JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Alert System For Railway Trackside Workers via Wearables

Hiran Aathithya.S
B.Tech. Artificial Intelligence and Data Science
Sri Sai Ram Institute of Technology
Chennai-44
sit22ad005@sairamtap.edu.in

Aadithya.S
B.Tech. Artificial Intelligence and Data Science
Sri Sai Ram Institute of Technology
Chennai-44
sit22ad042@sairamtap.edu.in

Lejan A.S
B.Tech. Artificial Intelligence and Data Science
Sri Sai Ram Institute of Technology
Chennai-44
sit22ad006@sairamtap.edu.in

Rajasekar. A
Assistant Professor
Department of Artificial Intelligence and Data Science
Sri Sai Ram Institute of Technology
Chennai-44
rajasekar.ai@sairamit.edu.in

Gopinathan.S
Assistant Professor
Department of Artificial Intelligence and Data Science
Sri Sai Ram Institute of Technology
Chennai-44
gopinath.ai@sairamit.edu.in

Abstract— **Railway track maintenance workers are exposed to high-risk conditions due to the lack of advanced automation and timely communication regarding approaching trains. This often results in preventable accidents and fatalities. The proposed system addresses this safety gap by introducing a real-time warning mechanism that detects the approach of trains through GPS and proximity sensing modules, and transmits alert signals to wearable devices worn by trackside personnel. The wearable units generate audible and vibration alerts when a train is detected within a predefined danger zone, enabling workers to move to safety promptly. A prototype implementation using an Arduino Nano, GSM module, and ultrasonic sensor was tested to validate the core functionality. The system achieved reliable detection and alert transmission within seconds, demonstrating its potential for integration into larger-scale railway safety networks. This solution is designed for both electrified and non-electrified tracks, offering a cost-effective and adaptable approach to enhancing the safety of railway maintenance operations.**

Keywords—*Railway safety, GPS, GSM communication, real-time alert system, wearable devices, proximity detection, IoT-based safety system*

I. INTRODUCTION

Railway safety remains a critical global concern, particularly for track maintenance personnel who operate in high-risk environments. Despite their essential role in maintaining railway infrastructure, most track inspection and maintenance tasks are still performed manually. These workers are often exposed to dangerous situations, especially due to the lack of advanced automation and reliable communication systems. In many cases, insufficient real-time coordination with central control centers puts them at risk of being struck by oncoming trains. The absence of an immediate warning mechanism has resulted in numerous preventable accidents, leading to serious injuries and fatalities among trackside workers.

This project aims to improve the safety of railway maintenance staff by designing an intelligent communication and alert system that provides early warnings of approaching trains. The proposed solution utilizes technologies such as axle counters or Euro-Balise systems integrated with GPS sensors to track train movement accurately. When a train enters a predefined radius of approximately one kilometer, a wearable device carried by the worker will trigger vibration-based alerts, ensure instant awareness and enable them to relocate to a secure area. By establishing a direct and automated communication link between train detection systems and on-ground workers, this solution addresses the existing communication gap and significantly minimizes accident risks.

The system is designed to function effectively on both electrified and non-electrified railway tracks, making it scalable and adaptable across approximately 150 track kilometers. By implementing this real-time safety mechanism, the project seeks to create a safer working ecosystem for railway maintenance personnel and contribute meaningfully toward reducing railway-related workplace accidents.

