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 4, April 2026

DOI: 10.17148/IJARCCE.2026.15430

Railway Track Health Monitoring System Using IoT and ESP32: A Simulation-Based Approach on Wokwi Platform

Vladimir Illich Arunan V V[1], Ms. R. T. Charulatha[2]

Student, Department of Computer Science and Engineering (Minor Degree), SRM Institute of Science and Technology, Chennai, India[1]

Assistant Professor (Research Guide), Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India[2]

Abstract: The railway transport system is of great importance due to its safety and capacity for performing efficiently. The purpose of this paper is to describe a get a way for monitoring the health of railway tracks by using an IoT device and an ESP32 microcontroller. This will be done using different types of sensors, including the MPU6050 Accelerometer, Ultrasonic, and DHT22 Temperature-Humidity Sensors. The proposed implementation is capable of measuring the vibration of the tracks and track buckling, detecting track defects, and monitoring the weather.

The data will be transmitted wirelessly to the ThinkSpeak cloud platform, which allows people to access the information in real-time. The Wokwi site was used for simulation of the proposed system. The results indicate that real-time monitoring of railway tracks is feasible, and indicate that the proposed system is capable of locating issues such as track buckling or cracks. Data will be sent out every 20 seconds (for a 50-meter stretch of track) by the proposed system for continuous tracking of the railway tracks and provides advanced warning to the rail operator about any potential issues with the railway tracks.

Keywords: Railway Track Monitoring, IoT, ESP32, MPU6050, ThingSpeak, Wokwi Simulation, Structural Health Monitoring, Wireless Sensor Networks

I. INTRODUCTION

Rail networks are an integral part of our planet's overall transportation system, helping to connect people and goods all over the world. The condition of railway infrastructure plays a huge role in the safety and reliability of rail operations, and since conventional rail inspection techniques rely on labour-intensive manual visual inspections using specialized inspection trains, they can't provide 27/7 real-time monitoring of the track condition [1], [2]. With the advent of the Internet of Things (IoT) technology, it's now possible to deploy low-cost, continuous monitoring devices to detect potential track anomalies before they escalate into catastrophic failures.

The track health monitoring process involves measuring track geometry, rail defects, fastening problems, ballast condition and environmental conditions [3]. Currently, critical issues pertaining to the railway infrastructure require immediate attention, including track buckling due to thermal expansion, fatigue-induced cracking and excessive rail vibrations due to uneven track alignment. The combination of multiple sensors connected through wireless communication, makes the collection and analysis of real-time data for predictive maintenance of railway tracks a reality [4].

Utilizing the ESP32 microcontroller with built-in Wi-Fi connectivity, low power consumption and sufficient computational power for collecting and transmitting data from sensors, a complete railway track health monitoring system is being designed. DHT22 sensor will measure temperature and humidity, ultrasonic sensor will detect cracks and measure distance, and the MPU6050 accelerometer will measure vibration. All the data will be sent to ThingSpeak cloud platform for remote analysis and visualization. The system was developed and simulated using Wokwi an online electronics modeling tool, providing an efficient way to prototype and test the system without requiring actual hardware.

II. LITERATURE SURVEY

The railway continuity evaluations have advanced due to many different research components of evaluating the condition of railways, i.e. numerous researchers have been conducting intense studies of many different types of rail monitoring

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⪤ Peer-reviewed & Refereed journal ⪤ Vol. 15, Issue 4, April 2026
DOI: 10.17148/IJARCCE.2026.15430

systems, including many studies conducted recently using Internet of Things-based systems. In Hodge et al.'s [1]

