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IoT-Enabled Railway Track Crack Detection System

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Abstract
The proposed IoT-enabled crack detection system enhances railway safety by addressing undetected rail track cracks that can lead to derailments and economic losses. This innovative solution utilizes automated anomaly detection, geolocation tracking, and cloud-based analytics through a compact autonomous robotic unit that traverses rail tracks to identify surface and sub-surface defects with high precision. Upon detecting a crack, the system generates immediate alerts via audible alarms and visual signals while transmitting geotagged data to a cloud platform for remote monitoring and predictive maintenance. Experimental validation demonstrates its effectiveness in ensuring timely defect detection and localization, significantly mitigating derailment risks and safeguarding lives.
Index Terms
Rail track,GPS,Cracks,IR sensor,Ultrasonic sensor,Thingspeak,Thing View

I. INTRODUCTION

Railways serve as the lifeblood of transportation in India, connecting millions of people and facilitating economic growth. As one of the world's largest railway networks, the Indian Railways plays a crucial role in the country's development. However, the system grapples with the persistent threat of accidents, particularly derailments, which pose a significant risk to passenger safety and operational efficiency. While various factors contribute to railway accidents, including collisions, level crossing incidents, and fires, derailments remain a major concern. These incidents often stem from track-related issues, such as the presence of cracks, which can lead to track instability and ultimately, derailment. The traditional reliance on fishplates and bolts, while gradually being replaced by welding techniques, still presents vulnerabilities. Misplaced or loose bolts can compromise track integrity, increasing the risk of derailment. Furthermore, the presence of cracks, whether caused by fatigue, wear and tear, or other factors, poses a significant threat to track stability and safety. Addressing these challenges requires a multi-pronged approach, including rigorous track inspections, advanced maintenance techniques, and by applying cutting-edge technologies, we aim to improve track safety and minimize the occurrence of derailments. This research aims to investigate the root causes of derailments, focusing on track-related issues such as crack formation and the impact of maintenance practices, with the goal of contributing to a safer and more reliable railway system in India.
Figure 1 illustrates the distribution of the reasons for consequential train accidents in India from 2018- 19 to 2023-24. As evident in the graph, derailments emerge as the most significant contributor to these accidents, consistently accounting for a substantial majority of incidents throughout the analyzed period. Collisions are the second largest cause, while other factors such as train fires, level crossing accidents, and miscellaneous accidents contribute to a lesser extent. This visual representation underscores the critical need for a comprehensive approach to improving railway safety, with a particular focus on mitigating derailments, which pose the most significant threat to the safety and efficiency of the Indian rail network.

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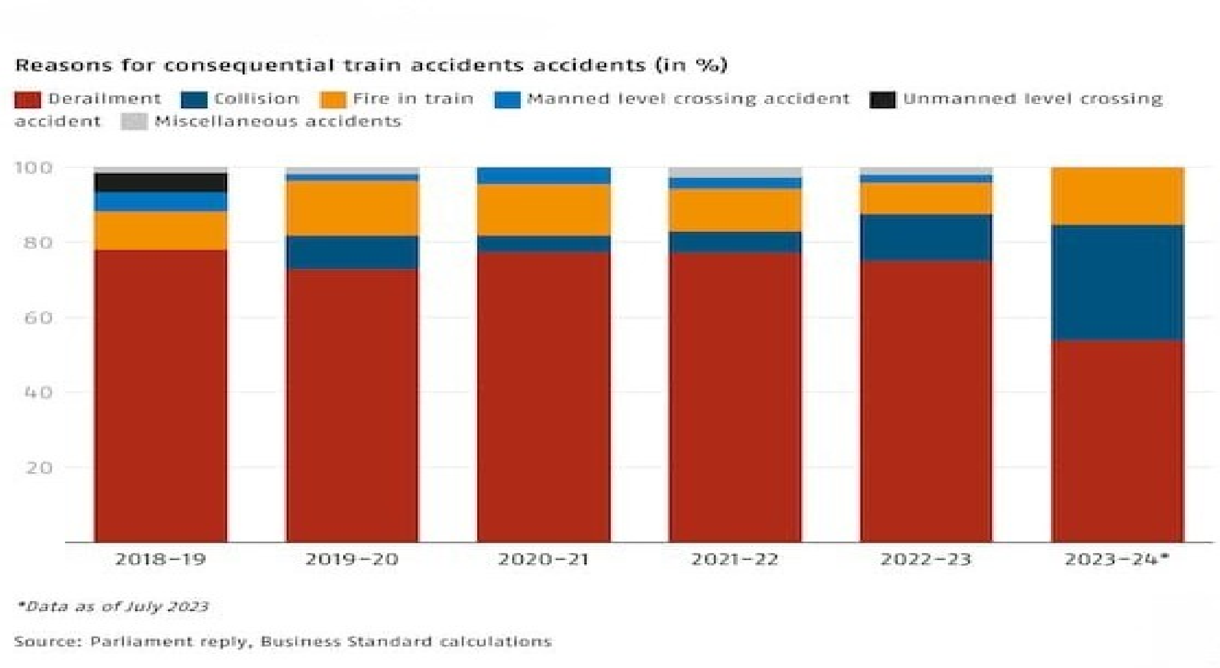

