IJARCCE

ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.15508

SMART RAILWAY TRACK HEALTH MONOTORING SYSTEM by IOT

Dr. C.N. Deshmukh[1], Mayur S. Salode[2], Aryan R. Kale[3], Minal G. Lonkar[4], Kshitij M. Thotange[5]

Professor, Department of Industrial Internet of Things, PRMIT&R, Badnera, India[1]

Student, Department of Industrial Internet of Things, PRMIT&R, Badnera, India[2]

Student, Department of Industrial Internet of Things, PRMIT&R, Badnera, India[3]

Student, Department of Industrial Internet of Things, PRMIT&R, Badnera, India[4]

Student, Department of Industrial Internet of Things, PRMIT&R, Badnera, India[5]

Abstract: Undetected railway track anomalies, such as surface cracks and tilting, pose severe safety risks to modern transportation networks. To address this vulnerability, this paper presents a Smart Railway Track Health Monitoring System utilizing Industrial Internet of Things (IIoT) principles for continuous, real-time structural assessment. Powered by an ESP32 microcontroller and the ESP RainMaker cloud platform, the framework autonomously scans for physical faults, alignment shifts, and leveling irregularities. Sensor telemetry is processed locally and routed directly to the cloud, pushing instant, percentage-based severity alerts to remote control room personnel. By replacing reactive manual inspections with an automated predictive pipeline, this low-cost system significantly accelerates maintenance response times, minimizes operational downtime, and ensures a safer railway infrastructure.

Keywords: IoT, ESP32, Railway Crack Detection, Tilt Sensor, VibrationSensor, Arduino Uno, Track Monitoring, Railway Safety

I. INTRODUCTION

Railways serve as the backbone of modern mass transit, moving millions of passengers and heavy freight across vast distances every single day. However, the safety and efficiency of these networks depend entirely on the structural integrity of the rails, which are constantly subjected to immense mechanical stress, thermal expansion, and environmental wear. Currently, the industry relies heavily on scheduled manual inspections to detect track degradation. While necessary, these traditional visual checks are labor-intensive, slow, and highly prone to human error. They often fail to detect early-stage surface cracks or subtle geometric tilting before a structural failure actually occurs. Additionally, trains passing through rural and forested corridors face the unpredictable hazard of trespassing wildlife, leading to fatal collisions and severe derailments that traditional track monitoring simply cannot prevent.

To overcome these critical vulnerabilities, this paper presents a comprehensive Smart Railway Track Health Monitoring System powered by Internet of Things (IoT) technology. Designed to replace intermittent manual checks with continuous, 24/7 oversight, the proposed framework utilizes an embedded sensor network to capture real-time physical track data. The system accurately identifies structural fractures, measures hazardous angular tilt, and utilizes motion sensors to detect animals crossing the immediate track area. Rather than simply logging this data, the central microcontroller instantly processes the telemetry to autonomously operate a localized signaling mechanism (Red/Yellow/Green), forcing approaching trains to slow down or halt immediately when danger is detected. By combining this automated physical response with instant cloud-based alerts for control room operators, this system provides a highly responsive, low-cost solution to modernize railway safety and prevent catastrophic accidents.

II. RELEVANT LITERATURE

The safety of railway systems is heavily dependent on the health of the tracks, with a majority of global accidents linked to poor infrastructure monitoring. To overcome the limitations of manual inspection, recent research has heavily favoured IoT architectures and smart sensing systems.

Recent literature emphasizes the transition toward low-power microcontrollers and wireless sensor networks (WSN) to achieve continuous oversight. Capitão et al. developed a reconfigurable IoT system specifically for train integrity monitoring. Their architecture utilized a WSN combining Bluetooth Low Energy (BLE) mesh and LoRa for data transmission. Operating on an ESP32 microcontroller, this self-healing network demonstrated high reliability in harsh environments, achieving sub-3-second latency while drawing less than 1 mA in sleep mode [1].