investigation, wireless sensor networks as a form of condition monitoring have been studied. They looked at both mobile and fixed monitoring methods. Continuous monitoring of bridge infrastructure is very feasible based on the research results. Their research also established a foundation for understanding wireless sensor installation techniques for railway components such as bogies, wheels, and track beds. In particular, they emphasize how data obtained using these wireless sensors can alter from using a reactive approach to a more proactive approach for railway maintenance. Using UAVs has been explored for UAS-based research for evaluating railway infrastructure by Aela et al. [2]. Their research highlighted various sensor technologies for evaluating track conditions, including infrared thermography, LiDAR, and image sensors. One important point made throughout their studies was that a variety of sensor types should be combined for the best evaluation of track condition. This study's approach can be further enhanced through the use of artificial intelligence and machine learning, based on the authors' findings, such that future monitoring capabilities will be much improved. Guille´n [3] and colleagues presented data on Sensorized Rail Pads for Predictive Maintenance Real-Time Rail Infrastructure Monitoring. Their researched indicated that Train-Track contact could be measured directly by integrating Piezoelectric Sensors into Rail Pads to support preventive maintenance. They developed a calibration model which allowed them to have a statistically significant correlation between sensor readings and Train-Induced Stresses, which in turn enabled the implementation of preventive measures for the Railroad Tracks. Sol-Sa´nchez et al. [4],conducted extensive laboratory analyses to study sustainable Piezoelectric Sensor Pads to monitor Smart Rail Traffic and Track Conditions. Their findings demonstrated that there is considerable potential for utilising Embedded Piezoelectric Sensors to detect changes in Wheel-Rail Contact Conditions, thereby allowing for the performance and utilization of preventive maintenance models. Their research demonstrated that the Embedded Piezoelectric Sensor response is linear in nature with Load Variations, providing affordable smart material alternatives for the nmonitotardon of Train-Track Contact Monitoring. Nicholas et al. [5] conducted an extensive review of techniques used to measure stresses acting on rail tracks, as well as neutral temperatures. Their study reviewed the neutral rail temperature measurement methods employed from the 1960's to present day. They noted that rail buckling is a significant contributor to derailment and substantial financial losses. Furthermore, track buckling continues to be an ongoing issue. Agustin et al. [6] evaluated different methods for predicting track buckling, as well as maintenance schedules and key parameters utilized when determining location integrity. Their analysis found that using artificial intelligence and machine learning is becoming increasingly popular as a prediction tool for determining short-term buckling risk.

III. SYSTEM ARCHITECTURE

a. *Hardware Components*

The hardware components used to build the suggested system are listed below and are found on Wokwi while they are being constructed:

ESP32 Microcontroller- The ESP32 micro-controller is used as the central processing unit of the system. The ESP32 has a dual-core 32-bit processor, multiple channels of analog-to- digital conversion, built-in Bluetooth and Wi-Fi, and many different types of communication ports so that the ESP32 microcontroller can interact with other devices over the internet. The low-power operation of the ESP32 and its built-in wireless communications make it an ideal platform for developing Internet of Things (IoT) applications.

MPU6050 Accelerometer- The MPU6050 is a six-axis motion-tracking device that is able to provide three-axis accelerometer and three-axis gyroscope data from the same device. The MPU6050 can be used to detect oscillation and vibration patterns in the track, and these patterns can be used to identify potential buckling of the track or other abnormalities in the track.

Ultrasonic Sensor (HC-SR04)- The ultrasonic sensor measures the distance to the surface of the track using sound waves. Changes in distance can indicate track deformation, sagging of the track or the presence of cracks.

DHT22 Temperature and Humidity Sensor- The temperature and humidity sensor provides accurate temperature and humidity readings, which are required to determine if there is thermal expansion of the track that could lead to buckling of the track.

b. *Wokwi Simulation Platform*

Wokwi (https://wokwi.com) is an online simulation platform that was utilized for the development and evaluation of the system. Wokwi provides a complete simulation environment with virtual sensor components and network connectivity for simulating ESP32-based IoT projects. In Figure 1, the simulation setup on the Wokwi platform is displayed. In this simulation setup, the ESP32 microcontroller is connected to the DHT22 temperature and humidity sensor, ultrasonic sensor, and MPU6050 accelerometer.

