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Autonomous Railway Track Monitoring Robot with Real-Time Alerting and Live Video Streaming

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Abstract - Railway infrastructure plays a vital role in the transportation system, requiring regular monitoring to prevent accidents caused by track cracks. This paper presents the design and development of an autonomous Railway Track Crack Detection Bot using STM32F103C8T6 as the central controller. The system employs an ultrasonic sensor to detect major cracks on the railway track by continuously measuring the surface distance. Upon detecting a significant crack, the bot automatically halts and transmits the real-time location using a GSM module integrated with GPS data acquisition. Additionally, an ESP32-CAM module is deployed to provide live video streaming and manual movement controls via a web-based user interface, enabling remote intervention if needed. The bot is programmed to start moving automatically upon activation, ensuring initial autonomous operation. The motor driver circuit, controlled through GPIO pins of the STM32 microcontroller, enables forward, backward, and directional movement based on commands received or detection events. Emphasis is placed on robust communication between modules, precise crack classification, and real-time alerting to minimize human inspection effort and enhance railway safety. The proposed system demonstrates an efficient, low-cost, and scalable solution for proactive railway track maintenance. Future enhancements may include machine learning-based crack severity analysis and multi-sensor fusion to improve detection reliability under various environmental conditions.

Key Words: Railway Track Monitoring, Crack Detection, STM32F103C8T6, Ultrasonic Sensor, GSM Module, GPS Tracking, ESP32-CAM, Autonomous Bot

1.INTRODUCTION

Railway transportation systems form the backbone of many nations' economic and social development. The maintenance of railway tracks is crucial to ensure the safety and efficiency of train operations. Cracks or structural defects in railway tracks can lead to catastrophic accidents, resulting in loss of life and property. Therefore, the early detection of track faults is a major research focus [1]. Traditional inspection methods often involve manual labor, which is time-consuming, expensive, and prone to human error. To address these limitations, automation and real-time monitoring solutions are increasingly being explored.

This paper proposes a smart Railway Track Crack Detection Bot using the STM32F103C8T6 microcontroller as the core processing unit. The bot utilizes an ultrasonic sensor to monitor track conditions continuously and identifies major cracks based on predefined threshold values. A GSM module is used to transmit alerts along with GPS-based location data whenever a critical defect is detected. Furthermore, an ESP32-CAM module enables live video streaming and provides manual control features via a wireless web interface, enhancing the bot's flexibility in difficult terrains.

The bot is designed for autonomous operation, with the capability to start movement automatically upon activation. In the event of a major crack detection, the bot halts and transmits critical information to a remote monitoring station. By integrating real-time sensing, wireless communication, and manual control functionalities, the proposed system aims to provide a cost-effective and scalable solution for enhancing railway safety. This research builds upon earlier studies [2][3], improving upon limitations through the integration of modern microcontrollers and IoT modules.

1.1 PROBLEM IDENTIFICATION

Railway transportation plays a vital role in the movement of goods and passengers due to its cost-effectiveness and efficiency. However, track-related failures such as cracks, misalignments, or deformations are among the leading causes of railway accidents. Traditional manual inspection methods are time-consuming, labor-intensive, and often fail to detect defects promptly, especially in remote or less accessible areas. This delay in detection can lead to catastrophic accidents, loss of life, and major financial setbacks. Moreover, most existing systems lack real-time monitoring and automated alert mechanisms, making it difficult to ensure continuous track health surveillance. Therefore, there is a significant need for an autonomous, real-time, and efficient railway track monitoring system that can automatically detect track cracks, locate them accurately using GPS technology, and alert authorities through GSM communication. Additionally, live video surveillance is essential for remote monitoring and manual control during critical inspection activities. This project aims to address these challenges by developing a low-cost, reliable robotic solution using STM32 microcontroller, ultrasonic sensors, GPS, GSM, and ESP32-CAM modules for integrated crack detection, location tracking, communication, and visual monitoring.

1.2 PROPOSED SYSTEM

The proposed system is an autonomous Railway Track Crack Detection Bot designed to automatically monitor and detect cracks on railway tracks. The bot is built around the STM32F103C8T6 microcontroller, interfaced with an ultrasonic sensor for crack detection, a GPS module for acquiring precise location coordinates, and a GSM module for sending real-time alerts when a major crack is detected. In addition to autonomous operation, the bot is integrated with an ESP32-CAM module that provides a live video stream and manual control buttons through a web interface, allowing remote monitoring and navigation if required. The robot starts moving automatically on track power-up and continuously monitors for track irregularities. Upon detecting a critical crack based on pre-defined thresholds, the system halts the bot, captures the GPS location, and transmits the crack details via GSM to concerned authorities. The ESP32-CAM interface enables the operator to manually adjust the bot's position through UART-based commands if needed. This system minimizes human intervention, ensures real-time detection and reporting, and enhances railway track safety with minimal infrastructure costs. By combining hardware sensors with live video surveillance and communication technologies, the proposed system provides an effective, scalable, and reliable solution for early crack detection and prevention of railway accidents.

