Structural Health Monitoring Using IOT

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ABSTRACT

In the construction industry, maintaining structural integrity is pivotal for safety, efficiency, and economic viability. Traditional inspection methods, often sporadic and reliant on visual assessments, can overlook critical issues, especially in challenging environments where access is restricted or hazardous. The integration of IoT (Internet of Things) technology has revolutionized structural health monitoring by enabling continuous, remote data collection and analysis through sophisticated sensor networks. These networks, comprising wireless sensors strategically placed across buildings or infrastructure, monitor a range of parameters including temperature, humidity, light levels, vibration, and structural strain. This real-time data is transmitted wirelessly to central hubs or gateways, typically utilizing cost-effective solutions like Raspberry Pi devices programmed with Python for efficient data management. The collected data is then processed and stored in cloud servers, leveraging the scalability and accessibility of cloud computing to facilitate advanced signal processing and analysis. MATLAB is utilized for its robust capabilities in numerical computing and visualization, presenting the data in graphical formats that highlight trends, anomalies, and potential deterioration patterns. Crucially, this system incorporates an alert mechanism, notifying stakeholders via email of critical sensor readings or emerging issues, enabling swift responses to prevent accidents or structural failures.

The adoption of IoT-enabled structural health monitoring offers multifacetedbenefits to the construction industry and broader economic landscape. By continuously monitoring infrastructure health, this approach allows for early detection of defects or wear, facilitating proactive maintenance interventions that can significantly extend the service life of buildings and infrastructure. This proactive maintenance not only enhances safety and reliability but also reduces long-term costs associated with reactive repairs and unplanned downtime. Moreover, by minimizing the need for frequent physical inspections, IoT technology contributes to environmental sustainability by reducing carbon emissions associated with transportation and improving operational efficiency through data-driven decision-making. These efficiencies translate into tangible economic gains, as stakeholders can optimize resource allocation, prioritize maintenance efforts, and mitigate the financial impacts of unexpected structural failures or degradation. From a safety perspective, IoT-enabled monitoring systems enhance risk management by providing real-time insights into structural conditions. By identifying potential hazards or weaknesses early on, stakeholders can implement targeted interventions to mitigate risks and ensure compliance with stringent safety regulations. This proactive approach not only protects human livesbut also safeguards investments in infrastructure by preemptively addressing issuesbefore they escalate into costly emergencies. Furthermore, by leveraging cloud-based data storage and analytics, these systems empower stakeholders with unprecedented access to comprehensive, actionable insights.

CHAPTER 1

INTRODUCTION

In the realm of civil engineering, ensuring the safety and longevity of expansive structures such as buildings and bridges stands as an imperative task. Historically, achieving this goal has relied on periodic manual inspections, which are both labor-intensive and costly, and often fall short in promptly detecting evolving structural issues. Recognizing these challenges, the field of structural health monitoring (SHM) has emerged as a transformative approach, harnessing advanced technologies to deliver continuous, real-time assessments of structural integrity. Unlike conventional methods, SHM integrates computerized systems with wireless sensors to autonomously monitor and identify potential damage, offering substantial improvements in efficiency, precision, and cost-effectiveness.

SHM systems deploy a network of strategically positioned sensors throughout a structure to monitor key parameters indicative of its health. These sensors measure critical structural responses such as displacement, vibration, acceleration, temperature, and humidity. The data collected is seamlessly transmitted wirelessly to a central base station or cloud-based platform for immediate analysis and storage. This capability for real-time monitoring empowers engineers and stakeholders to consistently evaluate the structural condition, promptly detect anomalies or deterioration, and initiate timely corrective measures as necessary.

At the heart of modern SHM systems lie IoT-based sensors enhanced by artificial intelligence (AI). These sensors are distinguished by their compact dimensions, low power consumption, and seamless integration with cloud computing infrastructure. They enable precise and continuous monitoring of structural health indicators over extended periods, providing a comprehensive understanding of howthe structure behaves under various conditions and loads. By minimizing human intervention and maximizing data accuracy, IoT-based sensors ensure the swift detection of potential issues, thereby optimizing maintenance efforts and potentially extending the operational lifespan of infrastructure assets.

An illustrative example of SHM's impact can be observed in its application to concrete structures. Traditionally, monitoring the health and performance of concrete has been challenging due to its complex behavior under diverse environmental and loading conditions. IoT-enabled SHM systems, however, represent a breakthrough by facilitating real-time monitoring of critical factors such as compressive strength, cracking, and corrosion. These systems leverage advanced algorithms and predictive analytics not only to monitor current conditions but also to forecast future deterioration trends. This capability supports proactive maintenance strategies aimed at mitigating risks and minimizing repair costs over the structure's lifecycle.

