

Leveraging RFID for Road Safety Sign Detection to Enhance Efficiency and Notify Drivers [†]

Dhanasekar Ravikumar *, Vijayaraja Loganathan , Pranav Ponnovian *, Vignesh Loganathan and Bharanidharan Sivalingam

Department of Electrical and Electronics Engineering, Sri Sairam Institute of Technology, Chennai 600044, Tamilnadu, India; vijayaraja.eee@sairamit.edu.in (V.L.); sit22ee033@sairamtap.edu.in (V.L.); sit22ee012@sairamtap.edu.in (B.S.)

* Correspondence: dhanasekar.eee@sairamit.edu.in (D.R.); sit22ee058@sairamtap.edu.in (P.P.)

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Abstract: Road safety signboards are now difficult to see due to pollution and harsh weather elements such as snow and fog, which has resulted in more accidents. The problem is especially common in Western countries where snow can block these critical signs. An approach addressing this issue involves a system that uses Radio Frequency Identification (RFID) and Internet of Things (IoT). The real-time alerts that this system sends to drivers improve driver safety in complex environments. For this purpose, an RFID reader is placed in the vehicle, and passive RFID tags are attached to road safety signboards. The reader picks up the signal as a vehicle comes within range, and the warning for the vehicle is sent to the driver. It helps to reduce the number of accidents resulting from poor visibility. In addition, because its multi-lingual audio alerts the drive through speakers and visual warnings displayed on a display screen, the system is accessible to drivers from various regions. To make the system more sustainable, we added some solar panels to the system to cut costs as far as energy efficiency is concerned. The system combines GPS and GSM modules to provide the vehicle position in real time in the cloud. It gives better warnings and helps avoid accidents. In addition to improving road safety, the system offers support for the environment, by limiting emissions and waste of resources caused by accidents. Traffic patterns can thus be studied with the data, creating more efficient and ecofriendly transportation systems. This solution enables a smarter vehicle network that is safer and more sustainable with quick, accurate alerts.



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1. Introduction

Road accidents are a leading cause of global fatalities, with over 1.19 million deaths annually, according to the World Health Organization [1]. The inability of current systems to recognize and detect road safety signs raises a critical challenge to road safety [2]. This paper proposes an RFID-based system for in-vehicle detection of road safety signboards. The system employs the M7E-TERA-CB RFID reader to achieve high accuracy at elevated speeds. Critical flaws in existing solutions, such as variable message signs (VMSs), include their inefficacy in shaping driver behavior due to distracting non-critical information and poor integration with vehicle-to-everything (V2X) technologies [3]. Field studies in rapidly developing regions demonstrate negligible improvements in speed compliance or lane discipline despite costly infrastructure upgrades [4], while experimental flashing VMS

designs degrade driver performance in high-cognitive-load scenarios like heavy traffic [5]. Existing machine learning methods for traffic sign recognition also face limitations. Synthetic dataset-trained models struggle with real-world domain gaps in extreme weather, rendering them unsuitable for dynamic environments [6]. Multi-task frameworks achieve high accuracy but are computationally inefficient and geographically restricted, limiting adaptability to diverse urban settings [7]. Similarly, highway-optimized detection systems prioritize speed but neglect multi-lingual text extraction and weather resilience [8]. The proposed system ensures reliability across all weather conditions, overcoming these gaps. Vision-based approaches like YOLO work well at low speeds but fail at higher speeds and when signs are obstructed [9]. The approach is towards everyday traffic situations and the recovery from congestion [10]; a similar approach can be used for the proposed system. The contributions of this paper are given as RFID technology, which brings substantial benefits to the realm of road safety sign detection for improving traffic management and awareness among drivers. Real-time identification and surveillance of road signs mean the system rapidly recognizes signs near safety zones. It improves road safety, since timely notification enables drivers to react efficiently; at the same time, traffic management system effectiveness is increased due to the automation involved in sign detection and data acquisition. On the whole, RFID integration increases the efficiency of safety measures and the level of driving comfort. The organization of this paper is as follows: Section 2 describes the proposed system, Section 3 demonstrates the simulation of the proposed system, Section 4 outlines the hardware setup and real-world testing of the proposed system, and Section 5 highlights the conclusion and future scope.

2. The Proposed System

The M7E-TERA-CB RFID reader module fulfills the requirements for in-vehicle road safety sign detections. Table 1 presents the main characteristics of the M7E-TERA-CB RFID reader module with frequency range, read range, and power consumption data. The device operates effectively in speeding operations while monitoring traffic conduct at 100 km/h during real-time operations. The cost of the UHF passive tag is ₹20/piece, making the system cost effective.

