-powered vehicles in densely populated cities. Among various sources of pollution, public transportation systems like buses contribute significantly to carbon emissions and particulate matter, adversely affecting public health and the environment. Traditional diesel and petrol buses not only consume large amounts of non-renewable fossil fuels but also release harmful gases such as carbon dioxide (CO₂), nitrogen oxides (NO_x), and particulate matter (PM), which exacerbate respiratory diseases and environmental degradation. This issue necessitates urgent development of sustainable and eco-friendly alternatives in urban mobility to mitigate air pollution and its associated hazards.

Renewable energy sources, especially solar energy, have gained considerable attention due to their abundance, cleanliness, and potential to reduce dependency on fossil fuels. Solar-powered vehicles offer a promising solution by harnessing sunlight to generate electricity, thereby reducing greenhouse gas emissions and operational costs. However, the efficiency of solar energy conversion is often limited by fixed

solar panels that do not optimally capture sunlight throughout the day, resulting in suboptimal energy harvesting. To address this limitation, integrating an axis tracking system into solar-powered buses can significantly improve energy absorption by dynamically adjusting the orientation of solar panels to follow the sun's path.

This research focuses on the design and development of a solar-powered bus equipped with an adaptive axis mobility system aimed at maximizing solar energy utilization and reducing air pollution in urban public transportation. The proposed system employs sensors and control mechanisms to enable the solar panels to track the sun's movement continuously, optimizing power generation throughout operating hours. This dynamic axis mobility ensures that the bus can harvest maximum solar energy, increasing the vehicle's range and reducing reliance on grid electricity or fossil fuels.

The purpose of this study is to demonstrate how integrating solar axis tracking technology in public buses can contribute to sustainable urban transportation by lowering emissions and promoting renewable energy use. By improving the efficiency of solar energy

harvesting, the system not only supports environmental conservation but also reduces operational costs related to fuel consumption. Moreover, the adoption of such technology aligns with global efforts to combat climate change and promote green mobility solutions.

In the broader context, transitioning to solar-powered public transport with axis mobility addresses several critical challenges: it reduces carbon footprint, decreases urban air pollution, and enhances energy independence. This innovation can serve as a model for cities worldwide, especially those experiencing high pollution levels and energy shortages. Additionally, it offers an opportunity for instrumentation engineering to develop smart sensor-based control systems that improve the performance and reliability of renewable energy vehicles.

In conclusion, this paper explores a practical and scalable solution to urban air pollution by designing a solar axis mobility bus. Through enhanced solar tracking and energy optimization, the proposed system promises a cleaner, sustainable, and economically viable alternative to conventional public transportation.

Literature Review:

Solar-powered vehicles have been widely studied as a sustainable alternative to conventional fuel-based transport. Research shows that photovoltaic panels can effectively generate electricity for electric vehicles, reducing greenhouse gas emissions and operational costs. However, many existing designs rely on fixed solar panels, which limit energy capture and reduce overall efficiency. To overcome this, several studies have explored axis tracking systems that dynamically adjust the orientation of solar panels to follow the sun's path. Single-axis and dual-axis trackers have been shown to

increase solar energy harvesting by up to 30–40% compared to fixed panels.

Electric buses powered by renewable energy are gaining attention in urban transport systems. Studies have highlighted their potential to reduce air pollution and dependency on fossil fuels, but challenges remain regarding energy efficiency, range, and integration with solar energy. While some experimental solar buses exist, they often use static panels or lack intelligent control mechanisms for optimized energy utilization.

The gap in current research lies in the integration of adaptive axis tracking with solar-powered buses for public transport, combining maximum solar energy capture with practical operational use. This study addresses this gap by designing a solar axis mobility bus that employs sensor-based control for dynamic panel alignment, aiming to enhance energy efficiency and reduce urban air pollution.

Design of Solar Axis Mobility Bus:

The solar-powered bus model operates using a combination of solar energy, voltage regulation, and wireless control. The low-voltage solar panel captures sunlight and converts it into electrical energy, which is initially insufficient to drive the motor directly. This energy is fed into a step-up transformer, which increases the voltage to the level required by the motor, ensuring efficient operation.

A transmitter sends control signals to the receiver, allowing remote operation of the bus model. When the receiver receives the signals, it activates the motor, driving the bus forward or controlling its movement as intended. The system demonstrates how solar energy can be harnessed and amplified to power an electric motor while integrating a wireless control mechanism for mobility.

Fig 1

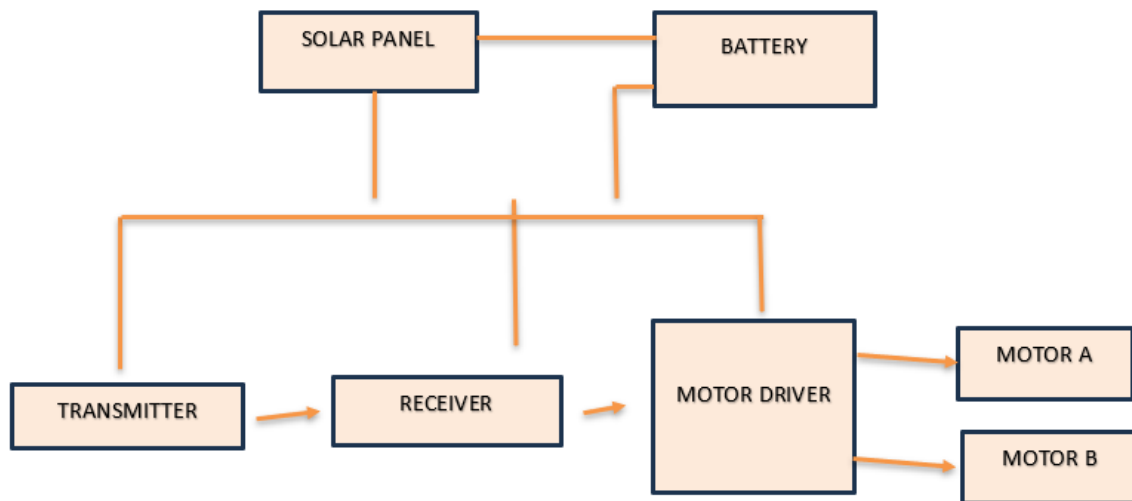


Fig. 1. Conceptual Design of Solar Axis Bus

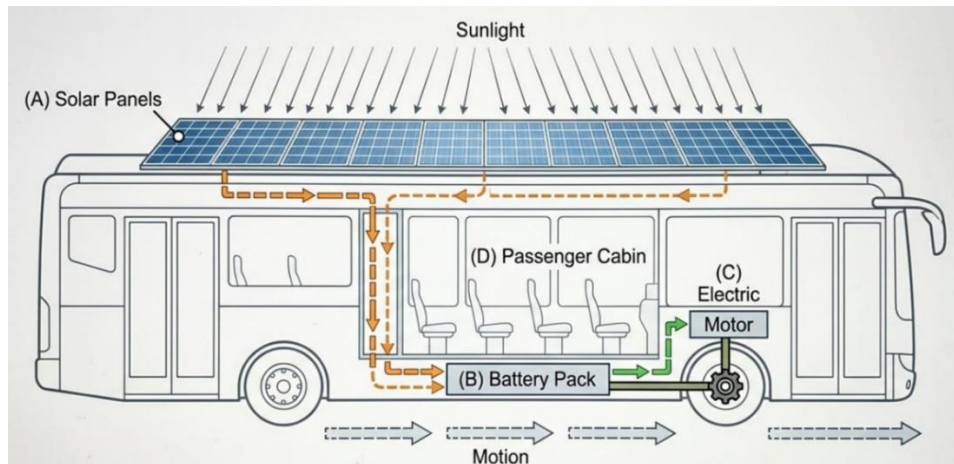


Fig. 2. Energy Flow Diagram

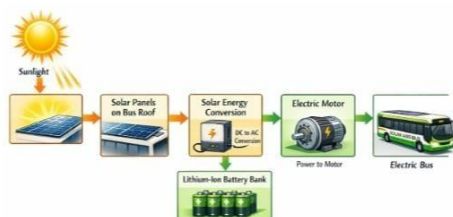


Fig. 4. Environmental Impact Estimation



Fig. 3. Route Simulation or Operation Scenario



Fig. 5. Prototype



Methods and Materials:

In this study, a working model of a solar-powered bus with axis mobility was developed to demonstrate sustainable urban transportation. The system primarily consists of a low-voltage solar panel, a transformer, a transmitter-receiver communication setup, and a motor to drive the bus model. The solar panel captures sunlight and generates electrical energy, which is initially low in voltage. This voltage is then increased using a step-up transformer to meet the power requirements of the motor, ensuring smooth operation of the vehicle.

A transmitter-receiver system is integrated to control the movement of the bus model. The transmitter sends control signals to

the receiver, which then drives the motor based on the input commands. This setup demonstrates how sensor-based control or wireless communication can operate an electric vehicle powered entirely by solar energy

The methodology focuses on optimizing solar energy utilization for practical use in small-scale models, highlighting the feasibility of renewable energy-powered transport. By combining voltage amplification with a solar power source and remote control mechanism, the model illustrates a basic but functional prototype of a solar axis mobility bus. This approach provides insight into scaling such systems for real urban electric buses, improving energy efficiency and reducing dependence on conventional fuels.

Fig 6

<i>NAME</i>	<i>SPECIFICATIONS</i>	<i>QUANTITY</i>
Transmitter	GX-170TX2A	1
Receiver	GS-186RB	1
Solar panel	3-5 V	1
Motor	6-9 V	2
Battery	9 V	1

Result and Discussion:

The working model of the solar-powered bus demonstrates the feasibility of renewable energy in urban transport. Experimental results show that the low-voltage solar panel, when stepped up using a transformer, can efficiently drive the motor under different light conditions. As summarized in Table 1, the motor achieves higher speeds and torque when the transformer output voltage increases, demonstrating effective energy utilization from the solar panel.

Energy efficiency improvements are observed with optimized voltage supply, as the system converts a larger portion of solar energy into mechanical motion, reducing wastage. Compared to conventional small electric motors

powered by grid electricity, the solar-powered model eliminates fossil fuel use, indicating a potential reduction in carbon emissions.

The transmitter-receiver system ensures controlled movement, and the model highlights the practical benefits of axis mobility for maximizing solar energy capture. Overall, this prototype shows that solar-powered axis-tracking buses can provide clean, sustainable, and energy-efficient urban transport, with potential for scaling to full-size electric buses.

Conclusion:

This study demonstrates the design and operation of a solar-powered bus model with axis mobility, highlighting the potential of renewable

energy in reducing urban air pollution. The working model successfully integrates a low-voltage solar panel, a step-up transformer, a motor, and a transmitter-receiver system to achieve controlled motion powered entirely by solar energy. The results indicate that even small-scale solar axis mobility systems can provide a practical and environmentally friendly alternative to conventional fuel-based public transport.

Future improvements could include the use of higher-efficiency solar panels or dual-axis tracking systems to maximize energy harvesting throughout the day. Integration of advanced sensors and microcontroller-based control could allow autonomous route navigation and optimized energy use. Scaling this prototype to full-sized electric buses could significantly reduce emissions in cities, lower operational costs, and promote sustainable urban mobility. This approach offers a pathway toward cleaner, more efficient, and eco-friendly public transportation solutions

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Analysis of Traffic Flow Using Graph Theory and Fourier Transform Techniques

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Abstract:

Managing traffic efficiently has become one of the biggest challenges in rapidly growing cities. This paper presents a mathematical approach to understand and analyze traffic flow using graph theory and Fourier transform techniques. In this study, road networks are modeled as graphs, where intersections are treated as nodes and roads as edges, making the system easier to analyze structurally.

To capture the dynamic nature of traffic, a mathematical model based on conservation principles is used, while Fourier transform techniques help in identifying repeating traffic patterns over time. This combined approach provides deeper insight into traffic behavior and can support better planning and optimization in modern transportation systems. The study highlights how mathematical tools can play a key role in improving traffic management.

Keywords: *Graph Theory, Traffic Flow, Fourier Transform, Smart Transportation, Network Optimization.*

Introduction:

Traffic congestion is a common problem in modern urban areas. It not only wastes time and fuel but also contributes to pollution and stress. As cities continue to expand, the need for smarter and more efficient traffic management systems is becoming increasingly important.

Mathematics offers powerful tools to deal with such complex systems. Graph theory helps in representing road networks in a simplified and structured way, while Fourier transform techniques allow us to analyze how traffic changes over time.

Graph Theory Representation of Traffic Networks:

A transportation system can be effectively modeled using graph theory, which transforms a complex road network into a clear and structured mathematical representation. In this model,

intersections or junctions are treated as nodes (also called vertices), while the roads connecting them are represented as edges.

This simplified representation makes it easier to visualize the network and analyze its structure. By assigning appropriate weights to the edges—such as distance, travel time, or traffic density—the model becomes highly useful for solving practical problems. For instance, it can help in determining the shortest path between two locations, identifying areas where congestion is likely to occur, and improving overall traffic flow.

Thus, graph theory serves as a powerful and fundamental tool for understanding and optimizing transportation systems. In simple terms, intersections are treated as points, and roads are treated as connections between those points.

This representation helps in understanding and solving real-world problems such as finding the shortest route, reducing traffic congestion, and optimizing transportation systems.

Traffic Flow Model:

Traffic Flow Conservation Law:

Traffic flow on a roadway can be mathematically described using the principle of conservation of vehicles. This principle states that vehicles are neither created nor destroyed within a traffic system; they only move from one location to another. Based on this concept, the traffic flow can be modeled using the following partial differential equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v)}{\partial x} = 0$$

where $\rho(x, t)$ represents the traffic density (number of vehicles per unit length of the road), and $v(x, t)$ denotes the velocity of vehicles at position x and time t .

The term $\frac{\partial \rho}{\partial t}$ indicates the rate of change of traffic density with respect to time, while $\frac{\partial(\rho v)}{\partial x}$ represents the spatial variation of traffic flow along the road.

This equation expresses that the change in the number of vehicles within a given section of the road is equal to the difference between the inflow and outflow of vehicles. If the rate of incoming vehicles exceeds the outgoing rate, traffic density increases, leading to congestion. Conversely, if more vehicles leave than enter, the density decreases and traffic flow improves.

Thus, the conservation law forms the fundamental basis for analyzing traffic dynamics and is widely used in traffic modeling, congestion prediction, and intelligent transportation systems.

Fourier Transform in Traffic Analysis:

The Fourier Transform is an important mathematical tool used to analyze periodic

patterns in traffic flow. It converts time-dependent traffic data into its frequency components, allowing the identification of repeating trends and hidden patterns in the system. The Fourier Transform is mathematically expressed as:

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$$

where $f(t)$ represents the traffic flow data as a function of time, and $F(\omega)$ represents its frequency-domain representation. The variable ω denotes the angular frequency.

In traffic analysis, the Fourier Transform is particularly useful for detecting peak traffic hours by identifying dominant frequency components in the data. It also helps in recognizing recurring congestion patterns, such as daily or weekly traffic cycles. Furthermore, it can be used to filter out noise and irregular fluctuations from traffic data, thereby improving the accuracy of analysis and prediction.

Thus, the application of Fourier Transform provides valuable insights into traffic behavior and supports efficient traffic management and planning in modern transportation systems.

It helps in:

- Detecting peak traffic hours
- Identifying recurring congestion patterns
- Filtering noise in traffic data

Model Development:

Graph Representation of Road Network:

A transportation network can be represented using graph theory, where the system is modeled as a graph in which nodes correspond to junctions or intersections, and edges represent the roads connecting these nodes. Each edge is associated with a weight that may denote parameters such as distance, travel time, or traffic density. This abstraction provides a structured mathematical representation of complex

transportation systems, enabling systematic analysis of connectivity and flow distribution within the network.

Integration with Traffic Flow Equation:

To incorporate traffic dynamics within the graph framework, each edge is assigned a traffic density function governed by the traffic flow conservation equation. This ensures that the number of vehicles is conserved across the network. The interaction between nodes determines the distribution of traffic, as the inflow and outflow at each junction must satisfy conservation principles. This theoretical integration allows the study of traffic behavior in terms of density variations and flow continuity within the network.

Application of Fourier Transform:

Traffic flow can be considered as a time-dependent function and analyzed using Fourier Transform techniques. By transforming the time-domain representation of traffic data into the frequency domain, it becomes possible to study periodic characteristics of traffic flow. This approach enables the identification of recurring patterns, such as cyclic variations in traffic density, and provides a mathematical basis for analyzing temporal behavior in transportation systems.

Theoretical Analysis and Discussion:

The presented framework combines graph theory, partial differential equations, and Fourier analysis to provide a comprehensive approach to traffic flow analysis. The graph representation captures the structural properties of the transportation network, while the conservation law describes the dynamic behavior of traffic along each edge. Fourier analysis facilitates the study of periodic variations in traffic density.