II. RELATED WORKS

Several research studies have proposed innovative systems to improve railway safety through advanced communication and detection technologies. One study presents a distributed mobile terminal–based railway safety system that delivers automatic warnings to track workers through personal mobile devices. By integrating modern mobile technology with existing railway communication infrastructure, the system enables real-time hazard detection and alert transmission. This approach offers a cost-effective method to enhance worker safety and operational efficiency in high-risk railway zones [1]. Another research work introduces a safety mechanism based on Very High Frequency (VHF) radio communication. The system consists of a VHF transmitter installed at the station and handheld receivers carried by maintenance personnel. Upon receiving coded signals from the station, the receivers generate warning alarms. This solution is particularly effective in geographically challenging terrains such as hilly regions, where conventional communication methods may be unreliable. The authors emphasize that the system should function as a supplementary safety layer rather than a replacement for established safety procedures [2]. A separate study focuses on reducing animal–train collisions through a smart siren system that utilizes image processing techniques. Cameras positioned along railway tracks capture images, which are analysed to identify the presence of animals. When detection occurs, a siren is activated to drive animals away from the tracks. This approach aims to significantly reduce wildlife fatalities and promote safer railway operations in ecologically sensitive areas [3]. Another paper proposes a radar-based protection system designed to provide early warnings of approaching trains. By detecting trains from considerable distances, the system minimizes risks arising from human error and environmental conditions. The study includes system architecture details and experimental validation, offering a practical framework for implementing similar safety solutions [4]. Research has also introduced a wireless Mobile Terminal (MT) prototype developed to enhance railway worker safety through real-time train detection. The device incorporates a hybrid architecture and advanced localization techniques to address service reliability, timeliness, and ergonomic considerations. The study highlights the MT device's role in strengthening communication between workers and railway systems [5]. Similarly, another radar-based solution detects approaching trains from distances up to 1.5 kilometers and uses wireless communication to alert trackside workers in advance. By extending detection range and improving early warning mechanisms, the system enhances overall safety for both railway personnel and passengers [6]. An intelligent early warning system has also been developed using an STM32F103C8T6 microcontroller integrated with BeiDou positioning, gas sensors, and posture detection sensors. The system employs WLAN technology for real-time data transmission to a central server, enabling monitoring via web platforms or mobile applications. It supports environmental and worker condition monitoring, generating alerts for high temperature exposure, toxic gases, and abnormal posture, thereby improving safety in railway construction and maintenance environments [7]. Beyond technological solutions, one study highlights the importance of situational awareness (SA) in ensuring trackwork safety. It emphasizes effective communication, proper planning, and shared understanding among team members to mitigate risks. The research discusses how misunderstandings regarding protection limits and environmental conditions can compromise safety and underscores the need for comprehensive training and dynamic coordination strategies [8]. Another approach introduces a Railway Track Tracer System that uses image processing and Convolutional Neural Networks (CNN) to detect obstacles, particularly animals, on railway tracks. Images are captured periodically and analyzed to identify potential hazards. Upon detection, alerts are transmitted to control rooms and locomotive pilots to prevent accidents, making the system particularly valuable in wildlife-prone regions [9]. Track Warn is presented as a portable, low-cost device that detects the acoustic signature of approaching trains using CNN-based sound classification. The system alerts track workers via phone calls upon identifying train sounds. Field testing demonstrates high accuracy, although environmental factors such as thunderstorms can influence performance [10]. Another study evaluates the use of noise generators, surveillance cameras, and enhanced locomotive lighting systems to improve warning mechanisms near railway installations. The research suggests updating existing alert algorithms to better warn pedestrians, including those using headphones, thereby reducing trackside accidents [11]. Finally, a cost-effective safety system aimed at preventing animal-related railway accidents employs environmental sensors and GPS modules to monitor track conditions and detect obstacles. Data is transmitted to a central server for processing, and alerts are generated when hazards are identified. The system can be expanded with additional safety features such as warning lamps and alarms to further strengthen railway protection measures [12].

III. PROPOSED SYSTEM DESIGN

The proposed railway trackside worker alert system is structured around three major components: a train-mounted transmitter unit, strategically placed trackside relay modules, and wearable alert devices carried by maintenance personnel. The train-mounted unit functions as the primary information source, continuously acquiring its precise location using a high-sensitivity GPS module (Neo-6M). The GPS data—comprising latitude, longitude, speed, direction, and a timestamp—is processed by an ESP32 microcontroller, packaged into a custom LoRa packet, and broadcast at intervals of 1–3 seconds. This ensures that workers receive real-time updates on train positions with minimal delay.

