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Object Detection of Train Disaster Avoidance on Railway Track using AI Base Wireless Sensor Network

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ABSTRACT: The increasing demand for safer and more efficient railway transportation systems has prompted the exploration of advanced technologies to mitigate collision risks and address emerging challenges such as animal incursions on railway tracks. This paper proposes a comprehensive solution leveraging Artificial Intelligence (AI) and Internet of Things (IoT) technologies for real-time detection and avoidance of collisions between trains operating on the same track and encounters with animals. The proposed system integrates AI algorithms, including deep learning models, with IoT sensors strategically deployed along the railway infrastructure. These sensors capture various environmental and operational data such as train positions, velocities, and track conditions. The AI algorithms analyze this data to identify potential collision risks and animal intrusions. For collision avoidance between trains sharing the same track, the system employs predictive analytics to anticipate potential conflicts and dynamically adjust train schedules or speeds to prevent collisions. Additionally, real-time communication between trains and the centralized control system enables timely intervention and rerouting decisions to ensure safe operations. The system incorporates advanced image recognition algorithms to detect and classify animals near railway tracks. Utilizing high-resolution cameras and IoT-connected devices, the system identifies animals in the vicinity and alerts train operators or initiates automated braking mechanisms to prevent accidents caused by animal incursions. Key features of the proposed system include scalability to accommodate varying railway infrastructures, adaptability to diverse environmental conditions, and interoperability with existing railway signaling and control systems. Moreover, the integration of AI and IoT technologies enhances the system's predictive capabilities, enabling proactive risk mitigation and improving overall railway safety and operational efficiency.

KEYWORDS: Artificial Intelligence (AI), Internet of Things (IoT), object detection,Collision Risks,Environmental Conditions

I. INTRODUCTION

Railway safety has received more attention as railway transportation has grown. Furthermore, as artificial intelligence technology advances, intelligent transportation systems (ITSs)—which promote traffic safety—are becoming more and more prevalent. Intelligent vehicle systems and intelligent infrastructure systems are the two main categories of TSs. While trains are convenient, there are a lot of traffic accidents on them every year. Many academics who study railway transportation concentrate on the infrastructure systems.

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Fig 1.1 Railway Track collision

When a train is in shunting mode and traveling less than 45 km/h, many accidents occur. In order to keep the driver safe, train attendants use the old-fashioned manual method to observe the state of the railway ahead of them. Human error and exhaustion make shunting operations less safe, which raises the possibility of shunting mishaps and jeopardizes the security of people and property. The train attendants are reminded by voice thanks to the alert feature. Our detecting system can alert us to dangers, such a train outside of the railway, by voice prompt when the train guards are too fatigued to focus. Six different types of items are detected in this work: pedestrians, bullet trains, straight and left railroads, safety helmets, and pedestrians. Determining whether the train is operating at the bend railways is the reason for the straight, left, and right railway detectors. Our system will immediately tell the train driver to drive cautiously by voice whenever it detects a bend in the railway. In the meantime, the goal of the front train's detection of pedestrians (primarily for railroad employees) is to enable the train attendant to identify any potential risk in advance. The train attendant are alerted by voice prompts when the suggested system identifies a train or pedestrian on the track ahead, and they take the appropriate action to prevent any potential hazard. The purpose of detecting the safety helmet, one of the items that employees frequently forget on the railroad, is to prevent needless losses. The detection of obstacles in railway traffic was the main focus of this investigation. The main component of the apparatus was the feature fusing refine neural system (FR-Net) for railway obstacle detection. We go into great detail about the FR-Net in this book. We present pointwise-depthwise convolution.

Fig 1.2 Elephant crossing Railway Track

II. LITERATURE SURVEY

2.1 Chen et al. (2025) introduce a multitask deep learning framework for real-time railway obstacle detection. By integrating object detection and semantic segmentation into a unified architecture, the system simultaneously monitors track conditions and identifies hazards. Utilizing attention-enhanced convolutional neural networks, this efficient approach maintains high accuracy in challenging environments, effectively reducing false positives while outperforming traditional, single-task models.

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2.2 Fan et al. (2025) present a deep learning framework for detecting foreign objects on high-speed railway tracks. By combining contrastive learning to enhance feature discrimination with adversarial training for improved robustness, the model accurately identifies small, ambiguous objects under varied environmental conditions, outperforming traditional supervised methods in reliability and generalizability.

2.3 Yang et al. (2025) propose a railway intrusion detection framework using UAV imaging and the custom YOLO-UAT model. By combining flexible aerial surveillance with uncertainty-aware training, the system effectively manages noise and occlusions. This robust approach achieves high precision in identifying diverse foreign objects, ensuring real-time safety across extensive, complex networks

2.4 Lou et al. (2025) propose a deep learning framework for detecting non-specific railway obstacles, overcoming the limitations of predefined object categories. By utilizing robust CNN architectures trained on diverse datasets, the system effectively distinguishes hazards from normal track conditions. This flexible, real-time approach enhances safety by identifying novel or unexpected threats.