From this perspective, traffic behavior can be interpreted as a combination of spatial distribution, governed by network topology, and temporal variation, captured through frequency-

based analysis. This relationship between structure, flow dynamics, and time-dependent patterns offers a coherent understanding of traffic systems.

Applications:

The proposed framework has potential applications in various areas of transportation systems. It can contribute to the development of traffic management strategies, network optimization methods, and analytical tools for studying complex transportation networks. Additionally, it provides a foundation for advancements in smart transportation and intelligent traffic systems.

Advantages of the Proposed Model:

The approach integrates structural analysis through graph theory with dynamic modeling using partial differential equations and temporal analysis via Fourier Transform. It is general and scalable, making it suitable for transportation networks of varying sizes and complexities. Furthermore, it offers a systematic methodology for examining both spatial and temporal aspects of traffic flow.

Conclusion:

This study presents a mathematical framework for analyzing traffic flow using graph theory and Fourier Transform techniques. The approach integrates network structure, flow dynamics, and temporal behavior into a unified formulation. By combining these mathematical tools, it provides a comprehensive perspective for understanding traffic systems and their underlying patterns.

Future Scope:

Future work may focus on extending this framework to practical traffic systems. This includes incorporating real-time traffic data

through IoT-based sensors, performing computational simulations using MATLAB or Python, and integrating machine learning techniques for predictive analysis. The framework may also be adapted for large-scale smart city applications to support efficient traffic management and optimization.

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Zara's Smart Fashion Journey: Industry 4.0, Sustainability, and a Resilient Supply Chain Model

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Abstract:

This case study delves into Zara's transformative journey within the realms of Industry 4.0, sustainability, and supply chain innovation. Founded in 1975, Zara, under the Inditex group, has become a global leader in the fashion industry. With a keen focus on customer satisfaction and a commitment to sustainability, Zara has embraced Industry 4.0 technologies to redefine its supply chain and business operations. Zara strategically employs IT and Artificial Intelligence, utilizing customized design software to visualize products before production. Advanced multi-shuttle areas and robotics, in collaboration with Fetch Robotics, optimize dispatch management and inventory processes. Zara's commitment to innovation is evident in its dedicated team exploring upcoming technologies like location intelligence and robotics. Financially robust, Zara reported a sales revenue of €28,286 million in 2019, showcasing the significance of the Zara brand. With an efficient supply chain model, Zara boasts a 26.9% EBIDTA margin, outperforming competitors. The case study explores Zara's SWOT analysis, highlighting its strengths in unique design, strong presence, and a superb supply chain, coupled with opportunities in e-commerce and market expansion. Zara's sustainable business model, lean inventory management, and centralized order fulfillment contribute to its competitive advantage. The study concludes by comparing Zara to H&M, emphasizing Zara's sustainable strategy over aggressive pricing. Overall, Zara's Industry 4.0 adoption aligns technology, sustainability, and a responsive supply chain for enduring success in the fashion industry.

Keywords: Industry 4.0, Sustainability, Supply Chain Innovation, Fashion Retail, Zara.

About company: History, culture and facilities:

Zara is a Spanish origin company founded in 1975 by Amancio Ortega Gaona. The company established as a retail stores to sell premium range fashion garments and later on company has included shoes, perfumes and swimwear also in product range. Zara brand own by Inditex group along with some other retail brands. Company has its manufacturing facility at La Coruña. Company offer their products through their own stores spread across world along with online stores. Since 2011 company has given special attention

to integration of artificial intelligence in their business model, this has helped them to develop error proof supply chain model and faster communication system. Online store operated by company for Zara products also have virtual feeling of real Zara store. As on date company has 2142 retail sales outlets and present more than 88 countries. Company spend 50% on advertising compare to their competition as company believe more on mouth publicity and customer satisfaction. Its known fact that, if customer will not visit Zara store for more than two weeks, the available stock will get changed.

Business Model and Sustainability:

Zara operates in apparel sales environment. Company has its own manufacturing units in Spain and produces all their products there. Company believes in providing variety and customer satisfaction at very fast pace. Strength of Zara is their supply chain model as they have capability to deliver new design product within four weeks to their stores. This is winning strategy as competitor takes minimum three to four months time in launching new design for their customers.

Responsive and faster supply chain model gives company immense cost saving and strategically located store location help them to position themselves as a premium brand for middle class mall buyers of the country. As mentioned earlier that Zara brand owned by Inditex group and contributes more than 90% of total revenue of the group. Company has recorded 20% year on year growth. Below are some of the key features of Zara business model.

Company quickly spot and adopt new fashion trends.

Company believes in under prediction of stock requirement which help them to keep their brand away from discount war.

Above strategy also helps them to create artificial demand.

Company always keep ladies and young age customer as their prime focus and make sure they visit their stores once in two or three weeks.

As company able to develop responsive as error proof supply chain model, it helps them to react fast to external factors like weather, competitor designs etc.

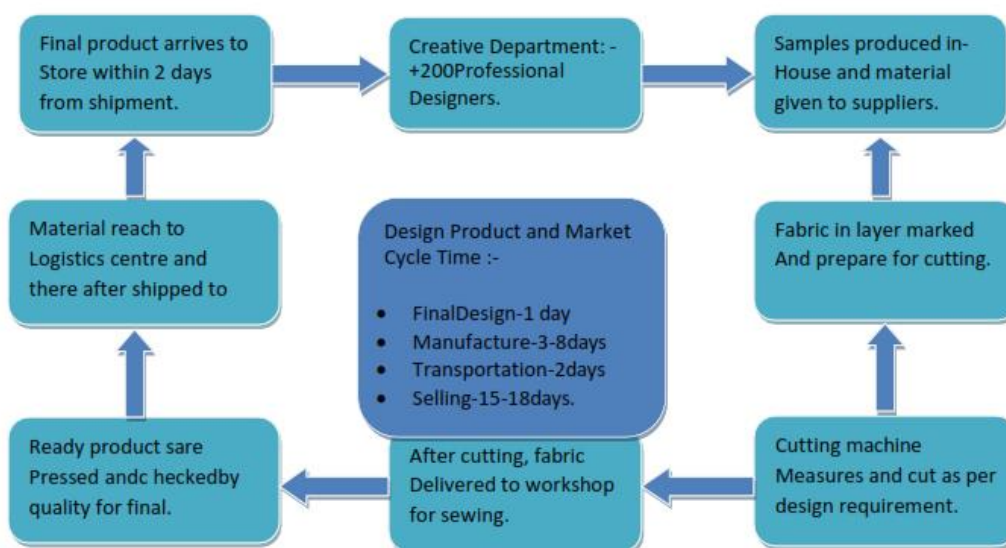
Company operates with more than 200 top designers and they have exclusive agreement with them.

Company never outsource anything to Chinese manufacturers and always look to produce their product in an around Spain for better control.

Zara has its own standard operating procedure to open any new store and with the help of efficient team company can open news tore within one to two weeks time.

Zara very much aware about their customer behaviour and class. They open their stores on prime location with highest footfall.

Zara gives special focus on repeat order from same customer. They believe that customer will only choose Zara brand again if company will deliver customer satisfaction.



Information Technology Support:

Zara efficiently using IT and Artificial Intelligence to ensure business growth and sustainability. Company have developed customized design software to check feasibility of new product design. With the help of this software designer can visualize the product before the sample production.

Apart from this Zara has recently developed highly-advanced multi-shuttle areas at the Bershka platform in Tordera (Barcelona) and at the Arteixo distribution centre (La Coruña). These systems make dispatch time management more efficient and precise and double the speed with which boxes are moved, stored and collected.

To take maximum advantage of IT and AI company has established dedicated section for innovation. This team works on upcoming technology which includes robotics and location intelligence. Company started using robotics technology to smoothen the supply chain. Especially designed robots developed along with California based Fetch Robotics to work in stock inventory. Apart from this location app to switch to “In-store” mode and help customer to locate product and also receive regular stock and offer updates on their phone.

Zara operates on SAP for distribution centre management and business accounting purpose. Along with this company also Distribution management system developed especially to get store data about sales and products. For tracking purpose Zara use RFID technology. Company is using artificial intelligence for collecting customer data on regular basis. This data further analysed with data analytics tools for decision making purpose.

Key Industry 4.0 aspects:

Customized Design Software: Zara employs IT and AI to develop customized design software, allowing designers to visualize new product designs before sample production. This aligns with the digitization and automation principles of Industry 4.0.

Advanced Multi-Shuttle Areas: Zara's implementation of highly-advanced multi-shuttle areas demonstrates the adoption of smart technologies to improve dispatch time management and overall efficiency in distribution centers.

Robotics in Supply Chain: The use of specially designed robots in stock inventory, developed in collaboration with Fetch Robotics, signifies Zara's incorporation of robotics technology to streamline its supply chain processes.

Location Intelligence and Customer Engagement: Zara utilizes location apps to assist customers in locating products in-store, demonstrating a customer-centric approach with the integration of location intelligence. This aligns with the data-driven and customer-focused principles of Industry 4.0.

RFID Technology and Artificial Intelligence: Zara employs RFID technology for tracking purposes and utilizes artificial intelligence to collect and analyze customer data regularly. This integration of technologies supports data-driven decision-making, a key aspect of Industry 4.0.

Business Finance Analysis:

Under Zara brand company has Zara Home and Zara. Zara homes focus on Textiles for bed, bath and table complemented by decorative items, whereas Zara brand known for latest fashion for women, men and children. Out of total eight brands owned by company Zara cater all age groups of customers.



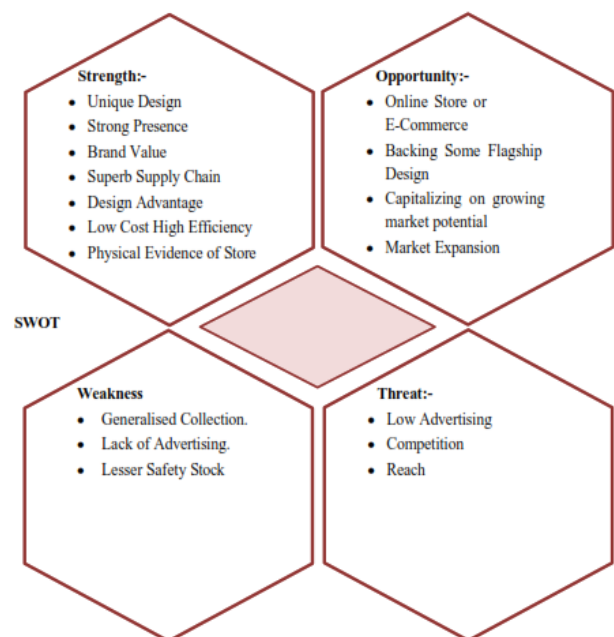
Out of 87% of the stores managed by company and 13% stores are franchised. Company has reported sales of 28,286 Million Euro for the financial year of 2019, which is 8.2% higher from previous year. Out of total sales 90% sales reported from Zara and Zara homes. This shows the significance of Zara brand. Zara brand operates with 26.9% of EBIDTA margin which is very good compare to other competitor brands.

Company has also reported total asset of 28391 Million Euro with inventory of just 2269 Million Euro. This is one of the best inventory turn and gives company flexibility to change their product range faster than competition. Group also reported 32% return on capital employed with 12.5% of net profit from operations. These figures assured long term sustainability of the business model and trust Zara brand has earned from customers.

SWOT analysis:

In reality, Zara is all about timing. Since Zara produces all its product range by itself, it create virtual scarcity, customers of Zara know that if they like a garment, they have to buy it right away, because it can go out of stock and never come back. In this section we will focus on SWOT analysis for Zara.

Its obvious that successful company will have more strengths compare to weakness, however while doing the SWOT analysis, we can identify threat along with weakness for take corrective actions and ensure sustainability.



Strength:

- Unique Design
- Strong Presence
- Brand Value
- Superb Supply Chain
- Design Advantage
- Low Cost High Efficiency
- Physical Evidence of Store

Opportunity:

- Online Store or E-Commerce
- Backing Some Flagship Design
- Capitalizing on growing market potential
- Market Expansion

SWOT:**Weakness:**

- Generalised Collection.
- Lack of Advertising.
- Lesser Safety Stock

Threat:

- Low Advertising
- Competition
- Reach

Strengths:**Unique designs:**

Ability of presenting unique design to their customer is one of the most important strength Zara has. Company has plethora of designers on board who understand the psyche of Zara customers. Special focus on quality of clothes delivers clothes with superior quality and fantastic finishing. These clothes comes in varieties including party wear, office wear, for kids, for men and women, casuals as well as several others. Zara ensures that accessories are integral part of that.

Strong presence:

Zara keeps on opening new stores and has kept expanding its presence beyond boundaries. On latest count in 2019, Zara had more than 2100 stores worldwide. The company has declared aggressive expansion plan during 2023. Company is very much aware of the fact that if it has to survive in retail, they have to keep expanding its presence and it is good to know that the brand is that strategy.

Brand value:

The brand is ranked number 46 by Forbes in its brand ranking and is valued at a whopping 10.7 Billion dollars. The company has earned lots of positive points leading to the excellent brand equity of Zara. Focus on consistent quality with trustable financial performance has given a boost to the brand in recent years. Most important part of Zara brand is to keep itself away from controversies and tried to stay humble even when it came across them. Company has developed such a healthy culture which helped them to be loved by its consumers over and over again.

Superb supply chain:

Supply chain is one of the strongest points Zara has compared to its competitor. The company had developed capability to deliver designs from conception and deliver to the stores in 2 weeks whereas it takes other competitors minimum 6 weeks or more. This makes Zara the trendiest store with latest in fashion. Zara designs more than 500 million items every year. This pushes their customers to visit the store frequently and check out latest available designs.

Design advantage:

Stable and reliable designer pool helps Zara to launch more than 1200's of new designs every year worldwide. As a result Zara develops curiosity in the mind of their customers, which

help to bring them in store every month. As compare to this customer visits competitor's stores twice or thrice a year to check out the latest in fashion. As company able to provide unique brand on regular basis, some customers dedicate their complete wardrobe to Zara brand. All the designed offered by Zara are elegant yet trendy, and are loved by their customers.

Opportunities:

Online Stores or E-commerce:

This is one of the biggest opportunity Zara has and company has given due importance to the same. Providing customer virtual experience of their store and analyzing customer buying behaviours through data analytics helping Zara to grow their business revenue. Company also using online platform for measuring customer's satisfaction and identifying upcoming trends for development

Backing some flagship designs:

If we compare with some of the top brands, these brands prefer to have some designs, which are flagship designs. Zara is lacking in these types of design and hence, It should have some designs which should become flagship design and available always at Zara store, demand can grow higher for these designs and will help building even more brand identity.

Capitalizing on growing market potential:

Zara become more and more popular and in demand wherever they establish their store, this gives company expected growth in brand along with earning potential. Zara become synonym of latest trend and customer feel proud to wear the brand. Hence, Zara needs to capitalize on the growing market potential of existing markets

Market expansion:

Company should look for new opportunities in terms and market expansion in developing countries, which can unlock further growth opportunities for the company. Special

focus on emerging market will help as the spending power of the people is increasing in these markets. Customer prefers to spend on a affordable premium brand like Zara and wants to wear better and more stylish clothing. This market expansion insures sustainable growth of the brand against saturation in developed countries where the competition is too high.

Key Features of Zara Supply Chain Model:

Synergy between Zara's business strategy and operational processes:

Zara prefer to produce their products at their own factory, rather than outsource. Unlike Zara other fashion brands would out source their products and buy them in bulk quantity to gain cost advantage. Zara produce these products in small batches and supply as per customer feedback from that particular region. Items with longer shelf-live are still outsourced to low-cost suppliers. This gives Zara a competitive edge when delivering products to customers with the items they want, when they want them. Brand has wide range of regular customers and they provide them regularly seasonal clothing as well as more basic items like t- shirts.

Just in Time production:

Zara has online order confirmation system. Through this system every store books their order once in a week. This is regular frequency with online record of all inventories available at different store. Order booked by store is get delivered within two to three weeks time in Europe and four to six weeks time outside Europe. This is very fast turnaround time compare to competition.

Lean Inventory Management:

Zara works with very minimum inputs. They believe in creating variety with minimum inputs. To ensure that they won't waste their efficiency on accumulation of inventory, company has standardized all the processes. Zara

has standardized colours and quality of fabrics and the same is outsourced in small batches from suppliers. This help to operate on lean inventory management.

Centralized Order Fulfilment:

All the stores are required to book their requirement through order management portal. This portal is controlled by centralised order management team. Once all they receive all the order they prepare production requirement and ensure delivery within standard time limit. As company operate through centralized order management system the chances of over production is very less.