Table 1. RFID sensor specifications.

Parameter	Specification
Frequency Range	865–928 MHz (UHF)
Protocols Supported	EPCglobal Gen 2 (ISO 18000-6C), ISO 18000-6B [11]
Read Range	Up to 7 m (depending on antenna and tag)
Read Rate	Up to 750 tags per second
Write Range	Up to 5 m
Power Supply	3.3 V DC
Power Consumption	Idle: 100 mW, Active: 1.5 W (typical)
Interface	TTL UART, 4 GPIO pins, 2 MMCX antenna ports

An illustration of the block diagram of the proposed invention is shown in Figure 1. The integration of ultra-high-frequency passive tags (UHF) to conventional signboards proves to be an affordable and sustainable solution. Because tags remain cheap and small in size, they serve as efficient options for wide implementation. The system leverages modern RFID technology for real-time interaction between vehicles and broadcasts updates about different alerts and road situations. The LCD provides a quick notification to the driver of dangers, highlighting vital information visually in the time frame. The speaker's output is also part of the system to generate acoustic alerts, which can improve and help in a safe way for a better situation.

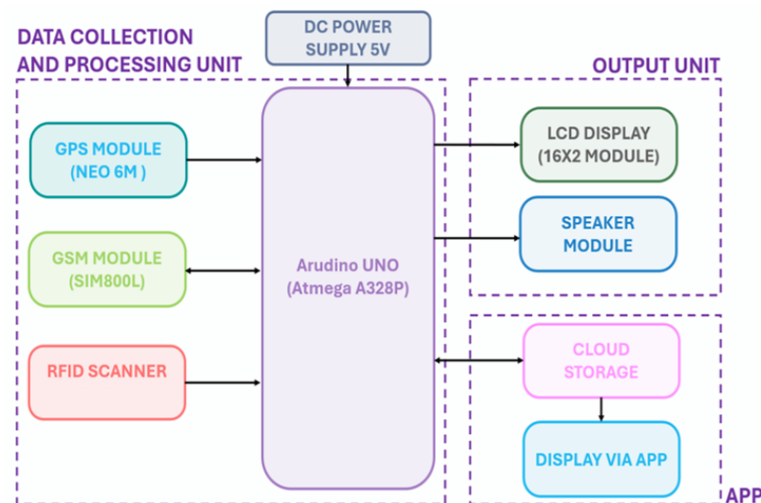


Figure 1. Block diagram of the proposed invention.

In order to improve the global positioning of vehicles, Specialized GPS (Global Positioning System) and GSM (Global System for Mobile Communication) modules are integrated into the device. This enables real-time tracking of the vehicle's location, which allows for more accurate map data in urban areas, but its functionalities in rural and forest areas remain limited. The NEO-M8N board features functionality to address weak signal regions by expanding the NEO-M8 module to support GPS, GLONASS, and Galileo constellation in the NEO-M8N GNSS component. The usage of a multi-constellation approach ensures better signal availability and higher accuracy in difficult environments. The system additionally includes dead reckoning technology and offline maps to operate in the absence of satellite signals for some time.

A cloud database containing the latest information about traffic signs is present in the system. If road authorities change traffic signs (obsolete maintenance or modifications), the change is stored in the cloud database. This database is constantly synced to the system to guarantee the most recent information, and real-time updates regarding road conditions and potential risks with the system will serve to make vehicular management and security a lot better. With the integration of RFID, GPS, and GSM technologies, the integration of them will help in the modernization of road infrastructures and vehicular communication systems as the integrated comprehensive solution. This completely explains the strategy drivers adhere to in order to drive safely in such a situation and also helps in reducing the total number of accidents.

3. Simulation of the Proposed Solution

The suggested system has been simulated in Proteus, one of the most powerful softwares for designing and testing electronic circuits. The schematic was connected one-by-one to define it on the processing unit, which was Arduino withan Atmega 328p microcontroller. This microcontroller is the brain of the system, coordinating the myriad inputs and outputs. Then, to form the location module, a part of the integration was done between the GSM and GPS modules, which are essential components for real-time tracking and communication with Arduino. The output of the location module can be viewed through the virtual terminal in Proteus. The virtual terminal provides data about the system under simulator conditions. The location module provides latitude and longitude data accurately; thus, the information is easy to read and accessible with the GPS module. It serves it up on a virtual terminal. Further, this data will be used for traffic analysis, which helps the user understand the patterns to make informed decisions. The system allows tracking of location in real time; hence, it is easier to monitor vehicles, pedestrians, and all

other objects, providing insight into the flow and congestion of traffic. The data can also be logged for future analysis to optimize routes and reduce travel time.