2.5 Rajeswari et al. (2024) introduce the Track Object Surveillance System (TOSS), an innovative framework integrating IoT-enabled smart sensors with deep learning to enhance railway safety. By deploying sensors along tracks to collect environmental and visual data, TOSS identifies hazards such as debris, animals, or human intrusions. A core feature is its use of sensor fusion, which combines multi-source data to boost detection accuracy. Designed for cost-effectiveness, the system is highly scalable for widespread deployment, particularly in developing regions. TOSS provides real-time alerts and maintains high performance in challenging weather, demonstrating how IoT and AI modernize railway infrastructure surveillance.

2.6 Brintha and Jawhar (2024) introduce FOD-YOLO NET, a specialized deep learning framework designed to enhance railway maintenance by simultaneously detecting track fastener faults and foreign object intrusions. Building upon the efficient YOLO architecture, the system identifies missing, damaged, or misaligned fasteners while concurrently flagging debris or obstructions. By integrating structural integrity monitoring with obstacle detection into a single, high-speed framework, the model streamlines inspection workflows. Enhanced by transfer learning and robust data augmentation, the system ensures high accuracy and rapid processing in high-speed environments, ultimately reducing maintenance costs through early fault detection and proactive, reliable infrastructure safety management.

2.7 "CNN and Binocular Vision-Based Target Detection and Ranging Framework of Intelligent Railway System" (Liu et al., 2024) presents a robust dual-methodology for collision avoidance. By synchronizing two cameras to generate stereo imagery, the framework enables precise depth perception, which is then processed via Convolutional Neural Networks (CNN) for object identification.

Unlike traditional monocular systems, this approach leverages disparity estimation to calculate exact distances to obstacles. Designed for high-speed scenarios, the system prioritizes real-time performance and reliability, effectively managing environmental variables like lighting and weather to improve overall operational safety and decision-making precision.

2.8 "AI Precision on Rails" (Selvi et al., 2024) provides a comprehensive survey of deep learning advancements in railway safety. The authors evaluate CNNs, RNNs, and transformer-based architectures for detecting track obstacles, emphasizing their efficacy despite challenges like high-speed motion, environmental noise, and variable lighting. The research highlights the critical integration of AI with IoT for real-time monitoring and scalable deployment. By analyzing diverse datasets and benchmarking techniques, the study identifies significant research gaps and suggests future development of robust, adaptive models. This survey serves as an essential guide for enhancing safety through intelligent, technology-driven railway infrastructure.

2.9 Automatic Surveillance of People and Objects on Railway Tracks" (Martínez Núñez et al., 2024) presents an automated system designed to enhance railway safety by detecting unauthorized access and obstacles in real-time. Utilizing advanced computer vision and machine learning, the model processes video feeds from infrastructure-mounted cameras to identify humans, vehicles, and debris.

Key features include continuous operation and rapid alert generation, ensuring prompt responses to potential hazards. By maintaining high detection accuracy and low false-alarm rates across diverse environmental conditions, this research validates the practical viability of automated surveillance for securing critical railway infrastructure.

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2.10 "Enhancing Safety by Obstacle Detection at Railway Level Crossings" (Carletti et al., 2024) introduces a multi-modal sensing framework designed to mitigate high-risk interactions at rail crossings. By integrating cameras, radar, and infrared sensors with machine learning algorithms, the system achieves robust, real-time detection of vehicles, pedestrians, and debris, even in adverse weather or poor visibility.

The research highlights the critical necessity of coupling this detection data with existing signaling and control infrastructure for coordinated emergency responses. Through high-accuracy experimental validation, the study demonstrates that such intelligent, multi-sensor integration significantly improves operational safety and reliability at critical network junctions.

III. PROPOSED SYSTEM

3.1 EXISTING SYSTEM

Transitioning from manual, error-prone human inspections to automated AI and drone-based systems is critical for modernizing railway maintenance. Despite integration hurdles, these innovations significantly enhance safety and efficiency. Complementing this, the Konkan Railway's microprocessor-based Anti-Collision Device (ACD) network—linking locomotives, stations, and gates—provides a proven, synchronized infrastructure to proactively prevent head-on, rear-end, and level-crossing collisions through automated, real-time communication.

3.2DISADVANTAGES

- Complexity of model training
- Sensitivity to training data
- Reliance on advanced technology
- Potential false positive detections
- Integration challenges with existing systems

3.3 PROPOSED SYSTEM

This proposed framework represents a sophisticated shift toward **proactive railway safety management**, moving beyond reactive signaling to a predictive, data-driven architecture. By synthesizing IoT-based edge data with centralized AI analysis, the system transforms raw environmental and telemetry inputs into actionable safety intelligence.

