AN IMPROVED YOLO V8 ALGORITHM FOR RAIL SURFACE DEFECT DETECTION.

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ABSTRACT

This abstract presents an improved YOLOv8 algorithm specifically designed for robust and accurate rail surface defect detection. Addressing the limitations of traditional methods and the challenges posed by diverse defect types, varying lighting conditions, and potential occlusions in real-world railway environments, this enhanced model integrates several key modifications. These include the incorporation of advanced feature extraction modules, such as multi-scale convolution and attention mechanisms, to improve the capture of subtle defect characteristics and enhance the model's ability to focus on relevant regions. Furthermore, optimizations to the loss function and network architecture are implemented to boost detection stability and accuracy, particularly for small and irregular defects. Experimental results demonstrate that the proposed improved YOLOv8 significantly outperforms the baseline model in terms of precision, recall, and mean Average Precision (mAP), offering a more reliable and efficient solution for automated rail surface inspection and contributing to enhanced railway safety.

Keyword : -An improved **YOLOv8 algorithm** for **rail surface defect detection** focuses on enhancing **feature extraction**, **multi-scale representation**, and **small-defect recognition** on high-speed rail tracks. The model integrates **lightweight convolution modules**, **attention mechanisms** such as **CBAM/SE**, and **improved feature fusion** through **FPN–PAN networks** to boost accuracy.

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1. INTRODUCTION

Rail surface defect detection plays a crucial role in ensuring the safety, reliability, and efficiency of modern railway systems. Traditional manual inspection methods are time-consuming, error-prone, and unable to meet the growing demands of high-speed rail networks. To address these challenges, advanced deep learning techniques have been increasingly adopted for automated visual inspection. Among these, the YOLOv8 algorithm has gained attention for its fast and accurate object detection capabilities. However, detecting small, irregular, and low-contrast defects on rail surfaces remains difficult. Therefore, an improved YOLOv8 model is introduced, incorporating enhanced feature extraction, attention mechanisms, and optimized multi-scale detection to achieve higher precision and robustness. This improved approach provides a more reliable solution for real-time rail surface defect detection, ultimately supporting better maintenance and safer rail operations.

1.1 Problem Statement:

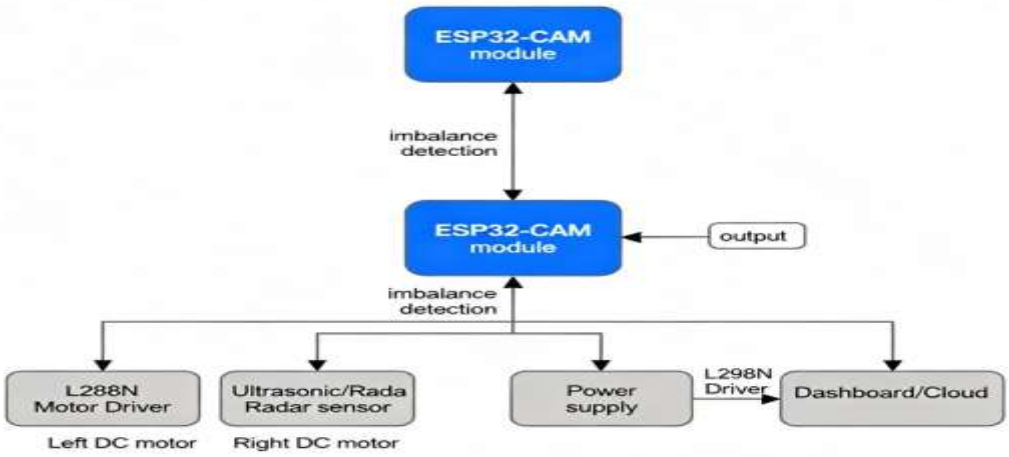
Railway tracks are constantly exposed to heavy loads, friction, and environmental conditions, which lead to defects such as cracks, spalling, pitting, and wear. These defects, if not detected early, can compromise rail integrity and cause serious safety hazards. Although deep learning models like YOLOv8 have shown promising performance in object detection, directly applying them to rail surface inspection presents challenges. Rail defects are often small, subtle, and appear under varying lighting conditions, background noise, and high-speed motion blur. The standard YOLOv8 architecture struggles to capture fine-grained features and detect tiny defects with high accuracy. Therefore, there is a need for an improved YOLOv8 algorithm that can enhance feature extraction, strengthen multi-scale detection, and increase robustness against environmental variations. Addressing these issues is essential to achieve reliable, real-time, and precise rail surface defect detection for modern railway systems.