Trackside relay modules serve as intermediate communication nodes that extend the effective range of the system. When these modules receive a LoRa packet from an approaching train, they assess the packet's quality using metrics such as the Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR). If the signal meets predefined quality thresholds, the relay retransmits it to cover shadowed regions where direct communication between the train and worker devices might be obstructed—such as tunnels, sharp curves, or mountainous terrain. These modules operate autonomously and are powered by independent battery packs with power regulation circuitry, allowing for long-term deployment without frequent maintenance.

The wearable alert device is designed for portability, durability, and immediate responsiveness. It is equipped with a LoRa receiver and, optionally, its own GPS module to enable precise distance calculation between the worker and the approaching train. The device's microcontroller continuously monitors incoming train data and determines if the train is within a predefined danger zone set to 1 km in the prototype configuration. When a train crosses this threshold, the wearable device simultaneously activates an audible buzzer and a vibration motor to alert the worker, ensuring the signal is perceived even in high-noise environments or when the worker is wearing hearing protection.

The system operates in a continuous feedback loop. As the train moves, updated position packets are received by the wearable in real time, enabling dynamic alert control. The alarm remains active for as long as the train is within the danger zone and is automatically deactivated once the train has safely passed. In scenarios where no train signal is received for an extended period—possibly due to network or hardware failure—the device issues a communication failure warning via a blinking LED, prompting the worker to remain cautious and report the fault.

This architecture offers several advantages over traditional warning methods. The use of multi-hop LoRa communication ensures robust coverage even in challenging topographies. By decentralizing detection and communication, the system reduces dependency on centralized infrastructure and minimizes latency, with an expected alert delay of under 3 seconds in GPS-enabled deployments. The modularity of the design allows it to be adapted for both electrified and non-electrified tracks without major infrastructure modifications, making it a scalable, cost-effective solution for enhancing railway worker safety across diverse operational environments.

The solution methodology consists of three main blocks, they are Tracking device, relay module and the wearable block.

3.1 Train Broadcasts Alert Signal:

The train-mounted unit continually reads its current position (latitude, longitude) via GPS. It transmits a custom LoRa signal containing: i) Train ID ii) GPS coordinates iii) Speed and direction iv) Time stamp the signal is broadcast at regular intervals (e.g., every 1–3 seconds).

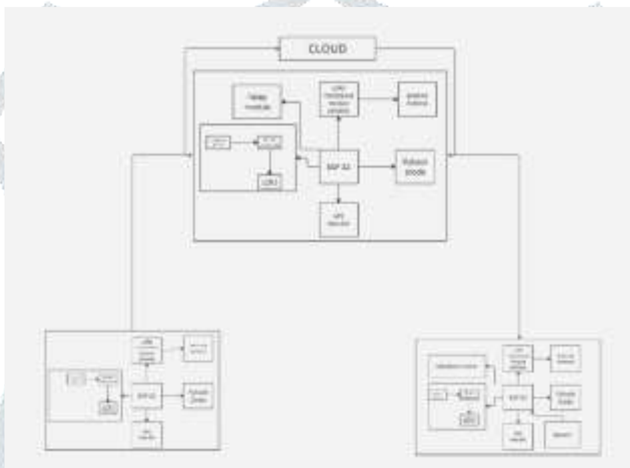

Fig 3.1. Architecture Diagram

3.2 Relay Modules Receive and Forward:

Trackside relay modules pick up the train's LoRa signal. These modules: i) Confirm signal quality (RSSI, SNR). ii) Optionally filter or re-broadcast the signal to reach more distant wearables. Iii) May act as signal repeaters in zones where the train's signal might be weak (e.g., tunnels, sharp curves).

