

AI-Driven Smart Concrete Curing System with IoT-Based Monitoring and Real time Strength Prediction

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Abstract - The conventional concrete curing process on construction sites is often inefficient due to the lack of continuous monitoring and precise environmental control, leading to inconsistencies in curing quality and reduced long-term durability of concrete structures. Traditional manual curing methods are labor-intensive, time-consuming, and prone to human error, which can result in defects such as plastic shrinkage cracks and reduced structural strength.

To address these limitations, this study proposes an IoT- and AI-enabled automated concrete curing system with real-time monitoring and intelligent control capabilities. The system employs wireless sensors to monitor critical parameters such as ambient temperature, relative humidity, and internal concrete temperature for strength maturity estimation.

Based on predefined thresholds and AI-driven decision-making, a smart control system with automated valves and sprinkler mechanisms regulates moisture levels to maintain optimal curing conditions, ensuring proper hydration of concrete and minimizing early-age cracking.

The proposed system enhances curing consistency, reduces manual intervention, and improves operational efficiency compared to conventional methods. Integration of IoT, automation, and artificial intelligence provides a scalable approach for smart concrete curing, contributing to improved durability and structural performance. A web or mobile dashboard enables real-time monitoring.

Keywords - Smart concrete curing system, Internet of Things (IoT), Artificial Intelligence, Machine Learning, Concrete maturity method, Real-time monitoring, Compressive strength prediction.

1. INTRODUCTION

Concrete is widely used in construction due to its strength, durability, and versatility. Proper curing is essential during

hardening to ensure full hydration of cement. Moisture content and temperature are key factors affecting concrete quality. Moisture controls the degree of hydration, while temperature affects reaction speed (Paskino, 2016).

Therefore, maintaining proper environmental conditions is critical. Evaporation caused by temperature, humidity, and wind must be minimized to avoid strength loss (Taffese, 2023).

Concrete curing is the process of maintaining moisture and temperature in fresh concrete. Evaporation is influenced by ambient temperature, relative humidity, wind speed, and concrete surface conditions. The ACI method is used to estimate evaporation rates from fresh concrete surfaces. Higher temperatures accelerate hydration, but uncontrolled conditions may lead to incomplete curing and reduced early strength. Traditional curing methods like ponding, sprinkling, and wet covering are commonly used, but they are difficult to control and monitor continuously (Baek, 2023).

Existing curing systems require manual monitoring and record-keeping, which is time-consuming and error-prone. Collecting accurate site data is challenging due to continuous construction activity and environmental variations (Mir, 2024).

1.2 Problem Statement

Traditional curing methods fail to provide continuous monitoring and precise environmental control. To address this, an IoT-based system is proposed to automatically maintain moisture and temperature in fresh concrete (Lau, 2024). The system uses multiple sensors to monitor temperature, humidity, wind speed, and moisture content. A water pump is integrated to automate curing when required, reducing manual effort and improving consistency.

Table 1.1 Hardware Components & Functions

S. No.	Component Name	Usage in Project
1	Breadboard	Circuit connections and prototyping without soldering
2	DHT11 Sensor	Measures ambient temperature and humidity
3	Relay Module	Controls water pump or sprinkler system automatically
4	Arduino UNO	Main controller for processing sensor data and system control
5	Temperature Sensor	Measures concrete/internal temperature for curing analysis
6	I2C Module	Enables communication with LCD/display for data visualization
7	MOSFET	Acts as electronic switch for controlling high-power devices
8	Resistors	Used for current limiting and circuit protection
9	Diode	Protects circuit from reverse current flow
10	Jumper Wires	Used for connecting components in the circuit

1.3 Proposed System Design

The proposed system is an IoT- and AI-based smart concrete curing system designed to monitor and control curing conditions in real time. The system integrates sensors to measure temperature, humidity, and moisture levels of concrete. This data is transmitted through an IoT module to a cloud platform for analysis.

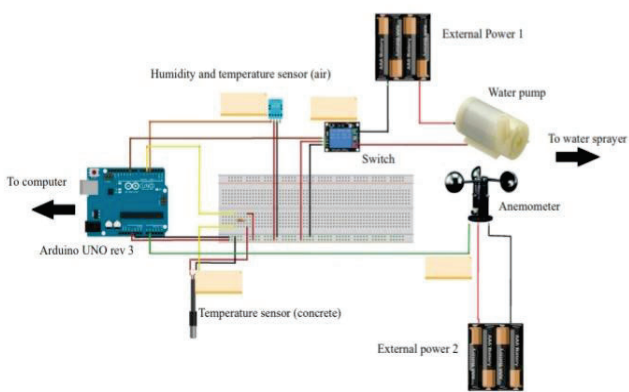


Fig 1.1 Devices Assembly Design

2.METHODOLOGY

The proposed IoT-based system is developed using ACI monograph parameters including concrete temperature, moisture content, air temperature, humidity, and wind speed. These parameters are continuously monitored using sensors integrated with a microcontroller and a water pump system.