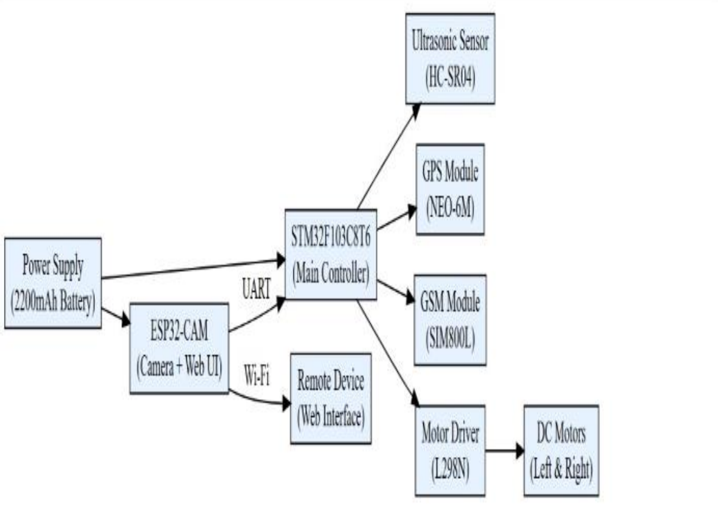

Figure 1: Block diagram

2. OPERATION OF SYSTEM

The operation of the Railway Track Crack Detection Bot begins with the automatic activation of its motors once powered on. The STM32F103C8T6 microcontroller controls the movement of the bot, maintaining a steady forward motion along the railway track. An ultrasonic sensor mounted on the bot continuously measures the distance between the bot and the surface of the track. If a significant dip or gap indicative of a major crack is detected, the bot immediately halts its movement. Simultaneously, the GPS module fetches the current location coordinates. These coordinates, along with a predefined crack alert message, are sent via the GSM module to a registered mobile number or control center.

In parallel, the ESP32-CAM module provides a live video feed of the track ahead, which can be accessed through a web interface. The web interface also offers control buttons for manual navigation, allowing an operator to move the bot forward, backward, left, or right if manual inspection is needed. Communication between the ESP32-CAM and STM32 is achieved through UART serial commands. All modules operate on a shared ground to maintain consistent electrical potential, ensuring reliable operation. The integration of automatic crack detection with manual remote control and real-time video monitoring makes the operation efficient, flexible, and highly reliable for railway maintenance applications.

The flowchart drawn below describes the step by step procedure involved in the working of our Model.

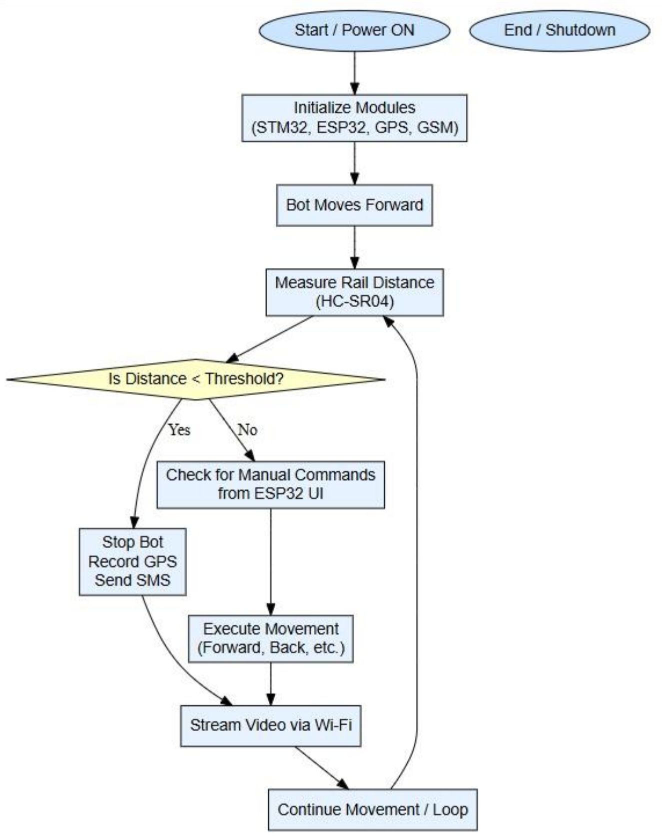

Figure 2: Flowchart for the sequence of events

3. REQUIRED COMPONENTS

3.1 STM32F103C8T6 Microcontroller:

The STM32F103C8T6 is a 32-bit ARM Cortex-M3-based microcontroller operating at 72 MHz. It features 64 KB Flash memory, 20 KB SRAM, multiple UARTs, and PWM outputs. In this project, it controls the entire system, processes ultrasonic sensor data, handles UART communication with GPS, GSM, and ESP32-CAM, and manages motor operations based on crack detection or manual commands.

Figure 3 STM32F103C8T6

3.2 L298N Motor Driver Module:

The L298N is a dual H-Bridge motor driver IC capable of driving two DC motors simultaneously in both forward and reverse directions. It receives low-current signals from STM32 and uses an external power supply to control high-current motors, allowing smooth movement and speed control via PWM.