Trustworthy distribution network:

Zara has its own outlets across the globe. As mentioned before that Zara has more than 2000 outlets owned by company and more than 300 franchised outlets. These outlets are having similar layouts and operate based on standard operating procedures defined by company. This gives trustworthy distribution network. Distribution channels are not allowed to violate

any procedure stated in operation manual. Brand recognition and fast fashion success.

Zara has developed brand credibility. Customers have immense trust on the brand and this makes the supply chain job comparatively easy. The forecasting and supply chain's prediction is more accurate as company know behaviour of their customer. Zara never have more than 10% unsold stock during the end of the season. Due to this company not forced to give extra discount to their customers to clear their inventories.

Logistics and Transportation model:

Zara operates on hub and spoke distribution model. All the products manufactured in factory will be first delivered at logistics centres. These logistics centres are responsible for delivering these products to stores for sale. Company refresh physical and online logistics centre once in two week and these products delivered within 48 hours anywhere in the world. As of now Zara has ten strategically located logistics centres.



All these logistics centre are located in Spain to reduce transpiration time from factory. As per the quote mentioned on website “A system this flexible and responsive has to be highly efficient and it is no coincidence that our ceaseless search for greater efficiency perfectly with our all-encompassing commitment to sustainability.”

Future Roadmap:

Zara believes in creating sustainable business model for future and to ensure that company trust on customer satisfaction. All the technological innovation and system changes are being done with focus of proving customer satisfaction. With the help of technology company now implemented RFID system. This helps in taking the stock fast at store and also helps tracking particular design from factory to store during transfer.

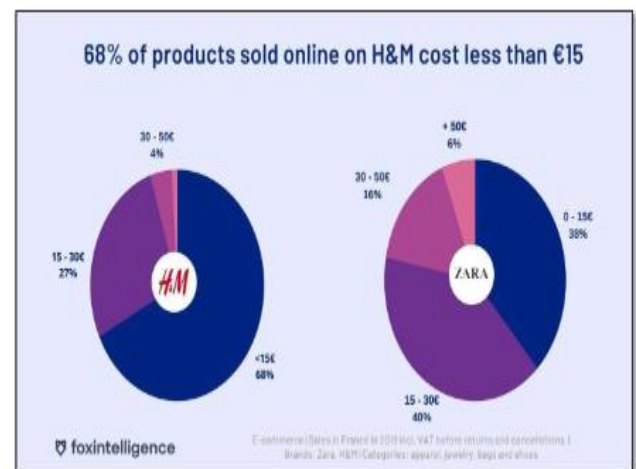
Company do very detail analysis of customer behaviour during their visit to store and online visit to their sales portal. Based on sales data of design region wise new products are prepared to launch. Company has already launched value added customer services and started “Same Day Delivery” at 70% of their business locations. Company has also started accepting Mobile payment to give as an alternative option to customers for payment transfer.

Company is giving due importance to social media platforms, for collecting customer feedbacks. With the help of online survey, completion and questionnaire company collecting desired information directly from customers.

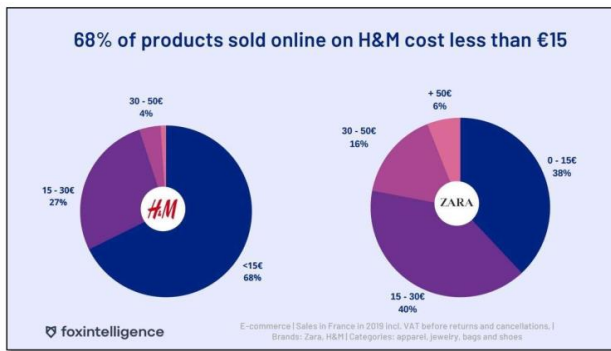
Competitive advantage Zara has over H&M:

Competition is growing between major player in retain apparel segment. Companies are taking more aggressive positions to win business battle from the competition. We are now comparing Zara and H&M.

Pricing: in 2019 product sold by H&M through online platform was double compare to Zara. The major reason behind this is pricing offered by H&M. Zara sold 40% of its products online with price range from 15 Euro to 40 Euro whereas H&M sold product less than 15 Euro. This strategy looks attractive from first look, how ever this is not sustainable model as H&M focus more on winning customer from Zara and forced to keep aggressive pricing strategy for the its products. Zara still believes on providing trendy design and quality of products.



Spend: In 2019 traditionally Zara customers have spend 40% of their budget on Zara whereastheyhavejustspend7.4%onH&M, similarly H&M customer have spend 21.6% on H&M and 9% of their budget on Zara. While analyzing the complete year data a Zara customer has spend average 142 Euro on Zara.com, whereas H&M customer has spend 102 Euro on H&M.



Conclusion:

In conclusion, Zara's journey through Industry 4.0, sustainability, and supply chain innovation stands as a testament to its visionary approach in the dynamic landscape of the fashion industry. Zara, founded in 1975, has evolved into a global fashion powerhouse, driven by a commitment to customer satisfaction, unique design, and a resilient supply chain. The strategic integration of Information Technology and Artificial Intelligence has been a cornerstone of Zara's success. The use of customized design software, advanced multi-shuttle areas, and robotics in collaboration with Fetch Robotics showcases a forward-looking mindset, enhancing efficiency, speed, and precision in supply chain operations. Financially robust, Zara's impressive sales revenue of €28,286 million in 2019, with a significant contribution from the Zara brand, underscores its market significance. The brand's 26.9% EBIDTA margin and prudent financial management affirm its sustainability and competitiveness in the market. Zara's SWOT analysis reveals its strengths in unique design, strong brand presence, and a superb supply chain. Opportunities in e-commerce and market expansion further position Zara for future growth. The comparison with H&M emphasizes Zara's sustainable approach over aggressive pricing, solidifying its competitive advantage. The case study demonstrates that Zara's industry leadership is not merely about following fashion trends but about pioneering technological advancements,

sustainable practices, and a customer-centric business model. As Zara continues its journey, it serves as a beacon for companies seeking a harmonious blend of innovation, sustainability, and operational excellence in the ever-evolving world of fashion and retail

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Water Quality Management and Risk Analysis Using Monitoring System

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Abstract:

Water quality is a critical determinant of public health, ecological balance, and sustainable development. Rapid urbanization, industrial discharge, and agricultural runoff have led to significant deterioration of surface and groundwater resources. This paper presents an IoT-based water quality management and risk analysis system that continuously monitors key parameters such as pH, turbidity, and total dissolved solids (TDS). Sensor data is processed using a microcontroller and evaluated through a Water Quality Index (WQI) model to classify risk levels. The system provides real-time alerts and visualization for proactive decision-making. Experimental results demonstrate the effectiveness of the system in identifying unsafe water conditions. The proposed solution is low-cost, scalable, and suitable for smart environmental monitoring applications.

Keywords: Water Quality Index (WQI), IoT, pH, Turbidity, TDS, Risk Analysis, Environmental Monitoring.

Introduction:

1. Background of the Study:

Water is a vital natural resource essential for sustaining life and supporting economic development. It plays a crucial role in domestic, agricultural, and industrial activities. However, rapid urbanization, industrialization, and population growth have significantly deteriorated water quality. The discharge of untreated sewage, industrial effluents, and agricultural runoff has led to contamination of both surface and groundwater sources. Consequently, effective monitoring and management of water quality have become critical concerns for environmental engineers and policymakers.

2. Importance in Civil Engineering:

In Civil Engineering, water quality management is a fundamental aspect of environmental and public health engineering.

Engineers are responsible for the design and maintenance of water supply systems, wastewater treatment plants, and drainage networks to ensure safe and reliable water delivery. Proper analysis of water quality supports the selection of appropriate treatment methods and enhances system efficiency. Furthermore, risk analysis is essential for identifying potential hazards and preventing failures in water infrastructure, thereby ensuring sustainability and operational reliability.

3. Societal Relevance:

Water quality management holds significant societal importance, as access to safe drinking water is a basic human necessity. Poor water quality is directly associated with diseases such as cholera, dysentery, and typhoid, particularly in developing regions. In addition, water pollution adversely affects aquatic

ecosystems, reduces agricultural productivity, and disturbs environmental balance. Therefore, there is a growing need for efficient systems capable of continuous monitoring and accurate risk

assessment. This project addresses these challenges by proposing a structured approach to water quality analysis and risk evaluation.

Literature Review:

Table 1-Review of Literature

Sr No	Author(s)	Title of Publication / Publisher	Year	Key Findings	Ref No
1	M. M. Islam, N. H. M. Sarker	Web-based Water Quality Monitoring System Using GIS and Cloud Services (Environmental Monitoring and Assessment, Springer, Scopus)	2025	Developed a web platform integrating GIS for visualization and cloud storage; allows remote access to quality data and trend analysis.	[1]
2	S. R. Gupta, T. Choudhary, A. Banerjee	Web-enabled Decision Support System for Water Quality Assessment (Journal of Environmental Informatics, Scopus)	2024	Proposed a web app that helps users assess water quality based on uploaded data and generates risk reports in real time.	[2]
3	H. Y. Kim, J. Lee, S. Park	Online Water Quality Predictive Analytics Using Machine Learning (Journal of Hydrology, Elsevier, Scopus)	2024	Introduced a web-based predictive tool using historical data to forecast future water quality levels with visualization dashboards.	[3]
4	P. Singh, R. K. Sharma	Cloud-based Water Quality Risk Analysis System (IEEE Access, Scopus)	2023	Designed a cloud system that performs risk analysis and offers interactive charts and alerts via web interface.	[4]
5	L. Zhang, F. Wang	Web-GIS System for Surface Water Quality Visualization and Reporting (Environmental Modelling & Software, Elsevier, Scopus)	2022	Developed a Web-GIS platform that maps water quality parameters, enables spatial queries, and supports report generation.	[5]
6	Abdulrahman A. Albraikan, Mohammed A. Alqarni, Ahmed S. Alfakeeh	Smart Water Quality Monitoring with IoT Wireless Sensor Networks (Sensors - MDPI, Scopus)	2024	IoT + WSN improves real-time monitoring; overcomes limitations of traditional sampling methods.	[6]

7	Zhen Qin, Yong Liu, Hao Wang	Algorithm for Monitoring Water Quality Using AI Data Mining (Scientific Reports - Nature, Scopus)	2024	Uses AI-based optical systems for advanced water monitoring; improves detection accuracy in polluted environments.	[7]
8	Rohit Sharma, Priya Singh	Monitoring Water Quality Using IoT and Machine Learning (IJISAE, Scopus indexed)	2024	Combines IoT sensors with ML for prediction and classification of water quality in rivers.	[8]
9	: Ankit Verma, Neha Gupta	Detection of Water Quality using Machine Learning and IoT (IJERT)	2021	Demonstrates ML + IoT for contamination detection; highlights automation benefits over manual methods.	[9]
10	S. R. Patel, K. K. Patel	Real-Time Water Quality Monitoring using WSN (IEEE Conference)	2018	Introduces wireless sensor networks for continuous monitoring; reduces delay in detecting contamination.	[10]

Methods:

1. Working Principle:

The proposed system operates on a data-driven approach rather than continuous real-time sensing. Water quality data is collected periodically (on a monthly basis) from various sources and stored in the form of structured CSV datasets. These datasets contain key parameters such as pH, turbidity, and total dissolved solids (TDS).

The collected dataset is uploaded by the user through a dashboard interface, where it serves as the primary input to the system. Once uploaded, the system performs data preprocessing and analysis, including validation, normalization, and parameter evaluation. The processed data is then used to compute the Water Quality Index

(WQI), which provides a quantitative measure of overall water quality.

Although the system does not perform real-time data acquisition, it enables real-time tracking and visualization of the uploaded dataset. This allows users to monitor trends, detect patterns, and evaluate changes in water quality over time. Based on historical data trends and WQI results, the system further performs risk analysis to classify water quality levels and predict potential future risks.

The final output is presented through the dashboard in the form of classifications (safe, moderate, unsafe) along with insights for preventive action. This approach ensures efficient monitoring, analysis, and decision-making using periodic data collection.

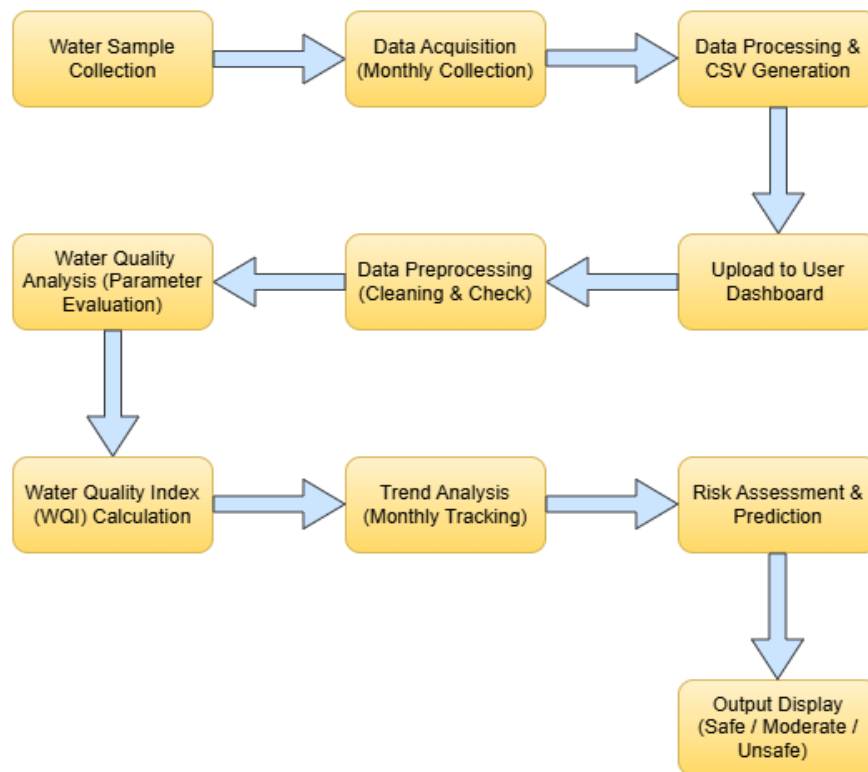
Block Diagram:

Figure 1. End-to-End Data Processing and Prediction Pipeline for Water Quality Analysis

2. Methodology:

The methodology of the proposed system is based on a data-driven and analytical approach for monitoring, evaluating, and predicting water quality. Water samples are collected on a monthly basis, and the data is stored in structured CSV files containing key parameters such as pH, turbidity, total dissolved solids (TDS), temperature, and dissolved oxygen (DO). This dataset is uploaded by the user through an interactive dashboard interface, where it serves as the primary input for further processing and analysis.

After uploading, the system performs data preprocessing, which includes data cleaning, handling missing values, normalization, and validation to ensure accuracy and consistency. Any anomalies or incorrect entries are detected and corrected to maintain data reliability. The processed dataset is then analyzed using statistical

techniques to evaluate each parameter individually and collectively.

The system calculates the Water Quality Index (WQI), which converts multiple water quality parameters into a single representative value indicating overall water condition. Additionally, the system compares current data with historical records to identify trends, seasonal variations, and sudden changes over time.

Based on the calculated WQI values and observed trends, the system performs risk analysis and classifies water quality into categories such as safe, moderate, or unsafe. It also applies basic predictive techniques (such as trend analysis or regression models) to estimate future water quality risks based on historical patterns.

Finally, the results are presented through a user-friendly dashboard, including graphs, alerts, and summaries, enabling users to easily

interpret the water condition and take appropriate preventive or corrective actions.