Beyond its technical merits, IoT-enabled SHM systems yield significant economic and societal bbenefits. By reducing reliance on reactive maintenance practices and enabling proactive interventions, these systems help minimize disruptions to public services and operations, thereby enhancing overall safety and reliability. Furthermore, by optimizing maintenance schedules and resource allocation, SHMcontributes to cost savings and efficiency enhancements in infrastructure management. This proactive approach not only bolsters infrastructure resilience against natural disasters and aging but also aligns with sustainable development objectives by reducing environmental impacts linked to frequent repairs andreplacements.

The adoption of IoT-enabled SHM signifies a paradigm shift in how civil engineering addresses the challenge of maintaining large-scale infrastructure. By integrating advanced sensor technologies with AI-driven analytics and cloud computing, SHM systems offer continuous monitoring, proactive maintenance, and data-driven decision-making capabilities critical to ensuring the safety, durability, and economic viability of civil structures. As technology continues to evolve, these systems promise further advancements in infrastructure resilience, efficiency, and sustainability, positioning SHM as a cornerstone of contemporary infrastructure management practices worldwide.

CHAPTER 2

LITERATURE REVIEW

1. An IoT based building health monitoring system supported by cloud: Intelligent IoT systems for civil infrastructure health monitoring:

In future smart cities, many critical infrastructure and emergency management decisions will rely on machine learning (ML) techniques. One significant application involves processing large volumes of visual images and various types of data to evaluate defects. This data is collected by a network of IoT devices, including mobile units such as small unmanned aerial vehicles(UAVs) and robots. The accurate identification, measurement, and location ofareas with defects are crucial for the success of these evaluation processes.

Furthermore, real-time assessment is often essential in such applications. It allows the IoT device network to determine the most effective strategy and actions for efficiently gathering data in unfamiliar environments. For instance, in scenarios like earthquake reconnaissance and rescue operations, where robots are deployed into buildings without prior knowledge of their layout, real-time assessment ensures optimal decision-making and action planning bythe device network.

2. A BIM-Based Visual Warning Management System for Structural Health Monitoring Integrated with LSTM Network:

Structural Health Monitoring (SHM) encompasses monitoring both completed and under-construction building structures, with potential techniques impacting structural elements and potentially leading to hidden damage affecting construction safety. Digital and intelligent SHM is prioritized for safety management, involving rapid updating of dynamic data. However, challenges arise from disjointed data storage and presentation, hindering intuitive spatial understanding of monitoring data.

Building Information Modelling (BIM) plays a crucial role in addressing these issues by accurately conveying a building's spatial layout and specific structural details. As a centralized platform for multi-source information visualization, BIM enables quick identification of hazard and disaster sources,real-time display of monitoring area data, and automated release of warning information and structural health status.The system architecture consists of two main sections. The first integrates SHM with BIM, comprising modules for data collection and storage, logic processing, warning identification, and visualization. The core subsystem integrates these modules to support comprehensive monitoring and management.The second component

involves integrating IoT with BIM. This approach proposes an IoT-integratedsmart monitoring alert system where sensors gather physical building data. This data is stored in a cloud database shared by BIM and SHMS (Structural Health Monitoring System). The IoT platform regulates warning indicators based on abnormal sensor values, activating visual cues at risky locations andtriggering alerts through coloured warning lights on-site.

3. Structural health monitoring by using a sparse coding-based deep learning algorithm with wireless sensor networks:

In China and globally, structural deterioration is increasingly problematic, especially for bridges exposed to factors like heavy traffic, wind stress, agingmaterials, environmental corrosion, earthquakes, and other stressors. These cumulative influences can lead to structural flaws and damage, significantly shortening a structure's lifespan. Subtle damages may escalate into catastrophic safety incidents such as collapse or subsidence, resulting in substantial casualties and property damage.

To mitigate these risks, structural health monitoring (SHM) methods have garnered significant attention. Initially rooted in model-driven strategies, early SHM studies focused on creating physical models that simulate real structures.These models employ mathematical modelling and physical principles to replicate structural conditions, enabling accurate assessment of damage extentand location.

