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IOT-BASED CRACK DETECTION IN CIVIL ENGINEERING STRUCTURES

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***Abstract*— Structural health monitoring is essential for ensuring the safety and durability of infrastructure such as bridges and buildings. Traditional crack detection methods rely on manual inspections, which are time-consuming, labour-intensive, and prone to human error, often delaying the identification of potential structural failures. This paper presents an IoT-based crack detection system using an ESP8266 microcontroller and an ADXL335 accelerometer, programmed via the Arduino IDE and integrated with the Blynk platform for real-time monitoring. The ADXL335 measures acceleration along three axes to capture subtle vibrations, which are processed by the ESP8266 and transmitted wirelessly to Blynk, where the data is displayed as a live graph. Frequency analysis is used to detect abnormal vibration spikes that may indicate cracks. When vibrations exceed a threshold, alerts are sent to engineers via the Blynk dashboard. This low-cost, wireless system provides a reliable, scalable alternative to manual inspection, enabling early detection and timely maintenance interventions.**

Keywords*— *Crack Detection, IoT (Internet of Things), ADXL335, Real-time Monitoring, Blynk, Anomaly Detection

I. INTRODUCTION

Ensuring the structural integrity of critical infrastructure such as bridges, buildings, and dams is vital for public safety and long-term functionality. These structures are exposed to environmental stressors, dynamic loads, aging, and natural disasters, all of which can lead to the formation of cracks. If undetected, such damage can escalate, resulting in costly repairs or even catastrophic failure. Traditionally, crack detection relies on manual visual inspections, which are not only time-consuming and labour-intensive but also highly subjective and prone to oversight. These limitations have necessitated the development of automated and intelligent monitoring systems.

With advancements in embedded systems and wireless communication, the integration of Internet of Things (IoT) with smart sensors has emerged as a transformative approach for real-time structural health monitoring (SHM). It offers continuous, remote surveillance and early fault detection, reducing the dependence on periodic manual inspections and enabling predictive maintenance strategies.

This paper presents the design and development of a compact, IoT-enabled crack detection device that utilizes the ADXL335 accelerometer and the ESP8266 Wi-Fi module. The ADXL335, a low-power, three-axis MEMS accelerometer, is highly sensitive to motion and vibration, making it suitable for identifying minute structural anomalies like micro-cracks. Integrated with the ESP8266, which enables efficient and seamless Wi-Fi communication, the device captures analog vibration data, processes it onboard, and transmits it wirelessly to a remote Blynk dashboard for real-time monitoring.

It also outlines the detailed design, implementation, and validation of the proposed system, emphasizing its capabilities in real-time data acquisition, anomaly detection, and wireless communication. Through this low-cost and scalable solution, the study aims to enhance the efficiency, accuracy, and reliability of structural health monitoring practices. It also sets the groundwork for future improvements using artificial intelligence and machine learning to make crack classification and risk assessment more intelligent and autonomous.

This paper presents an IoT-based crack detection system which is designed for seamless deployment and user- friendly operation, making it highly accessible to engineers, maintenance teams, and infrastructure managers. The system typically consists of wireless sensors, cameras, and AI-driven analytics software that continuously monitor structural health. Installation is straightforward, requiring minimal manual calibration, and

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the sensors can be easily affixed to bridges, buildings, or other concrete structures. Once deployed, the system automatically collects real-time data and transmits it to a cloud platform, where advanced algorithms analyze crack formation and progression.

Users can access insights via an intuitive web dashboard or a mobile app, eliminating the need for specialized technical knowledge. The system provides automated alerts in case of significant structural deterioration, allowing for timely intervention and reducing the risk of failure. With minimal maintenance requirements and remote monitoring capabilities, IoT-based crack detection systems ensure long-term reliability and ease of use for professionals responsible for infrastructure safety.

II. Literature Survey

Recent studies highlight the evolution of IoT-based crack detection in civil engineering, focusing on real-time monitoring and automated analysis. Saravanan demonstrated that combining IoT with intelligent sensors and non-destructive testing enables continuous, laboratory-scale structural health monitoring [1]. Shirkande proposed embedding sensors in concrete to track environmental and mechanical changes over time, facilitating early crack detection and maintenance [2]. Sohaib introduced an ensemble of quantized YOLOv8 models for fast, precise crack segmentation, making on-site, real-time analysis feasible [3]. Yuan developed a crowd-sensing framework using smartphones and deep learning to collect geotagged crack images, broadening community involvement in bridge inspection [4]. Jin leveraged UAV-mounted deep learning for high-accuracy crack detection in large structures [5], while Chen presented an electric-heating method for underwater concrete crack identification [6]. Jha et al. demonstrated the effectiveness of IoT-based monitoring for building infrastructure [7], while Sharma and Verma explored image processing with IoT for automated crack detection [8].