Fig. 1. Percentage Breakdown of Train Accidents in India (2018-2024). Data as of July 2023. Source: Parliament reply, Business Standard calculations [13].

II.NEED FOR EFFECTIVE RAIL TRACK MONITORING SYSTEM FOR CRACK DETECTION

In the world, the Indian railway network is one of the largest and is a vital component of the economic and social progress of the nation. However, it deals with significant safety issues, particularly frequent accidents such as derailments. Statistical data show that derailments are the main cause of major train accidents, accounting for a large proportion of these incidents. These accidents lead to tragic loss of life, injuries, and substantial economic costs due to service interruptions, infrastructure damage, and lost revenue. A key factor contributing to derailments is undetected cracks in rail tracks. Traditional methods of track inspection, though important, often depend heavily on manual labor and visual checks. These methods are not only time-consuming and labor-intensive, but also susceptible to human error, potentially missing subtle cracks or anomalies that could result in catastrophic failures. Consequently, there is an urgent need for efficient rail track monitoring systems. By adopting modern technologies such as automated inspection systems, advanced sensors, and AI-driven analytics, railway operators can greatly improve track safety and reliability. Effective monitoring systems offer several critical benefits. First, they improve the accuracy and speed of inspections, identifying defects that could be overlooked by manual methods. Second, they enable proactive maintenance through predictive analytics,prioritizing and addressing any potential failures in advance. This approach can significantly cut maintenance costs and boost the overall operational efficiency of the railway network. Additionally, by implementing advanced monitoring technologies, railway operators can demonstrate their commitment to safety, thereby increasing public confidence in the reliability and safety of the railway system.

III. RELATED WORKS

The authors in [1] developed a method using a neural network (NN) classifier for crack detection.

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Rail images undergo preprocessing, Gabor transformation, and GLCM feature extraction before classification and segmentation to identify cracks. While highly accurate, its complexity makes it unsuitable for real-time applications.

In [2], an image processing technique captures rail images with a camera, adjusts brightness, converts them to binary format, removes unnecessary portions, and checks connectivity to detect cracks. Although effective, this approach is sensitive to lighting conditions and requires precise camera alignment.

Reference [3] proposes a robotic system using an LED-LDR assembly for crack detection, along with GPS and GSM modules for real-time alerts. While reducing manual labor, it needs proper alignment and is limited to surface cracks.

[4] introduces a linear Charge-Coupled Device (CCD) sensor for detecting cracks through image processing. This method offers high sensitivity but relies on complex algorithms and expensive hardware. Wireless Sensor Networks (WSNs) are explored in [5] for continuous monitoring of vibrations, stress, and deformations. However, they require robust communication infrastructure and are vulnerable to interference.

Edge computing is proposed in [6] for local data processing, enabling low-latency alerts to railway authorities. While effective, it increases system complexity and cost due to advanced hardware require- ments.

Table I below compares all of the various rail track monitoring systems put forth by various writers with the aim of detecting fractureside a better understanding of all these monitoring techniques described in the literature survey.

