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RailTech: IoT-Based Smart Railway Wagon Load Monitoring and Overload Prevention System

Aastha Rajput[1], Anvi Tiwari[2], Ashwin Choudhary[3]

[1,2,3]Department of Electronics & Communication Engineering, LNCT Bhopal

Abstract

RailTech is an IoT-based railway wagon monitoring system designed to detect underloading and overloading in freight wagons. The system utilizes load sensors, microcontrollers, cloud computing, and wireless communication technologies to continuously monitor cargo weight and distribution. Traditional railway freight operations depend on periodic inspections that may fail to identify load anomalies during transportation. RailTech provides real-time monitoring, alert generation, and centralized reporting to improve safety, operational efficiency, and cargo management. The proposed system reduces infrastructure damage, minimizes cargo theft, and supports digital transformation in railway logistics.
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1. Introduction

Railway freight transport is one of the most economical methods of moving goods across long distances. However, improper loading remains a major challenge. Overloading can damage tracks, increase derailment risks, and reduce vehicle lifespan. Underloading results in poor utilization of transportation resources. RailTech addresses these challenges through continuous load monitoring using IoT technologies. The system captures load information, analyzes data in real time, and provides actionable insights to railway operators.
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2. Literature Review

Researchers have proposed various railway monitoring solutions using IoT, RFID, wireless sensor networks, and machine learning. Existing systems focus on load measurement, predictive maintenance, and cargo tracking. While these systems demonstrate the feasibility of smart railway monitoring, many lack integrated alert systems and centralized dashboards. RailTech combines sensing, communication, analytics, and visualization into a single platform capable of supporting modern railway operations.

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3. Problem Statement

Current wagon inspection methods are often manual and periodic. During transit, railway authorities have limited visibility into loading conditions. Unauthorized unloading, uneven load distribution, and overload conditions may remain undetected. A smart and automated monitoring solution is required to ensure safe and efficient freight transportation.

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4. System Architecture

The proposed architecture consists of load cells, strain gauges, an ESP32-based controller, GPS module, communication network, cloud database, analytics engine, and monitoring dashboard. Sensors collect data continuously. The controller processes readings and transmits them to a cloud platform. The dashboard displays wagon status and generates alerts whenever threshold values are violated.

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5. Methodology

The methodology begins with data acquisition through calibrated load sensors. Sensor readings are filtered and processed by the microcontroller. The system compares measured values with predefined thresholds. If the measured weight exceeds the maximum permissible value or falls below the minimum value, notifications are generated. Data is transmitted through Wi-Fi, LoRa, or cellular communication channels and stored in a cloud database for historical analysis.

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6. Hardware Components

The hardware setup includes load cells, strain gauges, ESP32 microcontroller, communication modules,

GPS receiver, rechargeable power supply, cloud connectivity interface, and alert notification mechanisms. These components collectively enable accurate monitoring and reliable communication.
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7. Mathematical Model

Let W represent measured wagon weight. Let Tmin and Tmax represent allowable minimum and maximum thresholds. If W < Tmin, the wagon is classified as underloaded. If W > Tmax, the wagon is classified as overloaded. Otherwise, the wagon operates within safe loading limits. The algorithm continuously evaluates sensor readings and updates wagon status in real time.
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8. Results and Discussion

Simulation studies indicate that the proposed system can effectively identify abnormal loading conditions. Real-time alerts enable corrective action before operational issues arise. Historical data supports trend analysis and predictive maintenance. The architecture is scalable and suitable for large railway freight networks. Continuous monitoring also discourages cargo theft and improves accountability.
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9. Advantages

The system improves railway safety, reduces maintenance costs, increases asset utilization, supports remote monitoring, provides historical reporting, enables predictive analytics, and minimizes manual inspections. It also offers scalability and easy integration with existing railway infrastructure.
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10. Future Scope

Future work may include machine learning-based anomaly detection, AI-powered predictive maintenance, blockchain-based freight tracking, renewable energy-powered sensor nodes, and integration with national railway management systems. Digital twin technology can further improve operational decision making.
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integration with national railway management systems. Digital twin technology can further improve operational decision making.

11. Conclusion

RailTech provides a practical and scalable solution for smart railway freight management. By integrating IoT sensing, cloud analytics, and real-time communication, the system enhances safety, efficiency, and operational transparency. The proposed solution aligns with Industry 4.0 objectives and demonstrates the potential of digital technologies in modern transportation systems.

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