For instance, consider a three-span bridge where 36 triaxial accelerometers arestrategically positioned on both the

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upper and lower surfaces, including at intersections with the bridge piers. These sensors are programmed to sample data at a rate of 5 Hz, recording five acceleration measurements per second ateach sensor location. This results in each sensor's data being represented as aone-dimensional vector, collectively forming a matrix from all 36 sensors overthe monitoring period. These raw sensor data undergo feature extraction for further analysis.

To effectively distinguish various bridge conditions and estimate damage severity, four scenarios are presented: one positive scenario and three negativescenarios. These scenarios aid in interpreting the status of the bridge and assessing the level of damage it has incurred.

4. Development of IOT Based Smart Instrumentation for the Real Time Structural Health Monitoring:

Efforts such as gradient image processing, fiber Bragg grating, and various neural network algorithms have historically been time-consuming indetermining real-time building damage. However, advancements in IoT-based instrumentation offer a solution by enabling immediate assessment ofstructural integrity. An accelerometer plays a crucial role in this setup by utilizing its non-linear frequency response to detect cracks or other forms of damage efficiently.

A significant challenge lies in establishing robust internet connectivity for these instruments post-installation. This hurdle is effectively addressed through the integration of microcontrollers and microprocessors such as Raspberry Pi 4, Node MCU, and My Rio. These components facilitate seamless communication with the accelerometer and connection to cloud platforms.The primary objective of this research was to develop an IoT-based instrumentation system capable of continuously assessing structural damage in real-time. Careful consideration was given to the selection of the accelerometer, communication protocols with Node MCU, and choice of cloud platform to ensure the functionality and reliability of the device,minimizing the risk of operational errors during implementation.

5. Cyber-physical systems for structural health monitoring sensing technologies and intelligent computing:

Mistakes in construction processes and monitoring can lead to significant errors caused by oversight, calculation, or testing inaccuracies. To mitigate these risks, there is a growing need for sophisticated monitoring systems with reduced human intervention. Initially, researchers integrate a few electronic devices to extract specific measurements, eventually evolving into sensor networks with intelligent capabilities. This minimizes human intervention, assensors are often temporarily deployed and remotely managed.

Structural monitoring is categorized into under-construction buildings and existing structures. Non-Destructive Evaluation (NDE) techniques are more readily applied during construction phases, whereas assessing existing buildings is more challenging as it requires identifying damage sites beforehand for optimal performance. The evolution of NDE through structural monitoring systems results in Structural Health Monitoring (SHM). SHM automates the NDE process using a wired network of sensors, with all detections and measurements conducted autonomously, leaving data gatheringand analysis tasks to human analysts.

However, the high installation costs, complexity of sensor deployment, and challenges in interpreting structural health from collected data necessitate alternative systems. Wireless Sensor Network (WSN)-based SHM is proposedas a viable substitute, offering potential advantages over traditional methods.

Ahmed Abdelgawad and Kumar Yelamarthi have developed a comprehensive real-time Structural Health Monitoring (SHM) platform that integrates with the Internet of Things (IoT) system. The platform comprises various components, including Pro-Trinket, NRF module, Wi-Fi module, and Raspberry Pi. This system enables remote monitoring and data storage in the cloud, accessible from any mobile device. Laboratory testing has validated the platform's effectiveness, demonstrating high accuracy in detecting damage location (1% error) and damage width (9% error).

6. Carmelo Scuro, sensors are intelligent because they not only measure physical quantities but also process and transmit data over the internet,enabling decision-making. The architecture of an IoT-based Structural Health

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Monitoring (SHM) system consists of smart objects (sensors), gateways, remote control and service rooms, and open platform communication servers. The IoT approach offers significant advantages in SHM systems, demonstrated through various examples, aiming to foster scientific research in this field. Notably, acoustic emission monitoring of building materials is apromising application, enabling low-power, continuous monitoring of existingand new structures, with significant potential for development in IoT-SHM systems.

7. **Brinda Chanv** et al., the Internet of Things (IoT) refers to a network of smart sensors that monitor and wirelessly transmit critical safety parameters of buildings and structures to remote computing units for continuous processingand monitoring. The system uses Arduino Uno to collect data, which is then stored and visualized in a bar chart format using Visual Studio. This enables the government to issue early warnings to residents based on cloud data, allowing for prompt legal action to prevent collapses. The system has the potential to be expanded to monitor additional advanced parameters, enhancing safety further. Moreover, this prototype can be applied to various fields, such as environmental health monitoring and greenhouse monitoring systems.