Water Quality Index (WQI) Calculation

$$WQI = \frac{\sum(Q_i \times W_i)}{\sum W_i}$$

Where:

- Q_i = Quality rating of the i-th parameter (calculated based on standard permissible limits)
- W_i = Assigned weight of the i-th parameter (represents its relative importance in water quality assessment)

Additional Formula for Quality Rating:

$$Q_i = \frac{(V_{ideal})}{(V_{ideal})} \times 100$$

Where:

- V_i = Measured value of the parameter
- S_i = Standard permissible value of the parameter
- V_{ideal} = Ideal value (e.g., 7 for pH, 0 for most other parameters)

Risk Classification:

Table. 1: Observation of Output

WQI Range	Water Quality
0–50	Excellent
51–100	Good
101–200	Poor
>200	Unsafe

Simulation:

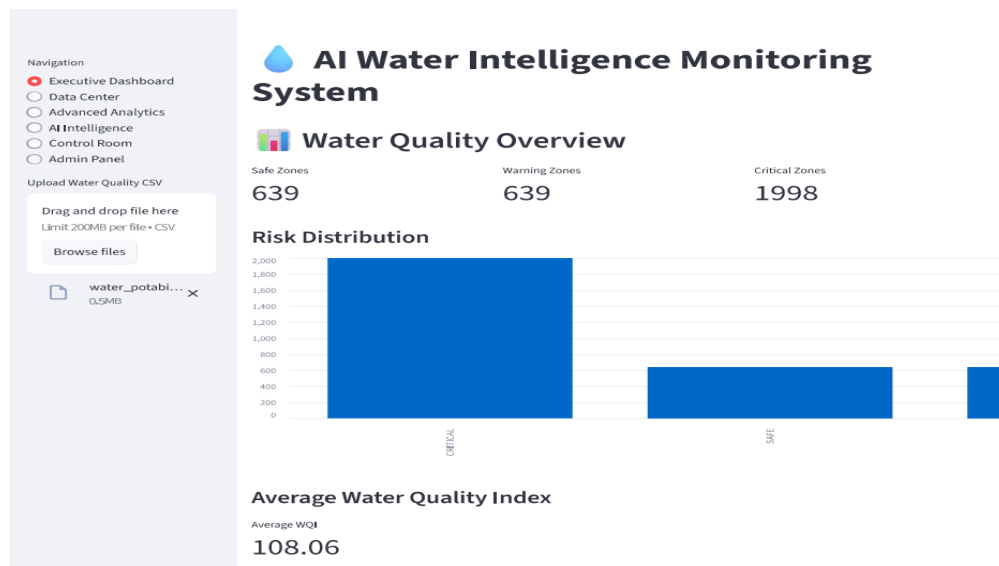


Fig. 2. Admin Dashboard of Water Quality Management and Risk Analysis

This chapter presents the simulation of the proposed water quality management and risk analysis system, which is carried out to test its functionality and accuracy using sample data. The simulation is performed using a computer system

with web-based technologies, where input data includes parameters such as pH, turbidity (NTU), dissolved oxygen (mg/L), and total dissolved solids (mg/L). The process begins with data input, followed by validation and processing to calculate

the quality rating for each parameter. The Water Quality Index (WQI) is then computed using the predefined formula, and based on the obtained value, the water is classified into categories such as good, moderate, or poor. The results are displayed in the form of tables and graphs, making them easy to understand and interpret.

The simulation results show that the system accurately calculates WQI and effectively classifies water quality. Overall, the simulation validates the methodology and confirms that the system can be used for practical water quality analysis and risk assessment

Result and Discussion:

1. Input:

Table. 2: Observation of the Input

Parameter	Variation
pH	5.5 – 8.0
Turbidity	5 – 100 NTU
TDS	200 – 1000 ppm

Table. 2. Observation of Output

Sample	pH	Turbidity (NTU)	TDS (ppm)	WQI	Status
Sample 1	7.2	5	300	45	Safe
Sample 2	6.5	20	600	120	Moderate
Sample 3	5.8	80	900	250	Unsafe

3. Output Graph:

© AI Model Intelligence

Prediction Probability Distribution

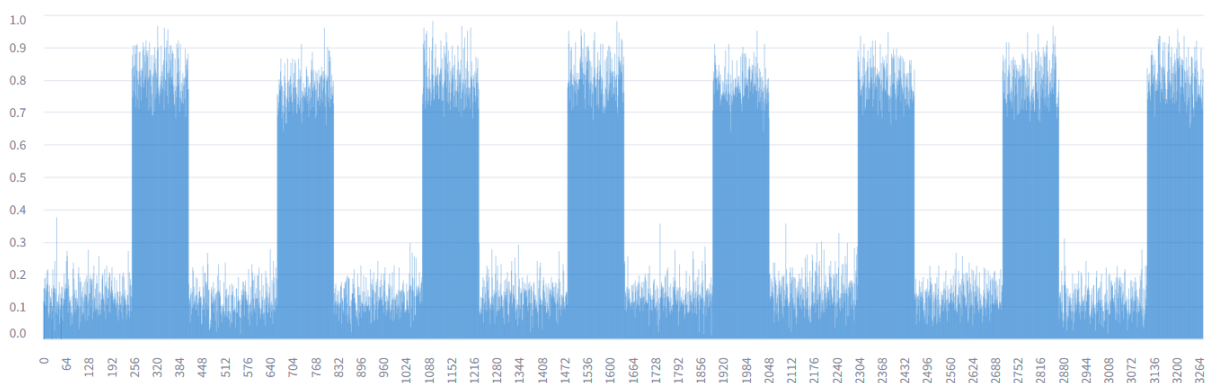


Figure.3. Prediction Probability Distribution of the Machine Learning Model

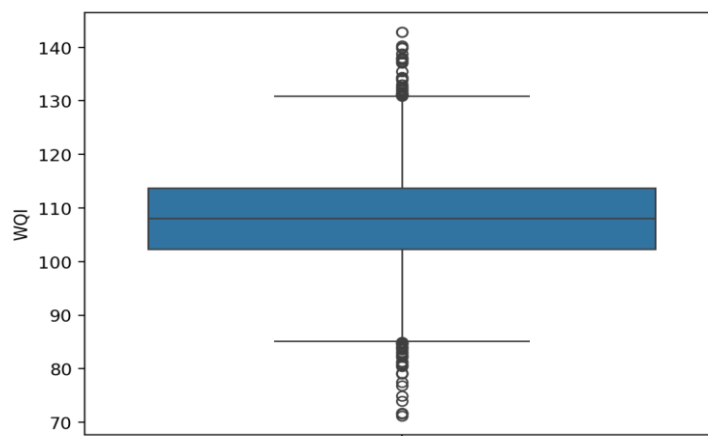


Figure. 4. Distribution of Water Quality Index (WQI) Values Across Samples

The analysis of the Water Quality Index (WQI) using a box plot reveals that the majority of water samples fall within a moderate quality range, with a median value around 108. The interquartile range indicates that most observations are consistently distributed between approximately 102 and 113, suggesting relatively stable water quality across the dataset. However, the presence of lower outliers (around 70–85) indicates regions with poor water quality, while upper outliers (above 130) represent areas with comparatively better water conditions.

Furthermore, the prediction probability distribution graph demonstrates that the machine

learning model exhibits high confidence in its classifications. Most prediction probabilities are concentrated near the extremes (close to 0 or 1), with very few values in the intermediate range. This indicates that the model is able to clearly distinguish between different water quality categories with strong decision boundaries. Overall, the combined analysis of WQI distribution and prediction probabilities confirms that the system provides reliable and consistent results for water quality assessment and risk analysis.

Graph Analysis:

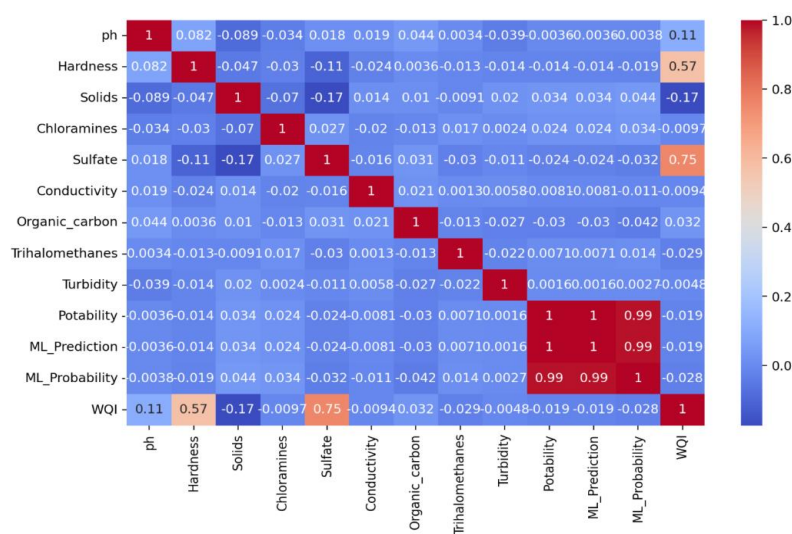


Figure 5. Heatmap Showing Correlation Between Water Quality Parameters, WQI,

The results indicate that as turbidity and TDS increase, the WQI value also increases, indicating deteriorating water quality. The system effectively identifies unsafe conditions and provides timely alerts.

Conclusion:

This project focuses on analyzing water quality and identifying risks using important parameters like pH, turbidity, dissolved oxygen, and total dissolved solids. The Water Quality Index (WQI) method is used to combine these parameters into a single value, which makes it easy to understand the overall water condition. The system takes input data, calculates WQI, and classifies water into categories such as good, moderate, and poor.

The main objectives of the project have been successfully achieved. The system is able to analyze water quality parameters correctly, calculate WQI, and identify possible risks. It also presents the results in a simple and clear way, which helps in better understanding and decision-making.

Overall, the project shows that a simple system can be used to monitor water quality effectively. It helps in improving awareness about water safety and supports better management of water resources.

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AI-Based Crop Health Monitoring and Disease Detection Using Deep Learning Techniques

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Abstract:

The Disease Detection System identifies crop diseases by analysing images of plant leaves, providing information on the Disease and suggesting the best cure for it. This approach aims to enhance yield and resource efficiency. The Plant Disease Prediction application utilizes image recognition technology to analyze images of diseased plant leaves, identifying the type of disease and offering insights into prevention or cure measures. With support for various crops, this application strives to mitigate crop losses due to diseases. A computer-based AI-powered crop Health Monitoring System is demonstrated in this Project. vision and machine Learning for early disease detection. With the growing demands in agriculture and the negative effects of climate change, prompt and accurate plant disease Detection and Health issues have become crucial. Our system analyzes leaf images and environmental parameters for classifying crop diseases, facilitating prompt action by farmers. This strategy minimizes the use of chemical pesticides, encourages environmentally friendly practices, and minimizes crop loss. The system is suitable for large-scale deployment because it demonstrated promising accuracy during real-world testing. Deployment. Deep learning (DL), a recent breakthrough in computer vision, has become a focal point in agricultural plant protection that can minimize the biases of manually selecting disease spot features. This study reviews the techniques and tools used for automatic disease identification, state-of-the-art DL models, and recent trends in DL-Based image analysis.

Keywords: Artificial Intelligence, Agriculture, Computer Vision, Crop Diseases, Deep Learning.

Introduction:

India's economy is mainly based on agriculture, and the changing weather conditions have both positive and negative impacts on agriculture. Ordinary farmers can't conduct regular and timely health checks of crops. For this, if agriculture is modernised, it will be possible to conduct health checks on farms on time and use the appropriate amount of preventive medicine. If AI and deep learning technologies are used in agriculture, farm production capacity and health checks will become easier and more convenient. Automated disease detection

technologies have revolutionised agriculture by providing accurate, efficient, and timely diagnostic solutions across farms of all scales. These approaches extensively utilise deep learning architectures, particularly Convolutional Neural Networks (CNNs), which have demonstrated remarkable performance in image classification tasks. CNNs employ multiple layers to extract complex spatial features from plant leaf images, enabling precise identification of disease patterns. Through visual recognition, these models can distinguish between healthy and infected crops with high accuracy, facilitating

early-stage disease detection and effective crop management. As a result, AI-driven detection systems contribute significantly to precision agriculture, minimising economic losses and promoting sustainable agricultural practices.

Problem Statement:

Implimentating of this system, ML and DL to detect crop diseases, we can get eassily identified the crop Disease and require suggestions about medicine or fertiliser. So it can be helpful to grow and maximise productivity, and quality of crops in ferm.

Methodology:

The proposed system for crop health monitoring and disease detection is designed using a structured approach that integrates image processing, deep learning, and environmental data analysis. The methodology consists of multiple stages, including data collection, preprocessing, model development, and deployment.

Data Collection A dataset of plant leaf images representing both healthy and diseased crops is gathered from publicly available agricultural datasets and real-time field captures. The dataset includes multiple crop types and disease categories to ensure model generalisation. In addition to images, environmental parameters such as temperature and humidity are considered wherever available.

Data Preprocessing The collected images undergo preprocessing to improve quality and consistency. This includes:

- Resizing images to a fixed resolution suitable for model input
- Noise reduction and normalization
- Image augmentation techniques, such as rotation, flipping, and scaling to increase dataset diversity
- These steps help in reducing overfitting and improving model robustness.

Feature Extraction Using Deep Learning A Convolutional Neural Network (CNN) is employed to automatically extract relevant features from the leaf images. Unlike traditional methods, manual feature selection is not required. The CNN identifies patterns such as discoloration, spots, and texture variations associated with specific diseases.

Model Training and Classification The processed dataset is divided into training and testing sets. The CNN model is trained using the training data, where it learns to map image features to disease labels. Common techniques such as:

Backpropagation Optimization algorithms (e.g., Adam optimizer) Loss function minimization are used to improve model accuracy. The trained model classifies images into categories such as healthy or specific disease types. **Integration of Environmental Parameters** To enhance prediction accuracy, environmental data (if available) is combined with image-based predictions. This hybrid approach improves reliability, especially in cases where visual symptoms alone are insufficient. **Model Evaluation** The performance of the model is evaluated using metrics such as:

- **Accuracy** measures the overall correctness of the model in identifying healthy and diseased crops.
- **Precision** ensures that crops predicted as diseased are actually affected, reducing false alarms.
- **Recall** evaluates the model's ability to detect all actual diseased crops, minimizing missed cases.

F1-score provides a balanced measure by combining precision and recall for reliable performance evaluation.

A confusion matrix is also used to analyze classification performance across different disease categories.

System Deployment The final model is deployed in a user-friendly application interface. Farmers or users can upload leaf images, and the system provides:

Disease identification suggested preventive or corrective measures The system is designed to be scalable and can be integrated with IoT devices for real-time monitoring in agricultural fields.

Objective:

The objective is to develop an AI-based system for automated crop health monitoring and

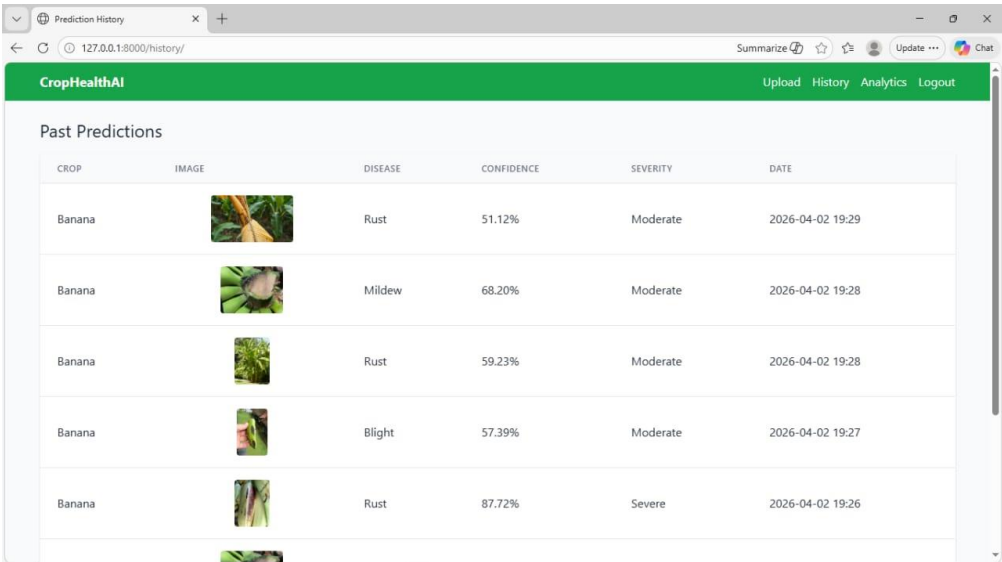
disease detection. It aims to analyze plant images and identify diseases at an early stage for timely action.

The system helps reduce crop losses by enabling early detection and intervention. It supports farmers in making informed decisions regarding treatment and preventive measures. The approach integrates machine learning and image processing techniques for accurate results. It also focuses on improving agricultural productivity through a scalable and user-friendly solution.