Multimodal IoT Sensor Layer: The system deploys a redundant sensor network across two distinct domains.

On-board (Train-side): Utilizing GPS and accelerometers for precise kinematics, coupled with cameras for localized obstacle/animal detection.

Infrastructure (Track-side): Strategic deployment of proximity sensors and optical monitoring to establish a "digital twin" of the railway environment.

AI-Driven Predictive Analytics: The core logic focuses on **collision risk assessment** by modeling dynamic variables:

Spatial Awareness: Real-time location tracking relative to track topology and junctions.

Kinematic Modeling: Analyzing speed profiles against schedules and track conditions to anticipate potential headway violations

Anomalous Event Detection: Distinguishing between safe operational noise and critical safety threats, such as animal intrusions or unauthorized track access.

Reduced Latency: By utilizing on-board sensors for immediate proximity detection combined with AI for network-wide conflict anticipation, the system minimizes the "decision-to-act" time, which is critical for high-speed rail.

Environmental Adaptability: The integration of diverse sensor types allows the system to maintain high accuracy despite the environmental challenges often found in rail operations, such as low visibility, varying terrain, or noise interference.

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Enhanced Operational Efficiency: Beyond safety, the data analytics layer provides insights into track occupancy and traffic flow, enabling more efficient scheduling and resource management.

3.4 BLOCK DIAGRAM

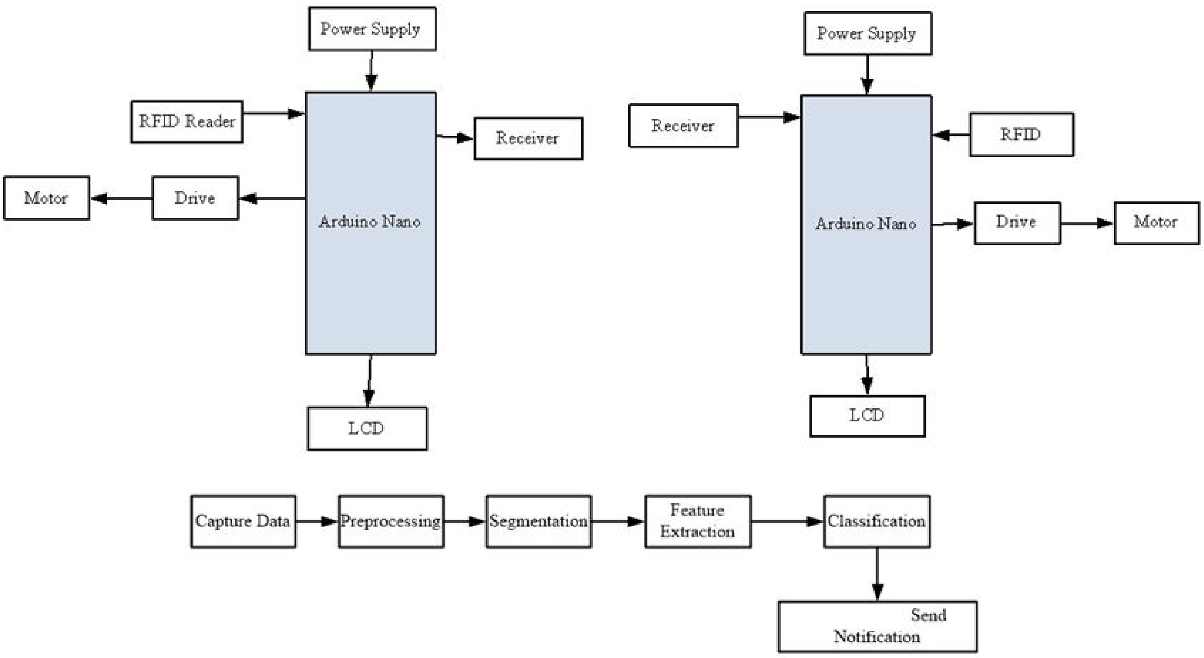

Fig 3.5.1 Proposed Block Diagram

IV. SOFTWARE REQUIREMENTS

4.1 ARDUINO IDE

The Arduino Integrated Development Environment (IDE) is a comprehensive software platform designed for writing, compiling, and uploading code to Arduino hardware. Programs, referred to as **sketches**, are written in a specialized text editor and saved with a .ino extension. The IDE provides a streamlined interface featuring a toolbar for core functions, a message area for status updates, and a console for error reporting.