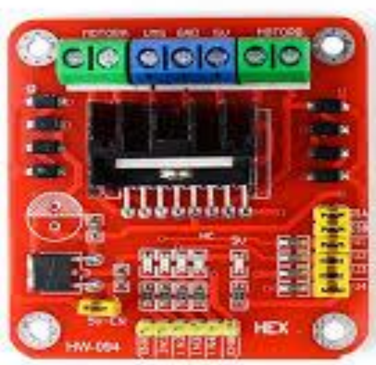

Figure 4 : Motor Driver Module

3.3 Ultrasonic Sensor (HC-SR04):

The HC-SR04 ultrasonic sensor measures distance by emitting ultrasonic waves and measuring their echo time after bouncing off surfaces. It detects cracks on railway tracks by measuring sudden gaps and comparing them to predefined thresholds, identifying whether a crack is minor, mild, or major.

Figure 5: Ultrasonic Sensor

3.4 GSM Module (SIM800L):

The SIM800L is a quad-band GSM module that provides cellular connectivity for SMS communication. Upon detection of a major crack, STM32 instructs the SIM800L to send a text message containing the crack location (latitude and longitude) to a predefined mobile number, alerting authorities.

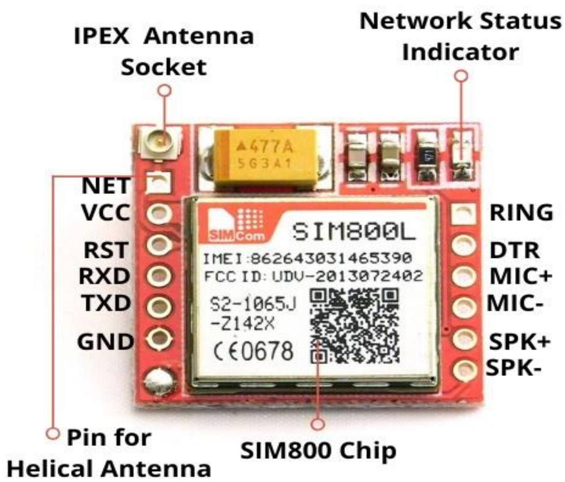

Figure 6 : GSM Module

3.5 GPS Module (NEO-6M):

The NEO-6M GPS module provides real-time geographical location data through UART communication. It constantly updates the latitude and longitude coordinates. In case of a major crack detection, these coordinates are sent via the GSM module to ensure precise incident reporting.

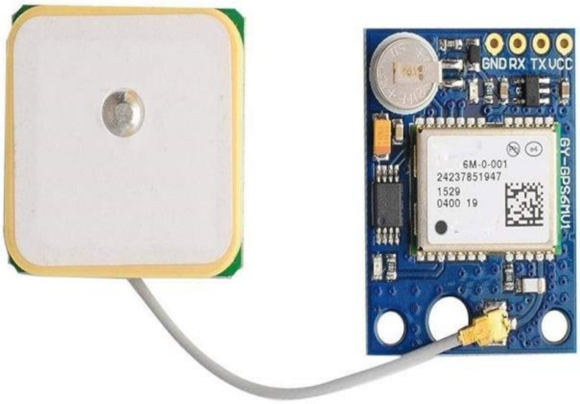

Figure 7: GPS Module

3.6 ESP32-CAM Module:

The ESP32-CAM module features an onboard camera and Wi-Fi capability. It hosts a local web server that streams live video from the bot's front and provides control buttons (forward, backward, left, right, stop). Commands are transmitted to the STM32 using UART for manual operation.

Figure 8 : ESP32-CAM Module

4 CONCLUSION:

This project successfully demonstrates the design and implementation of a smart railway track crack detection system using the STM32F103C8T6 microcontroller, ultrasonic sensing, GPS tracking, GSM communication, and manual control through an ESP32-CAM-based web interface. The system automatically identifies major cracks on railway tracks in real-time and promptly sends location-based alerts to the concerned authorities via GSM. The integration of ultrasonic sensors provides an efficient and low-cost method for crack detection, while the GPS ensures precise location tracking. The manual override through the ESP32-CAM offers flexibility in navigation and monitoring via live video feed. This project not only improves railway safety by enabling early crack detection but also reduces the risk of accidents caused by undetected track failures. Overall, the proposed system proves to be a robust, scalable, and cost-effective solution for modern railway monitoring applications, paving the way for further enhancements using advanced IoT and AI technologies.

5. FUTURE SCOPE:

The proposed railway track crack detection system can be further enhanced in multiple ways to achieve higher reliability and wider application. In the future, the system can be upgraded by integrating more advanced sensors such as LIDAR or thermal imaging cameras for better crack analysis. Machine learning models can be embedded on the STM32 microcontroller using TensorFlow Lite to enable real-time classification of crack severity with higher accuracy. Additionally, the communication system can be upgraded from GSM to 4G/5G or LoRa for faster and longer-range data transmission. Solar-powered modules can be incorporated to make the system energy-efficient for remote track monitoring. Autonomous path planning and obstacle avoidance algorithms can also be added to make the bot completely self-navigating. Furthermore, cloud connectivity and mobile app integration can provide centralized real-time monitoring, data storage, and analytics, helping railway authorities in predictive maintenance and efficient track management.

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