An I2C module will simplify the wiring, and the communication process allows for data transmission and reception in the most crowded conditions between LCD and Arduino. Hence, the I2C module makes the system more compact and convenient. Also, the I2C protocol ensures that the system is energy efficient, as it reduces the number of wires needed for communication. An LCD display shows real-time location data visually, ensuring that users can interpret the information easily.

Figure 2 shows the schematic diagram of the simulation: The schematic representation of interfacing all parts together is necessary for understanding the configuration of the system and identifying problems that need to be addressed at the time of implementation. From detailed testing to instant presentation, all of these take place in the software beforehand. Such an approach ensures that the system is robust, stable, and ready for applications in real life. Moreover, it helps in early detection of possible issues, thereby preventing costly mistakes at the time of physical implementation. As a result, the location tracking and alert system will be much more effective in general, providing consistent and timely data if implemented in the field.

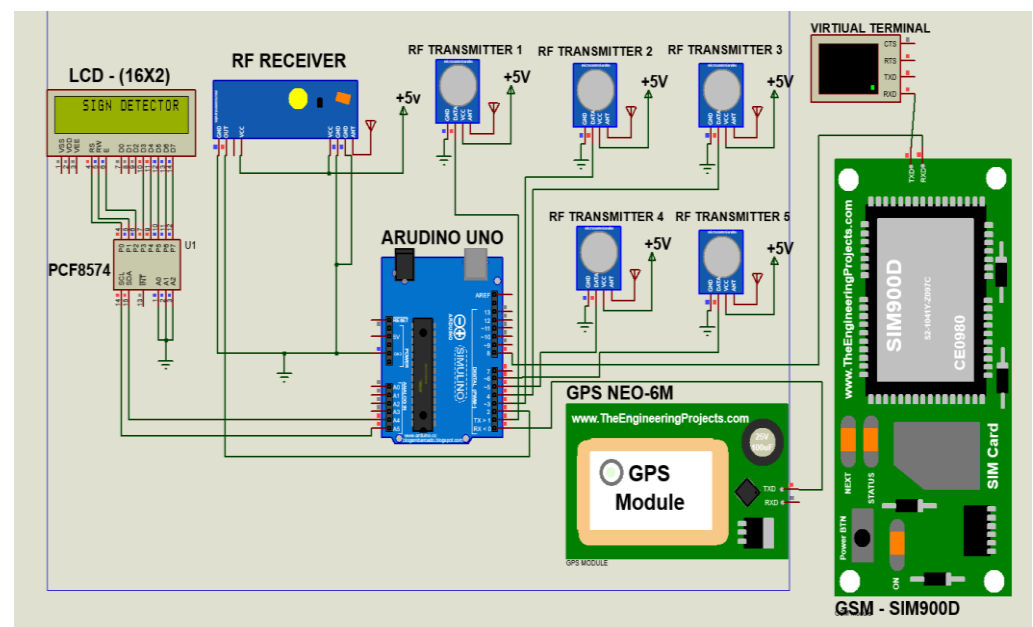


Figure 2. Simulation result—schematic representation of output.

Five tags in total are included in the simulation results. Each tag's output is shown on the liquid crystal display. The output for the different warnings is shown in the simulation results from Figures 3–5.

The UNO is the processing unit; it powers the required sensors including the GPS, GSM, RFID, and LCD display. In Figure 3, Transmitter 1 is powered, and it transmits the encoded data which is burned into it to the receiver, where the message is decoded, and the output is seen in the display as "SCHOOL ZONE". The output for the location module can be seen through the virtual terminal.

In Figure 4a, Transmitter 2 is powered, and it transmits the encoded data which is burned into it to the receiver, where the message is decoded, and the output is seen in the display as "SLIPPERY ROAD". The output for the location module can be seen through the virtual terminal.

In Figure 4b, Transmitter 3 is powered, and it transmits the encoded data which is burned into it to the receiver, where the message is decoded, and the output is seen in the

display as “NARROW ROAD”. The output for the location module can be seen through the virtual terminal.