TABLE I
COMPARISON OF RAIL TRACK MONITORING METHODS FOR CRACK DETECTION

S.No	Authors	Year	Method Used for Rail Track Monitoring for Crack Detection	Pros	Cons
1	R. Manikandan et al. [1]	2017	Neural Network (NN) Classifier with Gabor Transformation and GLCM	High accuracy; Suitable for automation	Requires high computational power; Complex
2	Aliza Raza Rizvi et al. [2]	2017	Image Processing (Brightness adjustment, Binary conversion)	Non-contact method; Automated	Sensitive to lighting; Requires alignment
3	K. Balakrishna et al. [3]	2014	Robot with LED-LDR Assembly, GPS, GSM	Real-time alerts; Reduces manual labor	Requires alignment; Limited to surface cracks
4	Qlao Jian-hua et al. [4]	2008	Linear CCD Sensor (Image processing)	High sensitivity; Continuous monitoring	Expensive setup; Intricate algorithms
5	E. Aboelela et al. [5]	2006	Wireless Sensor Networks (WSNs)	Continuous monitoring of rail tracks;Enables proactive maintenance through predictive analytics.	Requires robust communication infrastructure for WSNs,challenging to implement in remote areas.

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6	S. Kumar et al. [6]	2022	Edge Computing	Reduces latency by processing data locally at the edge;Minimizes reliance on centralized cloud servers, ensuring faster decision-making.	Complex edge computing setup increases system complexity and cost;Edge devices consume more power and require regular maintenance.

IV. PROPOSED SYSTEM

The proposed autonomous robotic system, enabled by IoT, is designed to enhance fracture identification on railroad tracks, addressing the limitations of current monitoring systems. This innovative solution automates the monitoring process, reduces manual labor, and improves passenger safety through the integration of sophisticated sensors, communication modules, and a microcontroller-based control unit. A key feature of this system is its incorporation of ThingSpeak, a cloud-based IoT platform that facilitates data storage and analysis related to crack detection. The compact autonomous robotic unit is equipped with infrared (IR) sensors, ultrasonic sensors, GPS modules, and a Wi-Fi module, ensuring comprehensive monitoring capabilities. Powering the robot are DC motors controlled via an L293D motor driver, which allows for smooth navigation along railway tracks. The Arduino Uno serves as the central processing unit, coordinating all components and ensuring real-time data processing. In addition, the system uploads critical data to ThingSpeak, enabling continuous monitoring and long-term analysis of rail track conditions. This approach not only improves operational efficiency, but also significantly contributes to maintaining safety standards within the railway infrastructure.