8. **Donato Abruzzese, Davide Bracale et. Al (2021)** Continuous observation of tiny structures using inexpensive instruments. The purpose of this analytical piece was to use a small, inexpensive gadget to monitor stress in thin structures. The load history will be recorded by this gadget. Send out notifications as needed at strategic locations to verify security against the possibility of collapse or simply to carry out maintenance or repairs. These devices consist of ordinary strain gauges and affordable, ready-to-wear natural

philosophy mounted victimization.Laboratory tests for steel beams, masonryslabs, and concrete slabs are used as application examples. The findings demonstrate how easily low-cost devices that we typically develop and enforce ourselves may be used to monitor stress levels permanently in new constructions.

9. **Suseela Alla , S.S. Asadi (2020)** Integrated technique for monitoring the structural health of civil structures. The dissemination of the SHM approach is the main objective of this study. this can be the result of SHM's opaque process for determining structural lifetime and dependability. As a result, theanticipated work methods are included in this document. Renovations to buildings are prohibited from affecting structural health monitoring. Victimization exposure estimations have generally been reliably assessed for basic talents. The majority of research estimated heap scores throughout a distinct, erratic range that was established by boundary adjustments and scaffold stacking.

10. **Donato Abruzzese, Andrea Micheletti et.al** IoT sensors for modern structural health monitoring: a replacement frontier (2020). The long-term objective of this project is to modify knowledge management code and wireless, low-cost devices for building condition monitoring and CEI. To measure stress as well as acceleration, use remote sensors that are incorporated into or connected to structural components. Any building outfitted with such a system will join the Internet of Things and notify both users and law enforcement in the event that the building becomes less safe or secure. The disorganized storage of measurement data over time is an important aspect. It requires the use of appropriate knowledge protection technologies and cannot rely solely on outside sources. This investigation was carried out by means of experimental testing and verification of created and implemented.

11. **K. SMARSLY, E. M. MTHUNZI, O. HAHN and J. PLANER (2019)** validation of a wireless structural health monitoring system for civil structures that is extremely affordable This article introduces a wireless structural monitoring system that's the least expensive and simple to set up. Anexemplary wireless SHM system made up of Ready-to-wear components were created and put into production for less than € thirty. The wireless SHM system's code is standard and extensible, allowing for IoT connectivity, low- power wireless communication, aboard knowledge analysis, and period acquisition. Because of this, the wireless SHM system is very affordable, simple to set up, and accurate enough to serve as a "fast tester" for examining

how short-term static observing campaigns affect the behavior of engineeringscientific infrastructure.

12. Ahmed Abdelgawad and Kumar Yelamarthi (2017) Internet of Things (IoT) Platform for Structure Health Monitoring.

This paper proposes an entire time period IoT platform for SHM.

1) The projected platform consists of a WiFi module, Raspberry Pi, DAC, ADC, buffer, and PZT. the 2 PZTs are hooked up to the structure and connected to a high speed ADC.

2) A buffer was used for level conversion and protection of the Raspberry Pi.The Raspberry Pi produces the excitation signal and {also the} DAC convertsit to analog.

3) we have a tendency to also used a Raspberry Pi to sight if the structure wasdamaged.

4) In addition, I used raspberries to send the health standing of the structure tothe net server. the information is hold on on an online server and may be monitored remotely from any mobile device.

5) The system was verified during a real check bench within the laboratory. The results show that the projected IoT SHM platform with success verified that the seat was healthy with 0% error. In addition, the proposed platform hasa slip-up of up to 1.03% in harm position and up to 8.43% in damage breadth.

13. Ahmed Abdelgawad, Kumar Yelamarthi (2016) Structural Health Monitoring: internet of Things Application during this document, the total period of time SHM platform is integrated into the IoT system.

1) The projected platform consists of ProTrinket, NRF module, WLANmodule, and Raspberry Pi a pair of.

2) The proposed mathematical model is enforced in ProTrinket to notice if thestructure is normal.

3) If there's damage, ProTrinket can verify the location and extent of the damage. ProTrinket uses the nRF24L01 + module to send this info to the Raspberry Pi 2.

4) The Raspberry Pi 2 acts as a hub for grouping knowledge from totally different locations within the structure. The Raspberry Pi a pair of uploads data to the cloud via the WLAN module.

5) Knowledge is keep within the cloud and may be viewed remotely from anymobile device. The system was valid in a very real check bench in the laboratory.