Sensor data is transmitted to the microcontroller, which processes the information and controls the water spraying mechanism to maintain optimal curing conditions. The system adjusts the amount and timing of water spray based on evaporation rate to ensure proper surface moisture and temperature.

For intelligent optimization, machine learning techniques are applied. A regression model is used for initial estimation based on environmental conditions, while deep learning models such as Artificial Neural Networks (ANN) are used to capture complex non-linear relationships. The AI model predicts concrete strength and curing efficiency using real-time sensor data and continuously updates its predictions for improved accuracy.

Table2.1: Methodological Framework of the Study

Step	Stage	Description
1	Problem	Identify issues in traditional concrete curing
2	Design	Develop IoT-based automated curing system using Internet of Things
3	Data	Collect temperature and moisture data
4	AI	Predict optimal curing conditions
5	Automation	Control water supply automatically
6	Optimization	Reduce water use and human effort
7	Improvement	Enhance strength and durability
8	Monitoring	Track conditions and provide alerts
9	Testing	Test system performance
10	Validation	Evaluate results and efficiency
11	Conclusion	Summarize outcomes

3.RESULTS AND DISCUSSIONS

The system was tested in both laboratory and field conditions.

Key Findings:

- Sensors provided accurate real-time data
- Stable IoT communication with no data loss
- Automated curing maintained optimal conditions

Performance Improvement:

- ✓ 10–12% higher early-age compressive strength

- ✓ 20–25% reduction in water consumption
- ✓ Reduced cracking and improved durability

Model Accuracy:

MAE = 5.3 MPa

RMSE = 7.6 MPa

$R^2 = 0.89$

3.1 Real-Time Data Acquisition, Monitoring, and Analysis

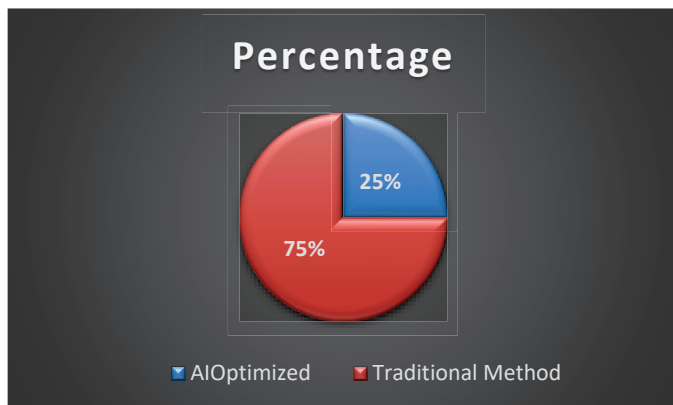


Fig 3.1 Resources Efficiency in Curing

Resource efficiency in concrete curing is a key requirement for sustainable and modern construction practices. It focuses on minimizing the consumption of water, energy, and human effort while maintaining optimal curing quality. Conventional curing methods often lead to uncontrolled water usage and resource wastage. In contrast, automated and sensor-based curing systems significantly improve efficiency and precision. Real-time monitoring of temperature and moisture conditions enables data-driven decision-making. Water is supplied only when required, eliminating unnecessary consumption. IoT-enabled systems ensure precise control over curing operations with minimal manual intervention. This reduces labor dependency and associated operational costs. Energy usage is optimized by activating curing mechanisms only during critical conditions. Distributed sensor networks ensure uniform curing across large structural elements. This prevents over-curing and under-curing conditions in different zones.

