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IOT and AI based On-The-Fly Visual Defects Detection in Railway Tracks

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ABSTRACT: The reliance on manual segmentation poses challenges due to its time-consuming nature and the susceptibility to human error. The need for trained individuals to carry out this task adds complexity and potential variability to the segmentation process. To address these issues, the integration of a microcontroller, LCD display, ultrasonic sensor and artificial intelligence offers an automated solution for tracking and acquiring data. When the crack is identified, data is gathered through the ultrasonic sensor, and the results are promptly displayed on the LCD, accompanied by a buzzer sound. And with respect to Artificial Intelligence part, this approach is implemented within a comprehensive database and live data collection using trained laptop camera, integrating Deep Learning enabling the efficient detection of cracks across various railway tracks. This automation not only streamlines the segmentation process but also enhances efficiency and reduces the dependence on manual labor, making the entire system more robust and reliable.

KEYWORDS: Railways, Accidents, Crack Detection, Internet of Things, Artificial Intelligence, Ultrasonic Sensor

I. INTRODUCTION

Rail transportation serves as a vital component of India's transit landscape, offering a rapid, punctual, and high-capacity option for urban public transport. However, the inherent challenges within rail systems, including operational security issues and overcrowding on trains and platforms, persist despite their safety advantages. Traditional rail construction methods, prevalent in many countries, involve the use of metallic rail tracks affixed to sleepers using specialized anchors or hooks. While advancements like pre-stressed concrete sleepers have enhanced stability, railway accidents such as fires, collisions, and derailments continue to occur. Derailments, in particular, present a significant risk to passenger safety and are often attributed to weak construction, cracks, or missing rail hooks.

Addressing the challenge of monitoring expansion gaps and assessing rail track quality is paramount in ensuring safe and efficient railway operations. This paper proposes a comprehensive software solution that utilizes image processing techniques to evaluate the condition of tracks and gaps. The proposed methodology employs a multi-step process, starting with image segmentation, where morphological operations are applied to enhance the visibility of gaps and rail lines. Subsequently, edge detection methods such as Sobel and Canny algorithms are employed to further refine the analysis and accurately detect the edges of the tracks.

In addition to traditional image processing techniques, the integration of state-ofthe-art YOLOv5 deep learning techniques in artificial intelligence significantly enhances crack detection capabilities. YOLOv5 is a cutting-edge object detection algorithm known for its speed and accuracy in identifying objects within images. By training YOLOv5 on a dataset of images containing examples of track irregularities, such as cracks and deformations, the model can learn to accurately identify and localize these irregularities in real-time, thereby improving the overall effectiveness of the track monitoring system.

Furthermore, the processed data obtained from image processing and YOLOv5 analysis is then fed into a microcontroller unit (MCU) for further processing and decision-making. The MCU coordinates data retrieval through an ultrasonic sensor, displaying findings on an LCD display, and emitting a distinctive buzzer sound in case of track irregularities. This integrated approach not only streamlines track monitoring but also offers real-time feedback through an automated and reliable system, thereby enhancing railway safety and operational efficiency.

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II. LITERATURE SURVEY

IOT based railway track faults detection and localization Using Acoustic analysis.
AUTHOR: Sandra Dudley
PUBLISHED YEAR: 2022
This work contributes significantly to railway track fault identification and classification based on acoustic analysis, as well as fault localization. Based on their frequency of occurrences, six types of track faults were first targeted: wheel burnt, loose nuts and bolts, crash sleeper, creep, low joint, and point and crossing. Support vector machines, logistic regression, random forest, extra tree classifier, decision tree classifier, multilayer perceptron and ensemble with hard and soft voting were among the machine learning methods used. The results indicate that acoustic data can successfully assist in discriminating track defects and localizing these defects in real time.
SYSTEM LIMITATIONS:

- This approach is very costly since it uses sensors for acoustic analysis.
- Uses basic and well-known Machine Learning Algorithms for detection.

SYSTEM ADVANTAGES:
Different machine learning models were trained and evaluated on this data. MLP achieved 98.4% accuracy.

Vision based railroad track extraction using Dynamic Programming
AUTHOR: Yusuf Sinan Akgul
PUBLISHED YEAR: 2021
In the studies, vision cameras (monocular, stereo etc) have been installed in front of the train engines to reduce the risk of a collision. These implementations can be used in two different types of applications: train driver assistant systems and fully automated train systems. As an example of implementation of board camera systems, presents ego motion estimation of the camera and moving object detection in railroad crossing: it consists of a monocular camera method applied to consecutive frames. Ego motion of the camera is estimated using image measurements of fixed points in the scene.
SYSTEM LIMITATIONS:
However, railroad environments often contain complex shapes and different surfaces like hills and vegetation along railroad tracks. For this reason, this method does not provide accurate estimation and produces false detections in most cases.
SYSTEM ADVANTAGES:
The proposed algorithm extracts the left and right rails using dynamic programming simultaneously. Our method does not need any static calibration process. For this purpose, a camera system was installed in front of a locomotive.