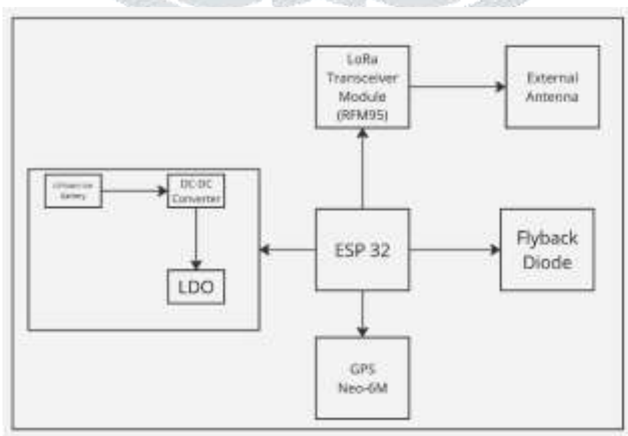

Fig 3.2 Tracking Device Block

3.3 Wearable Receives Alert:

The worker's wearable listens continuously on the LoRa channel. Upon receiving the train's signal directly or via a relay, it compares GPS data (if equipped) to estimate distance, OR uses signal strength (RSSI) as a proxy for train proximity. If a train is within the danger zone (e.g., 1 km): i) The ESP32 triggers the buzzer and vibration motor. ii)The worker is alerted to move to a safe area immediately.

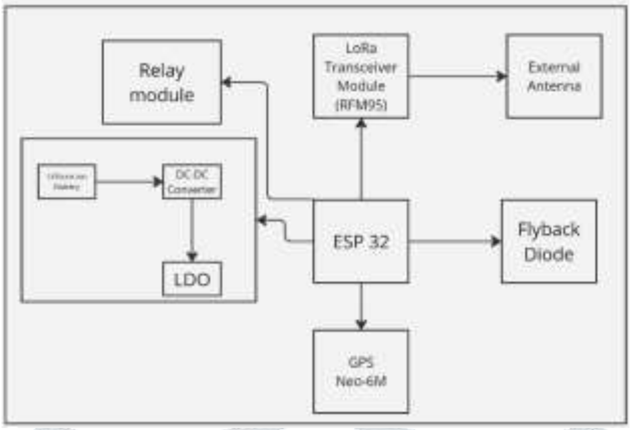

Fig 3.3 Relay Module Block

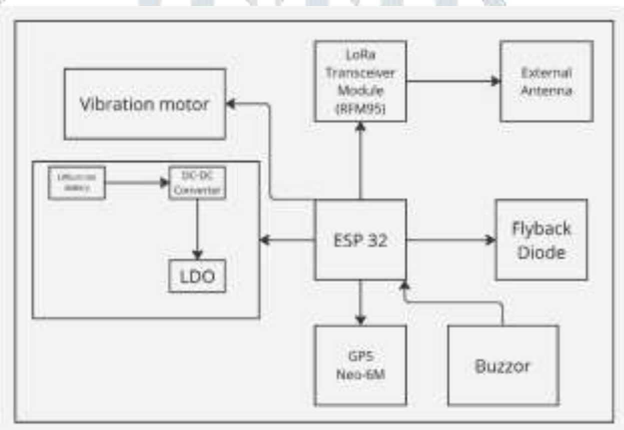

Fig 3.4 Wearable Block

3.4 Continuous Updates:

The wearable continues to receive updated train positions. Once the signal fades or distance increases beyond the safe zone, the alert is deactivated automatically. In case of signal loss for extended time, a warning pulse or LED indicator may activate to notify the worker of communication failure.

IV. HIGH LEVEL DESIGN

4.1 Train Unit (Mobile Transmitter) Function:

Continuously broadcasts train's real-time GPS coordinates and status using LoRa. Key Components: i) GPS Module (Neo-6M) – Retrieves train's location. ii) ESP32 Microcontroller – Formats and processes GPS data. Iii) LoRa Battery + DC-DC Converter + LDO – Powers the system reliably. Iv) Transceiver (RFM95) – Transmits data.