Patel, Gupta, and Kumar implemented a real-time IoT system integrated with deep learning to detect and monitor cracks in smart infrastructure [9]. Jones and Brown applied AI and IoT to railway track crack detection, improving safety in transport networks [10]. Golding et al. developed a deep learning model for concrete structure crack detection, showing high accuracy and efficiency [11]. Patel applied a multi-scale U-Net for robust crack detection in diverse infrastructural elements [12] and more recently, Nguyen showcased Edge-AI and IoT integration for instantaneous structural alerts [13]. A hybrid machine learning and deep learning approach has also been proposed for extracting crack features efficiently [14]. Kaveh surveyed these advancements, underscoring the rapid traction of AI-driven IoT solutions in structural health monitoring [15].

Together, these works underscore the transformative potential of coupling IoT, AI, and advanced sensing to achieve automated, scalable, and predictive crack detection.

III. Methodology

The crack detection system is designed to monitor structural integrity by identifying vibrations and anomalies that could indicate the presence of cracks. It utilizes an ADXL 335 accelerometer as the primary sensing device, an ESP8266 microcontroller for data processing and transmission, and the Blynk application for real-time data visualization. This system aims to provide a cost effective, reliable, and efficient solution for structural health monitoring, particularly in bridges, buildings, and other critical infrastructure.

The ADXL 335 accelerometer is a 3-axis sensor capable of measuring acceleration forces along the X,Y, and Z axes. It outputs analog signals proportional to the structural vibrations caused by stress, strain, or crack formation. These analog signals are fed directly into the ESP8266 microcontroller, which features an integrated Analog-to-Digital Converter (ADC) to digitize the analog data. The digitized signals are then processed to filter out noise and detect meaningful patterns. Signal conditioning techniques, such as filtering and amplification, are applied to improve accuracy and ensure reliable data for analysis. IoT has also been explored for crack detection in concrete structures [8].

Once the data is processed, the ESP8266 transmits it via Wi-Fi to the Blynk cloud platform. This wireless communication allows for real-time monitoring of structural health, with data visualized through a user- friendly dashboard on the Blynk app. The dashboard displays key metrics, including acceleration values and anomaly alerts, enabling quick detection of potential structural issues.

The system employs a threshold-based analysis algorithm to identify abnormal vibration levels that may indicate crack formation. By setting predefined thresholds based on historical data and structural characteristics, the system can trigger alerts when these limits are exceeded. For more advanced analysis, techniques like Fast Fourier Transform (FFT) can be implemented to analyze the frequency domain of the vibration signals. This helps in identifying subtle changes in vibration patterns that may not be noticeable through basic threshold analysis. Calibration is a critical step in ensuring the accuracy and reliability of the crack detection system. The accelerometer is calibrated using known structural conditions to adjust for environmental factors, sensor drift, and measurement errors.

After calibration, the system undergoes rigorous testing, both in controlled environments and real-world conditions, to validate its performance and reliability. This includes comparing the system's alerts with manual inspections and other diagnostic methods to confirm its accuracy. In practical applications, the system can be deployed f or continuous monitoring, providing ongoing data that can be analyzed over time to detect trends and predict potential structural failures. This proactive approach to structural health monitoring helps in early detection of cracks, reducing the risk of catastrophic failures and enabling timely maintenance.

Future enhancements to the system may include the integration of machine learning algorithms for predictive analysis, which can improve the accuracy of crack detection by learning from historical data. Additionally, optimizing the ESP8266 for low-power operation will support long-term deployment without frequent battery replacements. The system can also be expanded to incorporate additional sensors, such as temperature or humidity sensors, to provide a more comprehensive assessment of structural conditions.

In short, this crack detection system offers an effective solution for real time structural health monitoring. By combining the capabilities of the ADXL 335 accelerometer, ESP8266 microcontroller, and Blynk application, the system provides accurate, reliable, and user-friendly monitoring of critical infrastructure. Its scalable design and potential for future enhancements make it a valuable tool for ensuring the safety and longevity of structures.

IV. Design and Working

The ADXL335 and ESP8266 are soldered together on a custom PCB to form a rugged, field-ready crack detection module. The ADXL335's three-axis outputs—particularly the Z-axis—are used to track structural vibrations; its analog voltage is digitized by the ESP8266's ADC. A 9 V battery powers the unit through a voltage regulator, stepping down to a stable 5 V rail for the ESP8266. During installation, the accelerometer module was firmly affixed to a concrete beam using vibration-damping adhesive and shielded to minimize ambient noise.

Firmware, written in the Arduino IDE, begins with a calibration routine: 100 readings are averaged in a healthy, crack-free state to establish a baseline. The structure's natural frequency was measured at approximately 18.2 Hz, and the system flags any vibration deviation beyond ± 4 Hz as a potential crack event. In operation, the code continuously reads the Z-axis, computes deviation from the baseline, and measures time between significant spikes to calculate real-time frequency.