Detection of Transverse Defects in Rails Using Noncontact Laser Ultrasound
AUTHOR: Hajar Benzeroual
PUBLISHED YEAR: 2020
The present work deals with the theoretical analysis of an integrated contact-less system for rail diagnosis, which is based on ultrasounds. The generation of these waves was performed through non-ablative laser sources. Rotational laser vibrometer was used to achieve the reception of the echoes. Detection of flaws in the rail was monitored by considering special ultrasound wave signal based indicators. Finite element modelling of the rail system was performed, and transverse defect detection of the rail was analysed.
SYSTEM LIMITATIONS:

- Using this method, defect signature remains mostly small until the defect size reaches a significant value.
- This is still in theoretical study.

SYSTEM ADVANTAGES:

- This study is the influence of the position of the sensors on the signal amplitude. Once the distance changes, the influence of the amplitude also changes.
- The obtained results have enabled us to determine the best arrangement of sensor positions to operate the detection of transverse rail defects.

Accident Prevention and Crack Detection System for Railway tracks
AUTHOR: Ms.Mini Magdline, Mr.Mukul Pande
PUBLISHED YEAR: 2021
This paper aims to propose a defected rail track detection system. This project discusses railway track crack detection using image processing and is a dynamic approach which combines the use of Wheel encoder module to send alert messages of information of location and GSM. A Raspberry Pi 4 is also used to control and coordinate the activities of

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these devices. This project prevents train derailment by detecting a crack in railway track using image processing technology.

SYSTEM LIMITATIONS:

- High implementation cost
- Complex implementation techniques SYSTEM ADVANTAGES:
- Reduces manual labor.
- Reduce time consuming.
- To provide real-time monitoring of railway tracks and detection of any crack on them and in case of detection, send the information with the location to the receiver side using encoder module via GSM.

III. METHODOLOGY

The project for railway track crack detection using IoT and AI proposes a comprehensive methodology aimed at enhancing railway safety and maintenance practices. At its core, the project leverages a combination of IoT sensor technology and artificial intelligence algorithms to enable real-time monitoring and detection of track irregularities.

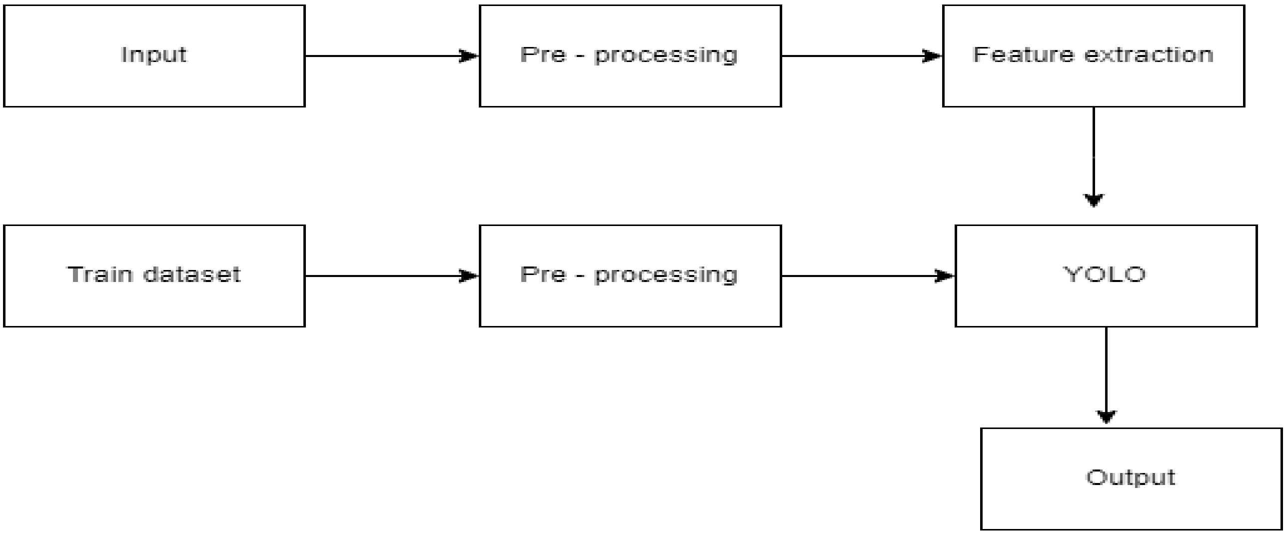
The data acquisition phase involves the deployment of ultrasonic sensors along the railway track. These sensors measure the distance between the sensor and the track surface, allowing for the detection of variations indicative of track irregularities such as cracks or deformations. The sensor data is then processed by a microcontroller unit (MCU), which acts as the central hub for data processing and communication.

In the artificial intelligence module, deep learning algorithms, notably YOLOv5, are employed for crack detection and classification. These algorithms are trained on historical and real-time data to accurately identify and localize track irregularities in images captured by the sensors. The decision-making logic within the AI module assesses the severity of detected irregularities and triggers appropriate responses based on predefined criteria or models. This may include initiating maintenance actions, adjusting train schedules, or issuing alerts to railway personnel.

The user interface module provides real-time visualization of track condition information to railway personnel through an LCD display. This interface presents detected irregularities, their locations, and severity levels, enabling informed decision-making and timely action. Additionally, an audible alert system, such as a buzzer, notifies personnel when critical track issues are identified, ensuring prompt response to safety concerns.

