Journal of **N**onlinear **A**nalysis and **O**ptimization
Vol. 15, Issue. 1 : 2024
ISSN : **1906-9685**

IMPROVING RAIL WORKER SAFETY: UTILIZING NRF-BASED WIRELESS SENSING TECHNOLOGY

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Abstract
Railway worker safety is paramount, yet existing methods for timely train detection often fall short. Traditional mechanisms and technologies offer early notifications but lack a comprehensive solution. In response, we propose a portable, low-power system utilizing an attachable accelerometer to detect train vibrations on rails. This wireless solution minimizes human intervention, ensuring continuous alerts for approaching trains, thus addressing the limitations of current methods. Our goal is to design a wireless alerting system for railway workers, providing ample time for critical decisions upon detecting an approaching train. To achieve this, we employ a cost-effective accelerometer sensor known for its high sensitivity to mechanical vibrations, allowing detection from significant distances. Positioned 200 to 500 meters from the worker, this sensor connects to an Arduino microcontroller. A key task is to notify the worker of the train's presence, achieved through an alerting actuator, specifically a vibrator, activated only upon train detection. The Arduino Uno microcontroller ensures a lightweight, portable, energy-efficient, and cost-effective system, meeting the requirements of mobile workers. Crucially, a wireless communication link is maintained between the track monitoring sensor and the alerting system, utilizing NRF24 transceivers. This approach enhances rail worker safety by providing timely and reliable alerts, significantly reducing the risk of accidents.

Keywords: Rail worker safety, train detection, accelerometer, wireless sensing, NRF24 transceivers, portable system, low-power, alerting system, Arduino microcontroller, vibrations, track monitoring, mobile worker, energy-efficient, cost-effective, timely alerts, risk reduction