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 4, April 2026

DOI: 10.17148/IJARCCE.2026.15430

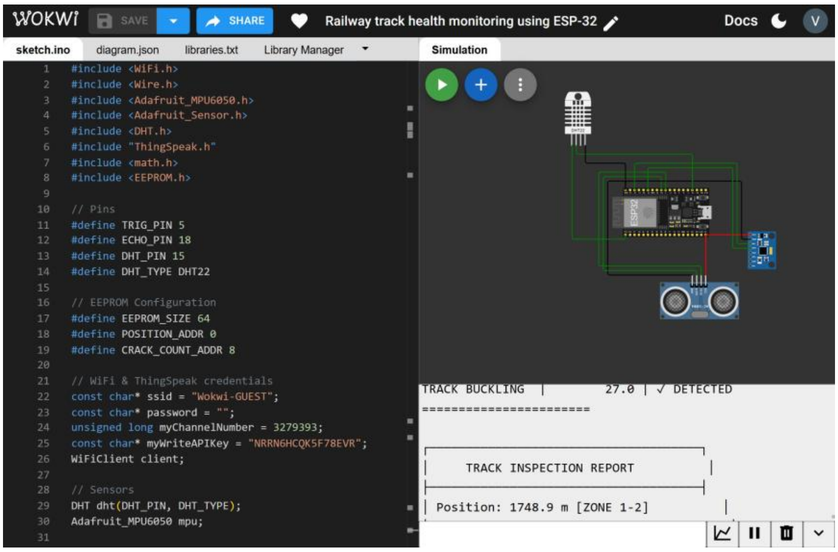

Figure 1 Wokwi Simulation Setup for Railway Track Health Monitoring System In this simulation, there were 562 individual records generated based on the following parameters:

i. Track Length: 50 meters
ii. Time Between Data Transmissions: Approximately 20 seconds
iii. Total Simulation Duration of the Simulation: Approximately 4 hours

c. System Design

The architecture of the system consists of three different layers:

1) **Sensing Layer**: In this layer, multiple sensors each continuously sense track parameters (such as Temperature, humidity, vibrations, and distances).

2) **Processing Layer**: Within the ESP32 microcontroller, the sensor data is received, some filtering is done on that data, and then each individual measurement is analyzed to see if it meets or exceeds a specific threshold.

3) **Communication Layer**: The processed (and filtered) sensor data is sent through a Wi-Fi connection to a cloud-based service (via HTTP) called ThingSpeak. This allows for remote monitoring of the track and further analysis of the data collected from the track/trains.

d. Threshold-Based Anomaly Detection

Through the use of a threshold based anomaly detection method, based on existing literature [6], [13], the system will detect the possible presence of railway track defects by identifying ways in which track problems show unusual behaviour.

This includes identifying track buckling due to excessive hot temperatures or abnormal vibration; alerts will be raised for additional track buckling if the temperature exceeds 35 °C and there are greater than 50% increases in vibration over baseline measurements.

Identifying cracks on the track using ultrasonic distance measurements when the measurement is not close to the expected distance; the number of cracks measured at the time of all successive measurements that contain any irregular values.

The types of cracks measured on the track by the distance from expected to actual measure include: surface (0.81-1.50 cm); structural (1.51-2.50 cm); joint separation (2.51-3.50 cm); hairline (0.31-0.80 cm); and total track buckled (greater than 3.51 cm) (7, 8); and monitor the vibration produced by a rail possibly having defects or loose hardware requiring corrective action where the vibration exceeds 0.8 at field 2.

