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Railway Track Crack Detection System

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Abstract: Railway safety depends heavily on the condition of tracks, yet traditional inspection methods rely on manual checks that are slow, costly, and prone to human error. This project introduces an railway crack detection system designed for continuous and automated monitoring. The system uses low-cost infrared sensors integrated with an ESP32 microcontroller and ESP32-CAM module, mounted on a mobile platform that scans railway tracks for surface irregularities. When a crack is detected, the system captures high-quality images and records GPS location and time details. This information is transmitted wirelessly to a cloud-based dashboard, allowing maintenance teams to receive instant alerts and assess issues remotely. By enabling early fault detection, the system supports preventive maintenance, reduces downtime, and improves overall railway safety. Its modular and scalable design allows future upgrades, such as more advanced machine learning techniques and integration with existing railway management systems, making it a practical and cost-effective solution for modern railway infrastructure monitoring.

Keywords: Railway Track Safety, Crack Detection System, Internet of Things (IoT), ESP32 Microcontroller, ESP32-CAM, Infrared Sensors, Real-Time Monitoring, Embedded Systems, Automated Railway Inspection.

I. INTRODUCTION

Railway systems are a critical part of modern transportation infrastructure, supporting both passenger travel and freight movement on a large scale. Due to continuous usage, heavy loads, and exposure to environmental conditions, railway tracks are prone to wear and structural defects over time. One of the most dangerous defects is the formation of cracks on the rail surface, which can gradually expand and lead to severe accidents such as derailments if not detected at an early stage.

At present, railway track inspection is largely performed through manual methods, where trained personnel visually examine tracks at scheduled intervals. Although this approach has been used for decades, it suffers several limitations. Manual inspection is time-consuming, labor-intensive, and highly dependent on human judgment, making it susceptible to oversight and error. Additionally, it does not provide continuous or real-time monitoring, which is essential for large railway networks with increasing traffic density.

With recent developments in embedded systems and Internet of Things (IoT) technologies, automated inspection systems have become a practical solution for improving railway safety. Low-cost sensors, microcontrollers, and wireless communication modules can now be integrated to continuously monitor track conditions and detect faults with greater reliability. These technologies reduce human involvement while increasing inspection frequency and accuracy.

This paper presents an IoT-based Railway Crack Detection System that uses infrared (IR) sensors and an ESP32-CAM module to identify cracks in railway tracks. The IR sensors act as the primary detection mechanism by identifying surface irregularities, while the camera module provides visual confirmation of the detected fault. Once a crack is identified, the system captures an image and transmits the data wirelessly to a remote monitoring platform. This combined approach improves detection accuracy, minimizes false alarms, and enables timely maintenance actions, thereby enhancing overall railway safety.

II. RELATED WORK

Several researchers have explored automated techniques for railway track monitoring to overcome the limitations of manual inspection. Early studies primarily focused on sensor-based crack detection using infrared and ultrasonic sensors. These systems demonstrated the feasibility of detecting surface-level defects but often suffered from false detections due to environmental noise and track surface variations. Some researchers introduced hybrid systems that combined IR sensors with camera modules to improve reliability. By capturing images of detected anomalies, these systems provided an additional layer of verification, which helped reduce incorrect detections. However, many such systems relied on wired communication or required expensive hardware, limiting their large-scale deployment. Wireless sensor network-based approaches have also been proposed, where multiple sensor nodes are deployed along railway tracks to monitor structural health. These systems emphasized real-time data transmission and scalability but lacked visual verification, making it difficult to assess the severity of detected faults.

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More recent studies have incorporated artificial intelligence and deep learning techniques to analyze railway track images. While these methods achieved high accuracy in crack classification, they often required significant computational resources and cloud infrastructure, increasing system cost and complexity.

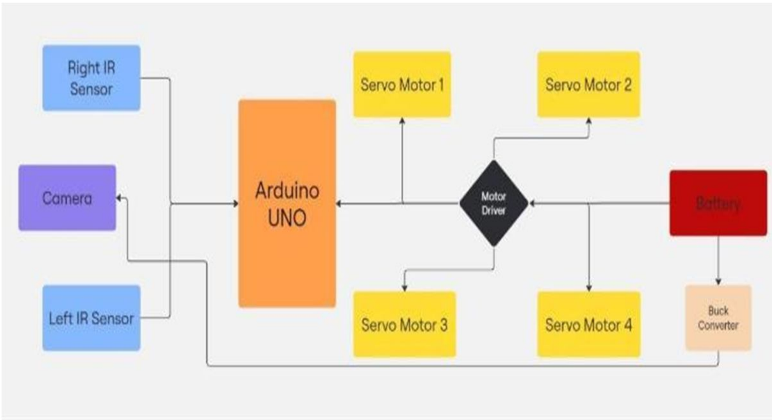
Compared to existing approaches, the proposed system focuses on achieving a balance between accuracy, cost, and practicality. By integrating low-cost IR sensors, an ESP32-CAM module, and Wi-Fi-based communication, the system provides real-time crack detection with visual validation while remaining affordable and easy to deploy across large railway networks.