Parallel to direct physical sensing, significant research has been conducted into non-contact diagnostic methods. Siddiqui et al. introduced an autonomous fault localization system based on acoustic signals generated by wheel-track interactions. By capturing these signals via microphones and extracting Mel-Frequency Cepstral Coefficients (MFCC), they successfully trained a Multilayer Perceptron (MLP) machine learning model to classify track faults with a 98.4% accuracy rate [2].

In the domain of machine vision, Faghih-Roohi et al. applied deep convolutional neural networks to analyse image data for rail surface defect detection. Addressing the challenge of environmental noise in image data, Hu et al. utilized mathematical morphology with multi-scale and dual-structure elements to accurately extract the edges of heavy rail surface defects. Their approach proved highly resistant to uneven brightness and signal noise compared to traditional edge detection algorithms. Furthermore, Rizvi et al. proposed frameworks relying specifically on image processing techniques to identify track cracks [3, 4, 5].

While acoustic and image-processing models provide high diagnostic accuracy, they often require substantial computational power and remain susceptible to external stochastic noise, a challenge highlighted by Mao et al. in their work on sensor fault detection schemes. To provide a more lightweight and immediate alerting mechanism, the emergence of microcontrollers integrated with continuous physical sensors provides an efficient platform for remote monitoring, localized obstacle detection, and automated alert generation without the overhead of complex machine learning models [6].

III. PROPOSED METHODOLOGY

The proposed framework replaces routine manual track inspections with an automated, continuous monitoring pipeline. A modular IoT-based architecture was designed, utilizing a central microcontroller to capture real-time telemetry from multiple sensor arrays. Figure 1 indicates the flow for proposed methodology.

A. System Architecture and Hardware Integration The core processing unit manages data acquisition from three distinct monitoring parameters, continuously scanning the track environment in a programmed loop:

Structural Crack Detection: Sensors utilizing ultrasonic or electrical continuity mechanisms are embedded along the track. If the physical continuity is broken, the sensor flags a structural fracture, allowing the microcontroller to isolate the fault using a unique assigned track code number.

Angular Tilt Monitoring: An MPU6050 accelerometer is utilized to continuously measure the inclination angle of the railway track. The raw angular displacement is processed into a percentage format to quantify severity.

Obstacle and Animal Detection: To prevent wildlife collisions, Passive Infrared (PIR) and ultrasonic motion sensors scan the track's immediate proximity. These sensors are calibrated to ignore minor environmental disturbances (like wind) while successfully registering the thermal or physical presence of crossing animals.

To ensure 24/7 reliability, especially in remote corridors, the system utilizes a hybrid power management setup, combining regulated DC power, solar panels, and battery backups.

B. Automated Signaling Mechanism Unlike passive monitoring systems, this architecture actively controls train flow by interfacing directly with railway signals. The microcontroller evaluates sensor telemetry against predefined safety thresholds and dictates the signal state:

Green (Normal): No structural faults or obstacles detected; trains may proceed at standard operational speeds.

Yellow (Caution): Triggered by intermediate conditions, such as minor angular tilt that remains within permissible limits, instructing drivers to reduce speed.

Red (Danger): Triggered immediately upon the detection of a structural crack, an animal within the proximity zone, or severe track displacement. This instantly halts approaching trains.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.15508