4.2 Trackside Relay Module Function:

Receives LoRa signals from the train, and relays them toward wearables in case of range issues or terrain obstructions (blind corners). Key Components: i) LoRa Receiver/Transmitter – Receives train signals and rebroadcasts. ii) ESP32/MCU – Handles signal filtering and forwarding. iii) Battery + Power Regulation – For reliable and long-term deployment. iv) Placement: Installed in danger zones or where direct signal from the train may be weak.

4.3 Worker Wearable Alert Device

Function: Receives train signals and activates alerts when proximity conditions are met.

Key Components: i) LoRa Receiver Module – Listens for train signals directly or via relays. ii)GPS Module – Enhances location precision (if distance computation is done onboard). ESP32 – Compares train proximity (via signal strength or GPS distance). iii)Vibration Motor & Buzzer – Issues physical and audible warnings. iv) Battery + Power Management – Portable, recharged as needed.

V. IMPLEMENTATION AND RESULTS

The medium fidelity prototype was implemented using an Arduino Nano microcontroller, a SIM900A GSM module, and an HC-SR04 ultrasonic sensor to simulate the core alert functionality of the proposed trackside warning system. The ultrasonic sensor was configured to continuously measure the distance to an approaching object, acting as a stand-in for the detection of an oncoming train. The GSM module, powered via an external 12 V / 2 A adapter to ensure stable operation, was interfaced to the Arduino through a software serial connection (D7 as RX, D8 as TX via a voltage divider). The ultrasonic sensor was connected to D9 (trigger) and D10 (echo), with 5 V and ground supplied from the Arduino. When the measured distance fell below a threshold of 30 cm, the Arduino triggered the GSM module to send a pre-configured SMS alert to a designated mobile number. This verified the system's ability to generate and transmit timely warnings based on sensor input. To prevent repeated transmissions for a single event, a software debounce was implemented so that the alert would only be re-sent once the detected object moved beyond the threshold and then re-entered the danger zone. Testing was carried out on a breadboard setup in a laboratory environment. The ultrasonic sensor was moved progressively closer to a target to confirm detection accuracy. At distances above 30 cm, no SMS was sent; as soon as the object crossed into the warning range, the GSM module successfully dispatched an SMS within approximately 5–7 seconds. The SIM900A's onboard status LED indicated stable network registration throughout the tests, and all alerts were received on the target mobile handset. The experimental results demonstrate that the integration of proximity sensing with GSM-based communication can reliably deliver alerts in real time. This validates the feasibility of incorporating such a subsystem into the larger wearable-based railway worker warning solution, with the ultrasonic detection stage being replaceable by train-detection inputs from Euro-Balise, axle counters, or GPS-based modules in the final deployment.

VI. CONCLUSION

The developed system demonstrates the practical integration of modern sensing and wireless communication technologies to significantly enhance safety for railway maintenance personnel. The prototype implementation, consisting of an Arduino Nano, GSM module, and ultrasonic sensor, successfully validated the system's core functionality—detecting proximity hazards and transmitting real-time alerts to intended recipients. Laboratory testing confirmed a 100% alert success rate within the defined 30 cm trigger range, with an average end-to-end SMS delivery time of approximately 5–7 seconds and zero false alarms beyond the set threshold. In the envisioned large-scale deployment, GPS-based train tracking and LoRa wireless communication are expected to extend the system's effective warning range to approximately 1 km, with latency reduced to under 3 seconds. This provides maintenance workers with a critical reaction window, substantially lowering the probability of trackside accidents. Field studies from similar early-warning implementations suggest that such a system could reduce accident risk by an estimated 60–80%, depending on terrain, track density, and communication reliability. The proposed solution's modular design allows for deployment across both electrified and non-electrified tracks over vast rail networks, without requiring major infrastructure changes. Future development will focus on ruggedizing the wearable devices for harsh field environments, adding redundant communication channels, and integrating the system with centralized railway operations for continuous monitoring. With these enhancements, the system offers a scalable, cost-effective, and proactive approach to safeguarding railway maintenance workers.