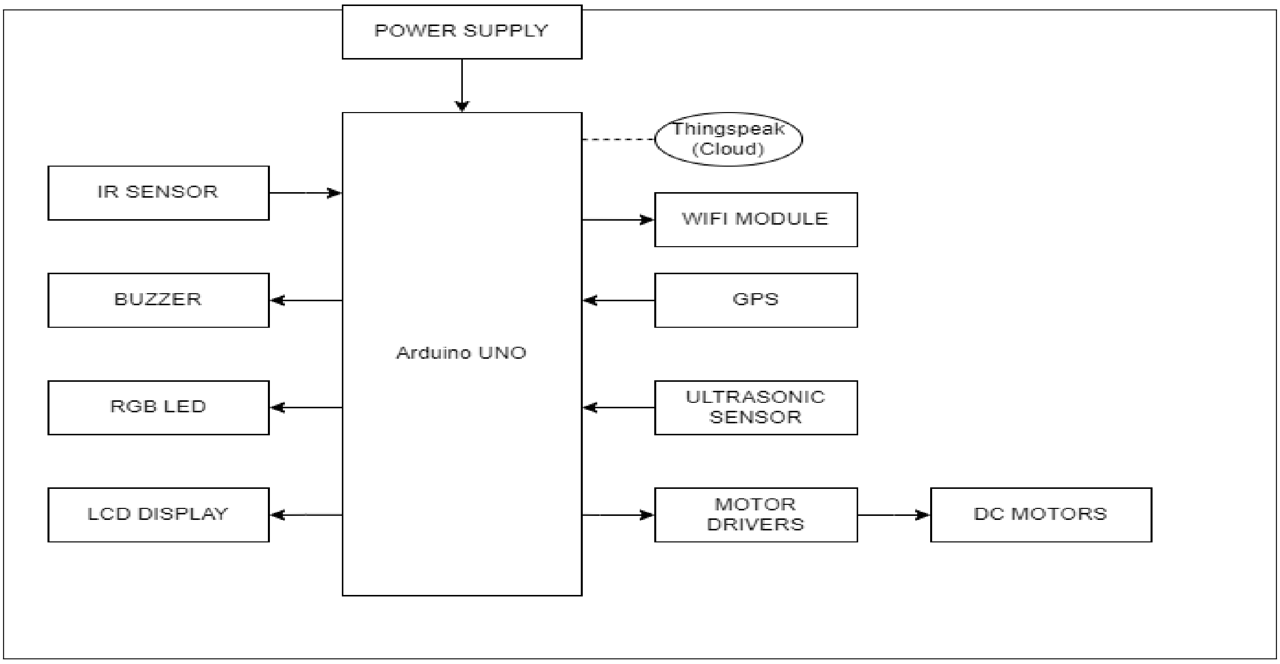

Fig. 2. System Block Diagram.

V. THINGSPEAK FOR REAL-TIME MONITORING AND ANALYSIS

ThingSpeak, an open-source IoT platform developed by MathWorks [7], plays a crucial role in the proposed railway track crack detection system by allowing real-time monitoring and analysis of sensor data. The platform facilitates seamless data collection, storage, and visualization through its cloud-based infrastructure, allowing railway authorities to remotely monitor track conditions via

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dashboards or the ThingView app [8]. With features such as real-time data streaming, GPS coordinate tracking, and alert notifications, ThingSpeak ensures timely identification of cracks and obstacles on railway tracks. By inte- grating ThingSpeak into the system, the proposed solution eliminates the need for complex wireless sensor networks (WSN) or edge computing sets-ups, reducing both cost and operational complexity. In addition, the scalability and affordability of the platform make it ideal for large-scale deployment across urban and rural railway networks, improving overall safety and reliability. Through its RESTful API, the system transmits data from the robotic unit (equipped with IR and ultrasonic sensors) directly to ThingSpeak's cloud database, where it is organized into channels for easy access and analysis. This integration not only improves decision making, but also supports predictive maintenance strategies, ensuring proactive responses to potential tracking issues.

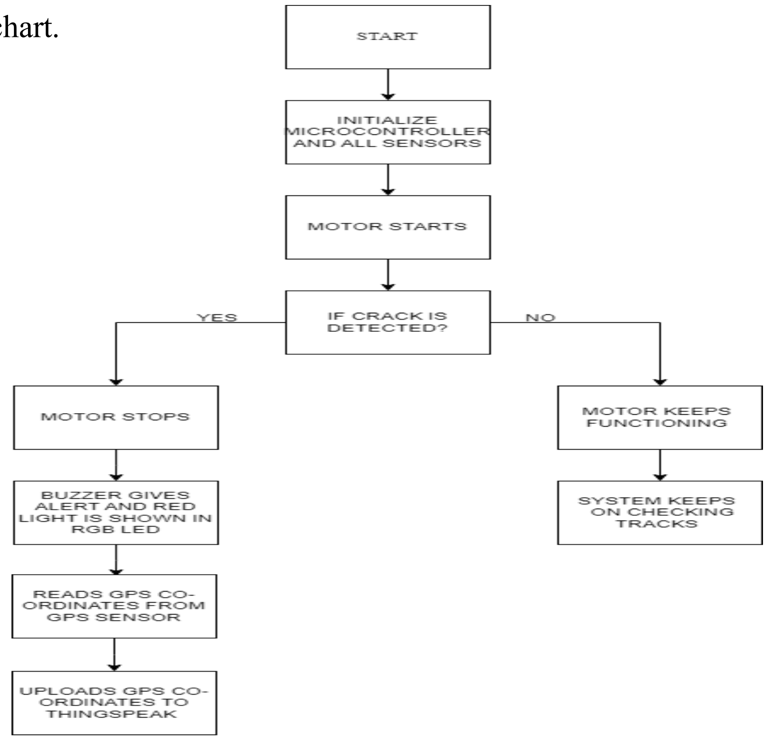
VI. METHODOLOGY OF PROPOSED SYSTEM

The proposed system automates the detection of cracks and obstacles on railway tracks, ensuring real- time data transmission and remote monitoring. It consists of a compact, autonomous robotic unit powered by DC motors (controlled via L293D motor drivers) and equipped with an Arduino Uno microcontroller as the central processing unit. Two IR sensors detect cracks using infrared signals, while an ultrasonic sensor identifies obstacles through high-frequency sound waves.