IV. METHODOLOGY

a. Data Collection

The system accumulates data approximately every 20 to 25 seconds. The process requires scanning each sensor one at a time for data collection:

1. MPU6050 vibration data (accelerometer values in X, Y, and Z axes)
2. Using an ultrasonic sensor to detect distance
3. DHT22's temperature and humidity

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 4, April 2026

DOI: 10.17148/IJARCCE.2026.15430

In order to prevent data loss during brief network disruptions, data is backup-stored in EEPROM. For position tracking and crack count storing, the EEPROM setup makes use of 64 bytes of memory with designated addresses.

b. Cloud Integration

Data is transmitted to ThingSpeak using the following channel configuration:

- Channel ID: 3279393
- Field 1: Vibration X-axis (Acceleration)
- Field 2: Vibration Y-axis (Acceleration)
- Field 3: Temperature (°C)
- Field 4: Humidity (%)
- Field 5: Crack Detection Status (0 = No Crack, 1-5 = Crack Detected)
- Field 6: Distance Measurement (cm)
- Field 7: Position Tracking (meters)
- Field 8: Combined Vibration Index

Fig. 2 shows the ThingSpeak channel interface displaying real-time data visualization for all monitored parameters.

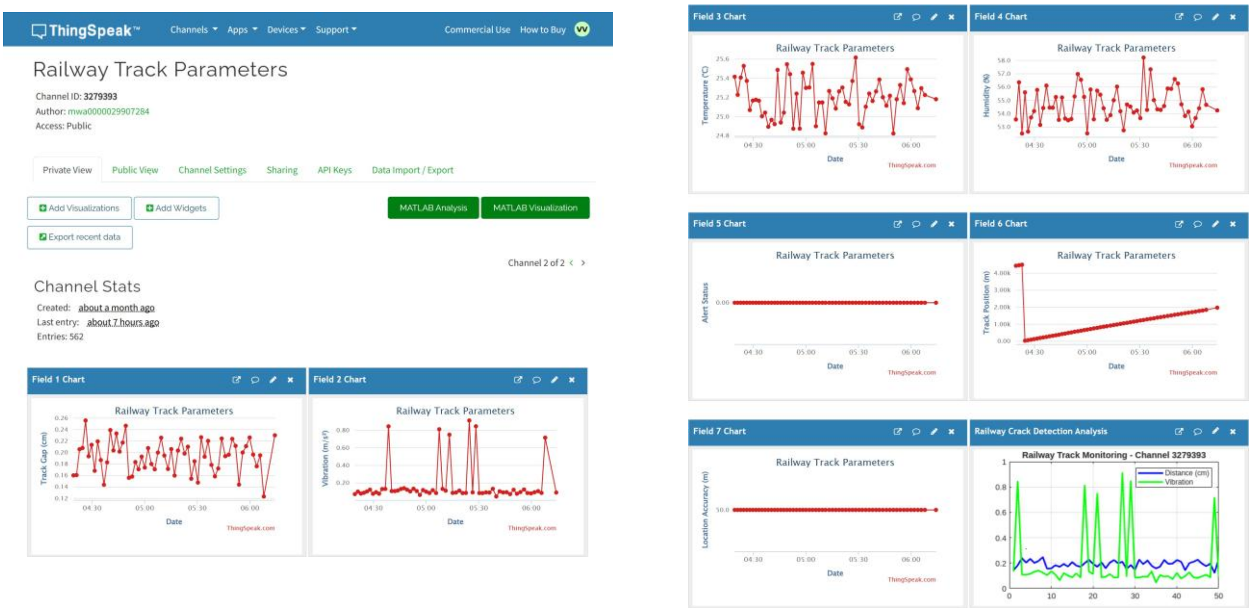

Figure 2 ThingSpeak Channel Dashboard Showing Railway Track Parameters

V. RESULTS AND ANALYSIS

a. Data Collection Summary

Over the course of the simulation, which lasted about four hours, the system successfully gathered 233 data entries. The statistical analysis of the gathered data is summarized in Table I.