Through continuous monitoring and feedback, the project facilitates proactive maintenance and intervention, contributing to enhanced railway safety and operational efficiency. Feedback from real-world deployments and incident reports is used to refine the AI models, update decision-making logic, and improve the overall effectiveness of the crack detection system. Ultimately, the integrated approach of IoT and AI technologies offers a robust and efficient solution for ensuring safe and reliable railway operations.

ARCHITECTURE DIAGRAM FOR SOFTWARE MODULE



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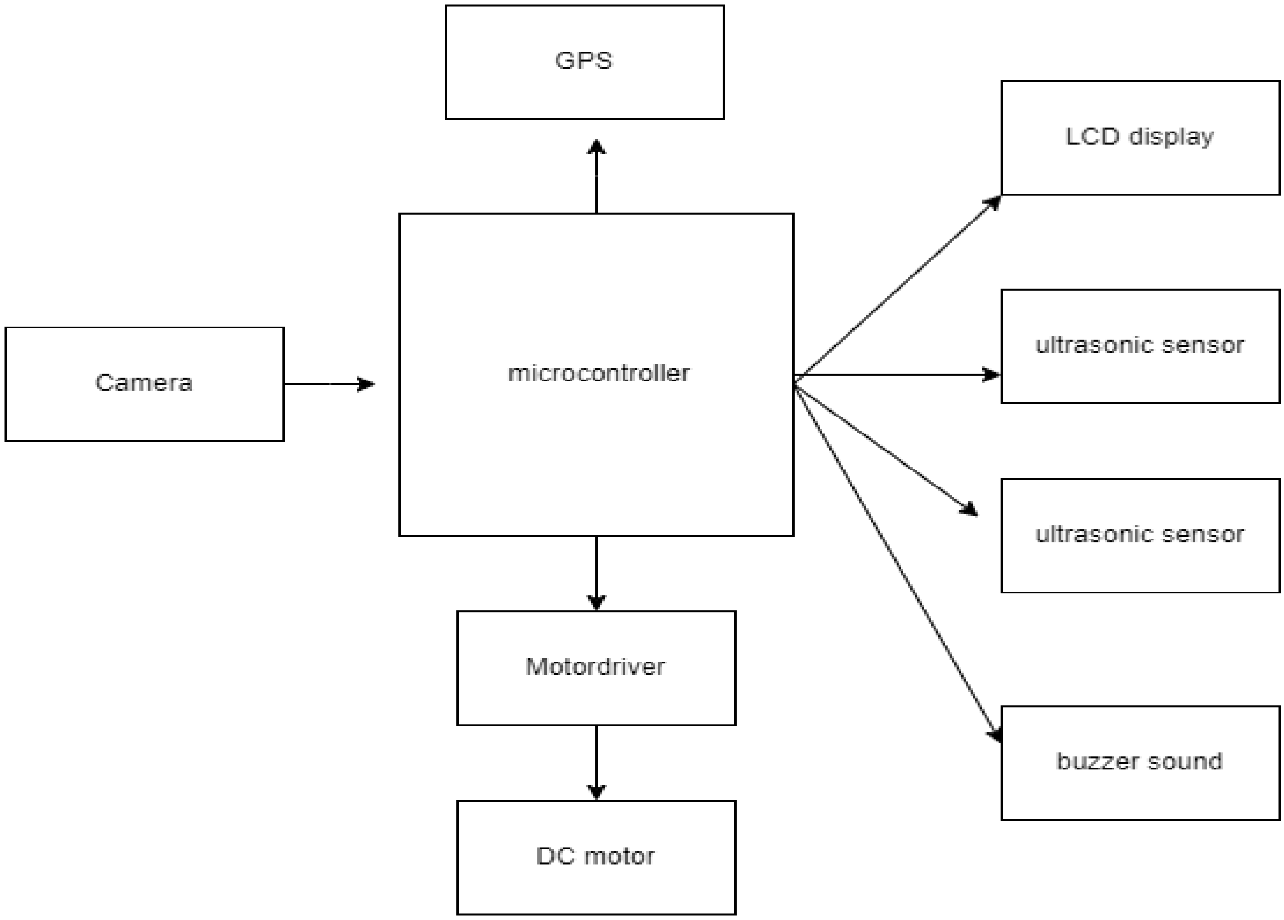
ARCHITECTURE DIAGRAM FOR HARDWARE MODULE



The integration of IoT and AI technologies plays a pivotal role in the project's methodology, enabling seamless communication and data processing for effective track monitoring and crack detection. At the heart of this integration lies the communication between the IoT sensor network and the AI module, facilitated by the microcontroller unit (MCU).

Upon data acquisition from the ultrasonic sensors deployed along the railway track, the MCU acts as the intermediary between the IoT sensor network and the AI module. It processes the raw sensor data, including distance measurements from the ultrasonic sensors, and prepares it for analysis by the AI algorithms.

In the AI module, deep learning algorithms, such as YOLOv5, are employed to analyze the sensor data and detect track irregularities in real-time. The trained AI models are capable of accurately identifying and classifying anomalies, such as cracks or deformations, based on the input sensor data.

The MCU then communicates the results of the AI analysis back to the user interface module, which includes the LCD display and audible alert system. Detected irregularities, along with their locations and severity levels, are presented in realtime on the LCD display, providing railway personnel with immediate visibility into the track's condition.

Additionally, in the event of critical track issues being identified, the audible alert system emits distinctive alerts to notify personnel, ensuring prompt response to safety concerns.