Upon detecting a crack or obstacle, the robot stops, triggers an alert via a buzzer, changes the RGB LED to red, and displays a warning message (e.g., "Crack Detected") along with GPS coordinates on the LCD screen. This information is then transmitted to ThingSpeak, a cloud-based IoT platform, using a Wi-Fi module. Railway authorities can access the data remotely via the ThingView app, enabling prompt action through real-time visualization of charts, graphs, or maps.

Once uploaded, the data remains accessible to authorized personnel at any time. After resolving the issue, the robot returns to scan for additional anomalies. By integrating IoT technologies like ThingSpeak and ThingView, the system ensures efficient, automated monitoring, reduces manual labor, enhances scalability, and improves passenger safety by mitigating accidents caused by undetected defects.

Fig. 3. System Flow chart.



VII. **RESULT**

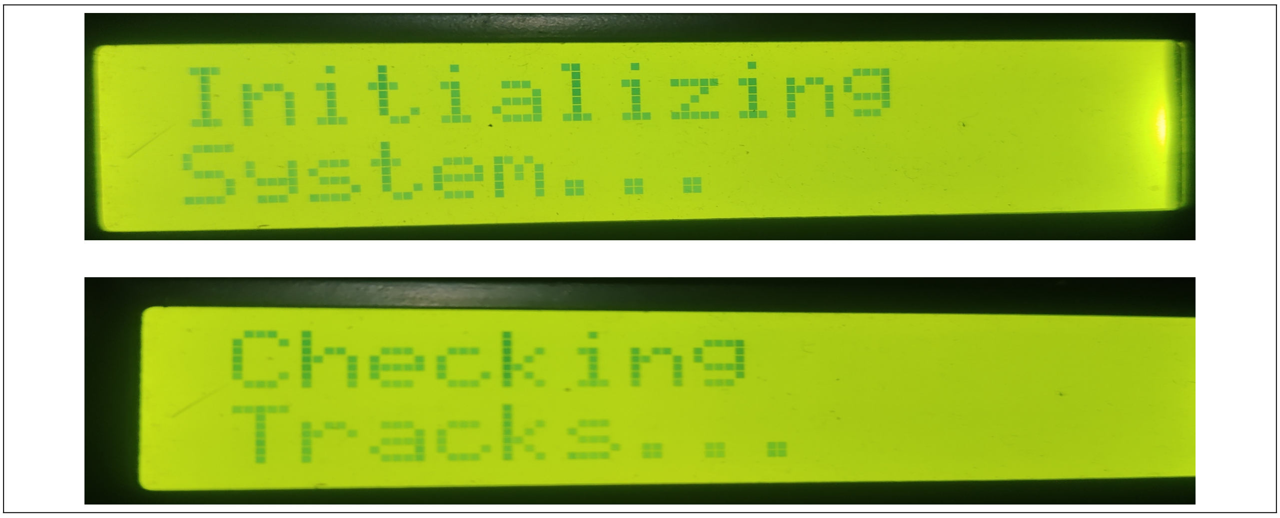


Fig. 4. Message on LCD after switching on the proposed system

Fig. 5. Message on LCD after detecting cracks or obstacles on rail tracks

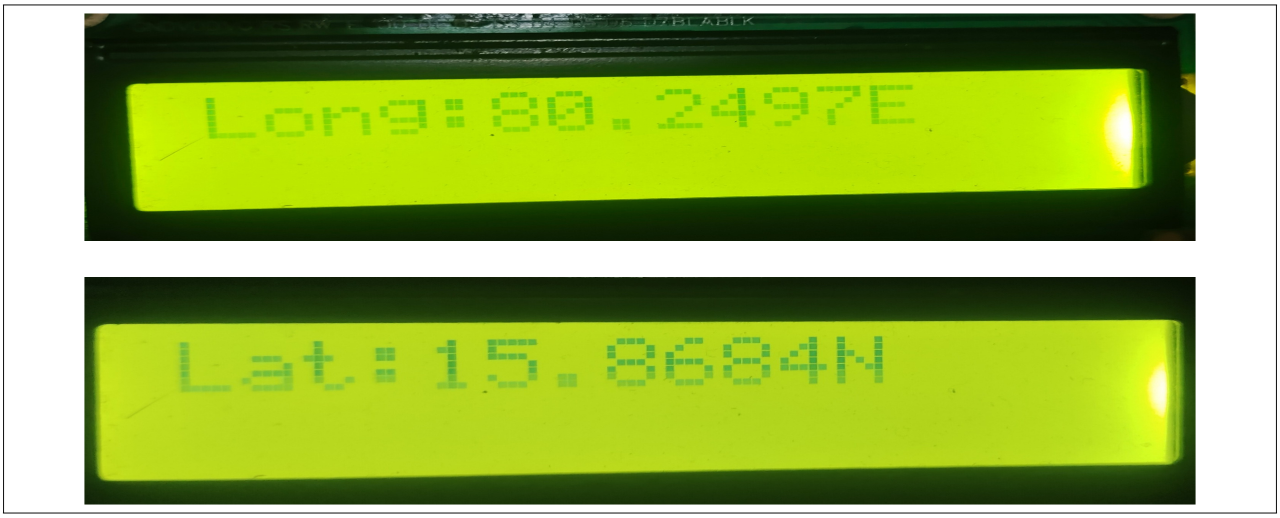


Fig. 6. Gps co-ordinates of cracks or obstacles

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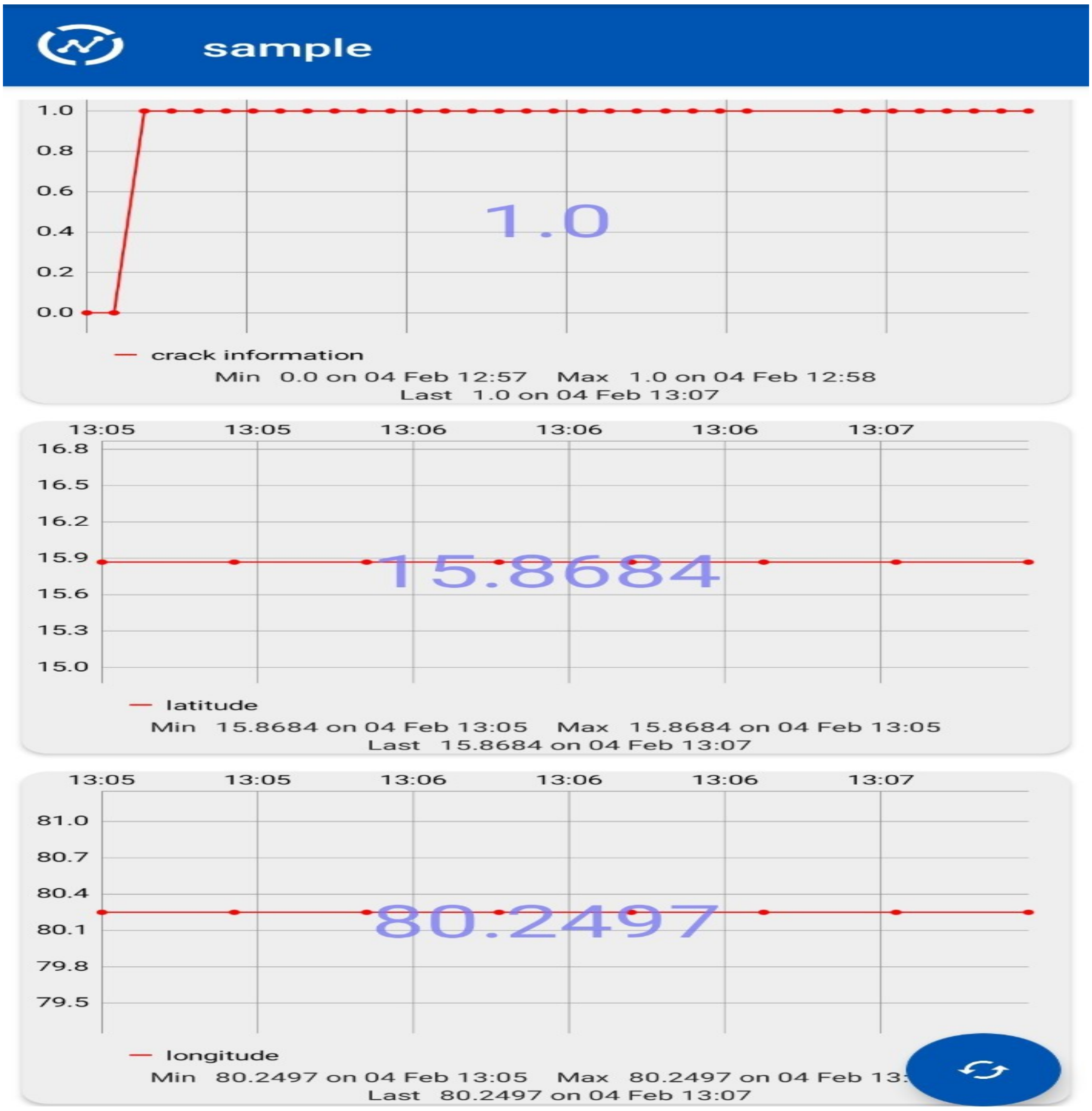