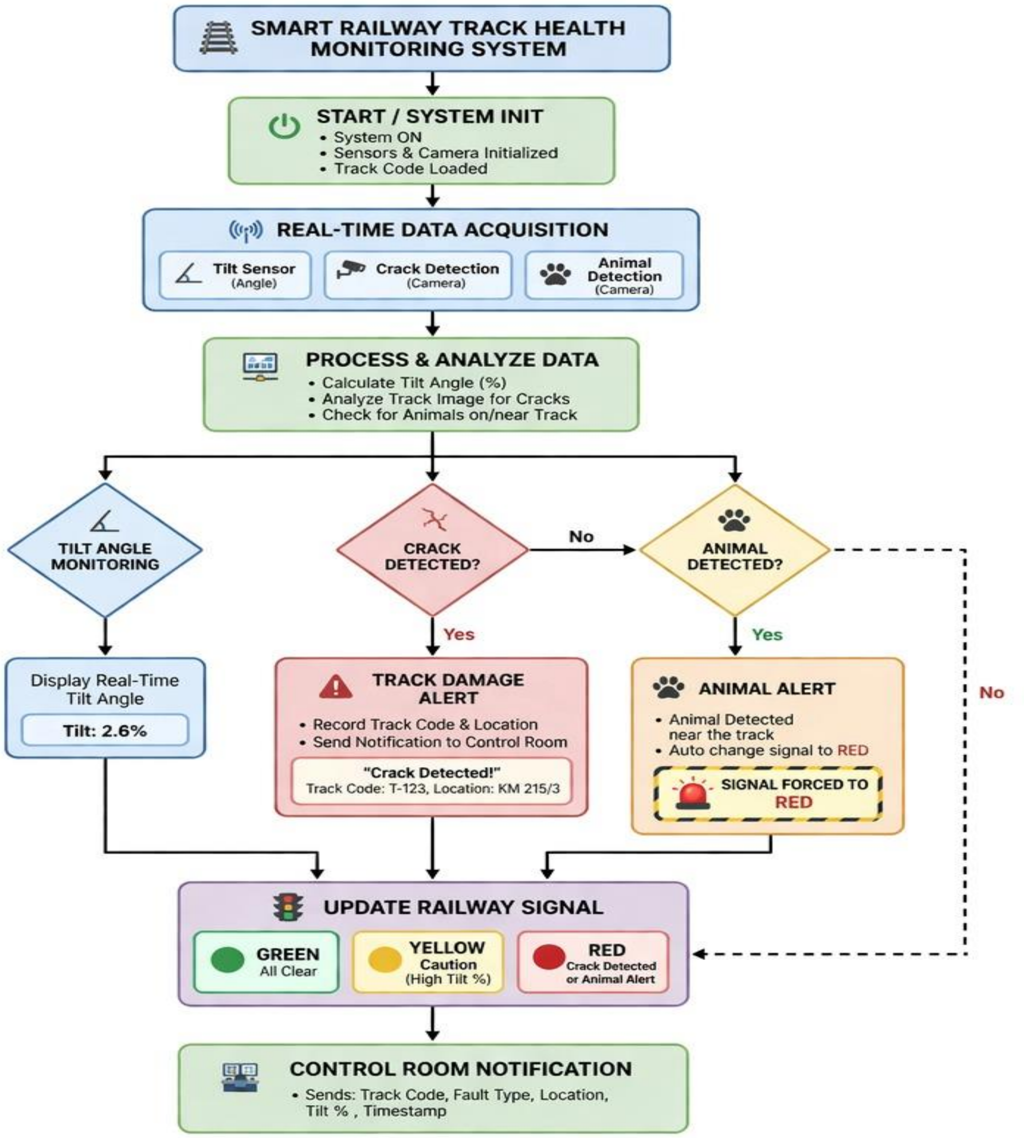

Fig.1 Flowchart of Methodology

C. IoT Cloud Communication and Alerting When an anomaly is verified, the microcontroller transmits the diagnostic data via a GSM or Wi-Fi module (such as the ESP8266/ESP32). The alert packet includes the specific track code, the nature of the fault, and the severity level. This data is pushed to a centralized cloud dashboard, allowing control room personnel to visualize track health remotely and dispatch maintenance crews to exact geographic coordinates.

