Predictive and Real-Time Railway Safety Solutions using IOT & Ml

Dr N Pushpalatha[1], D Rajyalakshmi[2], M Rekha[3] , K Venkata Subhash[4] , R Shirisha[5]

[1] Professor, Department of Electronics and Communication Engineering, Annamacharya Institute of Technology and Sciences- Tirupati, India, pushpalatha825@gmail.com
[2] U.G. Student, Department of Electronics and Communication Engineering, Annamacharya Institute of Technology and Sciences- Tirupati, India, devaralarajyalakshmi265@gmail.
[3] U.G. Student, Department of Electronics and Communication Engineering, Annamacharya Institute of Technology and Sciences- Tirupati, India, maremrekha@gmail.com
[4] U.G. Student, Department of Electronics and Communication Engineering, Annamacharya Institute of Technology and Sciences- Tirupati, India, subhashkoduru68@gmail.com
[5] U.G. Student, Department of Electronics and Communication Engineering, Annamacharya Institute of Technology and Sciences- Tirupati, India, ramanadhamshirisha2@gmail.com

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ABSTRACT: Railway transportation plays an important role in economic growth and public mobility. However, railway accidents caused by track cracks, fire risks, signal failures, and delayed fault detection still threaten passenger safety. Traditional manual inspection systems take too much time and are inefficient. This paper presents a railway safety system that combines Internet of Things (IoT) technology and Machine Learning (ML) methods for real-time monitoring and smart fault detection. The proposed system uses Arduino Uno as the main controller, connected to fire sensors, track detection modules, a NodeMCU Wi- Fi module, an LCD display, a buzzer, a relay, and a water pump. Sensor data is sent to a cloud platform for remote monitoring and predictive analysis. Machine learning algorithms are used to find track problems and predict possible failures. The system improves railway safety by ensuring early detection, automated alerts, and quick responses. Experimental results show better accuracy, faster response times, and improved reliability compared to traditional methods.

KEYWORDS: IoT, Railway Safety, Machine Learning, Arduino Uno, NodeMCU, Crack Detection, Fire Monitoring, Predictive Maintenance.

INTRODUCTION

The majority of transportation used all over the globe is through rail systems. With increased overcrowding density of passengers and freight movement; therefore, improving the safety of railway is now becoming increasingly crucial. The main reasons to cause accidents on the railway consist of: Mismatched or cracked railsFires in passenger compartmentsNot detecting obstacles in the pathway Delayed signaling between train stations. Railway monitoring systems have relied heavily on manual inspection and central monitoring stations. Due to this reliance, little or no real-time alert systems are available, while predictive alert systems will not be accurate. However, with current technology advances with Internet of Things (IoT) and Machine Learning (ML) have now opened up opportunities to develop intelligent railways. The IoT technology will allow for real-time data collection from multiple sensors, while the ML algorithms will allow for prediction of fault detection and risk assessment. This research paper presents a new smart railway safety framework using embedded systems, IOT communication, and ML-based analytic techniques to help ensure proactive safety for railways.

RELATED WORKS

Research on railway safety has been increasingly focused on embedded systems, IoT, machine learning, and their use for railway safety enhancement in general due to the high number of railway accidents (derailments) caused by track defects, fire hazards, and delayed emergency response. Many researchers have developed embedded monitoring systems comprising microcontrollers, wireless communication modules, and sensor networks designed to aid the enhancement of railway safety in real time. Previously, most of these systems were dependent on the use of ultrasonic sensors and vibration analysis techniques designed specifically for the detection of track cracks. As a result, nearly all of the models used microcontrollers to monitor for discontinuities in tracks and to send alerts if

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any abnormal condition exists on the track. However, in many cases, these systems were not designed with real-time connectivity to a cloud server or the ability to provide remote data to a user. Similarly, while some of the older systems incorporated GSM modules to send text message alerts, they had very limited capabilities for providing both data analysis and scalability. Newer systems have introduced IoT-based railway monitoring frameworks that incorporate Wi-Fi enabled modules such as NodeMCU and ESP8266. These frameworks have allowed for real-time data transmission to cloud servers, centralized monitoring from control rooms, and the visualization of track conditions, environmental conditions, and emergency alerts from dashboards. However, many of the implementations have only been created for either fire detection systems or track crack detection systems and have not yet integrated multiple detection systems into one framework