Literature Review:

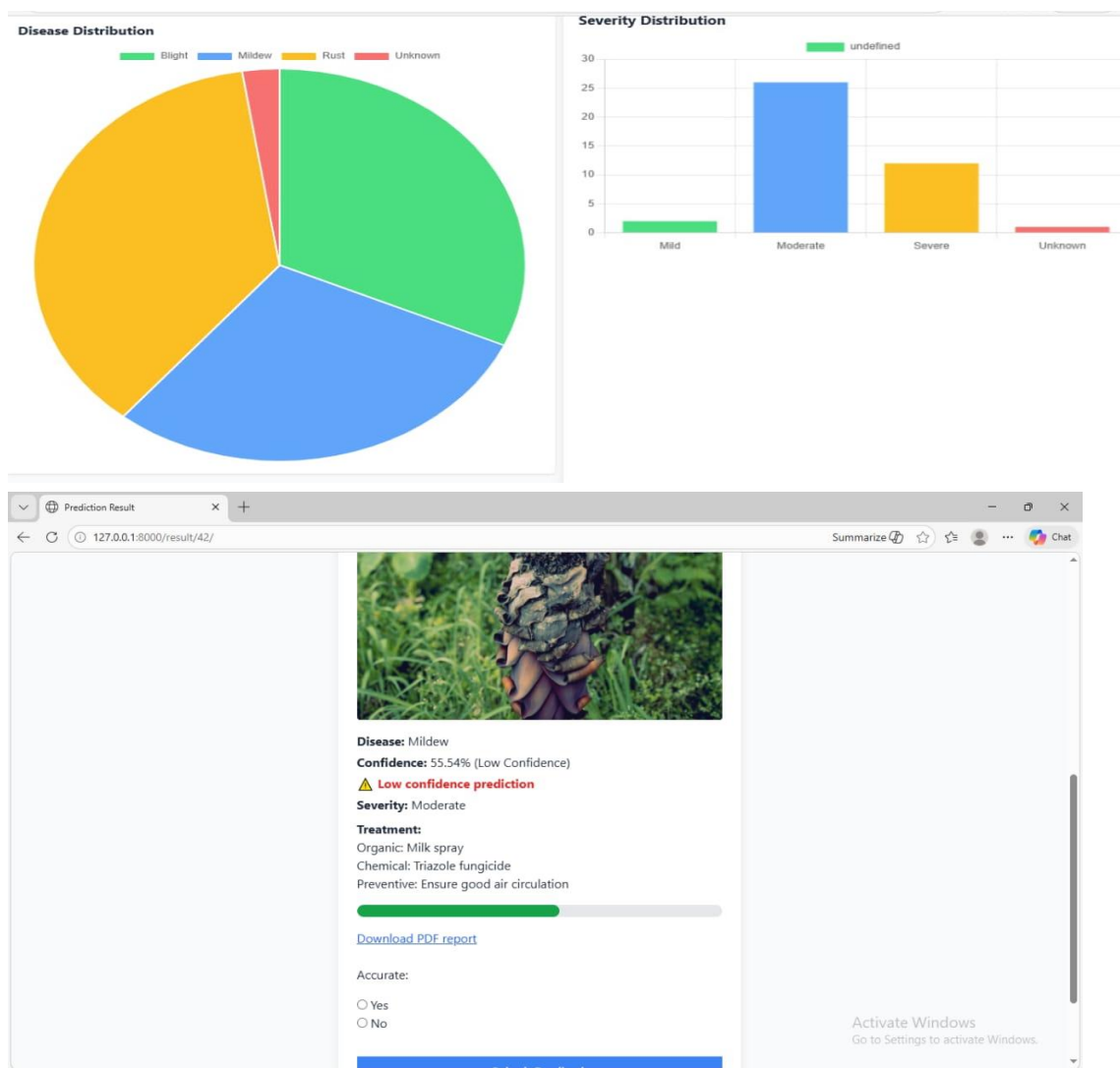
Author & Year	Objective	Method Used	Key Findings
Kaur et al. (2023)	To analyze various plant disease detection techniques and emphasize early detection	Traditional Machine Learning and Deep Learning (CNN), Image Processing (Segmentation, Feature Extraction)	CNN models provided better accuracy and efficiency compared to traditional methods; hybrid models suggested for practical use
Mohanty et al. (2016)	To demonstrate effectiveness of deep learning in plant disease detection	Convolutional Neural Networks (CNN) using large dataset of plant leaf images	Achieved very high accuracy under controlled conditions; potential for smartphone-based real-time detection
Ferentinos (2018)	To explore deep learning models for plant disease detection and diagnosis	Deep Learning models (CNN) with large and diverse dataset	Achieved exceptionally high accuracy; superior to traditional methods for complex image patterns

Result:



The screenshot displays the 'CropHealthAI' web application. The interface includes a green header with the app name and navigation links: 'Upload', 'History', 'Analytics', and 'Logout'. Below the header, a section titled 'Past Predictions' contains a table with the following data:

CROP	IMAGE	DISEASE	CONFIDENCE	SEVERITY	DATE
Banana		Rust	51.12%	Moderate	2026-04-02 19:29
Banana		Mildew	68.20%	Moderate	2026-04-02 19:28
Banana		Rust	59.23%	Moderate	2026-04-02 19:28
Banana		Blight	57.39%	Moderate	2026-04-02 19:27
Banana		Rust	87.72%	Severe	2026-04-02 19:26



The proposed AI-based crop health monitoring system successfully detected plant diseases using deep learning techniques. The Convolutional Neural Network (CNN) model demonstrated high accuracy in classifying healthy and diseased crop leaves. Image preprocessing and augmentation improved model performance and reduced overfitting.

The integration of environmental parameters such as temperature and humidity further enhanced prediction reliability. The system showed strong performance in evaluation metrics including accuracy, precision, recall, and F1-score, indicating effective disease classification.

The developed application allowed users to upload leaf images and receive disease

identification along with suggested remedies. The system reduced manual inspection efforts and enabled early disease detection, which helps minimize crop loss and improve agricultural productivity.

Overall, the proposed system proved to be efficient, scalable, and suitable for real-time crop health monitoring in modern agriculture.

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A Vision-Guided Quadruped Robot for Terrain Navigation and Target Tracking

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Abstract:

The increasing demand for stable, adaptive, and intelligent legged robots in exploration, surveillance, and assistive applications has highlighted the need for compact and efficient quadruped systems. Traditional wheeled and tracked robots face limitations in maneuvering over uneven terrains, while many existing quadruped designs suffer from limited stability and adaptability in real-world conditions.

To address these challenges, this project presents the design and development of a 12-servo quadruped robot named QuadroNav, featuring 12 degrees of freedom (DOF) for enhanced flexibility and control. The system is powered by a Raspberry Pi serving as the primary processing unit, responsible for motion control, sensor integration, and real-time decision-making. The robot's lightweight yet robust frame is constructed using custom 3D-printed components, optimized for legged mobility. Each leg is actuated by high-torque 35 kg-cm servo motors driven by a 16-channel PCA9685 module, ensuring smooth and precise motion control. An MPU6050 IMU provides balance feedback for posture correction, while inverse kinematics (IK) algorithms enable coordinated and natural leg movements.

To achieve fluid and stable locomotion, a Bezier curve-based gait generation algorithm is implemented, producing continuous motion patterns that mimic biological walking. A front-mounted camera module enables vision-guided navigation, allowing the robot to detect obstacles, plan paths, and adapt to environmental variations.

Compared to conventional quadruped designs, QuadroNav demonstrates superior adaptability, stability, and intelligence. The seamless integration of mechanical design, sensory feedback, and control algorithms allows it to perform dynamic walking, balancing, and navigation tasks efficiently, making it a versatile platform for advanced robotics research and real-world deployment.

Keywords: *Three Dimensional, Artificial intelligence, computer-aided design, Direct current, Degree of freedom, Back Right, front Left, Inter Integrated circuit, Inertial Measurement unit, Lithium Ion Battery.*

Introduction:

Quadruped robots represent one of the most active and challenging domains in the field of robotics, inspired by the efficient, adaptive, and biologically evolved locomotion of four-legged animals. [7, 8] These robots are capable of maintaining balance and stability while navigating through uneven and unpredictable terrains, making them highly suitable for

applications in exploration, surveillance, defense, and disaster response operations. Unlike wheeled or tracked robots, which often struggle on irregular surfaces or steep slopes, quadruped systems possess a unique mechanical advantage through legged motion that allows them to step over obstacles, adapt to varying terrain conditions, and perform dynamic maneuvers with

greater precision and agility. This combination of mobility, stability, and adaptability has made quadruped robotics a key area of research in modern robotic engineering.

The design and control of quadruped robots require a multidisciplinary approach, combining mechanical engineering, electronics, control theory, and computer algorithms. Achieving smooth, balanced, and stable motion involves careful coordination between mechanical structure, gait generation, and feedback control. Gait patterns such as walking, trotting, pacing, and bounding have been extensively studied to achieve energy-efficient and naturally inspired motion. [16, 12] Each gait type offers a specific trade-off between stability and speed, depending on the terrain and the desired behavior of the robot. In addition, advanced control algorithms utilize feedback from motion sensors and kinematic data to dynamically adjust leg trajectories, ensuring that the center of gravity remains stable during movement. [11, 9]

With the rapid evolution of mechatronic components, sensors, and embedded controllers, the development of quadruped robots has become increasingly accessible and customizable. Affordable servo actuators, lightweight structural materials, and open source control platforms have significantly reduced the complexity and cost associated with quadruped locomotion research. [14, 8] Furthermore, the integration of sensors such as accelerometers, gyroscopes, and ultrasonic modules has enhanced environmental awareness and balance correction capabilities, while modern fabrication methods like 3D printing enable rapid prototyping and modular design modifications. These advancements have allowed both academic institutions and independent researchers to explore quadruped robotics for educational, experimental, and industrial purposes.

This project, titled QuadroNav, focuses

on the design, development, and implementation of a four- legged walking robot capable of demonstrating stable quadruped locomotion through predefined gait algorithms. [9, 10] The system is built around a mechanically optimized leg structure, actuated by servo motors arranged to simulate the movement of animal limbs. A custom gait generation algorithm ensures synchronized and smooth leg motion, while maintaining balance and direction control during walking. The robot's design emphasizes modularity, allowing easy modification or expansion for future experiments involving obstacle detection, wireless control, or semi-autonomous navigation. The QuadroNav Quadruped Robot serves as a practical platform for exploring the principles of robotic locomotion, motion stability, and balance control. Its simplicity and affordability make it an ideal project for academic learning, research, and hands-on experimentation in robotics and automation. [8, 7]

Literature Review:

The literature review is a critical discussion and summary of statistical literature that is of general and specialized relevance to the particular area and topic of the research problem in statistics. This section describes the previous research already done by other researchers and provides a foundation for developing this project. Before designing the quadruped robot, a detailed review of existing technologies and research work was conducted. This review is divided into three categories: (a) Market Survey, (b) Paper Survey, and (c) Summary and Research Gap.

Market Survey:

Quadruped robots have become an important class of legged robots, capable of traversing complex terrains and performing tasks beyond the ability of wheeled or tracked systems. [7, 8] The global robotics market has seen rapid

advancements in quadruped design, focusing on modularity, adaptability, and intelligence. Depending on their application and complexity, quadruped robots can be broadly categorized into three main types:

Educational and Research Quadrupeds:

These are low-cost, lightweight robots designed for learning and experimentation. They typically use servo motors and controllers like Raspberry Pi or Arduino. Examples include open-source quadrupeds such as Peto Bittle, Stanford Pupper, and other 3D-printed models used in universities and labs. Their main objective is to support algorithm testing, gait learning, and AI-based control research at an affordable cost. [8, 7]

Industrial Quadrupeds:

These robots are built for real-world operational use, often featuring robust metal frames, advanced sensors, and AI-assisted navigation. Examples include Boston Dynamics' Spot, ANYmal from ETH Zurich, and Unitree's Go1. They are employed in areas such as inspection, mapping, logistics, and hazardous

environment monitoring. However, their high cost and proprietary systems limit accessibility for smaller research teams. [8, 7]

Defense and Tactical Quadrupeds:

These systems are specialized for military applications like reconnaissance, surveillance, and supply transport. Equipped with LIDAR, thermal cameras, and GPS modules, they can operate autonomously in challenging terrains and under adverse conditions. Defense quadrupeds focus on endurance, payload capacity, and mobility, but they are expensive and restricted for civilian or academic use.[7] Overall, the market trend shows a growing demand for affordable, modular, and intelligent quadruped robots that can bridge the gap between educational models and advanced industrial-grade systems. The increasing availability of compact computing platforms such as Raspberry Pi has enabled developers to create research-grade quadrupeds with features like camera-based feedback, wireless control, and semi autonomous operation. [8]

Methodology:

Overview:

Parameter	Value	Unit
Mass	1.9	Kg
Body Length	31.5	mm
Body Width	18.5	mm
Body Height	18.5	mm
Leg Link Length	100	mm

Table 1.1: Body design parameters of robot

QuadroNav is a four-legged (quadruped) walking robot designed to move on uneven surfaces more effectively than a wheeled robot. It uses servo-driven legs controlled through a gait pattern (walk/trot-style steps) where each leg follows a timed trajectory, and inverse kinematics (IK) converts target foot positions into joint angles. A controller (typically a Raspberry Pi /

microcontroller + servo driver) generates movement commands like forward, backward, left, right, and stop, while maintaining a stable body posture. The main goal of QuadroNav is reliable locomotion with basic navigation capability, making it suitable for education, prototyping, and robotics research demonstrations.



Fig 1: Side view (Actual photograph)



Fig 2 : Front view (Actual photograph)

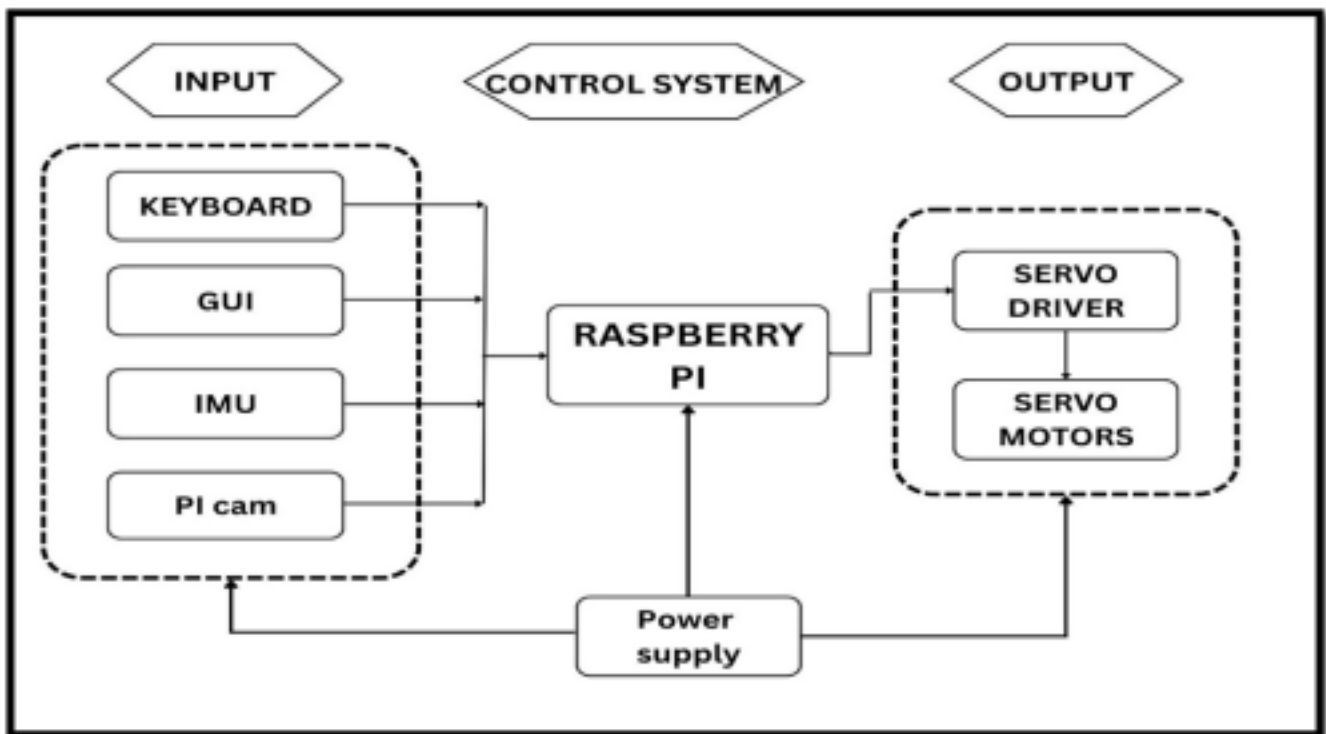


Fig 3 : Block diagram of Control Architecture

The block diagram of QuadroNav illustrates the complete control and feedback architecture of the quadruped robot. The system is divided into three main sections: Input, Control System, and Feedback, all coordinated through the central processing unit — the Raspberry Pi.

Input Section: The input section consists of the Keyboard and Graphical User Interface (GUI),

which allow the user to send commands or adjust parameters for the robot. These inputs are communicated to the Raspberry Pi, which interprets and processes them for motion or control actions.

Control System: The Raspberry Pi acts as the brain of the robot. It processes data received from the input section and executes control algorithms

that determine the robot's actions. The Raspberry Pi generates appropriate control signals that are sent to the actuators through servo drivers. This ensures precise movement of the robot's limbs according to user commands or autonomous decision-making.

Actuators: The actuators consist of Servo Drivers and Servo Motors. The servo drivers receive control signals from the Raspberry Pi and regulate the power and direction of the servo motors. The servo motors, in turn, perform the mechanical movement of the quadruped robot's joints, enabling walking, turning, and other actions.