CHAPTER 3 MATERIAL AND METHOD

Civil Structural Health Monitoring (CSHM) comprises two essential components
that work synergistically to ensure the integrity and safety of civil structures: theCivil Structural Monitoring System (CSMS) and the Remote Control Unit (RCU).

Civil Structural Monitoring System (CSMS)

The CSMS is an integral part of the structure being monitored, designed to be efficient, low-power, and cost-effective. It utilizes a wireless sensor network (WSN) to collect real-time data on various environmental and structural parameters. At its core is a Raspberry Pi, a versatile single-board computer renowned for its capabilities in IoT applications and educational programming. Installed with the Raspbian Jessie operating system on an SD card, the RaspberryPi serves as the central hub for data collection and transmission.

Key Components of CSMS:

Light Sensor (LDR): Essential for detecting light intensity variations, the Light Dependent Resistor (LDR) modulates its resistance based on ambient light levels. This component is crucial for light-sensing circuits, providing insights intonatural light conditions within the structure.

Temperature & Humidity Sensor (DHT11): A 4-pin sensor optimized for measuring relative humidity (20%-90%) and temperature (0 to 50°C). It employs a proprietary One Wire protocol for communication, ensuring accurate environmental monitoring crucial for assessing moisture levels and thermal conditions.

Vibration Sensor (SW420): Equipped with the SW-420 sensor and LM393 comparator, this module detects vibrations exceeding a user-defined threshold. The sensitivity can be adjusted via an onboard potentiometer, making it instrumental in identifying structural vibrations that may indicate potentialstructural issues or external disturbances.

Raspberry Pi 3: Known for its robust processing power and connectivity options, the Raspberry Pi 3 facilitates comprehensive data processing and management. It supports various software configurations and Linux-based operating systems, making it ideal for developing IoT projects like CSHM. Its built-in connectivity options streamline data transmission to external platforms for further analysis and storage.

Ethernet Connectivity: Utilizing the IEEE 802.3 standard, Ethernet connections ensure reliable and high-speed data transmission over local area networks(LANs). Ethernet cables establish a wired connection between devices, facilitating secure file sharing and internet access essential for integrating the CSMS into broader network infrastructures.

Remote Control Unit (RCU)

The Remote Control Unit serves as the user interface, enabling remote access to real-time data collected by the CSMS. Designed for deployment on personal computers, laptops, or smartphones, the RCU provides a graphical representation of sensor data and alerts users to any anomalies or critical conditions detected within the monitored structure.

Functionality of RCU:

- **Data Visualization:** Graphical representations generated by the RCU provide intuitive insights into environmental and structural conditions monitored by the CSMS. Users can view trends, fluctuations, and historicaldata to assess the long-term health and performance of the structure.
- **Alert System:** In case of abnormal readings or potential structural issues detected by the CSMS sensors, the RCU triggers alerts to notify stakeholders promptly. These alerts enable timely intervention and preventive maintenance measures, minimizing risks and ensuring the safety and operational continuity of the structure.

Integration and Advantages:

The integration of CSMS and RCU exemplifies a comprehensive approach to CSHM, leveraging advanced IoT technologies for proactive structural monitoring. By combining real-time data collection with remote accessibility andalert mechanisms, the system enhances decision-making capabilities and optimizes maintenance strategies. It offers cost-effective monitoring solutions
that reduce reliance on labor-intensive manual inspections, thereby improving operational efficiency and extending the lifespan of civil infrastructure.

The deployment of CSMS and RCU represents a significant advancement in civil engineering practices, empowering stakeholders with actionable insights into structural health. This integrated approach not only ensures the safety and longevity of large-scale constructions but also contributes to sustainable infrastructure management practices. As technology continues to evolve, CSHMsystems equipped with IoT capabilities promise further innovations in enhancingstructural resilience and performance monitoring across diverse environments.

CHAPTER 4

METHODOLOGY

The IoT-based structural health monitoring (SHM) system comprises sensors, a central server, and a user interface. Sensors are strategically placed on buildingsor bridges to gather data on parameters such as temperature, humidity, vibration, and stress. This data is transmitted wirelessly to a central server, where it is analyzed for anomalies. Alerts are generated if potential issues are detected, allowing authorities to monitor the structure's health in real-time via the user interface. The SHM process involves continuous identification of the state of materials, components, and the entire structure, aiding in timely maintenance and extending the structure's lifespan. Sensors measure critical parameters, and the data is processed to prevent structural failures. IoT enhances this process by collecting and sharing data over the internet, with components oriented towards the internet (middleware), sensors (mono- oriented), and knowledge (semantic-oriented). The system aims to ensure real- time building safety and durability by identifying weaknesses and damage due to aging and performing preventive maintenance before collapse. The IoT platform is deployed on a cloud computing environment, ensuring scalability, accessibility, and reliability. The system includes load sensors (Accelerometer- ADXL345), strain sensors (BF350 3AA), and moisture sensors, with data processed by an Arduino Uno and a Wi-Fi module (ESP8266). Data is stored andvisualized locally using Visual Studio, allowing users to monitor the building's state and initiate preventive maintenance if necessary. The Arduino Uno microcontroller averages 128 readings and sends the data to the cloud via the ESP8266 for further analysis, while also providing real-time data to a Vb.net desktop application.