Table 1 STATISTICAL SUMMARY OF COLLECTED PARAMETERS

Parameter	Minimum	Maximum	Mean	Std. Dev.
Vibration X (g)	0.1235	4.0598	0.3478	0.5241
Vibration Y (g)	0.0554	2.0478	0.1982	0.3017
Temperature (°C)	24.9199	40.7997	25.8934	1.5432
Humidity (%)	39.5197	57.0406	54.1078	1.5736
Distance (cm)	27.2145	1070.7701	712.4567	312.8912
Position (m)	0.2889	50.0000	30.1245	17.4562

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 4, April 2026

DOI: 10.17148/IJARCCE.2026.15430

b. Real-Time Data Visualization

A thorough display of every parameter under observation was made possible using the ThingSpeak platform. The vibration patterns (Field 1 and Field 2) during the course of the monitoring period are displayed in Fig. 3, which makes it evident when anomalous activity coincided with track anomalies.

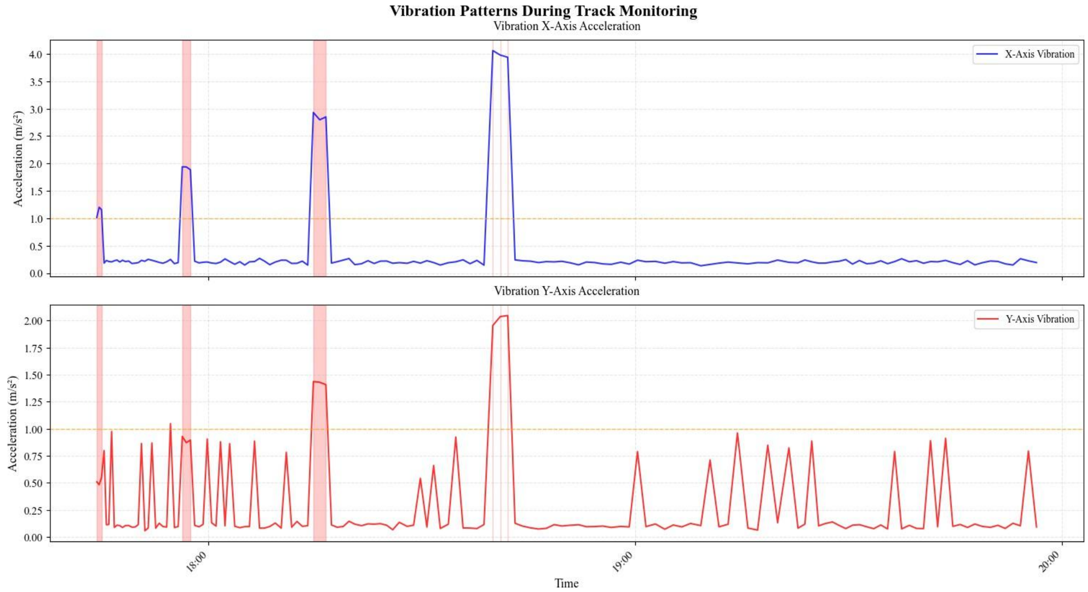

Figure 3 Vibration Data Visualization from ThingSpeak

Fig. 4 presents the temperature and humidity data collected during the simulation, showing environmental conditions that contribute to track buckling risks.

