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IoT Based Track Guard System for Railway Safety

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Abstract*—Railway safety is a critical issue due to the occurrence of track defects such as cracks, gaps, and mismatch, which may result in severe accidents. In order to provide continuous monitoring and real-time identifying issues, this study proposes an Internet of Things-based railway track guard system. In order to detect variations, the system integrates sensor units placed along the track with an ESP32 microprocessor. Data is analysed and sent to the Firebase cloud platform for remote monitoring and immediate alert generation upon the detection of a failure. Additionally, the system provides location-based monitoring and delivers instant alerts through LED indicators and a buzzer. Stable operation is confirmed by experimental findings in both normal and breakdown settings. The proposed fix outperforms conventional methods in terms of accuracy, automation, and efficiency. All things taken into account it improves railway safety and provides an inexpensive answer for modern railway systems.

Keywords*—IoT, Railway Safety, Track fault Detection, ESP32, Firebase, Real-Time Monitoring, Sensor Networks, Smart Railway Systems

I. Introduction

Since issues including track defects, alignment errors, and unexpected challenges that can cause serious accidents and accidents, railroad safety is still an important issue [1-2]. Modern checking methods are expensive, time-consuming, and not enough for continuous real-time finding of defects since they mainly depend on manual supervision and irregular maintenance [3-4]. The importance for intelligent and automated monitoring systems is made clear by the fact that these standard methods are becoming less effective due to the rapid growth of railway networks and increasing traffic density. Through allowing constant monitoring of railroad lines through networked sensors and communication technologies, the Internet of Things (IoT) offers a possible approach [5-6]. IoT-based systems use a variety of sensors, such as infrared light vibration, sound, and ultrasonic devices, to track conditions and detect problems early [7-9]. By sending real-time data to central or cloud-based platforms, these systems improve safety and lower the chance of accidents through providing prompt analysis and timely alerts to railway management. Railway monitoring systems are further enhanced by modern technologies like computer vision and data-driven methods in addition to IoT. Cracks, challenges, and defects in structure can be properly identified using cameras for analysis and image processing processes [10-11]. These automated methods boost operational dependability and lessen the need for human intervention. Furthermore, location data processing is made possible by edge computing and wireless sensor networks, which reduce latency and allow quicker decision-making in situations of emergency [12-13]. In present railway safety systems, maintenance planning has grown to be an important development. These systems predict possible failures before they happen by using machine learning algorithms and past sensor data, allowing safeguards to be implemented before [14-16]. This lowers maintenance expenses and downtime while increasing system reliability. Additionally, improvements in intelligent monitoring frameworks, multi-sensor data fusion, and artificial intelligence-based detection provide more reliable and accurate finding defects capabilities [17-19]. However, there are still a number of issues with the systems that are in operation. Many solutions are difficult for general acceptance due to their high implementation and maintenance costs. Certain methods may cause delays because they lack real-time alarm systems or depend significantly on central processing [20-22]. Furthermore, rather than providing a whole and integrated railway safety solution, the majority of current approaches focus on finding specific problems, like cracks or limitations [23-25].

II. Related Work

In an attempt to provide constant and real-time monitoring of railway equipment, the latest developments in railway safety have slowly accepted IoT-based monitoring systems that use connected sensors to evaluate important data like sound, temperature, and track condition [26]. In order to improve safety and lower the risk of accidents, these complex systems integrate a variety of sensing and communication technologies to quickly identify problems and issue early warnings [27]. Additionally, by analysing a

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great deal of sensor data to identify possible faults and improve maintenance tasks, a combination of machine learning methods enhances decision-making [28]. By using both data from the past and the present, maintenance planning techniques help identify problems early on, which lowers maintenance costs and downtime [29]. Furthermore, wireless sensor networks provide automated defect detection and quick alarm generation, providing fast reaction to risky situations while keeping stable and effective railway operations [30].

