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Smart Rail Guard – AI-Driven Protection for Passengers and Railways Infrastructure

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Abstract
The Smart Railway System integrates advanced technologies to enhance safety, efficiency, and sustainability. AI-based image processing detects unsafe behaviors like smoking, triggering alerts and notifying authorities. Real-time sensors monitor tracks for obstacles, activating safety protocols such as train deceleration and lighting adjustments. Automated alerts ensure quick responses to emergencies, while LDR sensors manage lighting and ventilation based on occupancy, reducing energy consumption and operational costs. Without such innovations, challenges like inefficient resource use, delayed hazard responses, and safety risks would persist. By leveraging AI, LDR sensors, and automated systems, the Smart Railway System ensures energy efficiency, enhanced passenger safety, and reliable, environmentally friendly operations.

Keywords: *AI-based image processing; Energy efficiency; Obstacle detection; Railway safety; Smart transportation.*

1. Introduction
The Smart Railway System employs advanced technologies to address critical challenges in safety, energy efficiency, and operational effectiveness within modern railway services. By integrating AI, Light Dependent Resistor (LDR) sensors, and automated monitoring solutions, the system optimizes resource use, enhances passenger safety, and reduces environmental impact. LDR sensors manage lighting and ventilation by detecting passenger presence, reducing energy waste, operational costs, and the system's carbon footprint.
AI-based surveillance enhances safety by detecting unsafe behaviors like smoking, triggering alerts, and minimizing fire hazards. Real-time obstacle detection on tracks, such as humans or animals, activates automatic responses like slowing trains, preventing accidents, and ensuring passenger security. Automated alert systems further enhance safety by notifying authorities and emergency services promptly, ensuring faster responses during critical situations. This innovative system redefines railway operations, creating an efficient, eco-friendly, and safer travel experience while meeting growing demands for modern transportation solutions. [1-4]

2. Literature Survey
L. Zhang, S. Wang, and X. Qu in their 2021 study, "Optimal electric bus fleet scheduling considering battery degradation and non-linear charging profile," addressed the complexities of electric bus fleet management. They employed a sophisticated set partitioning model, enhanced by a branch and price algorithm, column generation, and a multi-label correcting method. This approach aimed to optimize scheduling by accounting for battery degradation and non-linear charging profiles, leading to cost reduction, extended battery lifespan, and practical applicability in real-world scenarios. However, the method also presented challenges due to its computational complexity, high data dependency, and resource-intensive processing. Parth Yogesh Kulkarni and Varun Sandeep Kulkarni explored the development of an intelligent scheduling system for

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educational institutions in their 2022 work, "The Development and Impact of an Intelligent Scheduling System for Educational Institutions." They utilized genetic algorithms, web technologies, and Node.js with MongoDB to create a system that produced efficient timetable generation, reduced manual effort, and achieved conflict-free scheduling. Despite its benefits, the system's effectiveness was contingent on accurate input data, and it presented potential computational complexity. In their 2024 paper, "Artificial-intelligent-powered safety and efficiency improvement for integrated railway systems," Jun Liu, Gehui Liu, Yu Wang, and Wanqu Zhang investigated the application of artificial intelligence, large-scale models, machine learning, and multi-mode railway integration to enhance railway safety and efficiency. This integration resulted in enhanced operational efficiency and improved safety. However, the implementation of such systems posed implementation challenges and required high computational resources. Xuehan Li, Minghao Zhu, Beyang Zhang, Xiaoxuan Wang, and Zha Liu conducted a review of artificial intelligence applications in high-speed railway systems in their 2024 study, "A review of artificial intelligence applications in high-speed railway systems." They analyzed the use of artificial intelligence, intelligent manufacturing, and electrical control systems to achieve enhanced real-time perception, automated driving capabilities, and dialyzed services. Nonetheless, they identified challenges related to integration, data privacy concerns, and high cost. M. Arumugam, G. Arun, and Dhanapal C. focused on detecting railway accident risks using deep learning in their 2023 work, "Detection Of Railway Accident Risk Using Deep Learning Approach." They implemented deep learning and the YOLOv8 algorithm to achieve real-time hazard detection and enhanced passenger safety. However, the approach required high computational resources and had the potential for false positives/negatives. Junyu Chen, Haitao Hu, Minghua Wang, and Xinbo Ge examined power flow control and regenerative braking energy utilization in AC electrified railways in their 2024 study, "Power Flow Control-Based Regenerative Braking Energy Utilization in AC Electrified Railways: Review and Future Trends." Their analysis focused on power flow control and regenerative braking energy (RBE) utilization, which led to enhanced energy efficiency and effective RBE recycling. Despite these benefits, they acknowledged implementation challenges and potential high costs. Pravinkumar Gore, Ravishankar Dudheswara, and Rema Reins conducted a review of renewable energy and smart grid system applications in railways in their 2023 paper, "A Review of Renewable Energy & Smart Grid System applications in railways." They explored the application of renewable energy and smart grid electrical systems, noting the potential for reduction in greenhouse gas emissions and enhanced energy. However, they also pointed out the high initial investment costs and technical challenges in RTS integration. Lu Zhen, Nianzu Zhang, and Zhiyuan Yang explored integrated optimization for high-speed railway express systems with multiple modes in their 2023 study, "Integrated optimization for high-speed railway express system with multiple modes." They utilized a stochastic mixed integer programming model to achieve maximized net profit and efficient transportation. However, they acknowledged the complexity in model formulation.