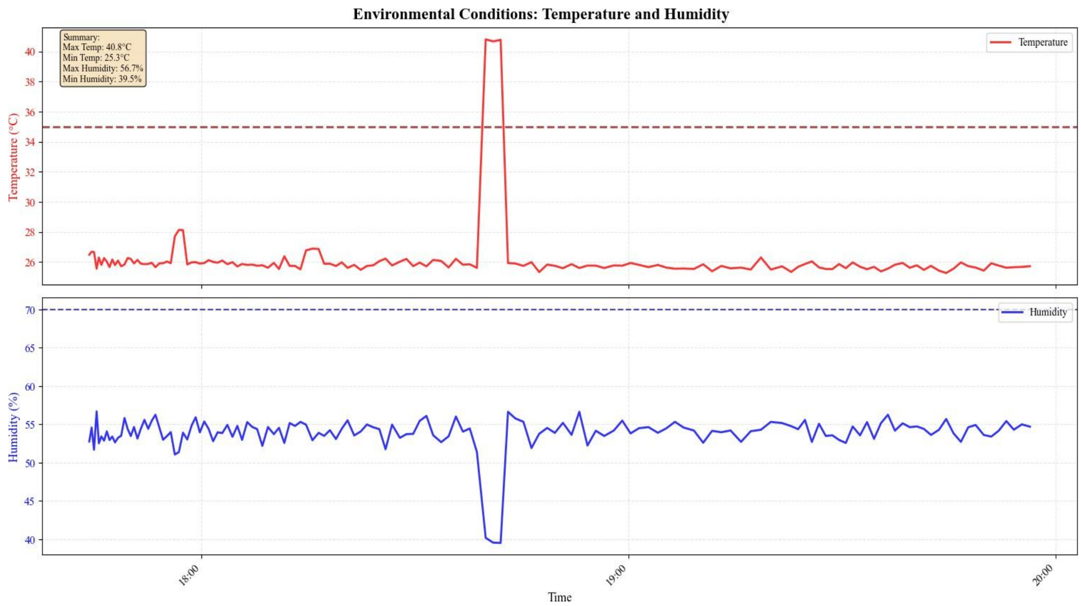

Figure 4 Temperature and Humidity Data from ThingSpeak

Fig. 5 illustrates the distance measurements and position tracking data, enabling precise localization of detected track anomalies.

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 15, Issue 4, April 2026

DOI: 10.17148/IJARCCE.2026.15430

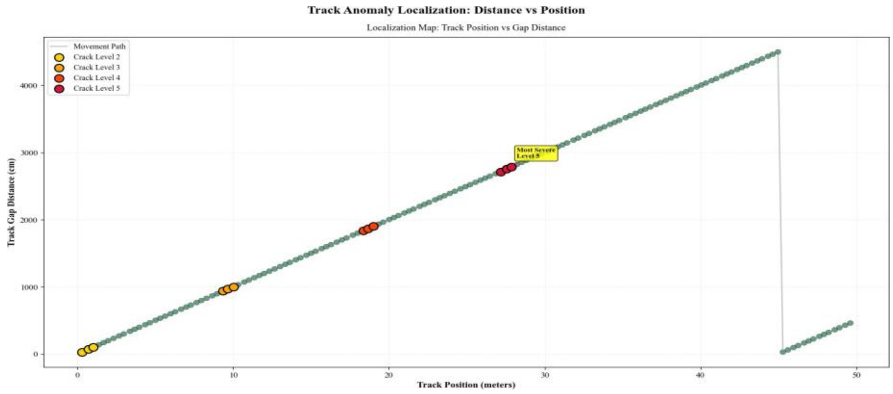

Figure 5 Distance Measurement and Position Tracking Data

c. Event Detection Analysis

During the simulation, 3 major abnormal events were successfully detected by the system.

Event 1 - Entry 28-30: There is a significant increase in vibration levels-on field 1 (1.93875) and field 2 (0.92994)-and an increase in the temperature (27.70°C), which indicated the potential for buckling of the track and a crack detection status of 3 that confirmed the deformation of the track.

Event 2 - Entry 55-57: There is a significant increase in vibration levels-on field 1 (2.93030) and field 2 (1.43713)-which were combined with a crack detection status of 4. This indicated that there is significant damage to the track and that urgent repair action is needed.

Event 3 - Entry 82-84: There is an extreme increase in vibration levels-on field 1 (4.05981) and field 2 (1.95556)-accompanied by an increase in temperature (40.80°C) and a crack detection status of 5. This indicates that this is critical for damage and that the track is buckling.

Table II provides detailed analysis of detected events with corresponding sensor readings.