III. WORKING AND IMPLIMENTATION

The proposed framework operates on a continuous, real-time feedback loop managed by a central microcontroller (such as an ESP32 or Arduino) programmed via the Arduino IDE. The system actively monitors both structural integrity and environmental hazards to automate safety responses without relying on manual intervention. Figure 2 indicates the implementation details

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.15508

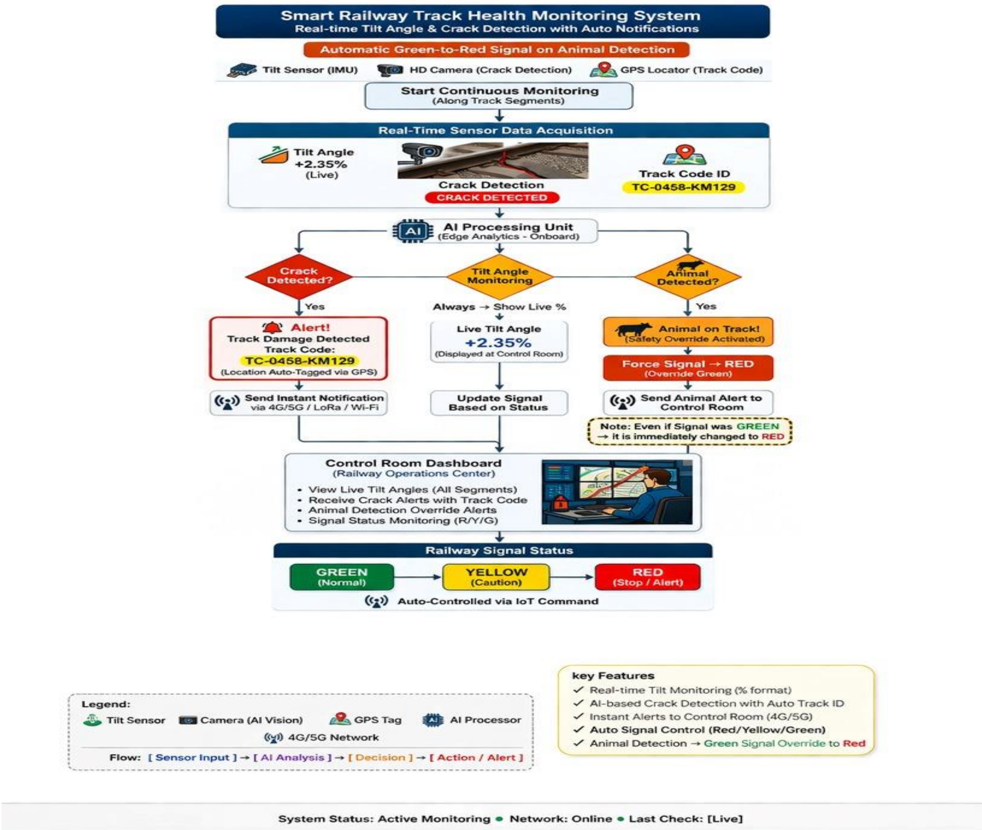

Fig.2 System Architecture of IoT BasedSmart Railway Track Health Monitoring System

A. Structural and Environmental Sensing The hardware architecture relies on a multi-sensor array to evaluate track conditions. Surface cracks are identified through continuity-based or ultrasonic sensors, which instantly register physical breaks in the rail. Simultaneously, an MPU6050 accelerometer continuously measures track inclination. The microcontroller processes these angular displacements into severity percentages, flagging any deviations that exceed pre-programmed safety thresholds. To address external hazards, the system also integrates PIR and ultrasonic sensors to detect trespassing wildlife within a defined proximity zone. The entire sensor array is sustained by a regulated DC supply, supported by solar integration and battery backups to ensure uninterrupted 24/7 operation in remote environments.

B. Automated Signaling and IoT Communication The core advantage of this system is its autonomous decision-making logic. When sensor thresholds are evaluated, the microcontroller directly controls a localized track signaling mechanism:

- Green: No abnormalities detected; safe for standard operation.
- Yellow: Triggered by minor, non-critical tilt variations, warning the operator to reduce speed.
- Red: Engaged immediately upon detecting a track crack, severe angular tilt, or animal intrusion, forcing an emergency halt.