3. Train Accident Data and Analysis

Train accidents are a serious issue, affecting passenger safety. In 2023-24, there were 40 train accidents in India. These accidents caused 313 deaths and injured 2,087 people. In the first five months of 2024, 18 train accidents occurred. Over the past decade, train accidents have decreased from 135 in 2014-15 to 40 in 2023-24. Many train accidents happen due to track failures, human errors, mechanical failures, and obstacles on tracks. Bad weather conditions like heavy rain and fog also increase accident risks. AI-based monitoring can help detect problems early and prevent accidents. Smart sensors can reduce human errors, and automated alerts can improve train safety. Although train accidents have reduced over time, more safety improvements are still needed. (Figure 1) [3]

4. Estimated Accident Reduction with Ai-Driven Railways

- Faster Hazard Detection (92%) – AI quickly finds dangers like people on tracks or broken

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rails. This helps stop accidents before they happen. (Figure 2)

- Accident Prevention (85%) – The system alerts the railway team about problems like track issues or obstacles, helping to avoid crashes. (Figure 3) [4]

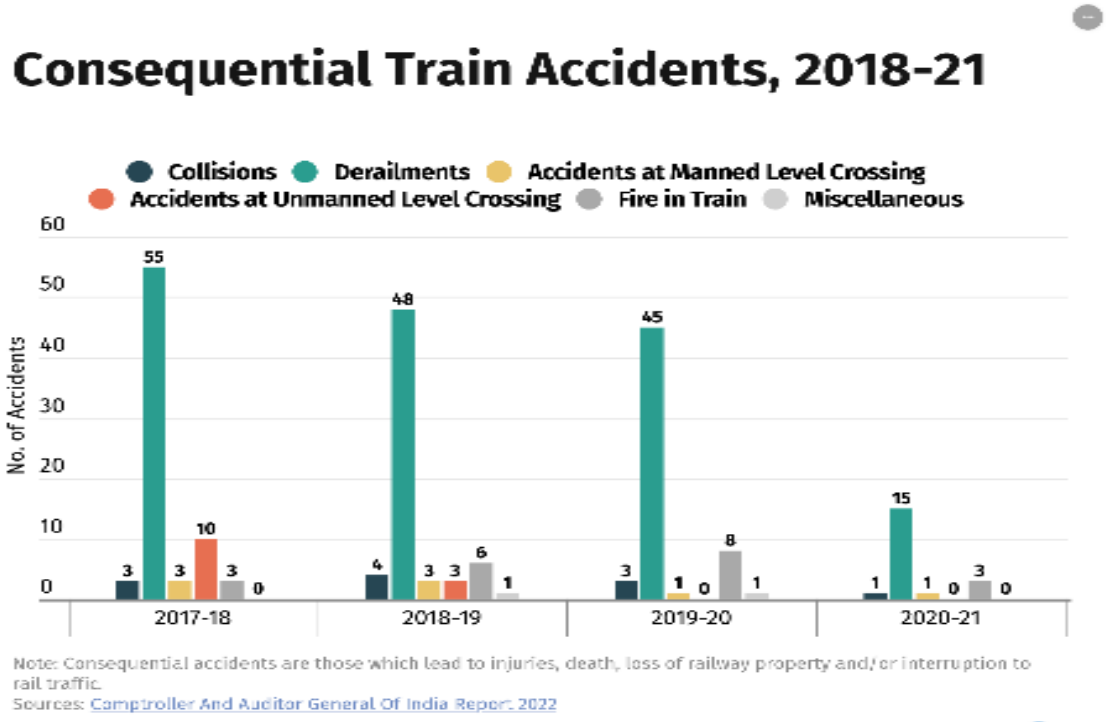

Figure 1 Chart Showing Consequential Train Accidents 2018-2021

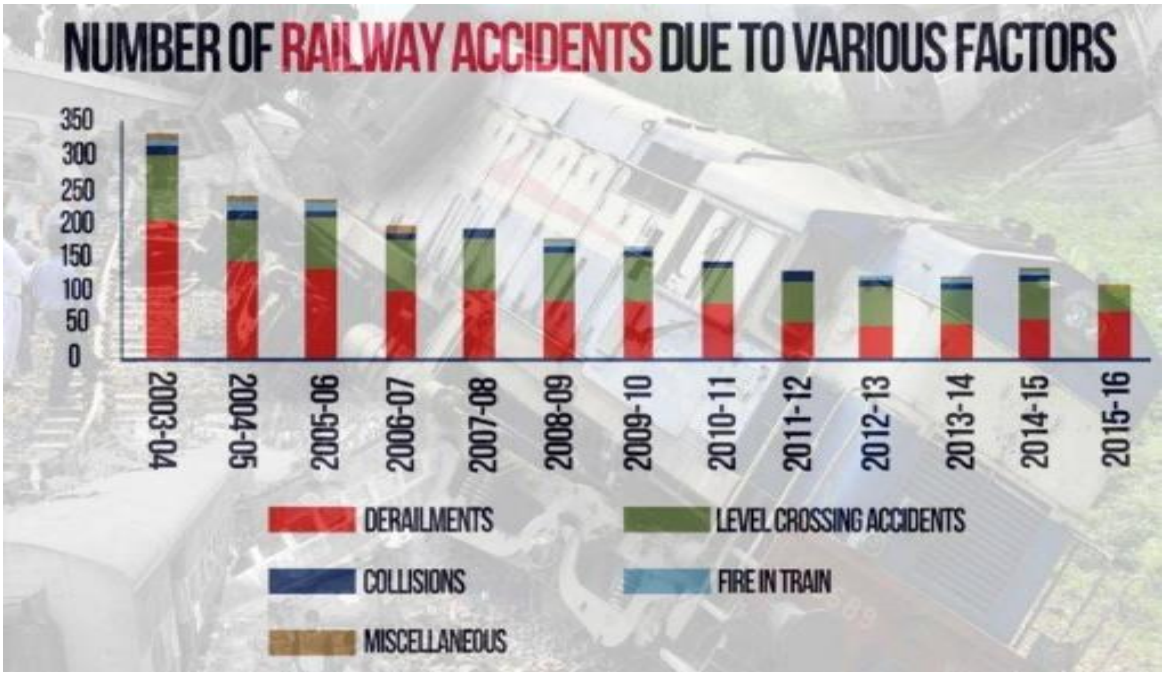

Figure 2 Chart Showing Train Accidents 2003-2016 Due to Various Factors

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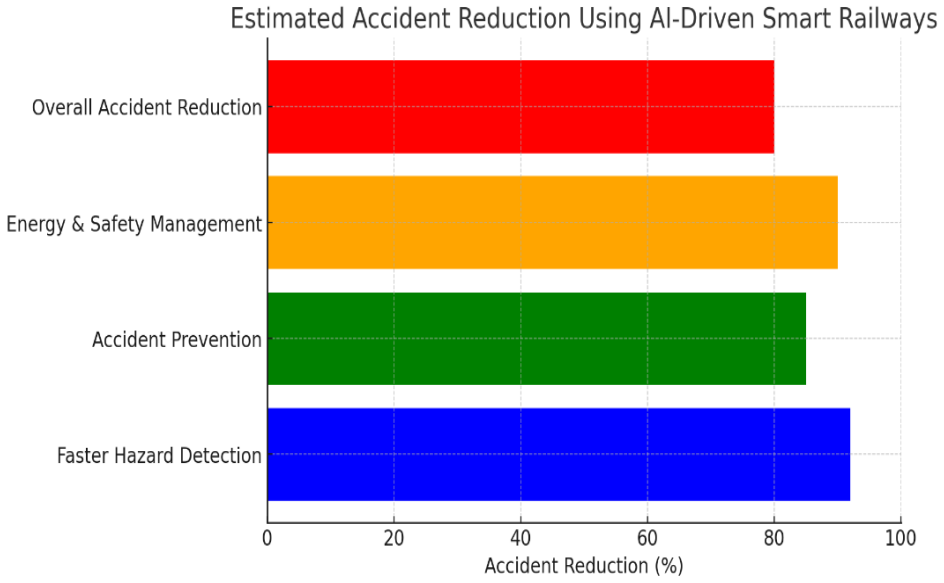

