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Railway Accident Prevention System For Collision Avoidance, Signals And Rail Track Detection

Prof.S.B. Kamble[1,a] ,Prachi D.Chaudhari[2,b],
Mayur M.Mane[3,c], Anjali A.Nanavare[4,d].
1-Professor PDEA's College of Engineering, Pune. 2,3,4,- Student PDEA's College of Engineering,Pune

Department of Electronics & Telecommunication Engineering
PDEA's College of Engineering (Manjari Bk.)
Pune, India, 412307

Abstract:

Railway accidents are a serious safety issue and are frequently triggered by track failures, signal malfunctions, and train collisions. In this paper, a Railway Accident Prevention System based on IoT-based sensors and real-time communication is proposed to improve railway safety. The system includes LiDAR sensors for detecting rail track cracks, wireless communication modules for train-to-train collision avoidance, and intelligent signaling mechanisms for avoiding human mistakes. The system to be proposed uses an ESP32 microcontroller for processing data and wireless notifications to inform railway authorities of impending dangers. Through real-time monitoring and automation, the system seeks to reduce derailments, signal accidents, and train collisions, making the railway network safer. Experimental results show enhanced accuracy in track anomaly detection and proper communication between trains and control stations. This study emphasizes the viability of IoT-based railway safety solutions for preventing accidents and enhancing operational efficiency.

Keywords:

Railway Accident Prevention, IoT-based Safety System, Real-time Monitoring, Track Failure Detection, Train Collision Avoidance, LiDAR Sensors, Wireless Communication, ESP32 Microcontroller, Intelligent Signalling.

1. Introduction:

Railway transportation is essential for efficient passenger and goods movement but is prone to accidents caused by collisions, signal failures, and track defects. These incidents result from human errors, mechanical failures, and track obstructions, leading to loss of life and infrastructure damage. To enhance railway safety, this research proposes an IoT-based Railway Accident Prevention System integrating ultrasonic, infrared (IR), and LIDAR sensors for real-time monitoring and automated alerts. The system includes three key components: collision avoidance, signal monitoring, and track defect detection. Ultrasonic sensors continuously scan railway tracks for obstacles like fallen trees, animals, or vehicles, triggering alerts for timely operator response. IR sensors monitor railway signals, detecting anomalies such as missing or malfunctioning signals to prevent misinterpretation. LIDAR technology enables precise track defect detection by scanning for cracks, misalignments, and deformations, ensuring proactive maintenance and reducing derailment risks.

A real-time alert mechanism using LED indicators and buzzers enhances train operator awareness, improving response time and accident prevention. By leveraging IoT-based real-time monitoring, the system reduces human intervention, ensuring cost-effective and scalable railway safety solutions. This research contributes to the development of a smart railway network, enabling early fault detection, efficient accident prevention, and enhanced operational safety.

2. Literature Survey:

2.1 KAVACH-An Indian Automatic Train Protection System Development, Challenges and Some Solutions.

KAVACH is an indigenous Automatic Train Protection (ATP) system developed by Indian Railways to enhance railway safety, inspired by global systems like ETCS and PTC. It prevents collisions, enforces speed restrictions, and applies automatic brakes when necessary, using RFID tags for train positioning and radio communication for real-time data exchange with locomotives.

The implementation faced challenges such as integrating with different locomotive types, ensuring multi-vendor compatibility, and setting up necessary infrastructure like communication towers and on board equipment. Additionally, the braking algorithm had to be optimized for efficient and safe operations.

After successful trials (2012–2016), KAVACH is now being deployed across major railway routes. Future improvements include standardizing loco fitment, enhancing real-time diagnostics through Network Management Systems (NMS), and refining braking logic. With continuous upgrades, KAVACH will improve railway safety and has the potential for global adoption.

2.2 A Systematic literature review of defect detection in railways using machine vision-based inspection methods.

Machine Vision-Based Inspection Systems (MVIS) enhance railway defect detection by using image processing, deep learning, and AI to identify faults in tracks, wheels, and components. Unlike manual inspections, MVIS ensures accuracy, efficiency, and cost-effectiveness. Key advancements include CNN-based models, feature extraction, and object detection for precise defect classification. Challenges like real-time processing and dataset standardization persist, but future research aims to integrate AI-driven predictive maintenance and IoT-based monitoring, making railway inspections smarter and safer.

2.3 Railway Accident Prevention System for Signals and Tracks.

Railway accidents, particularly collisions, pose significant safety risks and necessitate advanced prevention systems. Traditional safety measures rely on manual inspections and electronic signalling, which can sometimes fail due to signal errors, track switching issues, and human oversight. Modern railway accident prevention systems integrate sensor-based automation, real-time monitoring, and decision-support mechanisms to mitigate risks.