III. Existing System

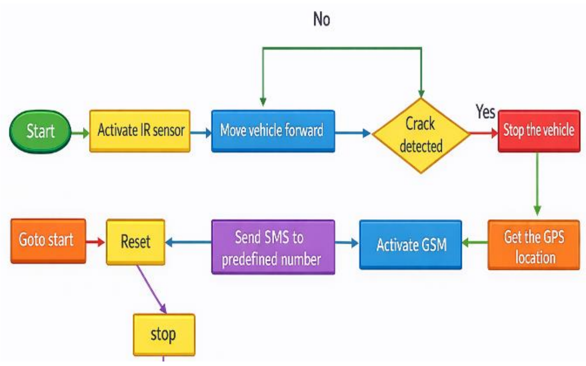


Fig. 1. Existing System for Railway Track Crack Detection and Alert [31]

The existing railway tracks breaking detection and alert system is shown in Fig. 1. An infrared sensor that continually monitors the state of the railway line is first started. The sensor constantly monitors the track for problems or cracks as the car moves. The system keeps running continuous if no defect is found. To avoid crashes the device immediately stops the car when it detects a crack. After that, it uses GPS to identify its exact location and uses the GSM module to send out an alarm. The system resets itself and keeps looking for new issues after the alert process [31].

IV. Proposed System

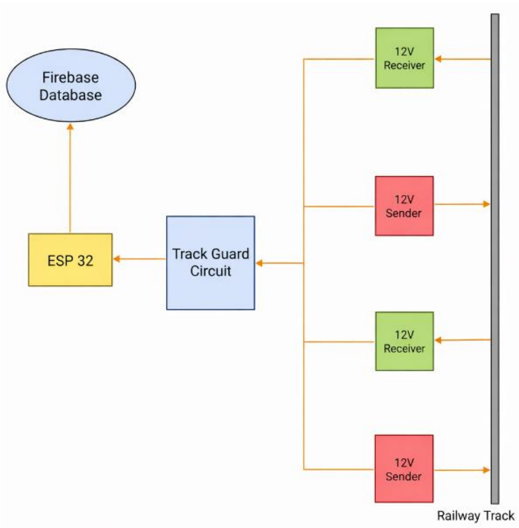
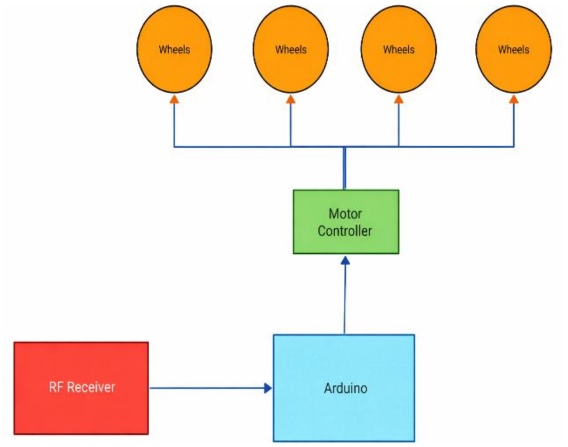


Fig. 2. Proposed IoT-Based Railway Track Guard System Architecture

Fig. 2 shows how the proposed Internet of Things-based railway track guard system is developed. The system is controlled and data from the road guard circuit is analysed by an ESP32 microcontroller. To keep track of the railway track's status, sender and receiver units are placed along it. These devices detect any defects or break in the track. The data is sent to the ESP32 for processing as soon as a defect is found. Real-time monitoring is made possible by sending the processed data to the Realtime database. This configuration provides a quick reaction to possible problems and enables remote access to monitor conditions. Overall, the system's built-in and constant monitoring improves



railway safety.

Fig. 3. Proposed Block Diagram of RF-Based Train Control System

The system consists of wheels that allow train movement, a motor controller, and an RF receiver, as shown in Fig. 3. Wireless signals are collected by the RF receiver and sent for processing. The motor controller, which controls the wheels motion, receives and produces suitable control signals based on the data received. This improves operational efficiency and security through the implementation of real-time train control.

A. Methodology / Principle of Operation

The system uses sender and receiver sections to constantly monitor the railroad track. Signals are sent along the track by the transmitter, and their continuation has been verified by the receiver. The ESP32 microcontroller detects

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and breaks the transmission when an error, such a crack, occurs. After processing the data, the ESP32 transmits it to Realtime for real-time tracking. This improves overall railway safety through allowing quick failure identification and prompt response.