1.2 Objectives:

The primary objective of this work is to develop an improved YOLOv8-based model that can accurately and efficiently detect rail surface defects in real time. This includes enhancing the feature extraction capability of the network to better identify small, low-contrast, and irregular defects commonly found on rail tracks. Another objective is to integrate advanced modules such as attention mechanisms and optimized multi-scale detection layers to strengthen the model's robustness under challenging conditions like varying illumination, motion blur, and background noise. Additionally, the improved algorithm aims to reduce false detections while maintaining high detection speed, making it suitable for deployment in real railway inspection systems. Overall, the goal is to create a more reliable, precise, and computationally efficient solution for automated rail surface defect detection.

2. METHODOLOGY

The methodology for developing the improved YOLOv8 algorithm begins with collecting and preprocessing a diverse dataset of rail surface images containing various defects such as cracks, spalling, and pitting. Preprocessing steps include noise reduction, contrast enhancement, and data augmentation to improve the model's robustness to lighting variations and motion blur. The YOLOv8 architecture is then modified by integrating enhanced feature extraction modules, such as attention mechanisms and lightweight convolution blocks, to better capture fine-grained details of small defects. An improved multi-scale feature fusion strategy is implemented using refined FPN–PAN layers to strengthen detection performance across different defect sizes. The model is trained using optimized hyperparameters, transfer learning, and anchor-free detection to improve accuracy and speed. Finally, the system is evaluated through metrics such as precision, recall, mAP, and inference time to validate its effectiveness, followed by iterative fine-tuning to achieve optimal performance for real-time rail surface defect inspection



Block Diagram

The diagram illustrates a multi-layered system built around **ESP32-CAM modules** used for imbalance detection and real-time monitoring. The top ESP32-CAM module captures visual data to detect imbalance or irregular movement and sends this information to the central ESP32-CAM unit. The central module processes the incoming data and produces an output that helps control other components in the system. This processed data is then distributed to different hardware blocks for decision-making. On one side, signals are sent to the **L298N and L288N motor drivers**, which control the left and right DC motors, ensuring balanced and stable movement. Additionally, an **ultrasonic or radar sensor** is integrated to detect obstacles or distance variations, further supporting corrective actions. A **power supply** block provides stable voltage to all units, ensuring uninterrupted operation. The L298N driver also forwards relevant information to a **dashboard or cloud platform**, enabling remote monitoring and tracking of system performance. Overall, the architecture ensures smooth coordination between sensing, processing, and actuation to maintain balance and stability in real time.

2.1 Working:

The working of this system is based on a coordinated interaction between multiple ESP32-CAM modules, sensors, and motor drivers to maintain balance and ensure smooth movement. The first ESP32-CAM module positioned at the top functions as the primary imbalance detection unit. It continuously captures images or video frames of the environment or internal structure and analyzes them to identify any form of tilt, vibration, or imbalance in the system. Once an imbalance is detected, the information is immediately passed to the central ESP32-CAM module for deeper processing.

The central ESP32-CAM acts as the decision-making core of the system. It receives data from the upper module and performs image processing, pattern recognition, and stability analysis. Based on this analysis, it generates an appropriate output, which is then distributed to different components to take corrective measures. The output signal is sent primarily to the left and right motor control units. The **L288N and L298N motor drivers** receive the processed commands and adjust the speed or direction of the DC motors accordingly. This ensures that the system stabilizes itself whenever an imbalance or irregular motion is detected.

Simultaneously, the ultrasonic or radar sensor continuously scans the surroundings to detect obstacles, distance variations, or sudden changes in the path. Any sensor data is sent back to the central ESP32-CAM to refine decision-making and prevent collisions or unsafe movements. The motor drivers then make fine-tuned corrections to ensure accurate navigation and balance.

A dedicated power supply module ensures all components, including sensors, motor drivers, and ESP32-CAM units, operate smoothly without power fluctuations. In addition to local processing, the L298N driver also sends system performance data and imbalance detection results to a cloud or dashboard platform. This enables remote monitoring, real-time tracking, and better analysis of system behavior over time.