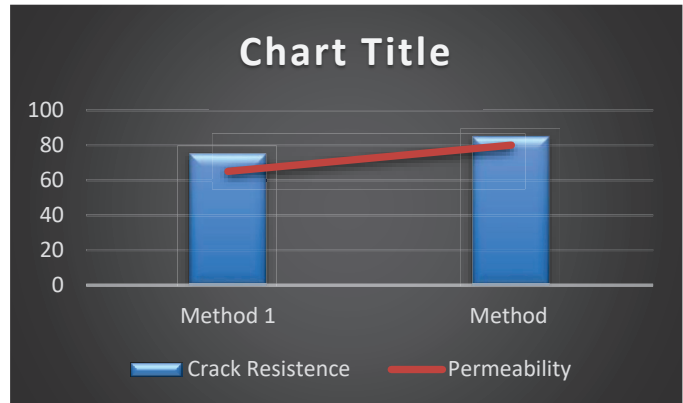


Fig 3.2 Impact of AI Optimization on Durability.

The temperature sensor also supports early-age strength prediction using maturity calculations based on temperature history. It is designed to be durable, waterproof, and chemically resistant for reliable performance in harsh environments. The real-time data is transmitted to an IoT system, enabling remote monitoring, automated control, and efficient curing operations.

The proposed system integrates temperature and humidity sensors, IoT gateway, and smart water valves to monitor moisture loss and control curing automatically. Water is sprayed when moisture drops below a set limit and stopped when adequate hydration is achieved. This closed-loop system ensures optimal curing, reduces cracking, improves strength, and minimizes manual intervention.

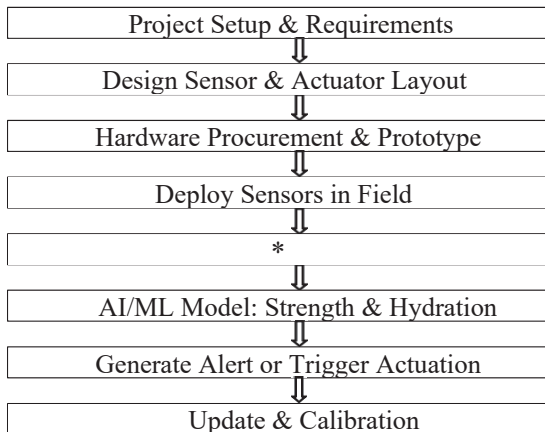
3.2 Model Performance, Accuracy Error Metrics

The AI-based model was validated using multiple error metrics and cross-validation techniques, demonstrating consistent and reliable performance. The Mean Absolute Error was 5.3 MPa and the Root Mean Squared Error was 7.6 MPa, indicating low prediction deviation. The R-squared value of 0.89 reflects a strong correlation between predicted and actual concrete strength. Furthermore, 10-fold cross-validation confirmed the robustness, stability, and generalization capability of the model.

Although the results indicate high accuracy, minor deviations may arise due to variations in material properties, environmental conditions, and sensor noise. However, these variations remain within acceptable engineering limits and do not significantly affect overall prediction reliability.

The model is capable of adapting to different curing scenarios with consistent performance. In addition, the integration of real-time sensor data enhances prediction precision and system responsiveness. Therefore, the proposed approach demonstrates strong potential for practical implementation in smart concrete curing applications.

Fig3.3 Designing An-IoT-Based System to Monitor and Control Curing Automatically



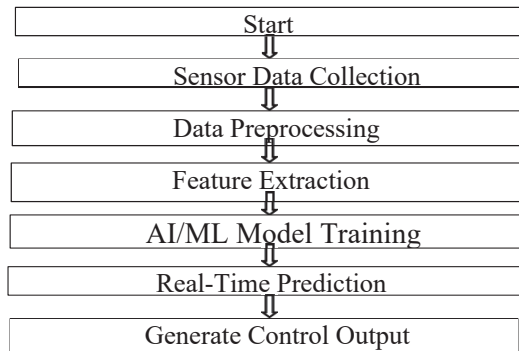
A structured experimental methodology was adopted to develop an IoT-based system for automated concrete curing monitoring and control. The study began by identifying limitations in conventional curing practices, including excessive water usage, inconsistent curing conditions, and reliance on manual monitoring.

An IoT-enabled smart curing system was designed to continuously monitor key parameters and enable automated control. The system integrated sensors (temperature, humidity, and moisture), microcontrollers (Arduino/ESP32/Raspberry Pi), actuators, and communication modules (Wi-Fi/GSM) to form a real-time data acquisition network. Sensor data were transmitted to a cloud platform for storage, monitoring, and alert generation.

A user interface was developed using IoT platforms such as ThingSpeak, Blynk, Firebase, or AWS IoT for real-time visualization of curing conditions. A threshold-based control algorithm was implemented to automate curing actions. When environmental parameters deviated from predefined limits, actuators were triggered for water spraying or mist curing to maintain optimal conditions.