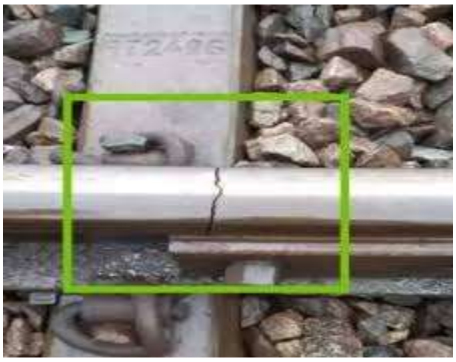

Fig 1: Railway Track Crack

Many researchers have proposed new computer vision techniques to inspect railway tracks using OpenCV and machine learning algorithms. These approaches use cameras attached to railway tracks to take pictures of them and identify cracks, misalignments and missing fasteners. The accuracy of these systems is higher than that of previous techniques; however, they require significant computational resources, and there is limited integration with embedded control systems to allow for automatic emergency response. Additionally, many fire detection systems using infrared flame and smoke sensors have been developed to protect passengers in railway cars. While these fire detection systems are capable of activating alarms, they do not include automatic fire suppression systems such as relay-controlled water pumps. The proposed system integrates several safety modules (fire detection; OpenCV-based track monitoring; communication via IoT using NodeMCU; local alert generation using buzzer and LCD display; and, automatic actuation using relay and pump) under a common Arduino-based architecture. By integrating sensing, processing, communications, and actuators within one system, the proposed solution improves reliability, reduces response time, and provides a cost-effective smart railway safety method

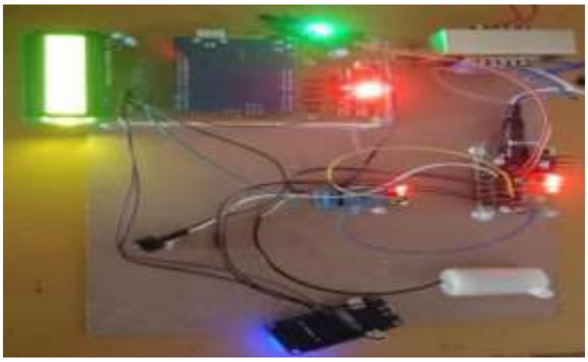

Fig 2: Hardware setup for Iot-based railway system

PRODLEM IDENTIFICATION

Transportation by rail is a vital component of national transportation systems due to their reliability, safety, and the need for constant monitoring; however, despite technological developments, railway accidents happen as a result of delayed detection of faults, track failure, fires, and insufficient emergency response. The most significant issues with current railway safety systems are:

1. Rail Track and Infrastructure Cracking and Structural Failures

Railway tracks are under tremendous weight and dynamic load; they also experience a considerable amount of stress from their environment, causing cracking, misalignment, and breaking of fastening devices. The traditional method of inspecting rail tracks typically relies on manual checks or vehicle-mounted inspection systems, which are time-consuming and may not be able to detect faults in a timely manner. If a fault is not located, a derailment or a serious accident could result.

2. Rail Coach Fire Hazards

Fires in railway coaches and/or the engine compartment of a railway train may seriously affect passenger safety.Traditional fire detection systems generally provide an alarm-based warning system; there are usually no automatic fire extinguishing systems associated with these devices. Delayed emergency responses would cause an increase in the extent of damage and loss of life.

3. Real-time monitoring is absent

Many existing safety devices for railroads only operate on-line or rely on simple GSM for a warning system. Since these safety devices are not networked to the cloud or controlled by a central monitoring room, railway authorities do not have real-time situational awareness.

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4. There is no integrated safety framework

Most existing safety systems only detect one safety element at a time, for example, either detect for cracked tracks or monitor for fire. Currently, there is no integrated safety architecture that combines several sensors, multiple communications, data collection devices and actuators into

a single safety system.