1 Introduction

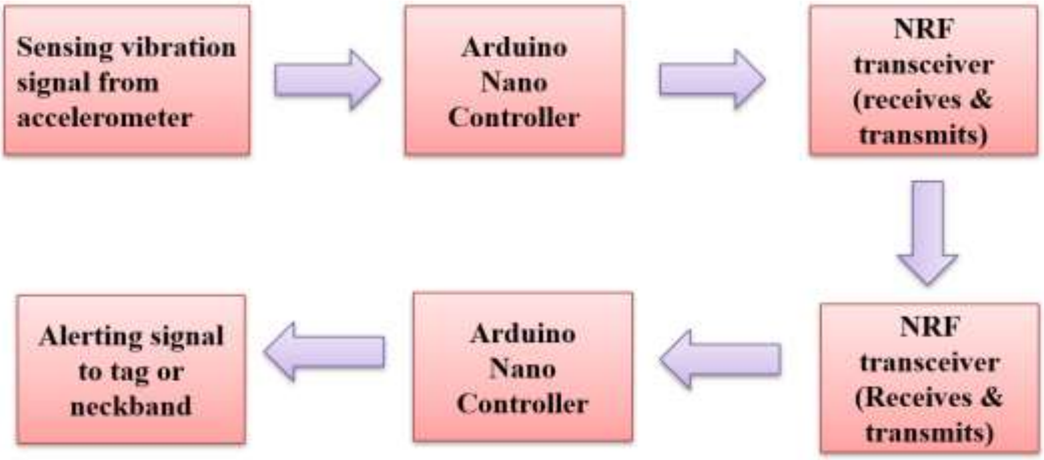
Railway accidents span various types, such as head-on collisions, derailments, fires, and more, with causes ranging from human error to mechanical failures and natural phenomena. This project aims to mitigate railroad accidents, including derailments, crashes, and workplace incidents, often stemming from adverse weather, miscommunications, technical challenges, lack of expertise, or negligence among railway personnel. In the domain of railway safety and alerting systems, this introduction outlines two primary detection mechanisms: Approach Detection and Early Detection. Approach Detection focuses on identifying train presence before reaching a designated area by installing warning devices at a significant distance from the work zone, commonly employed in Automatic Train Warning Systems (ATWS). Conversely, Early Detection involves localized train detection within the work zone, requiring sensors capable of detecting trains at considerable distances to provide adequate warning time. This method reduces the need for distant deployment but may pose complexity, especially if line of sight is necessary. The project aims to develop and elaborate on these detection mechanisms to enhance railway safety. By implementing advanced sensors and warning systems, it seeks to provide timely alerts to railway personnel, thereby reducing the risk of accidents. Through a comprehensive approach that addresses various types and causes of railway accidents, this project endeavors to contribute significantly to improving railway safety standards. A range of innovative technologies and systems has been developed to fulfill these detection mechanisms. The predominant Treadle Mechanism, utilized widely in contemporary rail systems, counts train axles accurately. These mechanical or electronic trigger plates are placed near the rail and activate warning devices as a train passes the "strike-in" point. Some variations can even determine the direction of the train, albeit the installation process demands significant effort. The Inductive Sensor (Rail Module)offers a compact alternative, serving the dual purpose of axle counting and determining train direction. Infrared (IR) technology, as demonstrated by Grace Industries, Inc., provides a cost-effective alternative to traditional electronic treadle mechanisms, though it is susceptible to environmental disturbances. Reflectometry (TDR), leveraging time-domain reflectometry, offers real-time train detection and potential early warning capabilities. Accelerometer sensors, capturing train-induced vibrations, reveal distinctivevibrational signatures and have the potential for early detection. Anisotropic Magneto-Resistive (AMR) Magnetometer sensors detect ferrous material Earth's magnetic field. This comprehensive landscape of detection mechanisms and technologies forms the foundation for enhancing railway safety and minimizing train-related incidents. In the realm of wildlife conservation and railway safety, this project report discusses a critical endeavor to mitigate train collisions with animals, as documented. The study focuses on the development and comparison of two innovative warning systems designed to protect both wildlife and humans in areas of high collision risk. The passing relay system, equipped with trackside sensors, detects approaching trains and activates warning signals, while the approach detector system harnesses train-inducedvibrations in track rails to identify trains at a distance. This comparative analysis assesses the performance, advantages, and limitations of these systems. The research conducted by 19 lays the foundation for this project, emphasizing the use of advancedtechnology, sensors, controllers, wireless communication systems, warning signals, and power sources to create effective warning systems. Furthermore, 2 proposed a wildlife protection method involving warningsignals activated by approaching trains, considering two designs: one detecting passing trains and wirelessly relaying information to warning devices, and the other integrating train detection and warning signals into a single device. This model holds the potential to significantly reduce wildlife-train collisions by providing animals with timely alerts, offering a cost-effective and practical solution for safeguarding wildlife and improving railway safety. This initiative aligns with the broader field of wildlife-vehicle collision mitigation, as demonstrated by 20, who found that wildlife exclusion fencing can effectively reduce such collisions 30 delved into various mitigation measures, including wildlife exclusion fencing, crossing structures, and wildlife warning reflectors. Their work provides insights into the diverse strategies employed to reduce wildlife-vehicle collisions. Additionally, the comprehensive handbook on road ecology by 21 highlights the ecological impacts of linear infrastructure and traffic on wildlife populations and ecosystems, underlining the importance of effective mitigation measures. In the realm of railway safety and alerting systems 3, this introductory section delves into the pivotal role of early detection in averting train derailments, a leading cause of railway accidents. The proposed system revolves around Piezo-electric vibration sensors and RF wireless transmitters and aimsto recognize abnormal vibration patterns indicative of potential train derailments. As a response to safety concerns in the Egyptian National Railway (ENR), this research gains paramount significance, given the ENR's extensive network covering 9570 kilometers and annual transportation of 500 million passengers. Alarmingly, statistics from the Central Agency for Public Mobilization and Statistics (CAPMAS) underscore the urgency of enhancing railway safety, with a significant rise in train accidents in Egypt, notably train errors. Notably, the challenges of evaluating certain train characteristics, such as wheel loads or broken suspensions, have necessitated innovative approaches To address the issue of train derailments, the project advocates the use of Wireless Sensor Networks (WSN) within the ENR industry. These WSNs are crucial in efficiently monitoring the intricate railway infrastructure. The research zeroes in on detecting variations in train vibrations that hint at potential derailments. It endeavors to predict such incidents using Piezo vibration sensors, known for their sensitivity, and RF transmitters that facilitate wireless data transmission. By meticulously analyzing vibration patterns, the system can distinguish between normal train vibrations and abnormal patterns indicative of derailments. Notably, the project's testing environment involves a controlled setup with model trains and tracks, simulating derailment scenarios. There is much requirement of this project because there are much accidents happened to railway workers recently due to lack of alertness to the workers while they are engaged in their work. Here are the details of the accidents happened to railway workers who are engaged in their work. The following table shows the details of accidents happened in India.