The prototype was first validated in a controlled laboratory environment and subsequently tested at a construction site for field evaluation. System performance was assessed against conventional curing methods using parameters such as temperature stability, moisture retention, water consumption, and strength development. The results indicated improved thermal regulation and enhanced moisture retention compared to traditional curing practices. In addition, the system optimized water usage by supplying only the required amount based on real-time sensor data.

Fig 3.4 Integrating AI- Algorithms for Predicting Optimal Curing Conditions.



The integration of AI algorithms into the concrete curing process is based on continuous data acquisition through IoT-based sensors deployed at multiple locations within the curing environment.

These sensors record key parameters such as temperature, humidity, moisture content, ambient conditions, and surface hydration levels. The collected data is transmitted to a cloud database using wireless communication protocols such as Wi-Fi, GSM, or LoRaWAN, and stored in a time-stamped format for preprocessing.

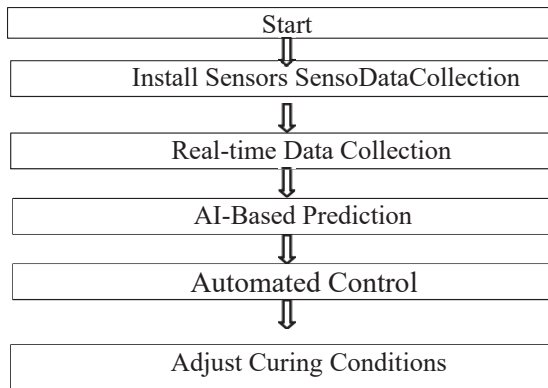
Before model development, the raw data undergoes preprocessing, including data cleaning, normalization, outlier removal, and noise filtering. Feature engineering is then applied to identify relationships between environmental variables and curing performance. Correlation analysis is used to select the most relevant features for model training.

Multiple machine learning and deep learning models, including Random Forest, Support Vector Regression, Artificial Neural Networks, and LSTM, are trained and evaluated using a split dataset. Model performance is assessed using metrics such as MAE, RMSE, and R^2 , and the best-performing model is selected for deployment.

The selected model is integrated into a decision-support system that analyzes real-time sensor data and compares it with predicted optimal curing conditions. When deviations are detected, the system generates alerts and recommends corrective actions such as adjusting water spraying, activating misting systems, or modifying curing conditions.

Finally, the system is validated through field deployment, where AI-based curing is compared with conventional methods in terms of strength development, moisture retention, durability, and cost-effectiveness. The AI model also enables estimation of optimal curing duration based on environmental variations and material properties.

Fig 3.5 Minimizing Human Effort, Water Usage



The proposed methodology reduces manual effort, water usage, and data inaccuracies in concrete curing by implementing an IoT-based automated monitoring system. Sensors continuously measure key parameters such as temperature, humidity, and moisture content, enabling real-time data acquisition without frequent manual inspection.

An automated control mechanism using solenoid valves and misting devices regulates water application based on predefined sensor threshold values, aiming to ensure efficient and uniform curing while minimizing water wastage.

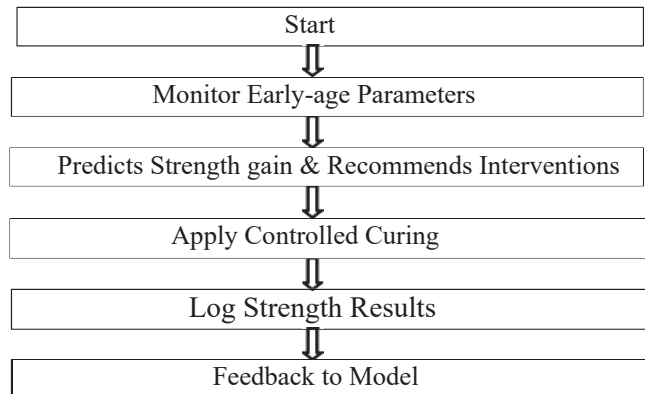
All sensor data are transmitted to a cloud platform where filtering and preprocessing are applied to reduce noise and improve data reliability. A digital dashboard enables real-time monitoring and automated reporting, thereby reducing manual record-keeping and the need for frequent site visits.

Predictive analytics is integrated to optimize water usage by learning from historical and real-time data, supporting adaptive and data-driven curing decisions for improved efficiency and concrete quality.

Overall, the system promotes sustainable curing practices with improved monitoring accuracy, operational efficiency, and reduced labor and resource costs, making it suitable for modern smart construction applications. The approach further supports engineers by providing data-driven insights for better planning and resource management in construction projects.