This integrated approach streamlines track monitoring and crack detection, offering real-time feedback through an automated and reliable system. By leveraging the capabilities of both IoT and AI technologies, the project enhances railway safety and operational efficiency, ultimately contributing to the overall reliability of railway operations.

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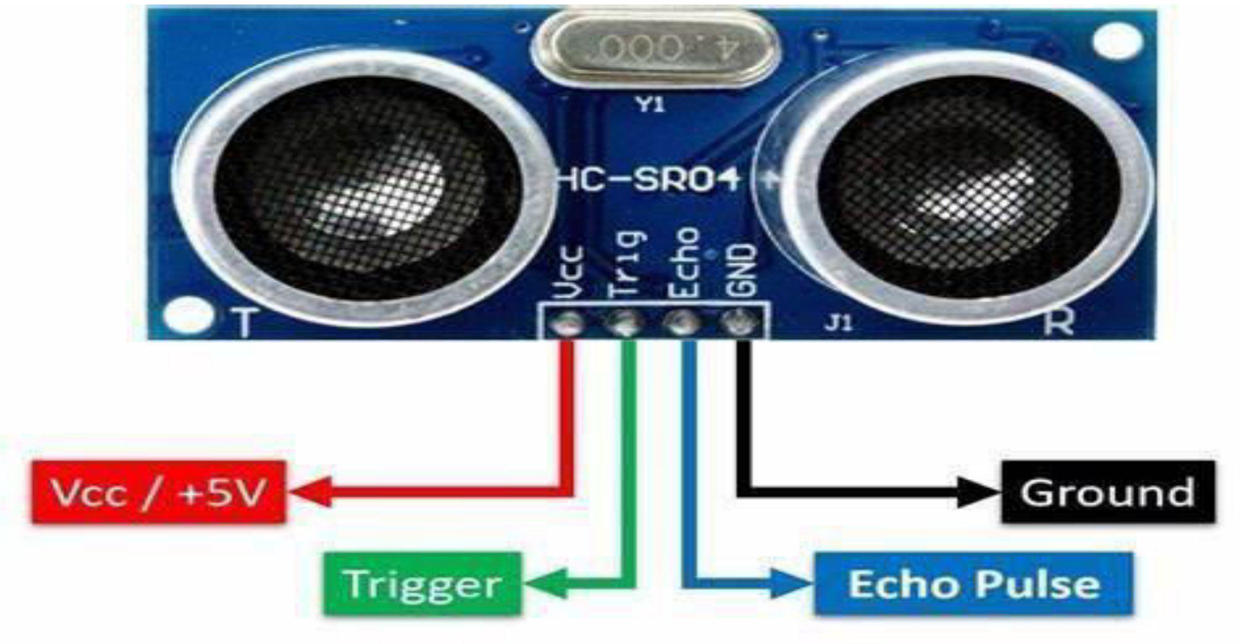
IV. RESULTS AND DISCUSSION

MODULES IDENTIFIED
Ultrasonic Sensor Module, Microcontroller Unit Module, Artificial Intelligence Module, User Interface Module

ULTRASONIC SENSOR MODULE

Functionality:
The ultrasonic sensor measures the distance between the sensor and the track surface using ultrasonic waves. By emitting ultrasonic pulses and measuring the time it takes for the pulses to bounce back, the sensor can calculate the distance.

Application:
In this project, the ultrasonic sensor is used to detect track irregularities by measuring variations in the distance between the sensor and the track surface. These irregularities could include cracks, gaps, or deformities in the track.



MICROCONTROLLER UNIT (MCU) MODULE

Data Processing Unit:
The MCU processes the raw sensor data received from the ultrasonic sensor. This processing may involve filtering noise, calibrating sensor readings, and extracting relevant features.

Communication Interface:
The MCU facilitates communication with IoT devices and external systems for data transmission and control. It uses protocols like UART and I2C to communicate with sensors, actuators, and other devices.

Application:
In this project, the MCU acts as the central processing unit responsible for handling sensor data, executing AI/ML algorithms, and communicating with the user interface module and external systems.