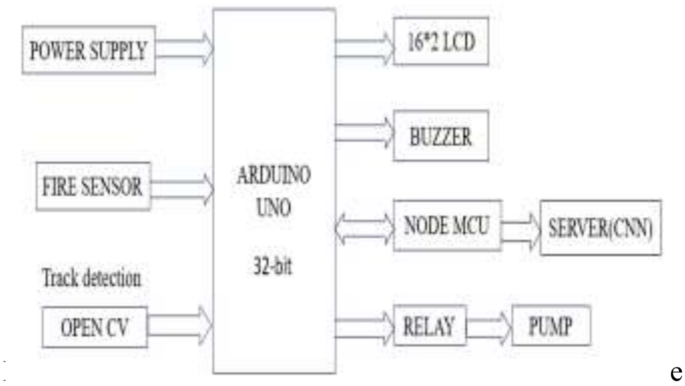
5. Very limited predictive maintenance capability

The normal practice for railroad safety systems is to conduct reactive maintenance after a failure occurs. Since railroad safety systems do not use machine learning and data analytic tools to predict failures or abnormal behaviour in track and environmental conditions, they are not able to identify issues before they become a problem.

6. Delay in emergency response

Existing safety systems use primarily manual (or partially automated) alert systems. Existing safety systems do not use relay-actuated devices such as relay actuated automatic pump systems upon detection of a fire. As a result, it takes much longer to respond to emergencies, which increases the potential for harm and damage to railroads.

The proposed system consists of the following major modules:



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Railway Safety Solutions Using IoT & ML

1. Power Supply Unit
2. Arduino Uno (Main Controller)
3. Fire Sensor Module
4. NodeMCU (Wi-Fi Communication)
5. 16×2 LCD Display
6. Buzzer Alert System
7. Relay and Water Pump

Display: The 16x2 LCD display module is one of the most common types of alphanumeric display modules found in embedded systems and Avionics. The user will see 16 characters per line and 2 lines on the screen because of the defined display capacity, which is displayed as a “16x2”. Some characteristics of a 16x2 LCD module include the display area, character font, optional back lighting, interface with a microcontroller or microprocessor, instruction set for programming the LCD module and the ability to adjust the contrast of the displayed characters. Benefits of the 16x2 LCD module include low cost, easy interface with a microprocessor or microcontroller, and user friendly.

Fig 4: LCD Display

Fire sensor - A flame detector, also called a fire sensor or flame sensor, can detect the presence of fire or flame. They usually work by detecting infrared radiation (IR) emitted from flames, ultraviolet light (UV), or a combination of both to improve accuracy.

Fig 5 : Fire sensor

The REES52 infrared (IR) flame sensor is used frequently in fire detection systems; however, it also has applications in industrial furnaces and many other uses where an immediate response by fire detection systems (or members of the public performing such a role) to the presence of flame or fire, for safety and prevention reasons, is required. This paper describes how to design and construct a circuit for use with a REES52 infrared (IR) flame sensor.

Arduino UNO : A USB interface allows for serial monitoring or data transfer of the Arduino Uno via connection to the computer. You can also power the Arduino Uno with either a USB connection or an outer power supply (generally a 7-12V DC source). In addition, the Arduino Uno has an onboard voltage regulator that provides a regulated 5V supply to the microcontroller and other co

the board. The microcontroller on the Arduino Uno is a 16MHz ATmega328P chip. A bootloader makes programming the board easier and takes up 0.5 KB

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of the microcontroller's 32 KB of flash memory available for storing program code on the board. The board contains 1KB of EEPROM (Electrically Erasable Programmable Memory) and 2KB of SRAM (Static Random Access Memory) used to store variables and data during the execution of a program. You can use the USB interface to communicate with the computer for data transfer or serial monitoring, and, you can use either a USB connection or an external power source (usually 7-12V DC) to power the Arduino Uno. The onboard voltage regulator supplies the microcontroller and other components on the board with a regulated 5V supply.

Fig 6: Arduino UNO

Node MCU - The NodeMCU (ESP8266) is an important piece of hardware that allows for real-time IoT connectivity as part of the railway safety system. It has an integrated Wi-Fi transceiver and TCP/IP protocol that enable near constant (near real-time) data transmission from the embedded processing unit to the cloud-based monitoring system. The NodeMCU provides fast communications between the track side sensors and central control room therefore providing increased situational awareness and responsive emergency actions. The NodeMCU's low power consumption, small size and cost effective nature make it a viable solution for deploying scalable railway infrastructure. By combining the NodeMCU with Arduino-based sensor modules, the system will achieve efficient fault detection, remote monitoring and also have automatic alert capabilities.