System Components:

- Sensors (temperature, humidity, vibration, stress)
- Central server
- User interface

Data Collection and Transmission:

- Sensors placed on structures collect data
- Data transmitted wirelessly to a central server

Data Analysis and Alerts:

- Server analyzes data for anomalies
- Alerts generated if issues detected
- Real-time monitoring via user interface

SHM Process:

- Continuous identification of material and structural state
- Timely maintenance to extend structure lifespan

- Use of sensors to measure critical parameters

Role of IoT:

- Enhances data collection and sharing over the internet
- Components: Internet-oriented (middleware), mono-oriented (sensors),semantic-oriented (knowledge)

System Objectives:

- Ensure real-time building safety and durability
- Identify and address weaknesses and damage due to aging
- Perform preventive maintenance to avoid collapse

Cloud Deployment:

- IoT platform deployed on cloud computing for scalability and reliability
- Infrastructure as a Service (IaaS) for platform portability

Specific Sensors and Units:

- Load sensor (Accelerometer-ADXL345)
- Strain sensor (BF350 3AA)
- Moisture sensor
- Data acquisition and processing unit (Arduino Uno, ESP8266 Wi-Fi module)

Data Processing and Visualization:

- Data processed by Arduino Uno, averaged over 128 readings
- Data sent to cloud for analysis via ESP8266
- Local data storage and visualization using Visual Studio
- Real-time data analysis via Vb.net desktop application

Preventive Maintenance Alerts:

- Alerts initiated if structural emissions exceed reasonable limits
- Allows users to take necessary preventive actions REPHRASE IT in same mannerin a more elaborative way

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CHAPTER 5

SUMMARY AND CONCLUSIONS

This project develops a wireless sensor network using IoT technology to monitor civil structures, enabling remote monitoring and control through a web-based platform or smart mobile phones. By leveraging low-cost single-chip processors, administrators can access real-time parameters from remote devices and send control instructions via the internet. The IoT platform provides extensive coverage and security features, including login and webpage security. The system is designed to be wireless, robust, and user- friendly, offering a flexible and adaptable solution for various civil structure applications. The email and web-based duplex communication system enables effective decision-making and remote control, making it an ideal choice for structural monitoring and management.

- Thermocouple temperature sensors accurately track temperature changes inconcrete during hydration, but temperature alone cannot determine concrete strength. Considering the time-temperature relationship improves strength evaluation.
- A simple, low-cost wireless sensor can monitor curing temperature and estimate concrete strength, enabling efficient and safe construction.
- Fuzzy logic simplifies data analysis and predicts concrete strength based onsignal flow.
- An IoT sensor (BHM) detects faults and transmits data to a cloud server for remote monitoring and structural health assessment, saving lives, time, and resources.
- Water cooling can damage concrete; instead, air or wetness cooling is recommended.
- A novel, non-destructive technique using the EMI principle accurately evaluates in situ concrete strength, outperforming traditional methods like ultrasonic pulse velocity.
- A low-cost, wireless embedded maturity sensor can monitor temperature and estimate concrete strength, developed using Arduino and other components.

The IoT-Structural Health Monitoring system is ideal for applications like smart homes and smart cities, offering a dual benefit: enhanced safety for people and property, and reduced costs associated with regular monitoring. This enables the system to predict the remaining lifespan of a structure and

optimize its maintenance, providing valuable insights for proactive decision- making.

This project explores the possibilities of technology in civil engineering, leveraging IoT, automation, monitoring, and management. Using accessible and affordable tools, suitable for educational settings, the project demonstratesa reliable system that integrates scientific rigor with technological innovation, bringing together civil engineering, mathematics, and art. By careful calculation and observation, the system's effectiveness is confirmed, paving the way for a new approach to civil engineering that combines theory and practice.

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