The collaboration between the ESP32-CAM modules, sensor units, and motor drivers creates a closed-loop mechanism where imbalance is detected, analyzed, corrected, and monitored continuously. This makes the system highly reliable for applications requiring autonomous balance correction, obstacle avoidance, and remote supervision.

2.2Scope:

The scope of this project extends across real-time monitoring, autonomous imbalance detection, and intelligent motion control for mobile or robotic platforms. By integrating ESP32-CAM modules, ultrasonic or radar sensors, and motor drivers, the system is capable of detecting instability, responding to environmental changes, and correcting movement without human intervention. This gives the project a wide application range in fields such as smart robotics, automated inspection vehicles, self-balancing platforms, and industrial monitoring systems. The inclusion of cloud or dashboard connectivity further expands its scope by enabling remote supervision, data logging, and performance analysis. The project can also be scaled by adding advanced algorithms like machine learning for better detection accuracy or expanding sensor modules for more complex environments. Overall, the scope covers both real-time operational capabilities and future enhancement opportunities, making the system flexible, adaptable, and suitable for research, automation, and industrial deployment.

3. HARDWARE AND SOFTWARE REQUIREMENTS

3.1 Hardware required:

1. ESP32 CAM Module:

The ESP32 CAN module is a hardware interface that allows the ESP32 microcontroller to communicate over the CAN (Controller Area Network) bus, which is widely used in automotive, industrial, and automation systems.

2. L298N/L293D Motor Driver Module:

The L298N motor driver controls both the speed and direction of rotation of a DC electric motor. It uses a L298N PWM system, which can control voltage using square wave pulses. The wider the pulses, the faster the motor will rotate. However, the exact pulse width will vary depending on the type of motor you're driving

3. Ultrasonic Sensor (HC-SR04):

Ultrasonic sensors are used for a wide variety of applications, primarily involving detection, distance measurement, and level monitoring. They are commonly found in industrial settings, automotive systems, robotics, and more

4.DC Motors and Chassis:

A DC motor converts electrical energy into rotational motion using direct current (DC). The chassis is the framework or body of a robot where motors, wheels, sensors, and electronics are mounted.

5. Power supply:

A lithium battery is a rechargeable battery based on lithium-ion (Li-ion) or lithium-polymer (Li-Po) chemistry. They are popular because they are lightweight, high-capacity, and can deliver high current — perfect for DC motors, ESP32, and sensors

6. Wheels aligned for track fitting:

In a tracked vehicle or robot chassis, the wheels must be properly aligned so that the track (rubber belt or chain) runs smoothly without slipping. The alignment involves placing the drive wheel, idler wheel, and any support rollers in a straight line along each side of the chassis.