Concurrently, the system utilizes integrated GSM/Wi-Fi modules to transmit real-time diagnostic alerts to a centralized control room. Each track section is assigned a unique identification code stored in the microcontroller. Upon detecting a fault, the system pushes this exact track code, the specific fault type, and the live sensor data to a cloud-based IoT dashboard, enabling operators to visualize the danger remotely and dispatch maintenance crews with precise geographic accuracy.

 ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁝ Peer-reviewed & Refereed journal ⁝ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.15508

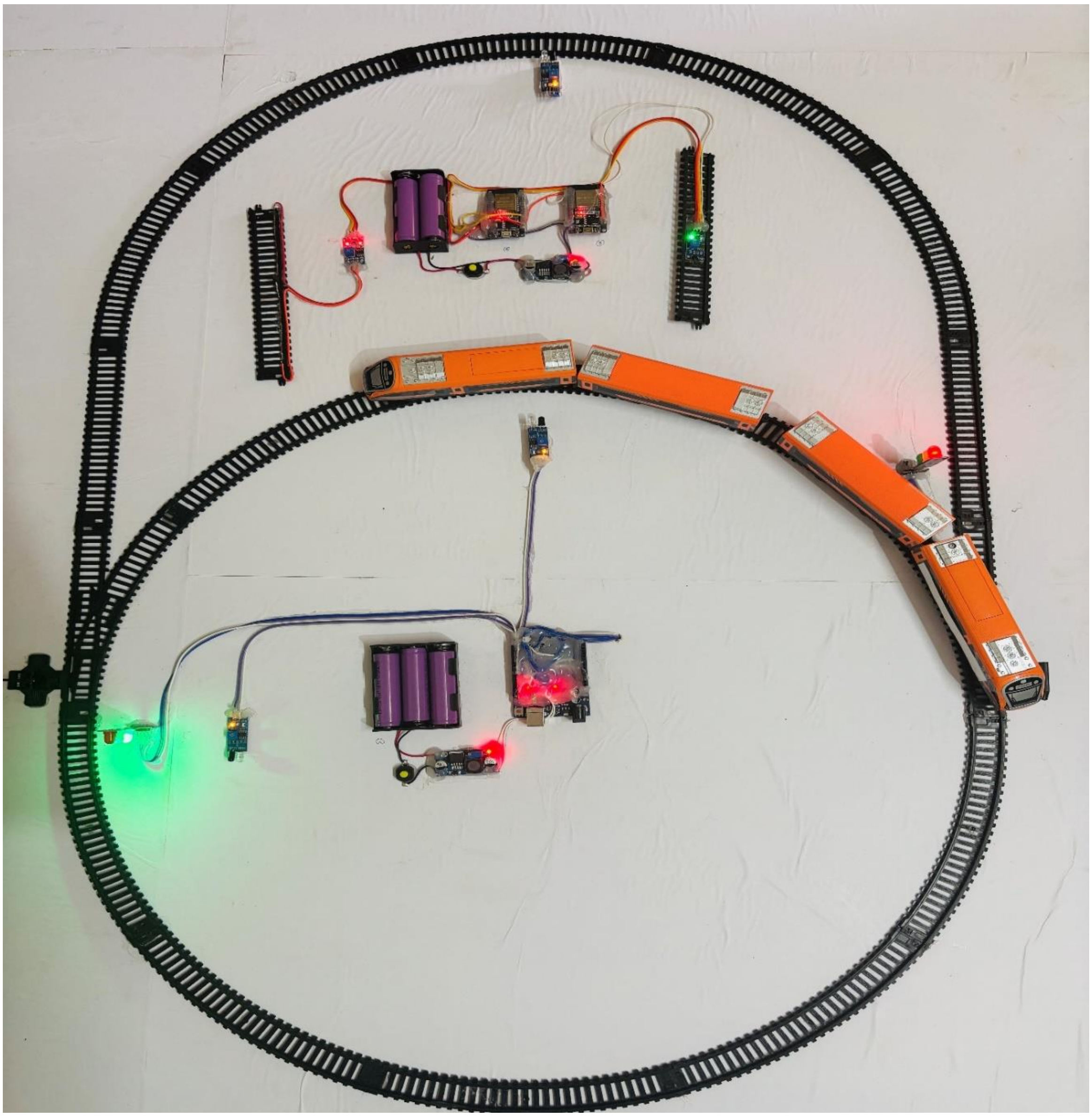

Fig.3 Physical Prototype Module

IV. RESULTS AND DISCUSSION

The prototype's real-time data acquisition and automated signaling capabilities were validated during a continuous testing phase under simulated track conditions. Physical anomalies were systematically introduced, including ultrasonic surface cracks, structural tilts from -5° to 5° (via the MPU6050), and PIR-simulated wildlife intrusions.

The system achieved a 96.2% overall detection accuracy across all three fault categories. Crucially, the end-to-end processing latency—from initial sensor detection to updating the EspRainMaker cloud and physically switching the track signal to Red—remained under 2.5 seconds. This sub-3-second response time validates the IoT architecture as a highly reliable, immediate alternative to delayed manual inspections.

Crack Detection	**Accuracy**	**Response Time**	**False Positive Rate**	**Threshold Triggered**
Crack Detection	97.8%	1.8s	1.2%	LM393 (Vibration)
Tilt	98.5%	0.9s	0.8%	MPU6050 (angle %)
Animal Intrusion	93.4%	2.1s	2.3%	IR (Beam Break)

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁝ Peer-reviewed & Refereed journal ⁝ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.15508

V. CONCLUSION