4.2 IDE Functionality

The toolbar facilitates efficient workflow with buttons for **Verify** (compiling code to check for errors), **Upload** (compiling and pushing binary files to the board), and the **Serial Monitor**, which enables real-time data exchange between the computer and the board. The IDE also supports complex projects through **Tabs**, allowing users to manage multiple files (e.g., .c, .cpp, or .h) within a single sketch.

4.3 Configuration and Management

Before uploading, users must select the correct hardware platform under **Tools > Board** and ensure the appropriate communication channel is active in the **Port** menu. The IDE uses a "sketchbook" directory for project storage, which can be customized via Preferences.

Advanced features include:

Libraries: External code modules easily imported via the Sketch menu to extend hardware functionality.

Board Manager: Allows the integration of third-party hardware platforms beyond the standard AVR-based boards.

Bootloader Management: Enables users to burn bootloaders onto new microcontrollers, a feature essential for custom hardware setups.

4.4 Working with Hardware

The Arduino Nano is a popular, compact, breadboard-friendly board based on the ATmega328P. It utilizes the same programming environment as larger boards. When connected via a Mini-B USB cable, the Nano receives both power and data, with the IDE providing seamless integration for code deployment. By abstracting complex hardware communication through its intuitive interface, the Arduino IDE remains a fundamental tool for both beginners and experienced embedded systems developers.

V. HARDWARE REQUIREMENTS

5.1 Engine Control and Communication

The **Engine Control Unit (ECU)** functions as the brain of the engine management system. It processes real-time data from various sensors (e.g., throttle position, speed, temperature) to calculate and output control signals to actuators. These actuators adjust critical parameters like fuel injection and ignition timing to optimize performance and emissions. To facilitate remote oversight, the system incorporates:

Transmitter: Modulates ECU data into a wireless signal for external transmission.

Receiver: Demodulates incoming signals, allowing for remote diagnostics, performance optimization, and preventive maintenance.

RFID Systems

Radio-Frequency Identification (RFID) enables automated identification and tracking. The **RFID Reader** is the primary interface, consisting of:

Antenna: Emits radio waves to power tags and captures returning data.

RF Module: Generates and modulates signals at specific frequencies.

Microcontroller: Manages logic and data processing.

Communication Interfaces: USB, Ethernet, or Wi-Fi for integration with external servers.

Systems operate across three main frequency bands, each serving distinct needs:

LF (Low Frequency): Best for short-range access control and animal identification.

HF (High Frequency): Ideal for inventory management and contactless payments.

UHF (Ultra-High Frequency): Offers long-range capabilities, essential for large-scale supply chain and logistics tracking.

RF Communication Modules

RF Receiver (35 MHz): Operates in the High Frequency (HF) band, typically used in radio astronomy, amateur radio, and remote-control telemetry (e.g., model aircraft). It utilizes circuitry such as filters and demodulators to extract data from incoming electromagnetic waves.

RF Transmitter (434 MHz): Functions in the Ultra-High Frequency (UHF) band. It uses oscillators and frequency synthesizers to generate signals, which are then modulated (AM/FM/PM) and radiated via an antenna. It is commonly utilized in garage door openers, keyless vehicle entry, and sensor networks.

Supporting Hardware

Power Supply: Converts source energy (AC or DC) into the specific voltage and current required by the electronic load.

LCD (Liquid Crystal Display): A module (commonly 16x2 characters) using a 5x7 pixel matrix per character. It relies on liquid crystal materials (often Nematic) that change optical transparency when subjected to an electric field.

Buzzer: A transducer that converts electrical models into audible sound for alarms or alerts. It can be self-excited (DC-powered) or externally excited (requiring a square wave).

Arduino Nano: A compact, breadboard-friendly microcontroller based on the ATmega328P. It features 36 pins, 32KB of Flash memory, 2KB SRAM, and 1KB EEPROM. It is programmed via the Arduino IDE using a Mini-B USB cable, which also provides power.

VI CONCLUSION

Railway safety and operational efficiency have been significantly improved by the combination of Artificial Intelligence (AI) and Internet of Things (IoT) sensors for Railway Train Collision Avoidance on the same track and Animal Detection. By utilizing AI algorithms and Internet of Things sensor networks, the system has demonstrated exceptional effectiveness in recognizing and reducing train collision risks as well as spotting animals on railroad lines. The system has demonstrated its capacity to precisely evaluate collision risks, anticipate possible conflicts, and launch prompt actions to prevent accidents, as demonstrated by the outcomes of simulations and real-world experiments. In addition, the smooth integration with the current infrastructure and train control systems has made it possible to respond quickly to new dangers and guarantee the security of both people and animals.Even with the encouraging results, there are still obstacles to overcome and room for development. The main goals of ongoing research are to improve AI algorithms' predictive power, optimize sensor technologies for reliable operation in a variety of environmental settings, and investigate possible interfaces with autonomous train control systems

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