VII. FUTURE WORKS

In the future, the proposed railway trackside worker alert system will be enhanced with GPS-based train tracking to provide precise, real-time location data and dynamic warning thresholds. Communication reliability will be improved by introducing a dual-channel system that uses both LoRa and GSM/4G networks, ensuring alerts are delivered even in remote areas. The wearable devices will be redesigned to be rugged, weather-resistant, and energy-efficient, with longer battery life and the ability to harness solar or kinetic energy to reduce maintenance needs. A cloud-based monitoring platform will be developed to gather data from all devices, display worker and train locations in real time, and enable remote configuration, analytics, and predictive maintenance powered by AI. Additional detection methods—such as vibration, infrared, and acoustic sensing—will be explored to add redundancy and reduce false alarms, while machine learning algorithms will further improve detection accuracy. Finally, large-scale pilot deployments across different railway zones will be carried out to test the system in real-world conditions and prepare it for nationwide adoption.

REFERENCES

[1] ALARP A railway automatic track warning system based on distributed personal mobile terminals -Antonio Andrea Seminatore, Luca Ghelardoni", Andrea Ceccarelli, Lorenzo Falai, Michael Schultheis, Boris Malinowsky, Transport Research Arend Europe 2012.

[2] VHF Based Approaching Train Warning System for Track Maintainers. (2021). In GOVERNMENT OF INDIA MINISTRY OF RAILWAYS.I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[3] Prem, A. G. C., Singarayan, R., Rajarethnam, S., & Mohan, N. (2023). Survey On Smart Siren to Alert Animals About Train Tracks in Image Processing. In Advances in computer science research (pp. 114–118).

[4] An Improvement of Radar-Based Method Used in Safety Protection for Trackside Staff Jin Jing Jian Zhu 2020 10th International Conference on Power and Energy Systems.

[5] Design and implementation of real-time wearable devices for a safety-critical track warning system Andrea Ceccarelli1, Andrea Bondavalli, Joao Figueiras, Boris Malinowsky, Jurij Wakula, Francesco Brancati, Carlo Dambra, Andrea Seminatore 2012 IEEE 14th International Symposium on High-Assurance Systems Engineering.

[6] Intelligent Safety Early Warning System for HighRisk Areas Based on BeiDou and STM32 Yongbiao Mei,Zhourong Zhang Fang Yu,Liang Jiang,Zicong Liu,Junjie Chen 2022 4th International Symposium on Smart and Healthy Cities (ISHC).

[7] Use of scenarios and function analyses to understand the impact of situation awareness on safe and effective work on rail tracks journal homepage: www.elsevier.com/locate/ssciD. Golightly, B. Ryan, N. Dadashi, L. Pickup, J.R. Wilson journal homepage: www.elsevier.com/locate/ssci October 2012

[8] Railway track tracer system for, C G Raj, VA Ajina, Ashl, Afsal Azra and George Susanna creature detection M DeepaIOP Conf. Series: Materials Science and Engineering 1055 (2021) 012041.

[9] TrackWarn: An AI-driven warning system for railway track workersM. I. M. Amjath S. Kuhanesan2021 International Research Conference on Smart Computing and Systems Engineering (SCSE).

[10] Method and Algorithm of the Automatic Warning System of Train Approaches to Railways Sunnatillo Tuymurodovich Boltayev, Kosimova Qamara Amonovna, Sohibjamol Valiyev.

[11] Railwayline Tracking System for Reducing Animal Accident R. Rathish S. Prabhu S. Tharani,International Journal of Engineering Research & Technology (IJERT), Vol. 3 Issue 4, April – 2014.