Figure 3 Chart Showing Estimated Accident Reduction Using AI-driven Smart Rail Guard

- **Energy & Safety Management (90%) –** Lights and fans turn off when no one is inside, reducing energy waste and improving safety.
- **Overall Accident Reduction (80%) –** If used properly, this project can reduce train accidents by 80% or more, making rail travel much safer. [5]

5. Methodology

5.1.Block Diagram

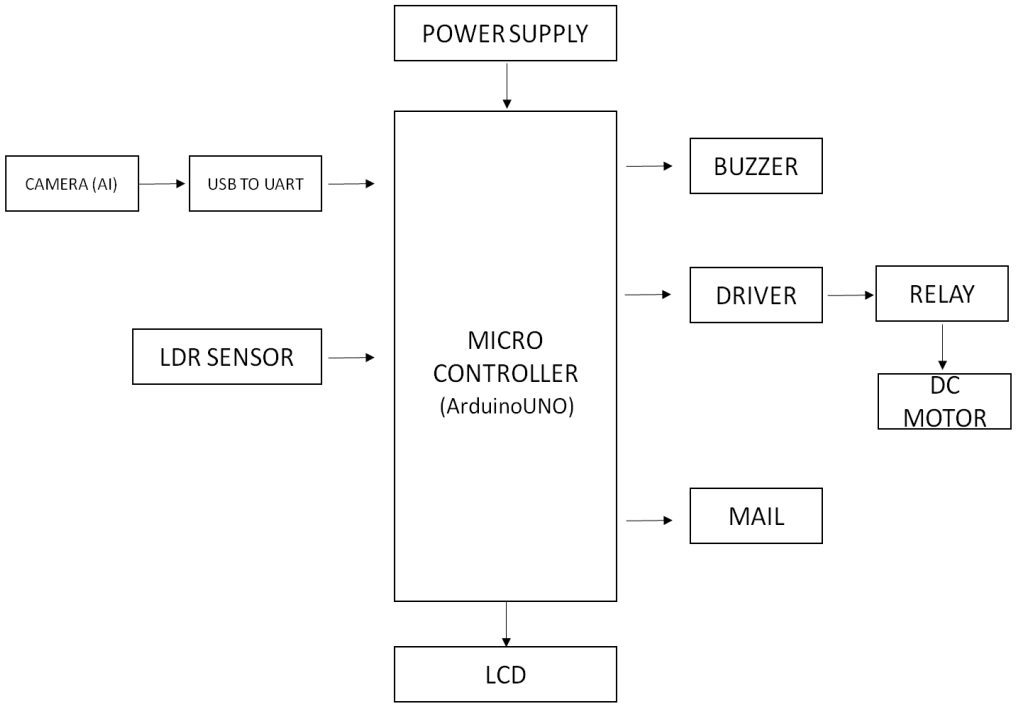

Figure 4 Block Diagram

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5.2.Hardware Requirement

- POWER SUPPLY (SMPS or Battery, Voltage: 5V/12V DC, Current: 1A–2A)
- BUZZER (Piezoelectric or Magnetic, 3V–12V)
- MICROCONTROLLER (ArduinoUNO,5V DC)
- LDR SENSOR (Resistance Range: 1kΩ–1MΩ (based on light intensity), Voltage: 3.3V–5V)
- DC MOTOR (5V – DC)
- LCD DISPLAY (16x2 Alphanumeric LCD, 5V)

5.3.Software Requirement

- MP LAB (MPLAB X IDE)
- EMBEDDED C (C programming)
- CNN – YOLO (Convolutional Neural Network)

6. Implementation

Smart Lighting & Ventilation Module: This module helps save energy by controlling the lights and ventilation system in the train compartments. It uses a Light Dependent Resistor (LDR) to measure how much natural light is present. If there is enough sunlight, the system automatically turns off the lights to avoid wasting electricity. Additionally, motion sensors detect whether passengers are in the compartment. If no one is present, both the lights and ventilation system are switched off. This smart system ensures that energy is only used when needed, making the train more efficient and environmentally friendly. [6]

