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ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

Automated Railway Track Crack Detection System using Raspberry Pi and Image Processing

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Abstract:

Railway safety is a critical concern, as undetected track cracks can lead to severe accidents, causing loss of life and economic damage. Traditional railway track inspection methods rely on manual labour, which is time-consuming, inefficient, and prone to human error. To overcome these limitations, this project presents an Automated Railway Track Crack Detection System that utilizes Raspberry Pi Pico, ESP32-CAM, and image processing techniques for real-time monitoring.The proposed system is equipped with IR sensors to detect cracks and ESP32-CAM for live video streaming, allowing continuous surveillance of railway tracks. Upon detecting a crack, the system captures GPS coordinates using a GPS module and transmits the location details via GSM to railway authorities, ensuring timely maintenance actions. The robotic system is powered by a lithium-ion battery and controlled using a motor driver module, enabling autonomous movement along the tracks.By integrating computer vision and IoT technologies, this project enhances railway maintenance efficiency while reducing human intervention. Future advancements could involve deep learning models for more accurate crack detection and integration with cloud-based railway monitoring systems for real-time data analysis and predictive maintenance.

Keywords: Railway Track Crack Detection, Image Processing, IoT in Railways, Raspberry Pi Pico, ESP32-CAM, GPS Tracking, GSM Alert System, Automated Railway Monitoring, AI in Railways.

1. INTRODUCTION

Railway transportation is a vital mode of travel and cargo movement, requiring continuous monitoring to ensure safety and reliability. Cracks or defects in railway tracks pose a significant threat, potentially leading to derailments, accidents, and infrastructure failures. **Timely detection and repair of these cracks are crucial** to preventing disasters and maintaining smooth railway operations. However, traditional inspection methods rely heavily on manual labour, which is not only **time-consuming and inefficient** but also susceptible to human errors.

To address these challenges, automated railway track inspection systems have emerged as a viable solution. Recent advancements in IoT, image processing, and embedded systems have enabled the development of intelligent monitoring systems capable of real-time crack detection. By leveraging ESP32-CAM for live video streaming, IR sensors for defect detection, and GPS-GSM modules for alert transmission, this project aims to automate the process of railway track monitoring and enhance maintenance efficiency.

with increasing advancements in computer vision and artificial intelligence, future iterations

this system could incorporate deep learning algorithms for enhanced crack detection accuracy and cloud-based predictive maintenance solutions. By implementing such technologies, the railway industry can significantly improve safety standards, reduce operational risks, and ensure uninterrupted service.

2. LITERATURE SURVEY

Sensor-based systems are emphasized for effective real-time crack detection in railway tracks, reducing manual inspection efforts and ensuring early fault identification.

Live video streaming using ESP32-CAM for remote visual inspection provides a cost-effective and efficient alternative to traditional image processing methods.

Real-time location tracking with GPS modules ensures the exact position of detected cracks is reported, facilitating quick maintenance response.

GSM modules are integrated to send immediate alerts to authorities, enabling faster decision-making and reducing accident risks.

Automated robotic systems equipped with sensors and cameras are utilized for railway track monitoring, reducing human intervention and improving accuracy.

Low-cost microcontrollers like Raspberry Pi Pico are used for sensor data processing and robot control, making the system affordable and scalable.

Solar-powered monitoring systems are introduced for continuous operation in remote areas, ensuring reliable and uninterrupted functionality.

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Efficient fault detection is achieved by integrating multiple sensors, such as ultrasonic and IR sensors, which improve the system's accuracy.

The system design emphasizes the use of edge computing for faster data processing at the local level, reducing latency and reliance on cloud-based analysis.

Real-time visual confirmation through IP-based video streaming enhances operational reliability, as track faults can be visually verified before taking corrective action

3. PROPOSED METHODOLOGY

The Automated Railway Track Crack Detection System is designed to enhance railway safety using Raspberry Pi Pico, ESP32-CAM, image processing, and IoT technologies. The system continuously monitors railway tracks, detects cracks in real-time, and sends alerts to railway authorities with location details.