Feedback Section: The feedback section includes the IMU (Inertial Measurement Unit) and Pi

Camera. The IMU provides real-time orientation, acceleration, and angular velocity data, helping the control system maintain balance and stability.

The Pi Camera captures visual data from the surroundings, which can be used for vision-based navigation or object detection. Both feedback sensors send data back to the Raspberry Pi, enabling closed-loop control for improved accuracy and adaptive movement.

Quadruped Robot: The mechanical body of the quadruped robot integrates all the actuator and sensor systems. It executes the motion commands generated by the control system and provides feedback for correction, completing the control loop.

Results:

3D Printed Parts:



Fig 4 : 3D Printed leg tibia

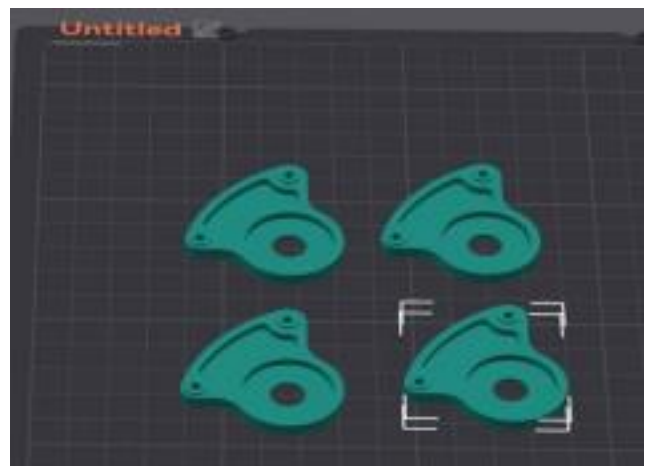


Figure 5: Leg for tibia and femur

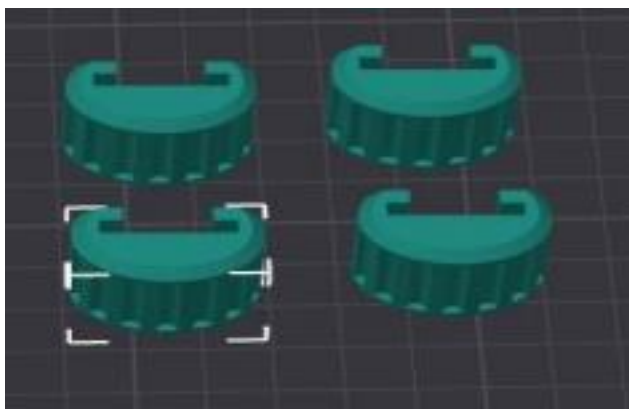


Figure 6 : Servo Mount Brackets

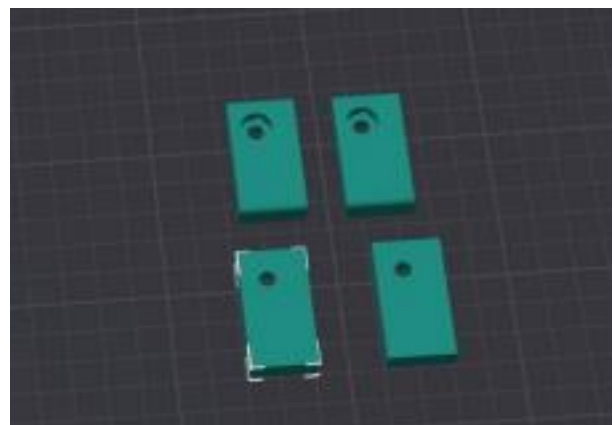


Figure 7: legs grips

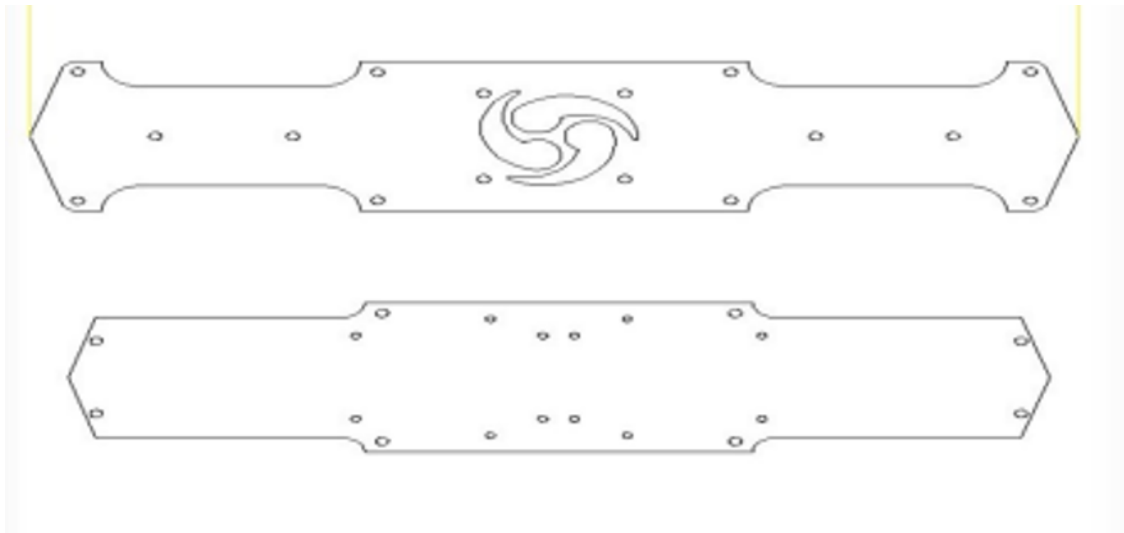


Figure 8 : TOP and BOTTOM plates cover

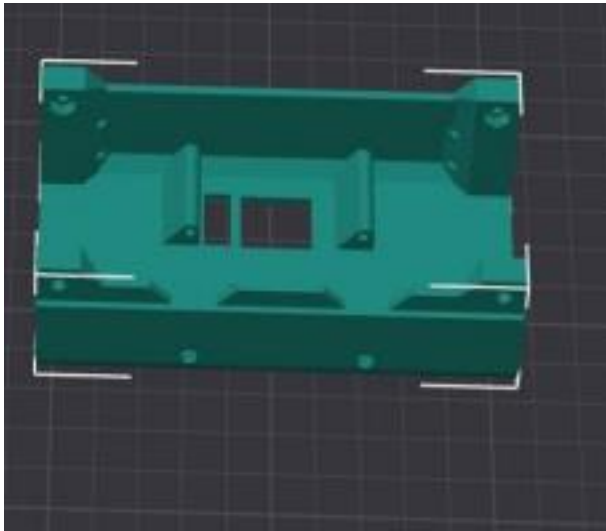


Figure 9 : 3D Printed legs femur



Figure 10 : side covering of body

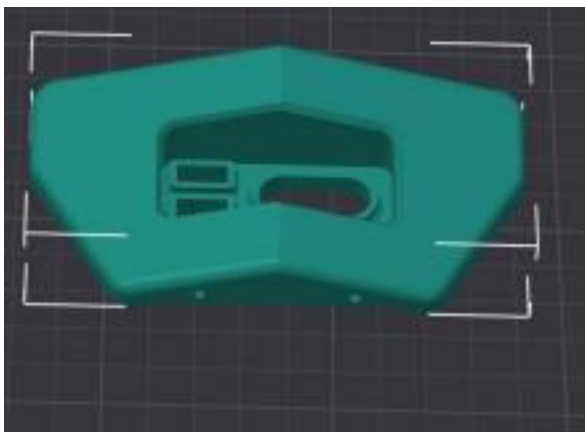


Figure 11 : side covering of body

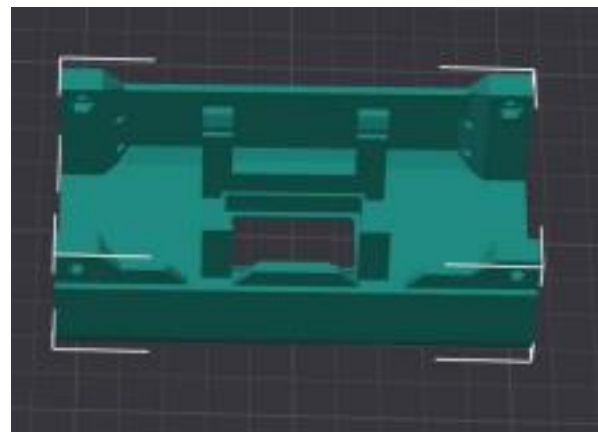


Figure 12 : side covering of body

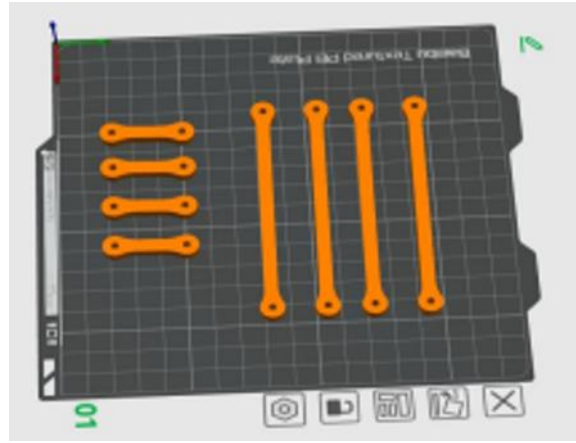


Figure 12 : links 100mm and 35mm

Conclusion:

The development of the vision-guided quadruped robot QuadroNav has been both a challenging and fulfilling experience, showcasing the integration of mechanical design, embedded control, and intelligent navigation. The project successfully demonstrated key concepts in legged robotics such as balance stabilization, inverse kinematics-based motion control, and smooth gait generation. Built using 12 high-torque servo motors, a Raspberry Pi controller, a 16-channel servo driver, and a 3D-printed mechanical structure, the robot achieved stable walking and posture control on varying terrains.

A significant accomplishment of this project was the seamless integration of hardware and software, enabling real-time feedback from the MPU6050 IMU sensor for dynamic balance and adaptive movement. The use of Bezier curve-based gait generation ensured smooth and natural locomotion, while the addition of a camera module enabled vision-assisted navigation and environmental awareness. This combination of sensory inputs enhanced the robot's ability to maintain stability and perform coordinated leg movements under varying conditions.

The project also provided an in-depth understanding of robotics concepts such as inverse kinematics, servo synchronization, and motion planning, while offering practical

experience in 3D modeling, control system design, and embedded programming. Although the robot successfully demonstrated stable walking and navigation, there remains scope for improvement in terrain adaptability, gait smoothness, and power efficiency. Future work may include integrating machine learning-based terrain

recognition, optimizing gait transitions, and adding advanced sensors such as LiDAR or ultrasonic modules to improve environmental perception. Overall, the QuadroNav project stands as a comprehensive demonstration of modern quadruped locomotion principles, combining mechanical innovation with intelligent control for autonomous, stable, and adaptive robotic motion.

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Role of Innovative Approaches in Language Teaching for Higher Secondary Classes at Saraswati Junior College, Paras, Tehsil Balapur District Akola: My Experiences

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Abstract:

The present research paper is an account of various innovative projects successfully carried out for higher secondary students. These six projects covered the big canvas of routine classroom teaching over thirty plus years. These innovative activities are basically related with learning of English language for communication. Another aspect is the real-life experiences, hands on activities and participation of students. These classroom activities are complemented by tours on bicycle, numismatic, notaphily, philately and phillumeny collections, feathers and various natural objects. The vital and ever-changing role of technology contributed in grand success of these ventures, particularly after the Covid pandemic. Community support, foreign scholarships, awards, research papers presented at various International/ National conferences, seminars, workshops and the media coverage spread the word. The NEP 2020 document focus on new ways of learning and these projects could serve the purpose. At the same time points out the excessive and unmindful use of modern technology. The message is clear; innovative projects backed up with hands on activities and ground level efforts can sustain in long run.

Keywords: *Numismatics, Notaphily, Philately, Phillumeny, Innovative Projects.*

Introduction:

English is the most difficult subject especially for the rural area students. The subject teachers hardly go beyond textbooks. Rote memorization of grammatical rules added with use of vernacular language add to the worries. Use of secondary materials such as guides, Question Banks, work books, test series and above all the Board exam result pressure hardly allow English teacher to think out of box.

The researcher worked as an English teacher for higher secondary classes from July 1991 to May 2024, a tenure of 32 years and 10 months. The initial years were devoid of multiple resources. Consequently, textbook was the only source and the only teaching aid in the classrooms. Later on, patterns, textbooks

changed, new lessons, poems and story section created space for innovative activities. The 21st century opened many avenues and thus created scope for different activities. The present research paper discusses about six major projects carried out in the classrooms over these years. They show how the use of technology increased and made learning English interesting. The goal was to improve communication skills, speaking skills and also maintain the academic results.

Literature Review:

1) Arther's Hat and story telling:

Provide a random, intriguing object (i.e. an old key, a vintage hat) and tell students it is a historical artifact. Students invent a detailed, creative backstory for the object in

English, enhancing descriptive skills and narrative tenses.

2) The Mystery shoebox:

Fill the box with random items (toys, tools, kitchen utensils) to teach specific vocabulary, prepositions and commands. Students can practice Total Physical response (TPR) by following instructions like “Place the stapler next to the scissors”

3) Real World Price estimation:

Bring items like groceries, clothing or gadgets to class. Have students guess the prices in English, negotiate or order them from least to most expensive. This fosters functional language for shopping, comparisons, and asking/ answering questions.

4) Realia based Charades:

Use tangible items rather than cards for charades. A student acts out an action using the object and classmates guess in English, promoting active vocabulary use.

5) In some Z.P. Schools in rural parts of Maharashtra, English teachers painted and wrote English words, sentences, phrases on compound walls, house walls, boards and students on their way saw and learned words, sentences and names of objects.

Methods and Materials:

The researcher carried out innovative projects during his tenure of 30 plus years at Saraswati Junior College, Paras. Basically, an English teacher, he has been allotted six periods a week of History to fulfill the workload norms. Environment Science was added from 2001 as it was introduced as a compulsory subject by the Government of Maharashtra. While teaching History the researcher used numismatic and philately collection along with philately. For Environment Science, the use of matchbox pictures (phillumeny) was added along with

philately (collection of postage stamps). Students, fellow teachers, parents and the whole society contributed handsomely. In course of time within ten years, a pool of resources was created with addition every passing year.

Learning resources created for History and Environment science were used for learning English lessons and poems. Interdisciplinary approach was focused naturally. Technology played a vital role along with hands on activities. Photographs were developed as posters. In the later period cellphones, pictures, social media videos, YouTube, email were used for learning purpose.

Following are the six innovative projects along with some activities. The materials used are mostly from waste and low-cost materials. Some projects are backed up by some rigorous activities. Such projects were not limited to classrooms but carried some other objectives and emerged as effective.

Project One:

Lessons, Cycle tours, Activities.

In the new textbook, there was a lesson titled, ‘In the Lap of Himalaya’ by Binoy Gupta. It carried a detailed description of nature around Yamunotri. But words were not enough. With the aim to portray a vivid picture with the help of some authentic pictures, the researcher visited the area on bi-cycle covering a distance of nearabout 4000 kms during the hot and scorching summer of 2002. (3rd May to 12th June) Bi-cycle was deliberately used to cover every inch of the area and to celebrate ‘The International Year of the Mountains’. With the help of a simple Kodak camera, clicked photographs according to the lines in the lesson.

Back home, the pictures were developed as big size posters. A new activity was designed. These posters were exhibited in the classroom during the lesson. Students were given the task to

match the lines with the posters. Observation, concentration, enthusiasm, collaboration, discussions were unleashed and students enjoyed every moment. These activities were complemented by travelogues, experiences, stories, culture, social life of the Pahari people, their food and innumerable questions related with the bi-cycle adventure.

The second cycle tour was in 2008 with the message 'Save Tree' covering Konkan, Goa and Karnataka and a distance of 3800 kms. During 2nd May to 12th June. This time a lesson on 'Devbagh' (Karnataka) in the textbook of grade XI was the target. Along with coastal Forts, flora and fauna of Western Ghats the pictures of the tourist destination Devbagh were taken again with a simple kodak camera. Posters were developed and the 11th Arts and Science classes buzzed with similar activities, enthusiasm and sheer joy. These activities were carried every year until the new textbooks arrived. Joy of learning and teacher-student bonding were the most fascinating outcomes of the projects.

Project Two:

Interdisciplinary Approach; Environment Science resources.

Environment Science (EVS) became a compulsory subject for grade XI and XII in 2000. Project work was compulsory. In the initial years, students mostly chose topics from the textbooks. Paras is situated in a rural area and students from 17 villages in the vicinity commute to learn daily. Most of them travel on foot or bi-cycles through fields, farms and along with the banks of river Mann. In 2005-06, the grade 12 Arts students worked on a mega project; 'Local Birds'. Students collected information, took pictures and collected feathers from various sources like fields, abandoned wells, farms, trees etc. They also brought broken egg shells of different colours and broken nests. The mega project was a grand success. We sorted out, classified and made sets

of feathers. The total number of feathers collected was over 2000. It became a perennial resource for our school.