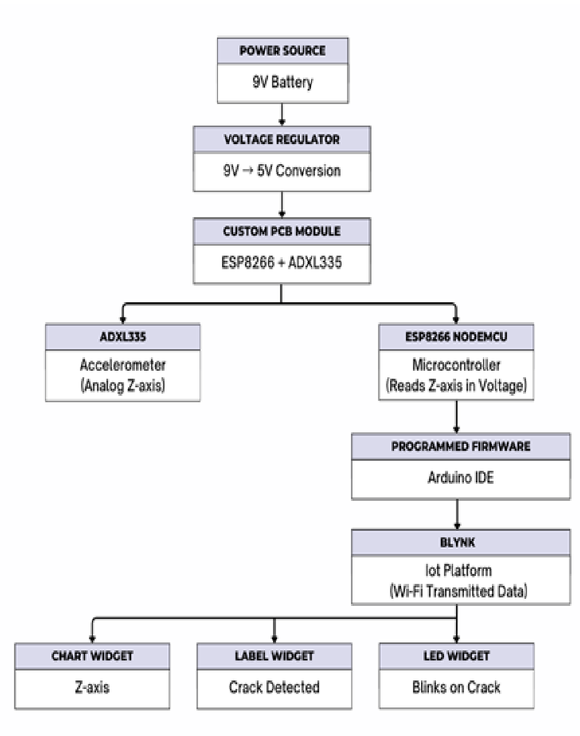

Fig. 1. Block Diagram of overall setup

All processed data is streamed via Wi-Fi to the Blynk IoT platform. A Custom Chart widget graphs Z-axis acceleration alongside calculated frequency, while a Label widget displays "Potential Structure Change Detected!" and an LED widget blinks whenever thresholds are exceeded. This end-to-end implementation—combining precise mounting, power regulation, calibration, anomaly detection logic, and intuitive IoT visualization—enables rapid, reliable crack detection and helps ensure the safety of critical infrastructure.

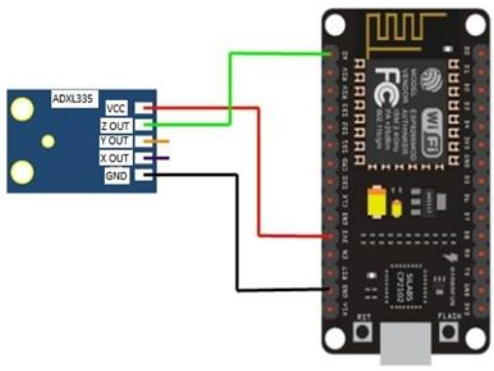

Fig. 2. Circuit Diagram for Interfacing ADXL335 with ESP8266

Fig. 3. Device Setup (Prototype)

V. Results & Discussions

The proposed real-time crack detection system—comprising an ESP8266 microcontroller, ADXL335 vibration sensor, and the Blynk IoT platform—was implemented and rigorously tested on a concrete beam whose natural frequency was experimentally determined to be 18.2 Hz. By continuously monitoring Z-axis vibrations and computing frequency variations, the system successfully identified structural anomalies.

During testing, the module exhibited high responsiveness, detecting abnormal vibration spikes within milliseconds of occurrence. Vibration data was streamed wirelessly to the Blynk dashboard, where a Custom Chart displayed both acceleration and calculated frequency in real time. When measured vibration frequency deviated beyond ±4 Hz of the natural frequency (i.e., outside the 14.2–22.2 Hz band), the system interpreted this as a potential crack event. In such cases, the Blynk LED widget blinked and the label widget updated to "Potential Structure Change Detected!", ensuring immediate operator notification. The developed dashboards for the crack detection is shown in below.

Remote monitoring was facilitated by the ESP8266's Wi-Fi link, while the Arduino Serial Plotter provided parallel, local visualization for calibration and validation. Across multiple test cycles, the system proved reliable, cost-effective, and scalable, accurately signalling early-stage damage in both static and dynamic loading scenarios.

Fig. 4. Blynk Dashboard when there is no crack

Fig. 5. Blynk Dashboard when a crack is detected

These results confirm the efficacy of coupling baseline-frequency calibration with threshold-based anomaly detection. Future enhancements could incorporate AI-driven crack classification, multi-sensor data fusion, and cloud analytics to further boost accuracy and enable predictive maintenance of critical infrastructures.

VI. CONCLUSION

The proposed IoT-Based Crack Detection system for civil engineering structures demonstrates the potential of smart monitoring systems in ensuring the safety and longevity of infrastructure. By integrating IoT-enabled sensors, real- time data collection and cloud-based analysis, this system effectively detects and monitors structural cracks, allowing for timely intervention and maintenance. The implementation of this technology enhances the efficiency of structural health monitoring by reducing manual inspection efforts and providing accurate, continuous surveillance. The system's ability to detect early-stage cracks minimizes the risk of catastrophic failures, ensuring structural integrity and public safety.

Future advancements in this field could include AI-powered predictive maintenance, improved sensor accuracy, and integration with building information modelling (BIM) for more comprehensive structural assessments. Future work may also consider hybrid deep learning and machine learning approaches for enhanced detection [14]. Overall, this project highlights the transformative role of IoT in modern civil engineering, paving the way for smarter and safer infrastructure management.

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