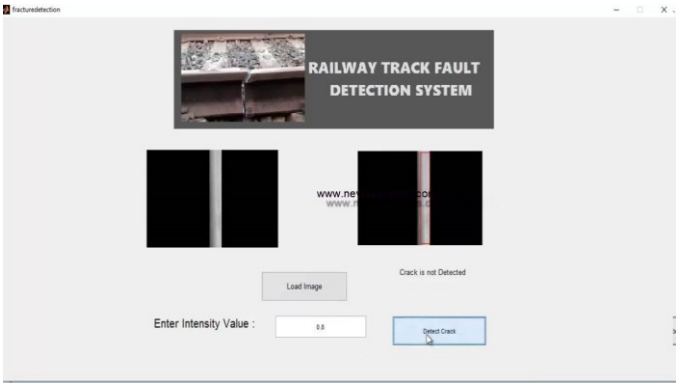

Figure 1: Proposed crack detection system.

The proposed methodology typically includes the following key components:

• **Live Video Streaming:** The **ESP32-CAM** continuously streams live video of the railway track, providing real-time monitoring.

• **Image Processing & Crack Detection:** The **Raspberry Pi Pico** processes the video feed using image processing algorithms, such as **edge detection**, to identify cracks.

• **Automated Alert System:** When a crack is detected, the system **sends an alert via GSM**, along with the **GPS coordinates**, to railway authorities for quick action.

• **Power Management:** The system is powered by a **lithium-ion battery** with a **buck converter** to regulate power supply to different modules.

• **Motorized Inspection System:** The camera is mounted on a **robotic platform** that moves along the track, covering long distances efficiently.

• **Evaluation and Benchmarking:** The system's performance is assessed using **accuracy metrics**, ensuring reliable crack detection and minimal false alarms.

Applications:

• Live Video Streaming: The ESP32-CAM continuously streams live video of the railway track, providing real-time monitoring.

• Image Processing & Crack Detection: The Raspberry Pi Pico processes the video feed using image processing algorithms, such as edge detection, to identify cracks.

• Automated Alert System: When a crack is detected, the system sends an alert via GSM, along with the GPS coordinates, to railway authorities for quick action.

• Power Management: The system is powered by a lithium-ion battery with a buck converter to regulate power supply to different modules.

• Motorized Inspection System: The camera is mounted on a robotic platform that moves along the track, covering long distances efficiently.

• Evaluation and Benchmarking: The system's performance is assessed using accuracy metrics, ensuring reliable crack detection and minimal false alarms.

Advantages :

- Real-Time Monitoring: Provides continuous surveillance of railway tracks, ensuring immediate detection of cracks.
- Automated Operation: Eliminates the need for manual inspection, reducing human effort and improving efficiency.
- Quick Alerts: Sends instant notifications with GPS coordinates to railway authorities via GSM for timely maintenance.
- Cost-Effective: Uses affordable components like Raspberry Pi Pico and ESP32-CAM, making it a budget-friendly solution.
- High Accuracy: Image processing algorithms ensure precise crack detection, minimizing false alarms.
- Energy Efficient: Operates on a lithium-ion battery with a buck converter, optimizing power consumption.
- Versatile Deployment: Can be used on different types of railway tracks, including urban and remote areas.
- Scalable Design: Can be upgraded with AI-based processing for enhanced crack detection and classification.
- Low Maintenance: Requires minimal upkeep due to its robust and automated system design.
- Improved Safety: Helps prevent accidents by detecting track defects early, ensuring safer railway operations.

4. EXPERIMENTAL ANALYSIS

The Figure 2 shows a railway track crack detection robot prototype designed and built for my project. It is placed on a track prototype to simulate real-world railway conditions. The system integrates various components like Raspberry Pi Pico, ESP32-CAM, sensors, and GSM forreal-time monitoring and fault detection.