Fig. 7. Information recieved in thingview app on mobile regarding detection of crack

Fig. 4 shows the content displayed on the LCD screen immediately after switching on the proposed system. The message indicates that the system is operational and ready to begin monitoring the railway tracks. This ensures that the user is informed about the system's status at startup. Fig. 5 shows the message shown on the LCD when a crack or obstacle is detected on the railway tracks. The LCD updates to show a warning message such as "Crack Detected" along with additional details, enabling quick identification of the issue. This immediate feedback ensures that nearby personnel are alerted to the presence of anomalies. Fig. 6 illustrates the GPS coordinates of the detected crack or obstacle. The exact location (latitude and longitude) of the defect is displayed on the LCD. This feature ensures precise localization of the issue, allowing railway authorities to quickly locate and address it. Fig. 7 shows the information on the thingview app.Three graphs are shown in the thingview app, which the first graph shows values 0, 1 where value 1 indicates crack or obstacle detected and 0 indicates no crack or obstacle detected. The remaining two graphs display the GPS coordinates (latitude and longitude) of the detected crack in real time. Table II below compares the proposed system with existing systems.

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TABLE II
COMPARATIVE ANALYSIS OF PROPOSED SYSTEM WITH EXISTING SYSTEMS

Features	**R.Manikan -dan [1]** (NN Classifier)	**A.R.Rizvi. [2]** (Image Processing)	**K.Balakrish -na . [3]** (LED-LDR Assembly)	**Proposed System**
Automat -ion	Partially automated	Requires manual alignment	Semi-automated	Fully automated
Real-Time Alerts	No real-time alerts	No real-time alerts	Real-time alerts via GSM	Real-time alerts via ThingSpeak and SMS
Data Storage & Analysis	Local processing	Local processing	Limited data storage	ThingSpeak for real- time analysis
Sensor Technology	Image-based	Camera-based	LED-LDR assembly	Dual sensors (IR + Ultrasonic)
User Interface	Requires technical expertise	Requires technical expertise	Basic LCD display	LCD display, RGB LED, buzzer
Environm -ental Resistance	Sensitive to environmental factors	Sensitive to lighting conditions	Sensitive to alignment	Built to withstand diverse conditions
Maintena -nce Approa -ch	Reactive	Reactive	Semi-proactive	Predictive maintenance enabled
Key Advantages	High accuracy; Suitable for automation	Non-contact method; Automated	Real-time alerts; Reduces manual labor	Fully automated, IoT- enabled, cost-effective
Key Limitations	Complex algorithms; High computational power	Sensitive to lighting; Requires alignment	Requires proper alignment; Limited to surface cracks	Power supply constraints; Network dependency

VIII. ADVANTAGES OF OUR SENSORS OVER EXISTING SOLUTIONS

Reference papers [3],[4],[5], and [6] use various sensors for detecting cracks on railway tracks, each with unique advantages and limitations. Paper [3] employs an LED-LDR assembly to detect cracks via light intensity changes but requires precise alignment and is limited to surface cracks, making it unreliable under dirt or uneven lighting. In [4], a linear CCD sensor offers high sensitivity and non-contact detection but involves complex algorithms, expensive hardware, and degraded performance in poor lighting or adverse weather. [5] explores Wireless Sensor Networks (WSNs) for continuous monitoring using vibration, stress, and deformation sensors, enabling predictive maintenance; however, it requires robust infrastructure, is vulnerable to interference, and introduces latency issues during real-time monitoring. Lastly, [6] uses edge computing to reduce latency but increases system complexity, cost, and power consumption due to advanced hardware requirements.In contrast, our proposed system integrates IR and ultrasonic sensors, overcoming these limitations. IR sensors provide alignment-free operation and robust performance across varying environmental conditions, while ultrasonic sensors detect odstacles. GPS modules ensure precise location tracking, and Wi-Fi enables real-time data transmission to ThingSpeak, eliminating

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WSN complexities and enhancing scalability. The IoT-enabled design of the system combines cost-effectiveness, simplicity, and user-friendliness through visual indicators , audible alerts, and an LCD display. Remote monitoring via the ThingView app ensures timely intervention by railway authorities. By integrating advanced sensors and IoT technologies, the system delivers a scalable, reliable, and efficient solution for crack detection, improving passenger safety and operational efficiency.