In the new grade XII English textbook, there was a lesson titled, 'Where have all the birds gone' The information collected during project, sets of feathers proved authentic resources to learn about various birds while learning the lesson. Students presented information along with original proofs. The highlight of the activity was, students understood the importance of nature and the concern of the writer over declining number of birds. Similarly, feathers were used in a grade X poem; 'The Kingfisher'. The rare feathers of white breasted kingfisher were the attraction.

Project Three:

Interdisciplinary approach; History

The researcher also taught History to complete the workload. To make the learning interesting, coins and currency notes were used. Thus students were acquainted with ancient India, Middle age Sultanate, Moghul Empire and modern coins of British rule. Based on the famous dictum, 'who don't want money', students were naturally attracted towards these metal and paper pieces exploring different periods. The researcher received Fulbright American Scholarship in 2012. He taught in an American school in Fairfax Virginia. The topic was 'Unification of America' and learning resources used was a special set of 50 state quarter dollar representing 50 states of the nation.

After return, the researcher taught the famous poem 'O Captain! My Captain! With the help of same set. Explained the concept of confederation. Students dramatized the Civil War. They learned the names of fifty states, The declaration of Independence, Civil War and the role of Abraham Lincoln. The same set was used to learn the grade XI poem 'Ageing in America' later on. Original coins, pictures and messages

inscribed, photographs, videos taken in US served as proofs for comprehension. Of these poems.

Project Four:

Enhancing the Board Exam. Results.

English has been identified as a killer subject for rural area students. Over the years particularly students from Arts stream performed poorly in English and brought down the results. Maharashtra government education Board changed question paper pattern for grade XI and XII in 2017. A new activity Sheet replaced the

traditional question paper. But the textbooks remained the same. It pressed the panic button among students.

There was an urgent need to tackle the problem. The researcher designed a pilot project to prepare the student for the 2019 Board exam. The biggest challenge was to root out the fear of the exam and particularly the new pattern of question paper. To make matters worse, the last year result of English of Arts stream was disappointing.

Table One

S. No.	Particulars	Girls	Boys	Total
1	Appeared	24	19	43
2	Passed	13	07	20
3	Percentage	54.16 %	36.84	46.51 %

Percentage difference between girls and Boys = 17.05%

The Project Sample:

Thirty (30) students out of 39 (39) were selected from Arts stream considering their poor and average performances in test exams. It included 14 boys and 16 girls from Arts. While from science stream the 10 low scorers were selected. It included 3 girls and 7 boys.

The Program:

Since the inception of new activity sheet in 2017, the researcher focused on two activities; reading and writing practice. Students were provided with opportunities of loud reading in the class throughout the year. That helped them to comprehend the textual matter. The comprehension exercise 'C' of every test was chosen for writing practice. Questions were discussed orally and written after discussions. That created a base for reading and comprehending the new activity sheet. Writing practice also increased their speed of writing answers. A one-day workshop was organized for

the S.Y.J.C. students about how to face the new activity sheet on 18th Jan. 2019. Five different activity sheets from different parts of Maharashtra were selected for practice in exam environment. These were taken from Kelikotul, Chopda, Kolhapur, Latur and Mumbai. It was all possible because of social media. Downloaded from various what's app groups, these activity sheets were used for practice. Students solved these activity sheets and the researcher himself was one of the examinees. Discussing every activity participants wrote answers. Use of mother tongue for instructions was one of the salient features of the project. And the last activity sheet was solved just a day before the English paper. Before leaving the hall, the researcher gave a final message;

“Guys don't bother too much about the result. Tomorrow, give your best shot”

They took it by heart. When the results announced, it created history.

Table Two

S. No.	Stream	Enrolled	Passed	Percentage
1	Arts	30	26	86.66
2	Science	10	10	100.00
	Total	40	36	93.33

It was the highest results of both the streams in the last decade.

Project Five:

Learning through What's app:

The Covid 19 pandemic resulted in a prolonged lockdown in 2020 and 2021 disturbing the educational tone and set up all over the globe. Schools remained closed almost for 500 days. The online/offline classes played hide and seek and uncertainty prevailed. Following were the challenges

- 1) Lockdown prevented contact and created physical void
- 2) Demand for online, a distant dream for rural schools.
- 3) Wild efforts with very little outcomes.
- 4) The revamp of evaluation pattern and textbooks.

The researcher used What's app to teach online and preferred;

- 1) Audio Clips,
- 2) Messages and
- 3) Video clips.

Listening is a basic skill. The researcher recorded some audio clips to introduce the theme, story of the lesson, central idea of the poem followed by instructions and points to be focused. Naturally an audio clip is bound to grab more attention. Video clips usually students watch in a haphazard manner. A long clip and you will find their finger scrolling frequently. A group of each class was created and students were communicated through messages. Each activity received response. They received opportunities to present their material also.

Podcast Show: Learning Adventures:

A language learner needs to consolidate listening skill in order to master any language. During lockdown personal contact with students became rare. They needed listening practice. Further sharing messages, pictures were having limitations. With the aim to shorten the communication distance, the researcher turned towards podcast and created a channel titled, 'Learning Adventures' Through seven episodes the researcher read and sang the poems, presented simplified summary, explained the theme in Hindi for better understanding. Along with academics, there were some episodes about American experience and language. All the material was published on various podcast platforms. The interesting thing about these podcast episodes is that it attracted listeners from other countries too.

Project Six:

The YouTube Channel:

The schools reopened on 23rd November 2020 but only for a few weeks. Lockdown was inflicted in February which continued almost throughout 2021. Students demanded some interaction in visual form and the researcher launched his You Tube channel named, 'International Teacher: Rajesh Patil'. The researcher covered poetry section. In video of each poem the theme, message and life of the poet in simplified English followed by a Hindi translation of the theme, concept and message. Each episode contains stanza wise explanation along with some information about the figures of speech. For the poem, 'The Inchcape Rock' the researcher made a pirate ship of ice cream sticks. In the poem 'Money', the researcher used actual paper notes, currency signs on the backdrop.

Satvahana coin shown to the students along with some odd values coins like 350 rupees, 1000 rupees etc. But the center of attraction was 100 billion dollars note of Zimbabwe.

Result and Discussion:

The first three projects were designed basically to create interest among students. The fourth one was need of the hour and the fifth and the sixth project were an outcome of the pandemic period. In the initial stage adventure, hands on activities, field work, co-operation, collaboration and peer learning were at the core and technology played a supportive role. Using camera, taking pictures, developing posters such were the tasks basically limited to certain extend. The success of the projects mostly relied on the participation of students and collaboration with teacher.

These projects naturally created a pool of learning resources. The numismatic collection swelled over 3000 marks with coins of ancient India from the Buddha period till the pandemic period. It also consisted equal number of coins from 200 nations of the globe. The notaphily collection contains currency notes of 190 countries of the world covering various themes like flora and fauna, national heroes, scientific inventions, freedom movements, art, literature and social life.

The philately collection consists of 16000 postage stamps from almost all countries of the world. These miniature paintings carry authentic pictures of almost everything. And the phillumeny collection of 15000 matchbox pictures covered local animals, birds, deities, national heroes, Bollywood stars, languages, numbers, tools and advertisements.

The last two projects were based on technology. The Covid pandemic changed the education drastically. With the modern technology like AI tools gaining the centre stage,

teachers are busy in finding new technological ways.

Conclusion: The Reverse Swing:

‘Strong technology cannot makeup for the weak pedagogy while strong pedagogy can be weakened by poor technology’ - Dr. Paul Sebastian at ‘Teach to Ignite’ workshop, Delhi 20-23 Sep. 2019.

With the ever-increasing use of technology, students rarely get opportunities for creative thinking. The modern schools are now providing everything ready made and the teachers have to carry it without giving a second thought. The incidents of misuse of technology is increasing day by day. Schools use technology to remained connected with the parents but ban use of cell phones by students in school premises. Misuse of AI to create false images, social media to spread false and tailored information is at spree. These need to be checked immediately otherwise we will create crippled generations with less regard for human values and wholly dependent on technology.

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Role of Virtual Reality and Augmented Reality in Environmental Education: Emerging Trends, Pedagogical Impact, and Future Possibilities

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Abstract:

Environmental education has become increasingly important in the twenty-first century because societies across the world are facing severe ecological crises such as climate change, biodiversity loss, pollution, and unsustainable resource consumption. Conventional classroom approaches often fail to provide learners with direct experiences of environmental problems, particularly those that occur at large geographical scales or in inaccessible ecosystems. In recent years, Virtual Reality (VR) and Augmented Reality (AR) technologies have emerged as innovative educational tools capable of transforming environmental learning into an immersive and interactive process. This review paper critically examines the role of VR and AR in environmental education by synthesizing studies published between 2015 and 2026. The paper discusses conceptual foundations, educational applications, pedagogical outcomes, technological limitations, and future prospects associated with immersive technologies. Findings indicate that VR and AR significantly improve learner engagement, conceptual understanding, empathy toward nature, environmental awareness, and collaborative learning. Immersive simulations enable students to visualize climate change, ecosystem degradation, disaster scenarios, and conservation practices more effectively than traditional teaching methods. However, challenges related to infrastructure, affordability, teacher training, accessibility, and curriculum integration continue to hinder large-scale implementation, especially in developing countries. The paper further highlights the importance of localized content, interdisciplinary collaboration, and policy support for sustainable integration of immersive technologies into environmental education. The study concludes that VR and AR possess transformative potential to develop environmentally responsible citizens and support sustainability-oriented education in the coming decades.

Keywords: *Virtual Reality, Augmented Reality, Environmental Education, Climate Education, Immersive Learning, Sustainability, Educational Technology.*

Introduction:

Environmental degradation has emerged as one of the most serious concerns confronting humanity today. Climate change, rising sea levels, water scarcity, deforestation, biodiversity depletion, and increasing pollution threaten both ecological stability and human survival. In response to these global concerns, environmental education has gained recognition as an essential component of modern educational systems.

Environmental education seeks not only to provide scientific knowledge but also to cultivate awareness, ethical responsibility, and sustainable behavior among learners.

Traditional methods of environmental teaching generally depend on textbooks, lectures, photographs, charts, and occasional field visits. Although these methods provide theoretical understanding, they often fail to create deep emotional engagement or experiential learning

opportunities. Many environmental phenomena are difficult to observe directly because they occur over long periods, in remote locations, or at microscopic and global scales. As a result, students may struggle to connect theoretical concepts with real-world environmental challenges.

The rapid development of digital technologies has opened new possibilities for addressing these limitations. Among these innovations, Virtual Reality (VR) and Augmented Reality (AR) have attracted considerable attention in educational research. VR creates a fully immersive digital environment that allows users to experience simulated realities through head-mounted displays and interactive interfaces. AR, on the other hand, overlays digital information onto the physical environment using mobile devices, tablets, or smart glasses. Both technologies encourage active participation and experiential learning.

In environmental education, immersive technologies have been used to simulate climate change scenarios, virtual ecosystems, disaster management situations, biodiversity exploration, and pollution mapping. Learners can virtually dive into coral reefs, walk through rainforests, or observe the long-term consequences of environmental degradation. Such experiences help bridge the gap between abstract scientific concepts and personal understanding.

The growing adoption of immersive technologies is also connected to the broader global agenda of sustainable development. The United Nations Sustainable Development Goals (SDGs), especially SDG 4 related to quality education and SDG 13 related to climate action, emphasize the importance of innovative and inclusive educational practices. VR and AR have the capacity to support these goals by making environmental learning more accessible, engaging, and impactful.

Despite increasing interest in this field, existing literature remains scattered across disciplines such as educational technology, computer science, environmental studies, and psychology. Furthermore, many studies focus on technical aspects while neglecting pedagogical and social implications. Therefore, this review paper attempts to provide a comprehensive analysis of VR and AR applications in environmental education, highlighting their benefits, challenges, and future possibilities.

Objectives of the Study:

The present review has been undertaken with the following objectives:

1. To examine the conceptual foundations of Virtual Reality and Augmented Reality in education.
2. To analyze the applications of immersive technologies in environmental education.
3. To evaluate the pedagogical and behavioral impacts of VR and AR on learners.
4. To identify the challenges associated with the implementation of immersive technologies.
5. To suggest future directions for research, policy development, and educational practice.

Research Methodology:

This paper adopts a systematic review approach. Relevant research articles, conference papers, book chapters, and reports published between 2015 and 2026 were collected from databases such as Scopus, Web of Science, IEEE Xplore, SpringerLink, ScienceDirect, and Google Scholar. Keywords used during the search process included “Virtual Reality in environmental education,” “Augmented Reality climate learning,” “immersive sustainability education,”

“environmental simulations,” and “VR/AR pedagogy.”

Initially, more than 120 studies were identified. After screening abstracts and removing duplicate or irrelevant studies, 68 publications were selected for detailed analysis. Priority was given to peer-reviewed empirical studies and review articles that focused directly on educational applications of VR and AR in environmental contexts. The selected studies were analyzed in terms of research design, geographical location, educational level, technological tools used, and major findings.

The review also considered interdisciplinary perspectives from psychology, pedagogy, sustainability studies, and educational technology. While the review provides broad coverage of the subject, certain limitations remain. Non-English publications and unpublished dissertations were excluded, which may limit representation of regional perspectives.

Conceptual Understanding of VR and AR:

Virtual Reality refers to computer-generated three-dimensional environments in which users interact through sensory devices such as VR headsets, motion controllers, and headphones. VR systems create a strong sense of presence by immersing users in artificial environments that respond to their actions in real time. Popular devices include Meta Quest, HTC Vive, Oculus Rift, and PlayStation VR.

Augmented Reality differs from VR because it does not replace the real world entirely. Instead, AR integrates digital elements into the physical environment. Through smartphones, tablets, or wearable devices, users can view additional information, animations, or interactive models superimposed onto real surroundings. AR applications are generally more accessible because they can operate on ordinary mobile devices.

Educational theorists often connect VR and AR with constructivist learning theory and experiential learning theory. According to constructivism, learners develop knowledge actively through interaction and exploration rather than passive memorization. Similarly, experiential learning emphasizes learning through direct experience and reflection. Immersive technologies support these approaches by allowing students to interact with virtual ecosystems, manipulate environmental variables, and observe consequences in simulated environments.

Another important concept associated with VR is “presence,” which refers to the psychological feeling of being inside a virtual environment. Higher levels of presence often result in stronger emotional engagement and improved learning outcomes. AR, meanwhile, supports situated learning because learners interact with educational content within real-world contexts.

Applications of VR and AR in Environmental Education:

One of the most significant applications of VR in environmental education is the creation of virtual field trips. Many schools and universities cannot organize frequent field visits because of financial, geographical, or safety limitations. VR overcomes these barriers by enabling students to explore forests, oceans, glaciers, deserts, and wildlife reserves virtually. Students can experience endangered ecosystems and understand ecological interdependence in greater depth.

Climate change education has also benefited substantially from immersive technologies. Scientific concepts such as global warming, carbon cycles, and sea-level rise are often difficult for students to visualize. VR simulations allow learners to witness the melting

of glaciers, flooding of coastal cities, and long-term consequences of greenhouse gas emissions. Such experiences make climate science more concrete and understandable.

AR applications are increasingly being used in biodiversity education. Mobile-based AR tools enable students to identify plant and animal species by scanning images or natural objects. Interactive 3D models help learners understand ecological relationships, food chains, and habitat structures. Several museums and science centers have introduced AR exhibits to increase public engagement with environmental conservation.

Environmental pollution is another important area where immersive technologies have shown educational value. VR simulations can demonstrate the spread of air pollution, industrial waste, plastic accumulation in oceans, and groundwater contamination. Learners are able to observe environmental damage from multiple perspectives, encouraging critical thinking and problem-solving skills.

Disaster risk reduction and environmental safety training represent another emerging application. VR-based disaster simulations expose students to floods, wildfires, earthquakes, cyclones, and oil spills in safe virtual settings. These simulations improve disaster preparedness and help learners understand the importance of resilience and environmental planning.

Immersive technologies are also increasingly used for environmental activism and public awareness campaigns. Environmental organizations and museums have adopted VR documentaries and interactive experiences to encourage public participation in sustainability movements. Such initiatives demonstrate that VR and AR can influence not only classroom learning but also community engagement and policy awareness.

Pedagogical Impact of Immersive Technologies:

Research findings consistently suggest that VR and AR improve student motivation and classroom engagement. Traditional environmental science lessons may appear abstract or theoretical to learners, whereas immersive technologies transform learning into an interactive experience. Students generally show higher levels of curiosity, participation, and enthusiasm when learning through simulations and immersive environments.