B. Hardware Implementation and Alert Mechanism

The ESP32 microcontroller acts as the base of the hardware system, which is connected with sensor units placed along the railroad track for ongoing monitoring. These sensors transmit information to the controller when they find problems like cracks or displacement. The ESP32 analyses the data when a problem arises and triggers notifications using an LED or buzzer. While optional GSM and GPS modules offer location-based alerts, the system also refreshes the Firebase database for real-time monitoring. This method provides increased railway safety, prompt notification, and quick defect detection.

C. Power Supply and System Requirements

The ESP32 is powered by a regulated power supply that uses 3.3 V from a 5 V source. To make sure correct operation, sensors and communication modules are supplied with the proper voltage levels. Batteries or solar electricity can be used for remote applications. Continuous monitoring and real-time data transfer require both Wi-Fi access and an accurate power source.

V. Results and Description

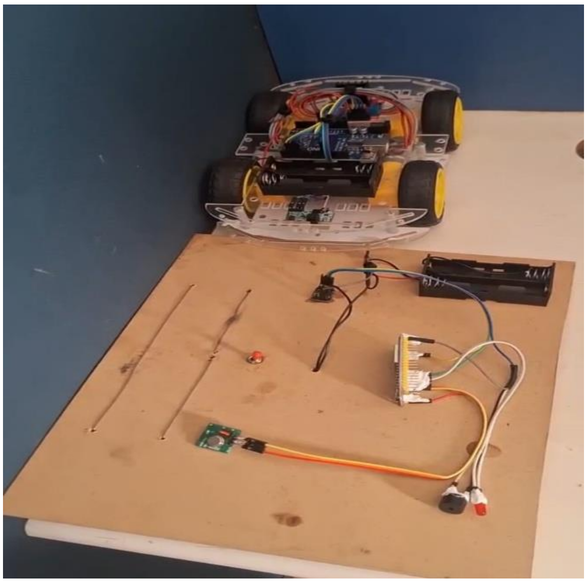
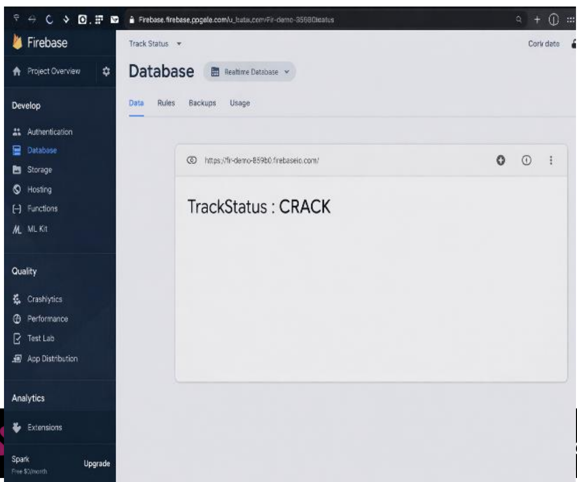


Fig. 4. Prototype of IoT-Based Railway Track Guard System Hardware



Setup

An ESP32 is installed on a wheeled vehicle to act as a track monitoring unit in the experimental setup of the railway track guard system, as shown in Fig. 4. The hardware prototype includes sensor modules that continuously monitor track conditions, represented by metal rods, to detect defects such as breaks or gaps. The system is powered by batteries, and faults are indicated through alert mechanisms like an LED and buzzer. This hardware prototype effectively validates the system's operation and demonstrates real-time fault detection.

Fig. 5. Firebase Track Monitoring Output Indicating Crack Condition

Fig. 5 shows the Firebase database's real-time monitoring output. It displays the track condition that the system has identified, with continuously updated status like "CRACK." This makes it easier to monitor remotely and identify defects quickly, allowing for quick action to increase railway safety.