TABLE III
ADVANTAGES OF PROPOSED SENSORS OVER EXISTING METHODS

Reference Paper	Sensors Used in Reference	Limitations of Reference Sensors	How Our Sensors Improve
[3] K. Balakrishna et al.	LED-LDR Assembly, GPS, GSM	Requires precise alignment for accurate detection; Limited to surface cracks only	Alignment-free IR sensors detect both surface and internal cracks; Multi-functional design for obstacle detection
[4] Qlao Jian-hua et al.	Linear CCD Sensor	Expensive hardware increases deployment cost; Complex image processing algorithms require high computational power; Sensitive to lighting conditions	Cost-effective IR and ultrasonic sensors reduce hardware costs; Simplified implementation avoids complex algorithms and ensures robust performance under varying lighting conditions
[5] E.Aboelela et al.	Vibration, Stress, Deformation Sensors	Requires robust communication infrastructure for WSN; Vulnerable to interference, affecting data reliability; Latency issues during real-time monitoring	IoT integration with ThingSpeak ensures low-latency real-time monitoring without WSN infrastructure; Wi- Fi module eliminates the need for complex communication setups
[6] S. Kumar et al.	Accelerometers, Vibration Sensors	Limited detection scope cannot identify all types of cracks; Complex edge computing setup increases system complexity and cost	Comprehensive detection using IR sensors for surface cracks and ultrasonic sensors for obstacle detection ; Simplified design avoids edge computing hardware, reducing complexity and cost

IX. BENEFITS OF PROPOSED SYSTEM

• Reduces manual labor by automating the crack detection process, requiring only a single operator instead of a team of 5–6 members.

- Ensures precise location tracking of cracks using GPS, providing exact latitude and longitude coor- dinates for efficient repairs.
- Scalable and can be deployed across extensive railway networks, including both urban and rural areas.
- Integrates with IoT platforms like ThingSpeak for cloud-based data storage, enabling remote moni- toring and predictive maintenance
- User-friendly design with clear visual indicators (RGB LED), audible alerts (buzzer), and an easy- to-read LCD display.
- Ensures faster and more accurate decision-making by providing actionable data in real-time.

X. FUTURE SCOPE AND POTENTIAL IMPROVEMENTS

Despite the significant advantages provided by the proposed system over current methods, there are still many opportunities for improvement. In the future, the focus should be on integrating advanced technologies like machine learning and drones to improve crack detection accuracy and coverage. In addition, improving GPS accuracy with inertial navigation systems and ensuring secure data sharing through blockchain can address current shortcomings. Developing a dedicated mobile application, includ- ing solar-powered operation, and expanding the system's scope to include environmental monitoring are all possibleimprovements. The system can increase its scalability, reliability, and effectiveness in ensuring railway safety by addressing these areas.

XI. CONCLUSION

Railways are an integral part of daily transportation, offering numerous benefits such as affordability, accessibility, and efficiency. However, the safety of passengers remains the top priority for railway authorities. The existing rail track monitoring systems, particularly those used in India, suffer from significant limitations, including manual operation, inefficiency, and limited coverage. These shortcomings have contributed to frequent rail accidents caused by undetected cracks in tracks, endangering lives and causing substantial economic losses.The proposed system addresses these challenges by introducing an automated, IoT-enabled crack detection system that ensures real-time monitoring and precise location tracking. By leveraging advanced sensors such as IR sensors, ultrasonic sensors , and GPS modules , the system detects cracks and obstacles on railway tracks with high accuracy. The integration of LCD display provides real-time feedback to operators. Furthermore, the use of ThingSpeak for cloud-based data storage and analysis enhances the system's scalability and usability, enabling railway authorities to monitor track conditions remotely and implement predictive maintenance strategies.

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