2 Literature Survey

The alerting system in is separated into two detection mechanisms. They are “Approach Detection” and “Early Detection”. The method “Approach Detection” involves detecting the train "at the approach" before it reaches a specific region of interest. It is commonly used in Automatic Train Warning Systems (ATWS). In this approach, warning devices are installed at a considerable distance on both sides of the zone to provide advance warning to personnel within the work zone. The safety operator must travel a significant distance to install these warning devices. The method “Early Detection” involves detecting the train locally from within the work zone. It requires only a single installation point and does not require traveling to distant deployment locations. However, the system must be equipped with sensors capable of detecting a train at a distance of several miles to provide sufficient warning time. This method can be more complex if line of sight is required. The predominant method for train detection in contemporary rail systems is the treadle mechanism, widely used in commercial systems like the Minimal 95 and the Autoprowa ATWS These mechanisms are installed in pairs at entry and exit points, spaced several miles apart, with the primary purpose of accurately counting train axles. Treadles are mechanical or electronic trigger plates located close to the rail, and they activate a warning device as a train passes the “strike-in” point, while incrementing an axle counter with each wheel passage. Some variations can even determine the direction of the passing train. However, installing these mechanisms requires significant effort, including ballast excavation for mounting brackets. Inductive sensors are another commonly employed technology in train detection, and they come in two main variations. The first utilizes inductive loops buried in the track ballast, but this approach is intrusive and unsuitable for portable work zone detectors. It also has limitations in signal dissipation and susceptibility to electromagnetic interference, including electrical storms. The second variation, known as the inductive sensor, is a compact unit attached to the rail structure, similar to treadle mechanisms. Like treadles, it serves the dual purpose of axle-counting and determining the direction of passing trains. This type of sensor is also commonly used in commercial ATWS systems. Infrared (IR) beam sensors have been utilized as quasi-axle counters to some extent. An example of this technology is demonstrated by Grace Industries, Inc., a U.S. company that offers a train detection system securely clamped onto the rail structure, employing an optical lens aimed at the inner rail's side to detect wheel passage in a beam-braking configuration, designed primarily for alerting railway maintenance personnel. IR beams serve as cost-effective alternatives to traditional electronic treadle mechanisms, butthey are susceptible to environmental disturbances, such as dirt and dust accumulation on the lens's optical aperture, as well as misalignments caused by the intense vibrational forces exerted on the rail structure by passing locomotives and railcars. Similar to treadle installations, significant work is required for the installation of IR sensors against the rail. A method explored in sought to employ time-domain reflectometry (TDR) for real-time train detection, enabling the prediction of a train's arrival time. TDR treats track rails as electrical differential transmission lines, injecting short, coded electrical pulses into them. These pulses travel along the rails at a known speed and are either absorbed or reflected back by the train's axles, which act as an electrical load. The distance from the system to the target is determined by half the 'time-of-flight' of these pulses. Under ideal conditions, the study demonstrated that TDR could theoretically track trains at distances of up to 5 miles, indicating its potential for early detection. However, excessive tie and ballast conductance betweenthe rails, caused by dirt, mud, and moisture accumulation, posed a challenge, altering the electrical characteristics of the rail tracks and limiting TDR's effective range. In a study detailed in, a detection technique involved the use of accelerometer sensors with flat frequency responses to capture and record mechanical vibrations induced into the rail structure by approaching trains, aiming to activate a train warning system. The study revealed that the train generated distinctive vibrational signatures, featuring both broadband and narrowband components, with greater energy concentration in front of the train than behind it. The broadband component, spanning the first 5kHz of the frequency spectrum, was linked to random track irregularities. Simultaneously, the narrowbandcontent within the same frequency spectrum was associated with periodic elements, such as wheel irregularities. This allowed for the determination of whether a train was accelerating or decelerating based on the narrowband content alone, up to a theoretical distance of 3000 feet or 0.57 miles above the noise floor baseline. Despite challenges related to different track types and accelerometer dynamics, this method displayed the potential for early train detection, akin to the TDR approach. A study outlined in delved into the application of anisotropic magneto-resistive (AMR) magnetometer sensors for train detection. These sensors were considered due to the significant presence of ferrous materials in locomotives and railcars, which disrupt the Earth's magnetic field and can be readily detected by vector-type magnetometer sensors. AMR sensors, known for their rapid signal response and dissipation, facilitated high-frequency sampling. This allowed for the creation of distinct magnetic signaturesfor metallic objects such as vehicles, locomotives, and railcars. These magnetic signatures exhibited a remarkable level of repeatability, making them valuable for various innovative train-based detection applications. Doppler radar uses radio waves to detect the motion of a train. It can detect passing trains and provides information about train speed. Doppler radar requires line of sight and can be used for both approach detection and early detection.