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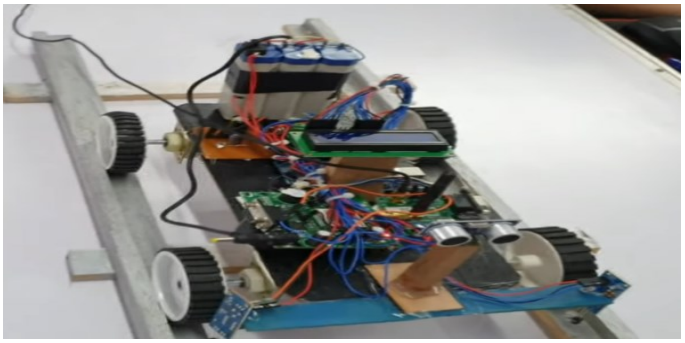

Figure 2: Robot

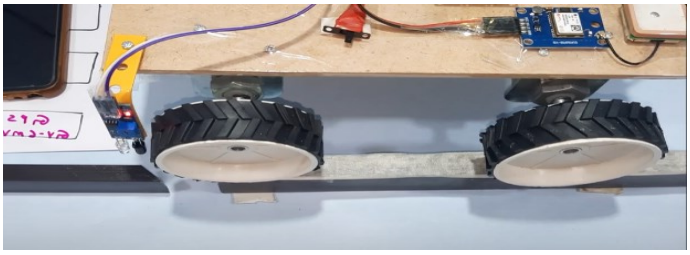

Figure 3: Crack Detected

The figure shows a railway track crack detection robot. Here, using a sensor, the track is detected, and when a crack is observed, the robot stops automatically. The system ensures immediate response to track faults, preventing further movement. Additional components like GPS and GSM modules can be used for location tracking and sending alerts. This enhances safety and reliability in railway maintenance.

Figure 3: Virtual Inspection

The figure shows a virtual live video inspection using an ESP32-CAM. The video feed is streamed in real-time, allowing remote monitoring of the environment. This setup is useful for applications like railway track crack detection, where visual inspection complements sensor-based detection. The live feed can be accessed via an IP address through a web browser, enhancing monitoring efficiency.

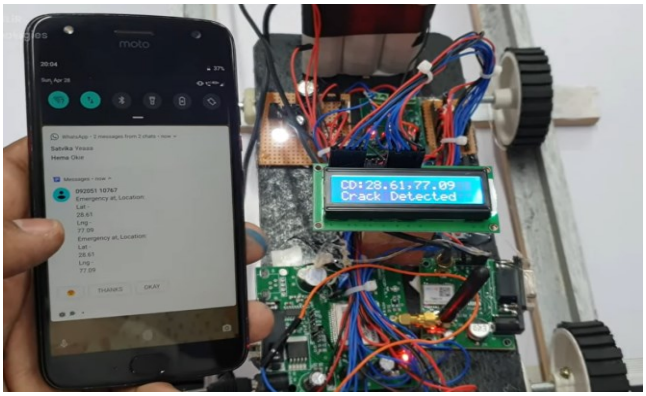

Figure 5: GPS Location

This image illustrates the functionality of the railway track crack detection system, showcasing its real-time alert mechanism. The LCD screen on the robot displays the detected crack along with its GPS coordinates, confirming the identification of a fault. Simultaneously, the system sends an emergency alert message containing the crack's location to a mobile device via the GSM module. This feature enables immediate notification to relevant authorities, allowing for prompt action and maintenance. The combination of sensor-based detection, GPS tracking, and wireless communication ensures a robust and efficient approach to railway safety.

5. CONCLUSION

The Automated Railway Track Crack Detection System enhances railway safety by identifying track faults in real-time. Using ESP32-CAM for live video streaming and Raspberry Pi Pico for processing, the system detects cracks efficiently. It transmits GPS coordinates through a GSM module for instant alerts to railway authorities. With its automated operation and reliable performance, the system reduces human intervention and improves the accuracy of fault detection. The integration of sensors ensures precise crack identification, while the motorized platform allows continuous track monitoring. A stable power supply using a lithium-ion battery and buck converter supports long-term operation. Additionally, real-time visual feedback aids in remote inspection and verification. This project offers a cost-effective and practical solution for railway track monitoring, contributing to safer and more efficient railway operations.

6. FUTURE SCOPE

In the future, this project can be improved by adding features like advanced sensors for more accurate crack detection. Real-time image processing using AI algorithms can be implemented to detect and analyze cracks more efficiently. The system can be enhanced to monitor multiple tracks simultaneously by deploying multiple robots. Solar panels can be used to provide continuous power in remote areas. Additionally, the concept can be applied to other transportation systems like metro rails and trams for crack detection and maintenance. Further developments may also include real-time data analysis and cloud storage for better tracking and predictive maintenance.

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