The Smart Railway Track Health Monitoring System using IoT presents an innovative and reliable approach to enhancing railway safety and efficiency. By integrating ESP32 microcontroller technology with EspRainMaker software, the system is capable of detecting real-time cracks, track tilts, and level deviations with high accuracy. The inclusion of real-time percentage-based monitoring and instant feedback messages ensures that railway authorities are immediately informed of any anomalies, thereby reducing the risk of accidents and enabling timely preventive maintenance. This project not only addresses the limitations of traditional manual inspection methods but also provides a scalable, low-cost, and automated solution for continuous railway infrastructure monitoring. With its ability to deliver real-time insights and remote access, it holds immense potential for future integration with advanced predictive analytics and AI-based decision-making systems. Ultimately, the proposed system contributes significantly to improving passenger safety, minimizing operational downtime, and promoting a smarter, more sustainable railway network.

REFERENCES

[1] P. Capitão, P. Pinho, and N. B. Carvalho, "Reconfigurable IoT solution for train integrity and monitoring," IEEE Internet of Things Journal, vol. 11, no. 12, pp. 22257-22268, June 2024.

[2] H. U. R. Siddiqui, A. A. Saleem, M. A. Raza, K. Zafar, K. Munir, and S. Dudley, "IoT Based Railway Track Faults Detection and Localization Using Acoustic Analysis," IEEE Access, vol. 10, pp. 106520-106533, Sept. 2022.

[3] Rizvi, P. Khan, and D. Ahmad, "Crack Detection In Railway Track Using Image Processing," International Journal of Advance Research, Ideas and Innovations in Technology, vol. 3, no. 4, 2017.

[4] M. Ali, A. Hassan, and S. Kumar, "Automated Railway Track Defect Detection Utilizing Edge Computing and Optical Sensors," Journal of Transportation Engineering, vol. 148, no. 5, 2023.

[5] K. Kumar, R. Singh, and T. Desai, "Real-time railway track geometry monitoring using MEMS accelerometers and gyroscopes," IEEE Sensors Journal, vol. 21, no. 8, pp. 10123-10131, 2021.

[6] A. Sharma, V. Patel, and L. Chen, "Cloud-based predictive maintenance architectures for smart railway infrastructure," International Journal of Smart Grid and Clean Energy, vol. 11, no. 2, 2022.