Recent advancements include Signalling Deployment Systems (SDS) and Train End Safety Systems (TESS), which utilize IR and ultrasonic sensors to detect train positions and ensure safe track switching. These technologies provide real-time alerts to loco pilots, improving their ability to make informed decisions and prevent collisions. Despite these innovations, challenges remain in system integration, accuracy, and large-scale implementation. Future research aims to enhance AI-driven predictive analytics and IoT-based railway monitoring for safer and more efficient railway operations.

2.4 Railway Track Crack Detection.

Railway track cracks are a major cause of train derailments, posing serious safety risks. Traditional manual inspection methods are slow, inefficient, and prone to human error. To address this, modern automated crack detection systems use ultrasonic sensors, GPS, and microcontrollers to accurately detect cracks and send real-time alerts to railway authorities. These systems provide higher accuracy, faster detection, and improved safety compared to conventional methods. Future advancements aim to integrate AI and machine learning for predictive maintenance and enhanced railway track monitoring

2.5 Real-Time Obstacle Detection Over Railway Track using Deep Neural Networks.

Railway accidents caused by track obstructions pose serious safety risks. Traditional monitoring methods rely on manual inspections, which are inefficient and costly. Recent research explores deep learning-based obstacle detection systems using convolutional neural networks (CNNs) to automatically detect objects like animals, vehicles, and debris on tracks. The MobileNetV2 model has shown 97% accuracy in real-time detection, outperforming other models like YOLOv5 and ResNet50. Future advancements aim to integrate IoT-based monitoring and automated response mechanisms for enhanced railway safety.

3. Model Architecture :

3.1 Block Diagram :

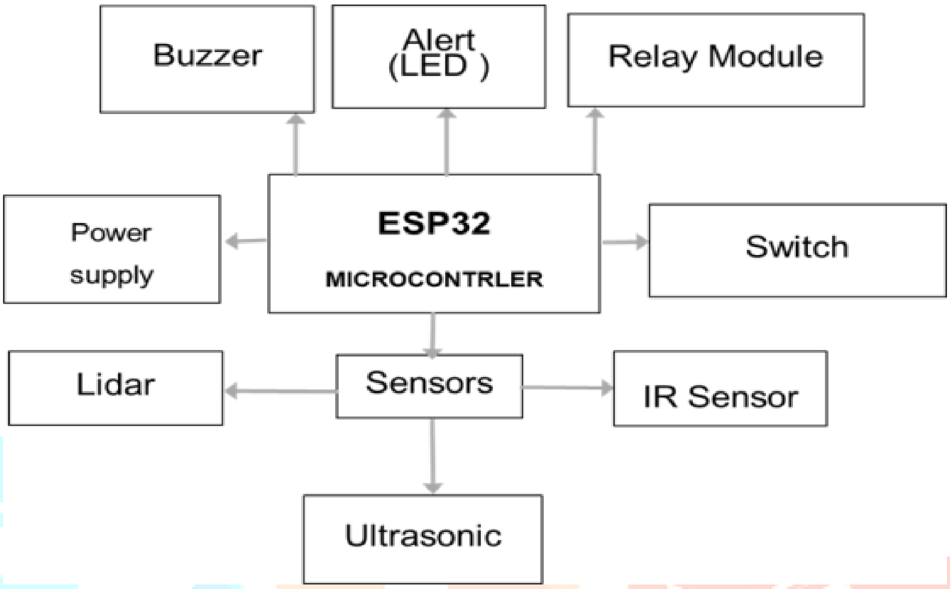

Fig3.1 Block diagram of Railway Accident Prevention System

1.ESP32 Microcontroller
Features:
Dual-core 32-bit LX6 microprocessor
Wi-Fi and Bluetooth connectivity
520 KB SRAM and external flash support
Low power consumption
Multiple GPIO pins for interfacing sensors
Specifications:
Operating voltage: 3.3V
Clock Speed: Up to 240 MHz
Flash Memory: 4MB
GPIO Pins: 34

2. Power Supply
Features:
Provides regulated power to ESP32 and sensors
Specifications:
Input: 5V (USB) and 3.7V (Battery)
Output: 3.3V for ESP32, 5V for modules

3. Sensors
Lidar Sensor (VL53L0X TOF BASED):
Features:
High-precision distance measurement
Specifications:
Range: 0.1mm to 40mm

Accuracy: ±2 mm
Communication: UART, I2C

Ultrasonic Sensor:
Features:
Measures distance using sound waves
Specifications:
Range: 2 cm to 400 cm
Accuracy: ±3cm
Operating Voltage: 5V