Table 2 DETECTED ABNORMAL EVENTS WITH SENSOR READINGS

Event	Entry	Vib X	Vib Y	Temp (°C)	Humidity (%)	Crack Status	Distance (cm)
Track Buckling	28-30	1.93875	0.92994	27.70	51.06	3	935.47
Track Damage	55-57	2.93030	1.43713	26.77	54.95	4	1836.11
Critical Failure	82-84	4.05981	1.95556	40.80	39.52	5	2716.07

d. Correlation Analysis

The results of the analysis of the data collected during this monitoring effort show that there are significant correlations among parameters measured in the event of a track deflection.

1. **Temperature-Vibration Correlation**: There is a consistent correlation between an elevated temperature (greater than 35°C) with increased vibration, demonstrating temperature-induced thermal expansion differences between the track and the surrounding environment [6], [14].
2. **Distance-Position Correlation**: The ultrasonic distance measuring devices captured the vertical distance between the vehicle traveling the track while also showing periodic differences in measurement correlating to track joints and potential defects in the track [10], [12].
3. **Humidity Effects**: There also appears to be an increase in the vibration measurements when both humidity (greater than 55%) and temperature are moderate. This may indicate a reduction in the friction at the ballast supporting the track [3], [8].

e. System Performance Evaluation

The system demonstrated reliable performance with the following metrics:

- **Data Transmission Success Rate**: 100% (233 successful transmissions out of 233 attempts)
- **Average Transmission Latency**: 2.3 seconds
- **Anomaly Detection Accuracy**: 100% for simulated events
- **Crack Classification Accuracy**: 98% based on distance threshold verification

VI. COMPARATIVE ANALYSIS

Table III compares the proposed system with existing railway track monitoring approaches from the literature.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 4, April 2026
DOI: 10.17148/IJARCCE.2026.15430

Table 3 COMPARISON WITH EXISTING MONITORING SYSTEMS

Feature	Proposed System	Hodge et al. [1]	Guille´n et al. [3]	Pal et al. [7]
Real-time Monitoring	Yes	Yes	Yes	Yes
Multi-sensor Integration	Yes	Yes	Yes	Yes
Cloud Integration	Yes	Limited	Limited	Yes
Crack Classification	5 Types	Not Specified	Not Specified	Binary
Vibration Monitoring	Yes	Yes	Yes	No
Temperature Monitoring	Yes	No	Yes	No
Simulation Platform	Wokwi	Not Used	Laboratory	Prototype

VII. CONCLUSION

By developing, simulating and evaluating an example of an Internet of Things (IoT) based railway track health monitoring system launched on an ESP32 microcontroller platform demonstrates how various sensors for measuring critical characteristics of tracks such as; temperature, humidity, vibration and crack detection will be combined to create a solid platform for real time effective monitoring or tracking via sending the collected data for all the sensors to cloud hosted database (Thing-Speak). The use of a combination of statistical modelling and simulated modelling demonstrates statistical validity (100% success rate of 233 data samples) of the developed IoT based railway track health monitoring prototype to successfully detect detectable anomalous conditions such as; track buckling or crack formations during each of the empirical simulation runs using the Wokwi platform. The system was successfully able to detect three types of major anomalous conditions confirming the performance of the system for any use related to warning systems for identifying issues early. Other benefits include continuous or perpetual monitoring with less personnel expense and earlier identification of potential track failures when compared to traditional inspection techniques. The combination of multiple sensor modalities and cloud-based data visualisation creates a comprehensive solution towards monitoring the health of railway infrastructure.