III. METHODOLOGY

The methodology defines the functional workflow and interaction between hardware and software modules used for toll automation.

A. System Components

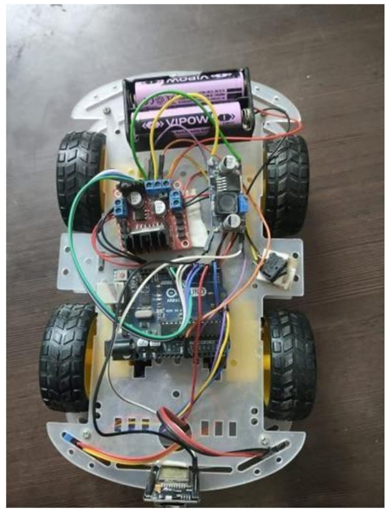
1) Arduino Uno
2) IR Sensors (Left and Right)
3) Camera Module
4) Motor Driver (H-Bridge Module)
5) Servo Motors (Motor 1–4)
6) Battery
7) Buck Converter



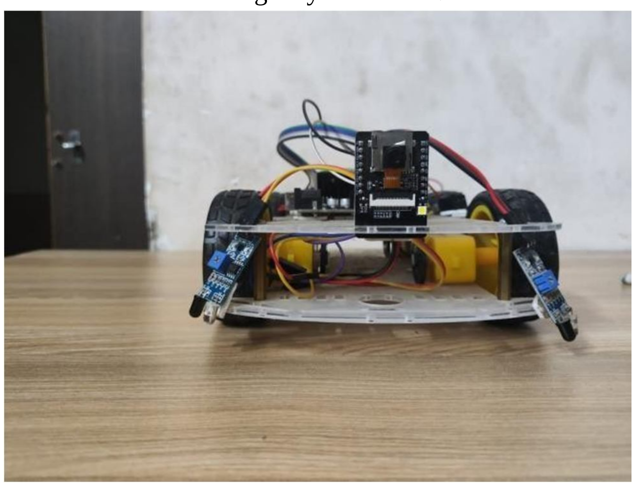
B. Process Workflow

1) The system is mounted on a mobile inspection unit that moves along the railway track.
2) Infrared (IR) sensors continuously monitor the surface of the railway track.
3) When the track surface is normal, the reflected IR signal remains within the predefined range.
4) If a crack or gap is present, the reflected IR signal changes significantly.
5) The IR sensor sends the detection signal to the ESP32 microcontroller.
6) The ESP32 processes the sensor data and compares it with the threshold value.
7) If the abnormality is confirmed, the ESP32 triggers the ESP32-CAM module.
8) The ESP32-CAM captures an image of the cracked section of the railway track.
9) The captured image along with the timestamp is prepared for transmission.
10) The ESP32 sends the data wirelessly through Wi- Fi to the cloud/server.
11) An alert is generated and displayed on the monitoring dashboard.
12) The crack information is stored in the database for future reference and maintenance planning.
13) The system continues to scan the railway track until the inspection process is completed.

C. Model and Analysis



The implemented model ensures reliable crack detection using a hybrid sensor.



IR sensors provide quick detection of surface irregularities by identifying changes in infrared reflection. The ESP32 processes the sensor signals using threshold-based logic to confirm crack presence. During testing, the sensors showed stable output on normal tracks and clear variation when cracks were present. The ESP32-CAM captures images of detected crack regions, enabling visual verification and reducing false detections. Wireless data transmission via Wi-Fi was stable and allowed timely reporting to the monitoring dashboard. Overall, the system demonstrated accurate detection, reliable operation, and suitability for real-time railway track monitoring.

IV. RESULTS

The IoT-based Railway Track Crack Detection System was successfully developed and tested on a prototype railway setup. The system demonstrated reliable real-time crack detection using IR sensors, visual verification through ESP32-CAM, and accurate location tagging via GPS. Whenever a crack was detected, the camera captured an image and the complete data—sensor reading, timestamp, image, and GPS coordinates—was uploaded to the cloud dashboard for remote monitoring.