6.1.AI-Based Safety & Alert Module

This module improves passenger safety by using AI-powered cameras that continuously monitor the train compartments. The system is designed to detect dangerous activities such as smoking, fire, or unauthorized access. If a hazard is identified, the module takes immediate action. It activates a loud alarm to warn passengers and alerts the train staff and control center. In case of fire, it can also trigger emergency measures like activating the fire suppression system. This system ensures a quick response to any potential danger, keeping passengers safe throughout the journey. [7]

6.2.Track Safety Module

The Track Safety Module is designed to prevent accidents by scanning the railway tracks ahead of the train. It uses AI-based object detection to identify obstacles like people, animals, or objects on the tracks. If something is detected in real time, the system immediately sends a signal to the train's control system. Depending on the situation, it can either slow down the train or apply the emergency brakes to prevent a collision. At the same time, an alert is sent to the train operator and control center. This technology helps avoid accidents and ensures safer travel for everyone.

6.3.Main Control Module

The Main Control Module is the central system that brings together all the information from sensors and cameras to make intelligent decisions. It helps in managing energy efficiently, ensuring passenger safety, and handling emergencies. A digital display (LCD screen) is installed in the train to show important updates, such as how much energy is being used and any safety alerts. The control system also decides when to turn the lights and ventilation on or off, based on the number of passengers present. The AI-powered cameras continuously monitor both inside and outside the train to detect any potential hazards. Additionally, the system generates reports on energy usage and safety incidents, which can be accessed by railway operators for maintenance and improvement. This integrated approach makes railway operations smarter, safer, and more efficient.

Discussion

The AI-Driven Smart Railway System is better than traditional railway safety methods in many ways. One big advantage is that it detects dangers faster. In old systems, people have to watch CCTV cameras to find problems like smoking or trespassing, which can cause delays. But with AI, the system can find these issues automatically and send alerts immediately, helping authorities take quick action. Another important benefit is real-time track monitoring. Traditional railways check tracks only at certain times, which means sudden obstacles or damage may not be noticed in time. This new system uses ultrasonic and LiDAR sensors to keep an eye on the tracks all the time. If something is wrong, the system

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detects it immediately, reducing the chances of accidents. The system also helps save energy. In many railway stations, lights and ventilation systems run on a fixed schedule, even when they are not needed. This wastes electricity. The AI system uses LDR sensors to turn lights and fans on or off based on the number of people present, which lowers electricity costs and makes the system more efficient. Passenger safety is also improved with this system. In traditional railways, emergencies rely on human response, which can sometimes be slow. This system automates emergency alerts, making sure help reaches faster and keeping passengers safer. Another great thing about this system is that it is affordable and easy to expand. Instead of spending a lot of money to upgrade railway infrastructure, this system uses AI and sensors to improve what is already there. It can be added to multiple railway stations without high costs. [8]

Conclusion

The Smart Railway System integrates cutting-edge technologies to address critical challenges in the railway industry. Through AI surveillance, it ensures passenger safety by detecting unsafe behaviors such as smoking and alerting authorities promptly. The system's real-time obstacle detection and predictive maintenance capabilities prevent accidents and breakdowns, ensuring smooth operations. By using LDR sensors to control lighting and ventilation based on occupancy, it reduces unnecessary energy consumption, leading to cost savings and a lower environmental footprint. Automated alerts enhance emergency response times, improving overall safety. This system optimizes energy use, boosts efficiency, and ensures that the railway service remains reliable, safe, and environmentally friendly. It is a crucial step toward modernizing the transport sector, providing a sustainable solution that benefits passengers, operators, and the environment.

Future Scope

Choose Your Seat – Passengers can pick their own seat when booking. Check Unreserved Compartment – Passengers can see if the unreserved coach is full or has space. Know Ticket Availability – Passengers can check if they can get a ticket based on how many people are already inside. Automatic Sanitation System –An automatic sanitation system helps keep train compartments clean without needing manual work. Sensors can detect when the compartment is empty and start cleaning the floor using robotic vacuums or spray disinfectants. Smart dustbins can sort waste and alert staff when they are full. Toilets can clean themselves using automatic flushing, UV light disinfection, and water-saving sprays. Air purifiers can remove dust and bad odors, while automatic air fresheners keep the compartment smelling fresh. Automatic Window System –An automatic window system makes train journeys more comfortable by adjusting windows based on the weather and air quality. If it's too hot, the windows can open to let in fresh air. If it rains, they can close automatically to keep water out. Sensors can also check air pollution levels and close the windows if the outside air is bad, while an air purifier keeps the inside air clean. Passengers can still control the windows manually using buttons or a mobile app.

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