The system architecture is designed to support scalability, allowing integration of additional sensors for larger construction sites without significant modifications. Data security measures are incorporated to ensure safe transmission and storage of sensor information on the cloud platform. Edge computing techniques can also be integrated in future work to reduce latency and improve real-time decision-making. The system performance is continuously evaluated through feedback loops between sensed data and control actions.

Fig 3.6 Improving Early-Age Compressive Strength and Durability.



Improving early-age compressive strength and durability requires a shift from conventional curing methods to a technology-driven, optimized approach. The methodology begins with identifying key curing parameters such as moisture retention, temperature, humidity, and hydration rate. IoT-based sensors are used to continuously monitor these parameters, enabling real-time assessment of hydration behavior and strength development.

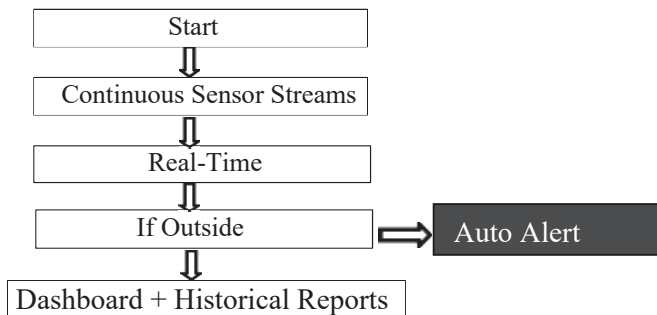
In addition to monitoring, material optimization is considered through the use of supplementary cementitious materials such as fly ash, silica fume, and slag, along with admixtures and optimized water-cement ratios. Smart curing materials like superabsorbent polymers are also explored to enhance internal moisture retention and reduce shrinkage.

An automated curing system is implemented using actuators such as solenoid valves and misting devices, which operate based on sensor feedback. This ensures consistent moisture supply and temperature control, preventing early-age cracking and promoting the formation of hydration products essential for strength development.

AI-based predictive models are integrated to analyze hydration trends and estimate microstructural development. These models help optimize curing duration and identify risks such as shrinkage or thermal cracking, enabling corrective actions like increased misting or insulation.

Finally, the system is validated through laboratory and field testing by comparing AI-based curing with conventional methods at 3-day, 7-day, and 28-day intervals. Performance is evaluated in terms of compressive strength, durability indicators, and crack resistance. Continuous learning from collected data further improves model accuracy and supports scalable, performance-based curing strategies for future construction projects.

Fig 3.7 Ensuring Optimal Curing Conditions by Continuously Tracking Environmental Factors



4. CONCLUSION

This study presents an AI-driven smart concrete curing system that integrates temperature and humidity sensors, IoT technology, and automated water control to optimize curing conditions. The system continuously monitors internal concrete conditions and applies the maturity method for early-age strength prediction, enabling precise and efficient curing.

The performance evaluation of the AI model demonstrates high accuracy with low error metrics, confirming its reliability in predicting concrete strength. The closed-loop automation ensures timely water application based on real-time data, reducing manual intervention, minimizing cracking risks, and improving overall durability.

Furthermore, the integration of IoT enables remote monitoring and data logging, enhancing construction management and quality assurance. The proposed system offers a scalable and efficient solution for modern construction practices, contributing to improved structural performance, resource optimization, and the development of intelligent infrastructure systems.

5. FUTURE SCOPE

The proposed system can be further enhanced by integrating advanced AI and machine learning models such as deep learning and reinforcement learning for adaptive, self-optimizing curing control based on real-time site conditions.

The development of a Digital Twin of the concrete structure can enable real-time simulation and prediction of temperature, moisture, and strength behavior, allowing proactive decision-making and improved lifecycle management.

Integration with Building Information Modeling (BIM) platforms can facilitate seamless data exchange between design, construction, and monitoring stages, enabling smarter construction workflows and data-driven decision support. Cloud-based analytics combined with edge computing can further improve system scalability, reduce latency, and support

large infrastructure projects.

Future advancements may also include multi-sensor fusion (temperature, humidity, strain, and crack sensors) for comprehensive structural health monitoring. Additionally, incorporating renewable energy sources such as solar power can enhance sustainability.

This system can ultimately evolve into a fully autonomous smart curing and monitoring solution for next-generation infrastructure, including smart cities, highways, bridges, and large-scale concrete structures.

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