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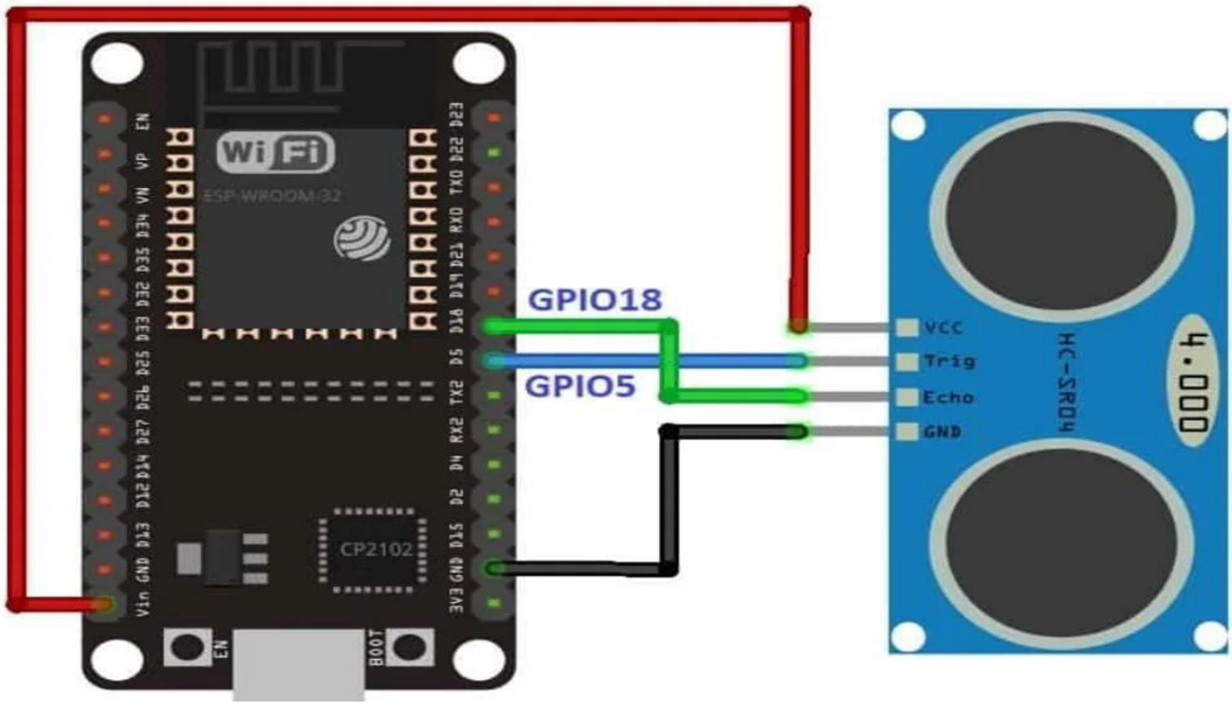


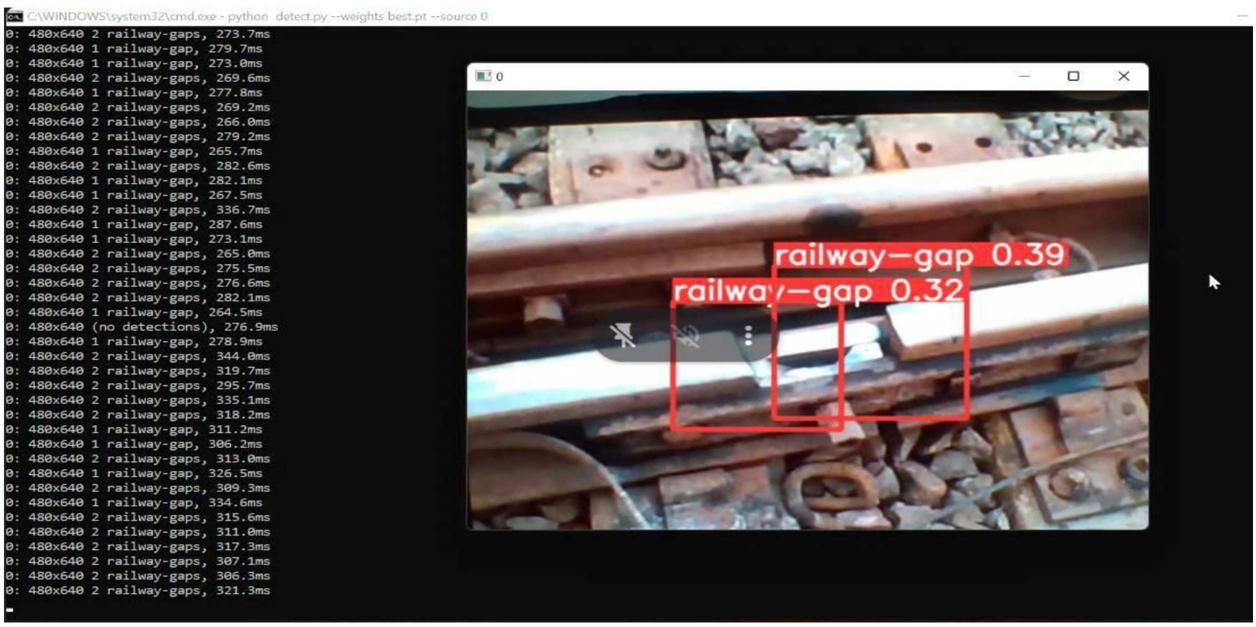
ARTIFICIAL INTELLIGENCE MODULE

Functionality:

YOLOv5 is a state-of-the-art object detection algorithm that can detect and classify objects within images with remarkable speed and accuracy. It operates by dividing the input image into a grid and predicting bounding boxes and class probabilities for objects within each grid cell.

Application:

In the context of this project, YOLOv5 can be used to detect track irregularities, such as cracks or anomalies, in the images captured by the ultrasonic sensor or other imaging devices. By training YOLOv5 on a dataset of images containing examples of track irregularities, the model can learn to accurately identify and localize these irregularities in real-time.



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USER INTERFACE MODULE

LCD Display:
The LCD display presents real-time track condition information, including detected irregularities, their locations, and severity levels. It provides railway personnel with immediate visibility into the track's condition, enabling informed decision-making and timely action.

Buzzer/Alert System:
An audible alert system such as a buzzer provides alerts to railway personnel when critical track issues are identified. This ensures that personnel are notified promptly and can take appropriate measures to address safety concerns.