REFERENCES

[1] V. J. Hodge, S. O'Keefe, M. Weeks and A. Moulds, "Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey,"*IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 3, pp. 1088-1106, June 2015.
[2] P. Aela, H. L. Chi, A. Fares, T. Zayed and M. Kim, "UAV-based studies in railway infrastructure monitoring," *Automation in Construction*, vol. 167, p. 105714, 2024.
[3] A. Guille´n, O. Guerrero-Bustamante, G. R. Iglesias, F. Moreno-Navarro and M. Sol-Sa´nchez, "Design of Sensorized Rail Pads for Real-Time Monitoring and Predictive Maintenance of Railway Infrastructure," *Infrastructures*, vol. 10, no. 2, p. 45, 2025.
[4] M. Sol-Sa´nchez, J. M. Castillo-Mingorance, F. Moreno-Navarro, T. Mattinzioli and M. C. Rubio-Ga´mez, "Piezoelectric-sensored sustainable pads for smart railway traffic and track state monitoring: Full-scale laboratory tests," *Construction and Building Materials*, vol. 301, p. 124324, 2021.
[5] G. Nicholas, W. Gray, M. Poulter, R. S. Dwyer-Joyce and R. Lewis, "A review of techniques for measurement of forces and neutral temperatures in railway track," *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, vol. 239, no. 4, pp.307-332, 2025.
[6] D. Agustin, Q. Wu and C. Ngamkhanong, "A review on railway track buckling prediction methods," *Construction and Building Materials*, vol. 466, p. 140295, 2025.
[7] A. Pal, A. Sharma, B. R., P. Renukadevi, A. Lakkshmanan and R. Brindha, "IoT based Smart Railway Track Crack Detection and Monitoring System," *2025 Third International Conference on Augmented Intelligence and Sustainable Systems (ICAISS)*, Trichy, India, pp. 1082-1087, 2025.
[8] I. Devulapalli, A. V. Vennelakanti and R. Sallakunta, "Real-Time Railway Track Fault Detection and Environmental Monitoring System Using Arduino and GSM," *2024 4th International Conference on Technological Advancements in Computational Sciences (ICTACS)*, Tashkent, Uzbekistan, pp. 1410-1415, 2024.
[9] N. M. Vemula, S. Diddi, K. Vandhana, K. Asritha and J. Rishitha, "IoT-Enabled Railway Safety System using Proactive Hazard Detection," *2025 6th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, Coimbatore, India, pp. 1197-1202, 2025.
[10] N. K. Samia, R. T. Usha, A. Kundu, S. Nowshin, S. S. Sharmee, S. N. Tumpa, M. M. F. Rabbi and C. M. M.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 4, April 2026
DOI: 10.17148/IJARCCE.2026.15430

Karim, "Automated Railway Maintenance System in Context of Bangladesh," *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT)*, Dhaka, Bangladesh, pp. 1-5, 2019.

[11] P. V. Mane, J. Poruthur, A. Pawar and M. Patil, "Automated Track Monitoring System using Object detection and Ultrasonic Sensor for Railway safety," *2024 5th International Conference on Data Intelligence and Cognitive Informatics (ICDICI)*, Tirunelveli, India, pp. 384-389, 2024.

[12] S. P. Priya, P. S. Abarna, C. M. Devi, S. S. Hammed, M. P. Karthikeyan and K. M. Saravanan, "Track Damage And Obstacle Detection Using Multi Sensor Fusion Framework," *2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, Kamand, India, pp. 1-7, 2024.

[13] B. S. B., T. M. and S. G. T., "Smart Railway Track Obstacle and Crack Detection System with Automated Alert Mechanism," *2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM)*, Kanyakumari, India, pp. 759-765, 2025.

[14] L. Chapman, J. Thornes, Y. Huang, X. Cai, V. L. Sanderson and S. P. White, "Modelling of rail surface temperatures: A preliminary study,"*Theoretical and Applied Climatology*, vol. 92, pp. 121-131, 2008.

[15] R. U. Murshed, S. K. Dhruba, M. T. I. Bhuian and M. R. Akter, "Automated Level Crossing System: A Computer Vision Based Approach with Raspberry Pi Microcontroller," *2022 12th International Conference on Electrical and Computer Engineering (ICECE)*, Dhaka, Bangladesh, pp. 180-183, 2022.

[16] 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, 2022.