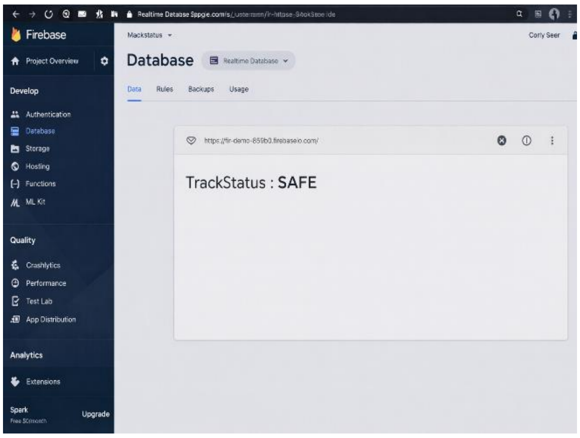


Fig. 6. Firebase Track Monitoring Output Indicating SAFE Condition

Fig. 6 shows the real-time monitoring output from the Firebase database. It shows the track state that the system found, with a constantly updated status like "SAFE." This makes remote monitoring simple and verifies typical track conditions, providing dependable operation and enhanced railway safety.

TABLE I. Experimental Results of Railway Track Guard System [11], [30]

Test Condition	Sensor	Response	Output	Result
Normal Track [30]	No fault	No action	OFF	Normal
Gap/Break Condition [11]	Detected	Immediate response	LED + Buzzer ON	Detected
Continuous Monitoring [30]	Active	Real-time	Varies	Stable

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The Railway Track Guard System's the outcomes across various track conditions are shown in TABLE I. Results show that the system operates normally when there are no errors and successfully identifies problems like gaps or breaks, responding immediately and sending an alert. The system exhibits steady real-time performance during ongoing monitoring. Overall, these findings support the suggested system's accuracy and effectiveness in detecting track defects and improving railway safety [11], [30].

The system response under different conditions is shown in Fig. 7, showing no action during normal track conditions to avoid false alerts, while providing an immediate response when a fault is detected, and maintaining stable real-time operation during continuous monitoring [11], [30].

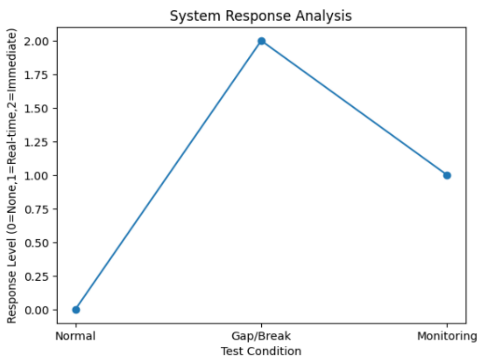

Fig. 7. Graphical Representation of System Response Under Different Conditions [11], [30]

The system response under different conditions is shown in Fig. 7, showing no action during normal track conditions to avoid false alerts, while providing an immediate response when a fault is detected, and maintaining stable real-time operation during continuous monitoring [11], [30].

TABLE II. Comparison of Existing and Proposed Railway Track Guard System [26], [28], [31]

Parameter	Existing System	Proposed System
Monitoring Method [26]	Limited monitoring	Continuous IoT-based monitoring
Fault Detection [28]	Detects cracks only	Detects cracks, gaps, breaks
Controller [31]	Arduino	ESP32
Alert Mechanism [26]	GSM/GPS alerts	LED, buzzer, cloud
Data Handling [28]	No cloud	Firebase cloud storage
Accuracy [28]	Moderate	High

A comparison of the proposed and existing systems is shown in TABLE II. The suggested solution makes use of an ESP32 controller, identifies several failure types and provides continuous monitoring via IoT technology. It is more efficient than the current system since it offers cloud-based data management via Firebase, improved alert mechanisms, increased automation, and greater accuracy [26], [28], [31].

VI. Conclusion

The proposed IoT-based Railway Track Guard System offers a safe and effective means of constantly tracking and identify track defects. The system allows for immediate warning production and real-time defect finding by merging the ESP32 microcontroller with sensor modules and the Firebase cloud platform. The results of the experiments show steady performance under normal conditions and quick reaction when errors occurred. The technology offers more automation, improved accuracy, and remote monitoring skills when compared to conventional techniques. As a result, it improves railway safety, reduces the chance of accidents, and provides an economical implementation.

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