Application:
The user interface module enhances situational awareness for railway personnel, enabling them to monitor track conditions effectively and respond promptly to irregularities or alerts.

SAMPLE OUTPUTS

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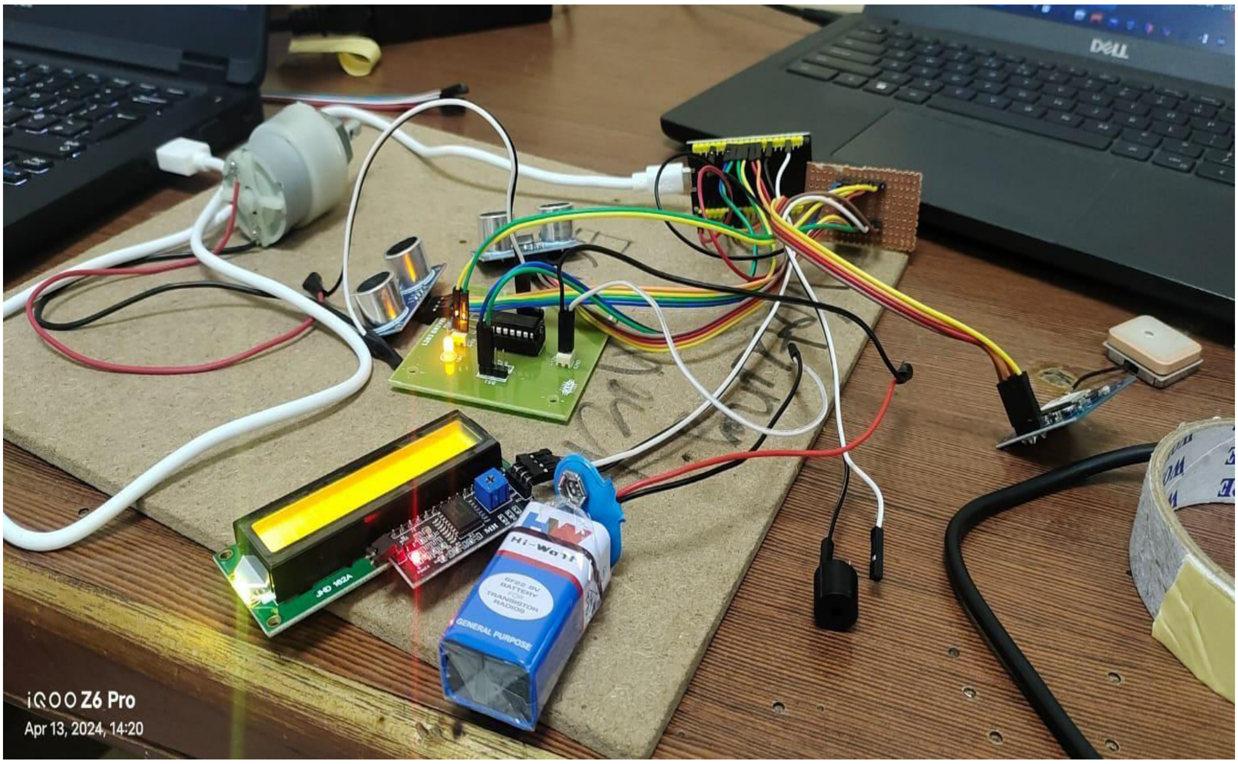