Another important educational benefit is improved conceptual understanding. Environmental systems involve complex interactions between physical, biological, and social processes. VR allows learners to visualize these interactions dynamically. For example, students can observe how deforestation affects soil erosion, biodiversity, and climate patterns simultaneously. Such multidimensional learning experiences enhance systems thinking and scientific reasoning.

Immersive learning also contributes to emotional engagement and empathy development. Environmental problems are often psychologically distant from learners because they occur in remote regions or affect future generations. VR experiences reduce this psychological distance by placing learners inside threatened ecosystems or disaster situations. Studies indicate that immersive experiences can strengthen emotional attachment to nature and encourage environmentally responsible behavior.

Collaboration and communication skills may also improve through multi-user virtual environments. Students working together in VR-based projects engage in discussion, problem-solving, and cooperative decision-making. Such collaborative learning environments reflect real-world scientific and environmental management practices. Several studies have highlighted the

inclusivity potential of immersive technologies. AR applications can support students with diverse learning needs through visual and interactive learning formats. Similarly, virtual field trips may provide opportunities for students who cannot participate in physical excursions because of disabilities or financial constraints.

At the same time, educators must recognize that technology itself does not automatically guarantee meaningful learning. Effective pedagogical design, guided reflection, and curriculum alignment remain essential for maximizing the educational value of immersive experiences.

Empirical Evidence from Recent Studies:

Empirical studies conducted in different countries demonstrate positive educational outcomes associated with VR and AR. Makransky et al. reported that students who participated in VR-based science learning demonstrated significantly higher engagement and knowledge retention compared to traditional instructional groups [1]. Similarly, Radianti et al. found that immersive learning environments improved conceptual understanding and collaborative learning outcomes in science education [2].

Research conducted in Singapore on coral reef education revealed that students who explored underwater ecosystems through VR displayed stronger empathy toward marine conservation than students who learned through ordinary video presentations [3]. In Finland, AR-based biodiversity learning tools significantly improved students' species recognition abilities and ecological awareness [4].

Japanese disaster education programs using VR simulations reported improved disaster preparedness and risk perception among learners [5]. These studies indicate that immersive experiences can influence both cognitive learning and behavioral intentions.

Studies conducted in India also reveal encouraging results. Pilot projects implemented in Maharashtra schools demonstrated improved student participation and environmental science performance after the introduction of low-cost VR modules [6]. Teachers reported that students who usually remained passive during classroom discussions became more actively involved during immersive learning activities.

Another important finding emerging from recent literature is the long-term impact of emotional immersion. Research suggests that immersive experiences may encourage sustainable behavior such as waste reduction, energy conservation, and support for environmental protection initiatives. Although more longitudinal research is required, existing evidence indicates that immersive learning can contribute to environmental citizenship and behavioral transformation.

Challenges and Limitations:

Despite promising educational benefits, the integration of VR and AR into environmental education faces several challenges. One major barrier is the high cost of hardware and software. Advanced VR headsets, computers, sensors, and content development tools require substantial financial investment. Many educational institutions, particularly in developing countries, lack adequate funding and infrastructure.

Teacher preparedness represents another critical challenge. Many educators are unfamiliar with immersive technologies and may feel hesitant to incorporate them into classroom teaching. Effective implementation requires technical training, pedagogical understanding, and confidence in managing digital learning environments. The digital divide also remains a serious concern. Urban schools generally have greater access to digital infrastructure compared to rural institutions. Unequal access to internet

connectivity, electricity, and technological devices may increase educational disparities rather than reduce them.

Certain physical and psychological limitations have also been reported. Some users experience motion sickness, eye strain, dizziness, or discomfort during prolonged VR use. Ethical concerns related to data privacy, surveillance, and psychological manipulation require careful consideration.

Another limitation involves the availability of localized and culturally relevant content. Much of the existing VR and AR material has been developed in Western contexts. Environmental challenges specific to countries such as India, including river pollution, monsoon variability, and local biodiversity conservation, are often underrepresented.

Curriculum integration presents an additional challenge. In many institutions, immersive technologies are treated as optional or supplementary tools rather than integral components of educational programs. Without proper curriculum planning and assessment frameworks, the long-term educational impact of VR and AR may remain limited.

Future Prospects and Recommendations:

The future of immersive environmental education appears promising due to rapid technological advancements and decreasing hardware costs. Affordable mobile VR systems and smartphone-based AR applications are making immersive learning more accessible to schools and communities with limited resources.

One important recommendation is the development of localized educational content. Educational institutions, environmental organizations, and technology developers should collaborate to create simulations related to local environmental issues such as Western Ghats biodiversity, Himalayan glacier retreat,

groundwater depletion, and urban waste management in India. Localized content increases cultural relevance and learner engagement.

Teacher training programs should also receive greater attention. Universities, teacher education institutions, and educational boards must organize workshops and certification programs focused on immersive pedagogy. Teachers need practical guidance on designing meaningful learning experiences rather than using technology merely for demonstration purposes. Policy support is equally important. Governments and educational authorities should integrate immersive technologies into national educational strategies and environmental curricula. Public investment in digital infrastructure, open educational resources, and rural connectivity can facilitate wider adoption.

Future research should focus on longitudinal studies examining behavioral outcomes and environmental attitudes over extended periods. Most current studies evaluate short-term learning gains, while fewer investigate whether immersive experiences produce lasting behavioral transformation. The integration of emerging technologies such as Artificial Intelligence, haptic feedback, and cloud computing may further expand educational possibilities. AI-driven adaptive learning systems can personalize immersive experiences according to learners' needs and performance levels. Similarly, haptic technologies may enhance sensory immersion by enabling users to feel environmental interactions virtually.

Interdisciplinary collaboration will remain essential for sustainable implementation. Environmental scientists, software developers, educators, psychologists, and policymakers must work together to ensure that immersive technologies remain educationally meaningful, ethically responsible, and socially inclusive.

Conclusion:

Virtual Reality and Augmented Reality are reshaping environmental education by providing immersive, interactive, and experiential learning opportunities. Unlike traditional teaching approaches, immersive technologies allow learners to observe environmental phenomena directly, engage emotionally with ecological issues, and participate actively in problem-solving processes. Evidence from recent studies demonstrates that VR and AR enhance learner engagement, conceptual understanding, empathy, and environmental awareness. The applications of immersive technologies in climate education, biodiversity conservation, disaster preparedness, pollution awareness, and sustainability learning highlight their transformative educational potential. However, widespread implementation continues to face challenges related to cost, infrastructure, teacher training, accessibility, and curriculum integration.

For developing countries such as India, immersive technologies present both opportunities and challenges. Strategic investment, localized content development, and inclusive policy frameworks are essential for ensuring equitable access and meaningful educational outcomes. If implemented responsibly, VR and AR can contribute significantly to sustainability-oriented education and the development of environmentally conscious citizens. The future of environmental education will likely depend on the ability of educators and policymakers to combine technological innovation with human-centered pedagogy. Immersive technologies should not replace teachers or traditional educational practices entirely; instead, they should function as complementary tools that enrich learning experiences and strengthen environmental responsibility among learners.

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Utilization of Fly Ash as an Industrial Waste As a Novel Catalyst for Pharmaceutical Preparations

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Abstract:

Heterogeneous acid catalysts are active in a wide range of applications. In this review, an overview is given of the current knowledge available about the fly ash catalysts and their catalytic activity in various organic transformations and Pharmaceutical Preparations. Atom effective, cost-effective recyclable and environmentally benign like attributes makes fly ash as catalyst a good alternative over hazardous catalyst.

Introduction:

Catalytic technologies play a key role in the economic development and growth of the chemicals industry and contribute to around 20% of world GNP (gross national product). Development of heterogeneous catalysts has been a relatively recent area of research in the organic synthesis. A major emerging and challenging area of heterogeneous catalysis is that of environmental pollution control, with tightening legislation on the release of waste and toxic emissions having serious implications for the chemical industry [1]. The need for development of heterogeneous catalysts has arisen from the fact that homogeneous catalysts used for organic synthesis pose a few drawbacks.

Heterogeneous acid catalysts can be prepared via several methods. Such as impregnation, precipitation, co-precipitation, chemical vapor deposition etc. Various characterization techniques like FTIR, pyridine FTIR, XRF, SEM-EDX, ESR, XPS and XRD can

provide the detailed information of acidic sites on the catalytic surface.

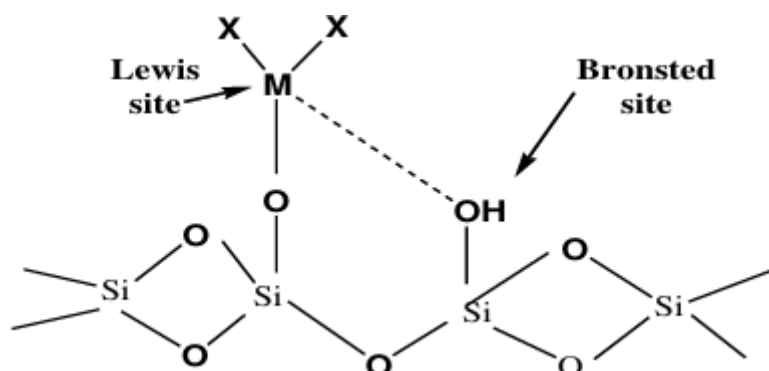
Heterogeneous catalysts offer several intrinsic advantages over their homogeneous counterparts: ease of product separation and catalyst reuse; bifunctional phenomena involving reactant activation/spillover between support and active phases; and process advantages through reactor operation in continuous flow versus batch configuration [2]. Heterogeneous catalysts are categorized as solid acid and solid base. A solid acid catalyst should possess high stability, numerous strong acid sites, large pores, a hydrophobic surface providing a favorable condition for reaction, and should also be economically viable [3]. This review focuses exclusively on fly ash supported solid acid catalysts as potential heterogeneous catalysts and their role in various organic transformations.

Generation of Acidic Sites:

Heterogeneous acid catalysts are generally categorized by their Brönsted and/or

Lewis acidity, the strength and number of these sites, and the morphology of the support (e.g. surface area, pore size, pore volume). The synthesis of pure Brønsted and pure Lewis acid catalysts attracts a great degree of academic

interest, although the latter is harder to achieve because Brønsted acidity often arises from Lewis acid-base complexation, as illustrated in Scheme 1.



Scheme 1. Brønsted acidity arising from inductive effect of Lewis acid center coordinated to a silica support

Materials of Heterogeneous Acid Catalysts:

Some materials which catalyze acid-catalyzed reactions are listed in Table 1.

Table 1: Materials for solid acid catalysts

Supports	Heterogeneous acid catalysts	Ref.
Silica supported metal oxides	HClO ₄ /SiO ₂ , CoBr ₂ /S	[10], [11]
Alumina supported metal oxides	Polyphosphoric acid/Al ₂ O ₃	[12]
Mesoporous acid materials	Al/SBA-15	[13]
Solid super acids	Tunstated zirconia-alumina	[14]
Pure metal Oxides	Nano sulfated TiO ₂ , WO ₃ /ZrO ₂	[15], [16]

Fly Ash Supported Solid Acid Catalysts:

FA contains high silica and alumina content, high degree of fineness, larger surface area, higher surface energy and more acting faces which make it suitable to be used as solid catalyst and catalytic support for acid catalyzed reactions under solvent free condition. To improve surface activity of fly ash, several activation techniques such as mechanical [17], thermal [18] and chemical treatments [17] have been discussed in the literature which enhances the reactivity of fly

ash from the combined effects of increased surface area and physicochemical changes induced in the bulk as well as on the surface.

Homogeneous acids such as H₂SO₄, H₃PO₄ [19] and heteropolyacids [20] represent the most commonly used catalysts for most of the important esterification reactions. But these acids are corrosive, hazardous, used in more than stoichiometric amounts, difficult to recover from reaction mixture, cannot be reused and leads to low selectivity of desired product with production

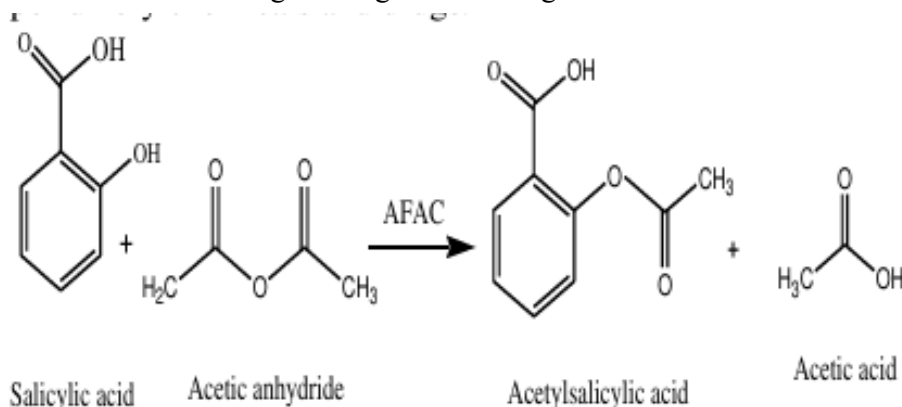
of large volume of environmentally hazardous acidic waste. New environmental legislations calls for the reduction of waste production and use of more environmentally friendly alternative catalysts, makes the current homogeneous system environmentally unacceptable. The substitution of traditional homogeneous Lewis and Brönsted acid catalysts by heterogeneous ones, e.g. solid acid catalysts such as sulfated zirconia, zeolites, acidified silica [21] constitutes a more environmentally friendly alternative to the organic reactions.

Acid activation of FA has been widely used for developing acidic sites for catalytic applications as solid acid. HCl treated fly ash catalyst was prepared by Anita et al. [22] to examine their catalytic activity in esterification acetic acid with n-butanol which gave high

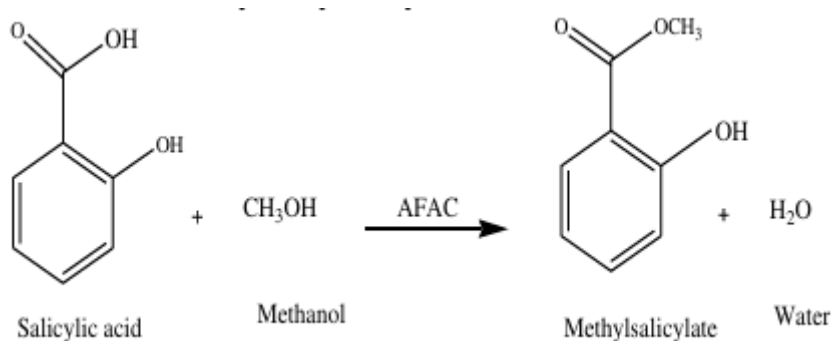
selectivity (99.6%) and high yield of n-butyl acetate.

Khatrri et al. [23] reported H_2SO_4 treated fly ash as nano-crystalline solid acid catalyst (AFAC) for esterification of salicylic acid with acetic anhydride and methanol to produce acetylsalicylic acid (aspirin) and methyl salicylate (oil of wintergreen) respectively in a single step, liquid phase and solvent free reaction condition with high yield >90% and purity (Scheme 2 & 3). Acetylsalicylic acid is commonly known by its trade name aspirin is an effective non-steroidal analgesic, antipyretic and anti-inflammatory drug [24]. The catalytic activity of the catalyst was efficiently reported upto 4 reaction cycles.

Esterification products have wide applications in flavors, perfumery chemicals and drugs.



Scheme 2. Esterification of salicylic acid with acetic anhydride to acetylsalicylate by AFAC



Scheme 3. Esterification of salicylic acid with methanol to methylsalicylate by AFAC

Recently, Coal fly ash supported Co_3O_4 catalysts were synthesized using impregnation method by Muhammad et al. [25]. These catalysts

were tested in peroxy monosulfate activation for sulfate radical generation and phenol degradation in aqueous solution. Kinetics study showed that

phenol degradation followed first order kinetics. Resource recovery is one of the most effective strategies in waste management. Using solid waste for other application provides a route for solid waste recycling and a reduction waste disposal to landfills, bringing in environmental benefits and economic profits.

Sulfated zirconia supported fly ash catalyst was investigated by Khatri et al. [26] which found to be effective in solvent-free liquid phase benzylation of benzene, or toluene with benzyl alcohol.

Friedel-Craft acylation of 3,4-dimethoxyacetophenone using veratrole and acetic anhydride was investigated over cerium triflate loaded fly ash as a solid acid catalyst by Khatri et al.

Conclusion:

This article deals with application of fly ash supported solid acid catalysts for various organic synthesis applied in recent publications. The process adopted for their preparation, their textural properties, thermal treatment, reuse, and leaching aspect have been discussed. The solid acid catalyst should be active, selective and stable under the reaction conditions.

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