Experimental results showed that the system could consistently identify surface-level cracks with high accuracy. The threshold-based IR detection responded within milliseconds, and image verification significantly reduced false positives. GPS mapping proved precise, allowing easy identification of the defect location. The robotic platform moved smoothly along the track while the ultrasonic sensor prevented collisions, confirming the effectiveness of autonomous operation.

Analysis of system performance indicated that detection accuracy was highest under good lighting conditions, while low-light environments slightly affected image clarity.

The Wi-Fi-based cloud upload worked efficiently in areas with stable connectivity. Power consumption remained reasonable, though continuous image capture and transmission increased battery usage. Overall, the system proved reliable, fast, and efficient for real-time railway track monitoring, showcasing its strong potential for practical deployment and scalable implementation.

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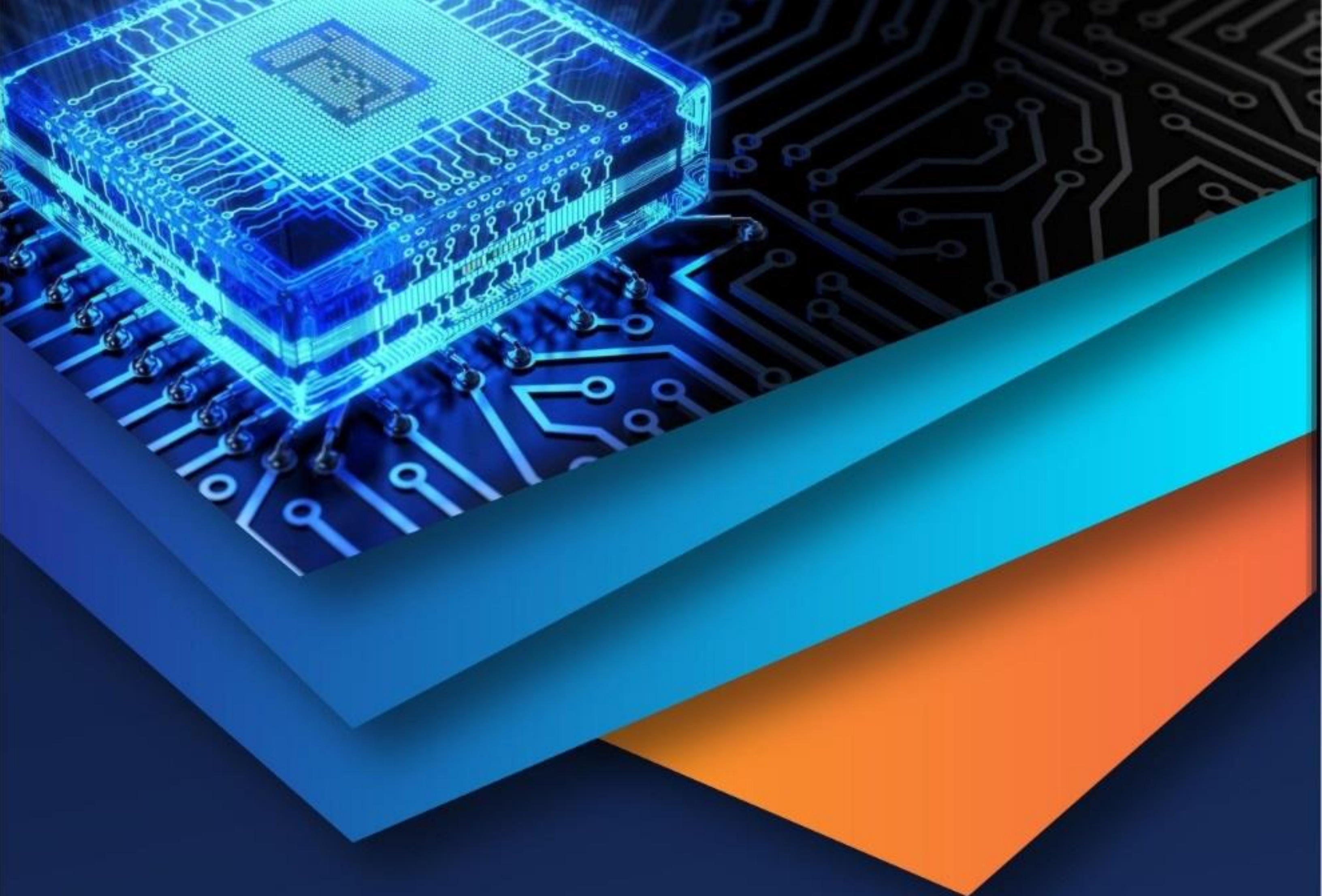

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