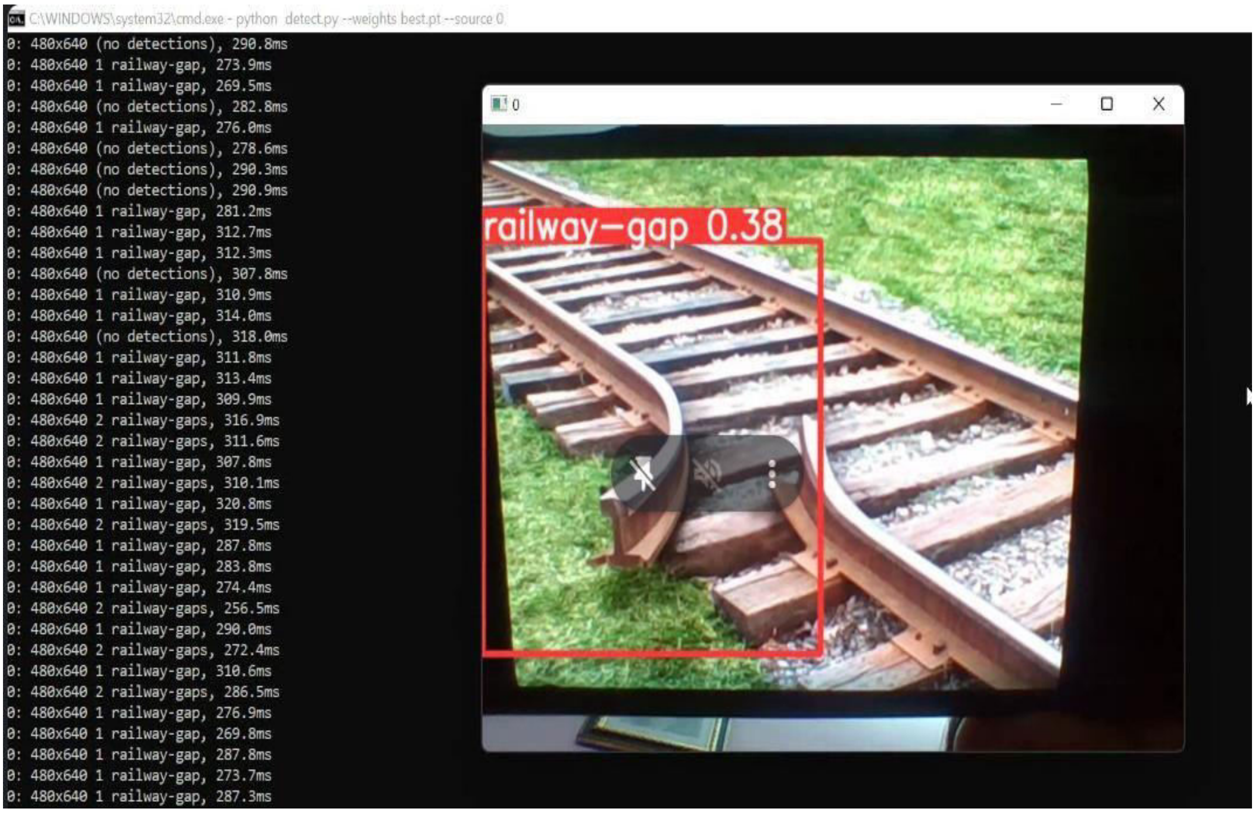

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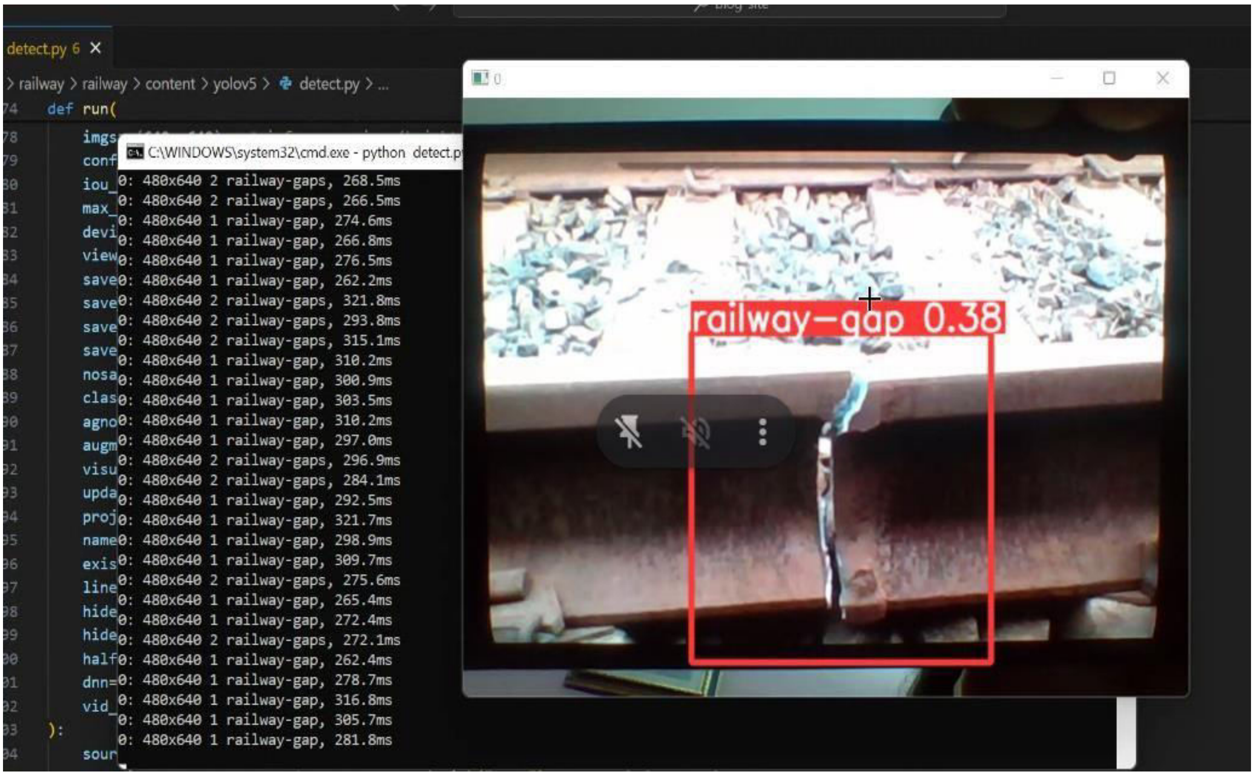