IR Sensor:
Features:
Detects obstacles and object movements
Specifications:
Range: 2 cm to 30 cm
Operating Voltage: 3.3V – 5V

4. Switch
Features:
Used to manually control the system
Specifications:
Type: Push-button
Operating Voltage: 3.3V

5. Relay Module
Features:
Controls high-power devices like motors or alarms
Specifications:
Voltage Rating: 5V control signal
Switching Capacity: 10A 250V AC

6. Alert System (LED and Buzzer)
LED Features: Visual indication for system alerts
Buzzer Features: Generates sound for warnings
Specifications:
LED Voltage: 3.3V – 5V
Buzzer Frequency: 2 kHz – 4 kHz

3.2 Flow Chart:

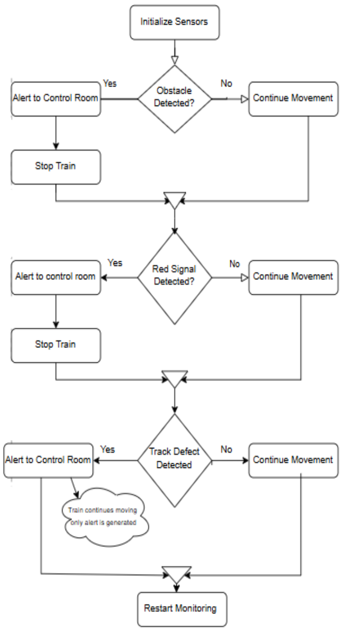

Fig3.2Flow chart of Railway Accident Prevention System

1 Initialize Sensors:

The system starts by initializing sensors to monitor obstacles, signals, and track defects.

2 Obstacle Detection:

If an obstacle is detected, an alert is sent to the control room, and the train stops.

If no obstacle is detected, the train continues moving.

3 Red Signal Detection:

If a red signal is detected, an alert is sent to the control room, and the train stops.

If no red signal is detected, the train continues moving.

4 Track Defect Detection:

If a track defect is detected, an alert is sent to the control room. However, the train continues moving (only an alert is generated).

If no track defect is detected, the train continues moving.

5 Restart Monitoring:

The monitoring process restarts to continuously check for obstacles, signals, and track defects.

3.3 Implementation and Features:

Implementation -

The Railway Accident Prevention System is designed to enhance railway safety by integrating collision avoidance, signal monitoring, and rail track defect detection using IoT, sensor-based detection, and real-time alert mechanisms. The system is implemented in the following phases:

1. Collision Avoidance System

Uses Ultrasonic sensor to detect obstacles on the railway track.
An ESP32 microcontroller processes sensor data and triggers an alert and train stopped if an obstacle is detected within a critical distance.

2. Signal Monitoring System
Uses IR sensors to detect IR signals emitted by railway signals to ensure correct signal interpretation by train operators.
If the IR sensor does not detect the expected signal, the system identifies it as a failure and sends an alert.
A real-time alert mechanism notifies the control center and train operators in case of signal anomalies or malfunctions.

3. Rail Track Defect Detection
Employs Lidar sensors to scan for cracks or deformations in railway tracks.
Sensor-based detection ensures accurate identification of track defects to prevent derailments.

4. Alert and Emergency Response System
Buzzer and LED indicators provide immediate alerts in case of an obstacle, signal failure, or track defect.
A relay module can automatically trigger train brakes in case of imminent collisions.

Key Features –

1. Real-Time Obstacle Detection:
Uses Ultrasonic sensors to detect obstacles on railway tracks.

2. Automated Signal Monitoring:
Uses IR sensors to detect railway signal IR emissions and ensure proper train response.

3. Rail Track Crack Detection:
Ultrasonic sensors locate track defects.

4. Automated Braking System:
A relay mechanism can trigger emergency braking when a collision risk is detected.

5. Energy-Efficient Design:
Low-power ESP32 microcontroller ensures continuous operation with minimal energy consumption.

4. Summary and Conclusion:

Railway accidents caused by collisions, signal failures, and track defects highlight the need for advanced prevention systems. Traditional manual monitoring methods are inefficient and error-prone, necessitating the adoption of sensor-based automation, deep learning, and IoT for real-time railway safety. Technologies such as IR and ultrasonic sensors, and deep learning models like MobileNetV2 enable accurate detection of obstacles, track cracks, and signalling issues, reducing human intervention and improving response times.

The integration of IoT-based monitoring, and automated decision-making is crucial for enhancing railway safety and operational efficiency. Real-time obstacle detection, track condition assessment, and signal management minimize risks and prevent accidents. Future advancements should focus on intelligent railway safety systems that combine deep learning, automation, and real-time data analytics, ensuring safer, more efficient, and reliable railway operations.

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