3 Methodology

Fig 1 Block Diagram



The diagram represents to show a conceptual design for a vibration sensing and alerting system. Here's a breakdown of the system based on the labels in the diagram:

- **Sensing vibration:** There's an accelerometer labeled "signal from accelerometer" which suggests the system uses an accelerometer to sense vibration.
- **Arduino Nano Controller:** The "Arduino Nano Controller" is labelled "receives & transmits" which suggests it receives the signal from the accelerometer and transmits a signal based on that data.
- **NRF Transceiver:** The "NRF transceiver" is also labelled "receives & transmits" which suggests it receives a signal from the Arduino Nano Controller and transmits it wirelessly.

- **Alerting signal to tag or neckband:** The diagram shows an "alerting signal" being sent to a tag or neckband, but it doesn't specify how the alert is delivered.

Results

Accelerometer Sensor is tested by placing on the bench and some weight is placed on it. Vibrations are produced by ringing the phone and we have used a vibrator to produce periodic vibrations. These vibrations are sensed by the Accelerometer sensor and generates an electrical signal. These signals are sent to Arduino Nano. Fig 4.1 shows the data received by the Arduino Nano from the Accelerometer sensor.

Fig.2 Accelerometer Sensing Data

As the vibrations generated are about to create a low voltage signal but in the field the scenario may be different because the vibrations created at the railway track may be larger which creates the larger signal.

Graph Representation

The graph in the project documentation portrays the recorded vibration data obtained from the

Fig 3 Signal Generated by the Accelerometer Sensor

accelerometer sensor integrated with the Arduino Nano. It visualizes the fluctuations in vibration intensity detected by the sensor over a specific time span. Each data point on the graph corresponds to a measured vibration level, with the x-axis representing time intervals and the y-axis indicating the magnitude of vibration measured in arbitrary units. The graph not only illustrates the dynamic nature of vibration patterns observed by the sensor but also highlights variations in intensity over time. Furthermore, the graph depicts threshold points delineating predefined levels of vibration intensity. These thresholds, represented by horizontal lines or markers on the graph, signify the minimum and maximum acceptable vibration levels. Analyzing the graph enables the assessment of the sensor's performance against these thresholds, facilitating the identification of instances where vibration levels exceed or fall below the specified limits. By incorporating threshold points into the graph, the documentation provides a comprehensive overview of the sensor's operational characteristics, aiding in the evaluation of its efficacy and reliability in detecting vibrations and triggering appropriate responses.

Testing NRF24L01 Transceiver Modules:

The connections between Arduino and transceiver module are as shown in the figure. The connections aresame for both the transmitter and receiver.