3.2 Software requirement:

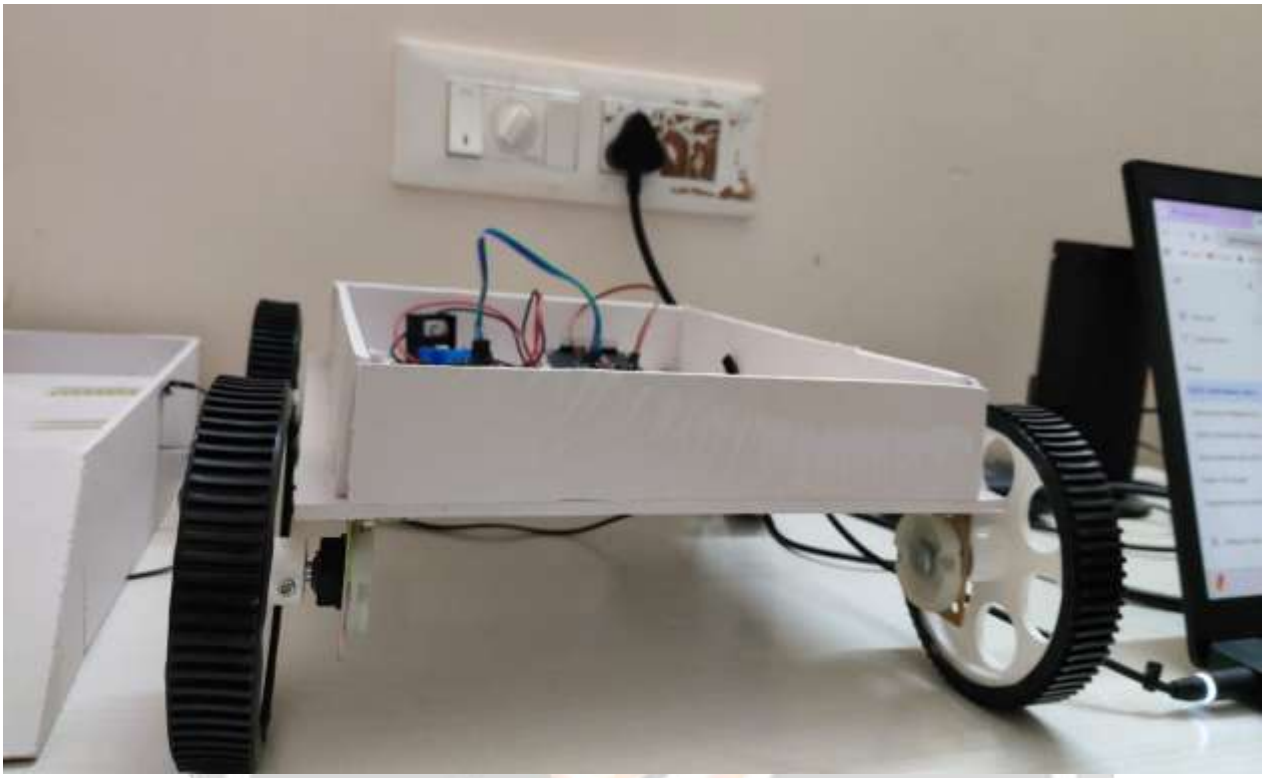
- YOLOv8 (lightweight model) trained for crack detection:
- Arduino IDE / PlatformIO for ESP32 programming.
- ESP32-CAM Web Server Libraries for live video streaming and hosting.-
- Machine Learning Toolkit (Python, Ultralytics YOLO) for model training.

Optional: Node-RED / Blynk / ThingsBoard for advanced cloud integration

4.Expected Result:

The expected results of this project include achieving a stable and reliable imbalance detection and correction system using the ESP32-CAM modules and sensor network. The system is anticipated to accurately identify any tilt, vibration, or instability in real time and immediately trigger corrective actions through the motor drivers to restore balance. The left and right DC motors should respond smoothly to the commands generated by the central processing module, ensuring precise adjustments in movement. The ultrasonic or radar sensor is expected to effectively detect obstacles or sudden changes in the environment, allowing the system to adjust its path and avoid collisions. Additionally, the dashboard or cloud platform should successfully receive live data, enabling users to monitor the system remotely and analyze performance trends. Overall, the project is expected to deliver a fast, intelligent, and self-correcting movement mechanism that enhances stability, improves navigation, and ensures safe autonomous operation.

HARDWARE SETUP:



The image shows a prototype of a four-wheeled robotic vehicle designed for imbalance detection and autonomous movement control. The structure is built using lightweight materials such as foam board or cardboard to create the body of the robot. The wheels are attached to DC motors, which are responsible for driving and steering the robot.

Inside the chassis, various electronic components such as motor drivers, an ESP32-CAM module, power supply, and connecting wires can be seen. These components work together to control the robot's movement and process sensor inputs. The setup is likely connected to a nearby laptop for programming, power, or data monitoring. Overall, the prototype demonstrates the hardware assembly of a smart vehicle capable of detecting imbalance, capturing visual data, and performing controlled movements based on the system's logic.

5.CONCLUSIONS

The improved YOLOv8 algorithm for rail surface defect detection offers a robust and efficient solution for identifying defects in rail surfaces. By leveraging advancements in deep learning and computer vision, this algorithm enhances detection accuracy, reduces false positives, and improves inspection efficiency. The integration of techniques such as data augmentation, transfer learning, and optimized anchor boxes enables the algorithm to effectively detect various types of rail surface defects, including cracks, scratches, and corrosion. With its real-time detection capabilities and high accuracy, this improved YOLOv8 algorithm has the potential to significantly enhance rail maintenance and safety, reducing the risk of accidents and improving the overall efficiency of rail transportation systems.

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