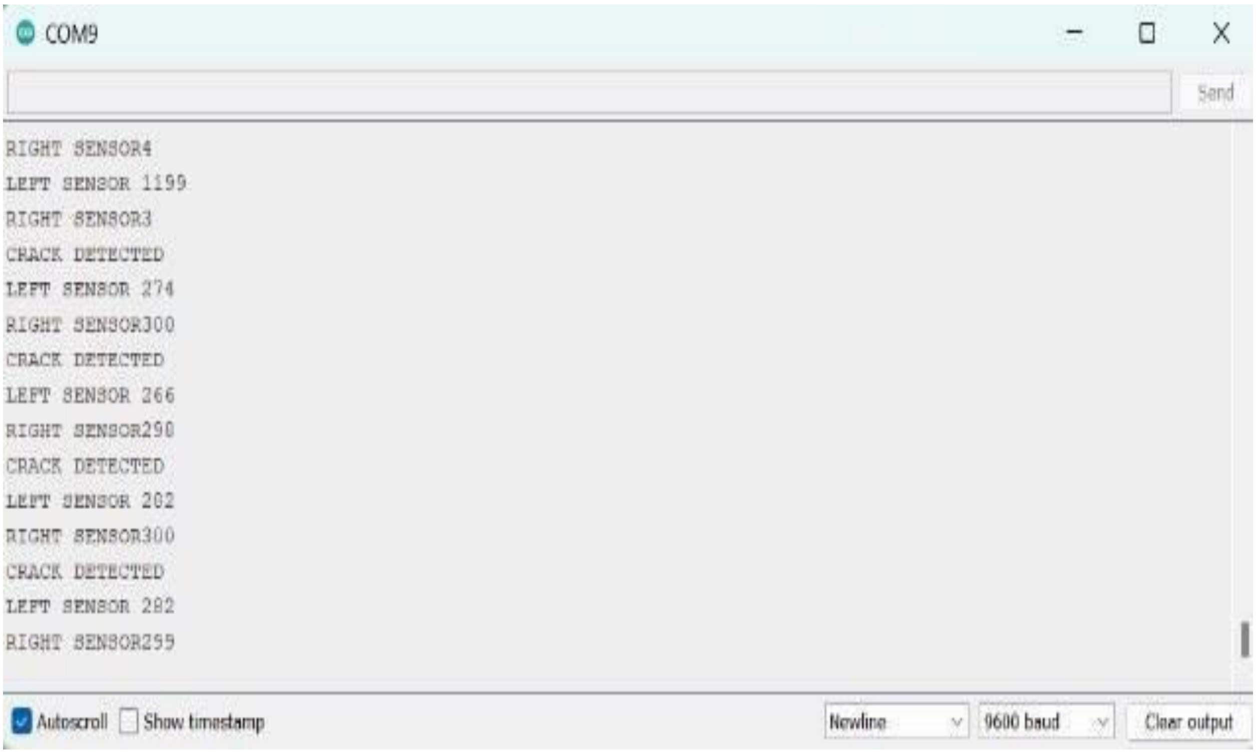

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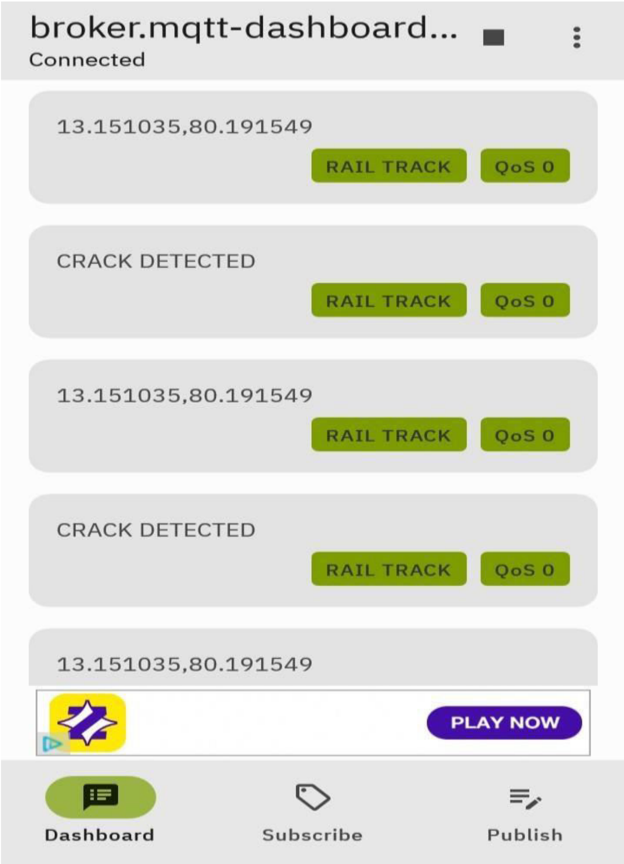

V. CONCLUSION

In conclusion, this project presents a novel approach for crack detection in railway tracks by leveraging image processing techniques. Unlike traditional methods that often require manual intervention, the proposed system minimizes human involvement by utilizing images as input for crack detection, thereby enhancing efficiency and automation.

The integration of a microcontroller, LCD display, Artificial Intelligence, Image Processing, and ultrasonic sensor enriches the system's functionality, enabling real-time monitoring and detection of track irregularities. Upon detecting cracks, the microcontroller seamlessly processes the data, triggers the ultrasonic sensor for further validation, and displays the results on the LCD display and the location coordinates of the crack being detected is sent for railway personnel to assess. These results are being displayed in the MQTT app and Python terminal for now.

Moreover, an additional safety measure is implemented through a buzzer sound alert, ensuring immediate attention to track irregularities and reducing the risk of accidents. This comprehensive solution not only guarantees accurate crack detection but also emphasizes the potential of image processing in Python for seamless track monitoring.

Overall, the project underscores the importance of technological advancements in railway safety and maintenance practices, offering a robust and efficient solution for ensuring safe and reliable railway operations.

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