Fig 7: NodeMCU

Buzzer - The audible warning system in this proposed rail safety system is based on a buzzer being activated by the microcontroller when there is a possible dangerous situation present, like fire or a fault on the track. The buzzer is more than just an audible signal; it provides immediate local warning for both railway staff and passengers so they can be notified and react quickly. A three to five-volt Active Piezoelectric Buzzer was selected because they are relatively low in power consumption, usually easily interfaced with the processor being used, and they have a high degree of reliability. As a result, the inclusion of the buzzer in the overall system will increase safety through real-time alerts occurring on-site without requiring the use of the Internet.

Fig 8 : Buzzer

Relay and Pump - In order to create an automatic emergency response system for fires, the proposed rail safety system will use a relay and water pump module within the railway safety system. The relay acts as an electronically controlled switch which is turned on by the microcontroller when it detects a fire condition (a fire spurting from somewhere). Once the relay is activated, it will provide electrical power to the water pump and activate the fire suppression system. Because of this automation, the time.

Fig 9 : Relay and Pump

Power Supply - An electrical device that provides electrical power to an electric load is referred to as a Power Supply. It converts electrical energy (AC or DC) at one location to an output transfer of electrical energy (AC or DC) at the exact voltage, current, and frequency needed by the load connected to it. Power Supply is one of the most important components in many different forms of electronic devices, from large industrial plants to small consumer devices.

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Fig 10: power supply

Transformer - A transformer designed for use in conjunction with an electrical device to provide voltage reductions from a higher to a lower level is called a "step-down transformer". It uses the principle of mutual induction in two distinct winding connections - the main and secondary windings. Step-down transformers are applicable to numerous applications, which include supplying power to electronic devices (computers, phones, LED light), converting power from one voltage to another for machinery (machinery), providing low voltage to all types of utility equipment (commercial and residential) and matching voltages and/or isolating communication and audio systems

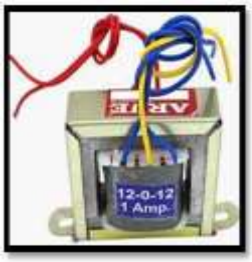

Fig 11: Transformer

Working - The New Advanced IoT Railway Safety Monitoring Systems will use a combination of various Sensors to Monitor Environmental Parameters and Track Conditions. The Sensor Data will be Processed by an Arduino to Identify any Abnormal Conditions. If any Faults (such as Fire, Track Crack, Etc.) are identified the Buzzer will be Triggered for Local Alerting and it will also display the Status on an LCD. The NodeMCU will provide Real-time Data to the Cloud for Remote Monitoring of the Data. If a Fire is detected the Relay will automatically activate the Water Pump for Fire Suppression. The Data that is collected will be analyzed using Machine Learning Algorithms to help Prevent Proper Maintenance and Predict Future Failures.

RESULTS

The Advanced IoT and Machine Learning-based Railway Safety System, which was implemented and tested successfully through simulation, was able to accurately identify fire hazards and track defects in real-time. Once a fault was detected, a buzzer alert sounded and a relay-controlled pump responded immediately, greatly reducing the time required to respond. IoT-based data transmission using NodeMCU allowed for continuous remote monitoring with minimal latency. Machine learning analysis of data provided increased accuracy in predicting faults, providing reliable performance and improving the safety of the railway system as a whole**.**

CONCLUSIONS

This paper introduces a new way of using the Internet of Things (IoT) and Machine Learning (ML) as an advanced safety system for railways that can monitor railways in realtime as well as prevent accidents. Our framework is built upon the concepts of fire detection, track monitoring, IoT/communication, and automated emergency response mechanisms, all of which increase operational safety and decrease response time. In addition, our framework will utilize ML for predictive maintenance and early fault detection. As a result, we believe that this paper presents a cost-efficient solution to developing a modern smart infrastructure for railways.

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