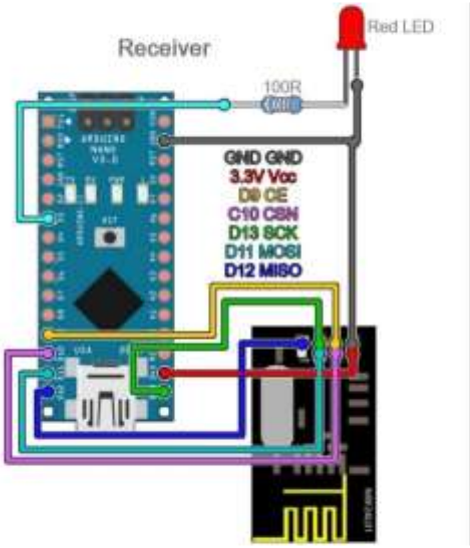


Fig 4. Connections between NRFL24L01 module and Arduino

Receiver End Data

The transmitted data from the accelerometer sensor, processed by the Arduino Nano microcontroller, is received wirelessly using NRF24L01 transceiver modules. These transceiver modules serve as the communication interface between the sensor node and the receiver node, facilitating the transmission of data over a wireless communication link. Upon receiving the transmitted data, the NRF24L01 transceiver module at the receiver end decodes the incoming signal and relays it to the Arduino Nano microcontroller for further processing and analysis. The Arduino Nano, equipped with a dedicated receiver code, interprets the received data packets, extracting relevant information such as vibration intensity levels and timestamp details. Subsequently, the Arduino Nano processes the received data, executing predefined algorithms or logic to trigger appropriate actions or alerts based on the detected vibration patterns. By leveraging the NRF24L01 transceiver modules for wireless communication, the project ensures seamless and real-time transmission of sensor data from the sensor node to the receiver node. The below data is about the received signal data from the NRF24L01 transceiver.

Fig 5 Data Received at the Receiver End

At the receiver end, the transmitted data from the sensor node is received via another NRF24L01 transceiver module. This module acts as a receiver, capturing the wireless signals transmitted by the sensor node. Upon receiving the signals, the NRF24L01 module processes the data and forwards it to the receiving Arduino Nano microcontroller. The Arduino Nano then decodes the received data and interprets it according to predefined conditions and logic implemented in the receiver code. Once the data is processed, the Arduino Nano can trigger various actions based on the received information, such as activating an alerting mechanism or logging the data for further analysis. This seamless transmission and reception process ensures real-time monitoring and response to vibrations detected by the sensor node, contributing to the overall.

Conclusion

Overall, our proposed solution offers a robust and effective means of enhancing railway worker safety by addressing the shortcomings of existing train detection methods. By leveraging a portable, low-power system equipped with an attachable accelerometer, we can reliably detect train vibrations on the rails, providing timely alerts to workers in the vicinity. The use of a high-sensitivity accelerometer sensor, Arduino microcontroller, and NRF24 transceivers ensures a cost-effective, energy-efficient, and lightweight solution that can be easily deployed in various railway environments. With the ability to detect approaching trains from distances of 200 to 500 meters, our system offers ample time for workers to make critical decisions and take necessary precautions. The inclusion of an alerting actuator, such as a vibrator, ensures that workers receive immediate notifications upon train detection, minimizing the need for constant human intervention and reducing the risk of accidents. By maintaining a wireless communication link between the track monitoring sensor and the alerting system, our solution ensures reliable transmission of data, further enhancing worker safety. Ultimately, our goal is to provide railway workers with a comprehensive alerting system that offers timely and reliable notifications of approaching trains, thereby mitigating the risk of accidents and improving overall safety on the tracks.

Feature scope

The proposed wireless alerting system for railway worker safety integrates an attachable accelerometer sensor with an Arduino Uno microcontroller and NRF24 transceivers to detect train vibrations on rails from distances of 200 to 500 meters. Upon detection, the system activates a vibrator alerting actuator to notify nearby workers, ensuring timely response and reducing accidents. Designed for cost-effectiveness, energy efficiency, and portability, this system offers a comprehensive solution to address the limitations of existing methods, enhancing overall safety for railway workers.

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