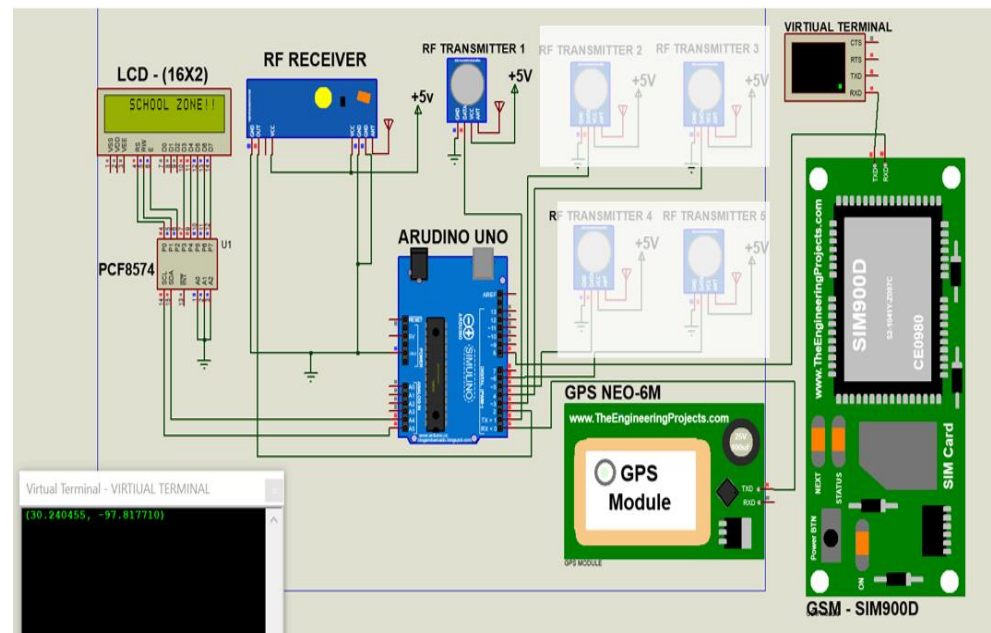


Figure 3. Simulation result for school zone signboard.

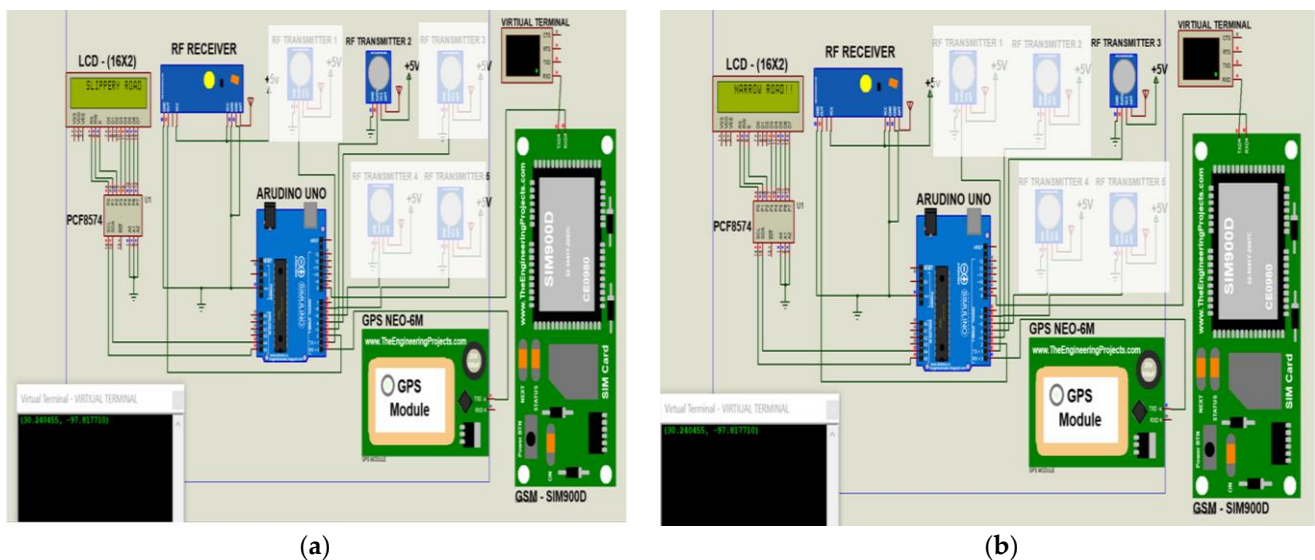


Figure 4. (a) Simulation result for slippery road signboard; (b) Simulation result for narrow road signboard.

In Figure 5a, Transmitter 4 is powered, and it transmits the encoded data which is burned into it to the receiver, where the message is decoded, and the output is seen in the display as “NO U-TURN”. The output for the location module can be seen through the virtual terminal. In Figure 5b, Transmitter 5 is powered, and it transmits the encoded data which is burned into it to the receiver, where the message is decoded, and the output is seen in the display as “GO SLOW”. The output for the location module can be seen through the virtual terminal.

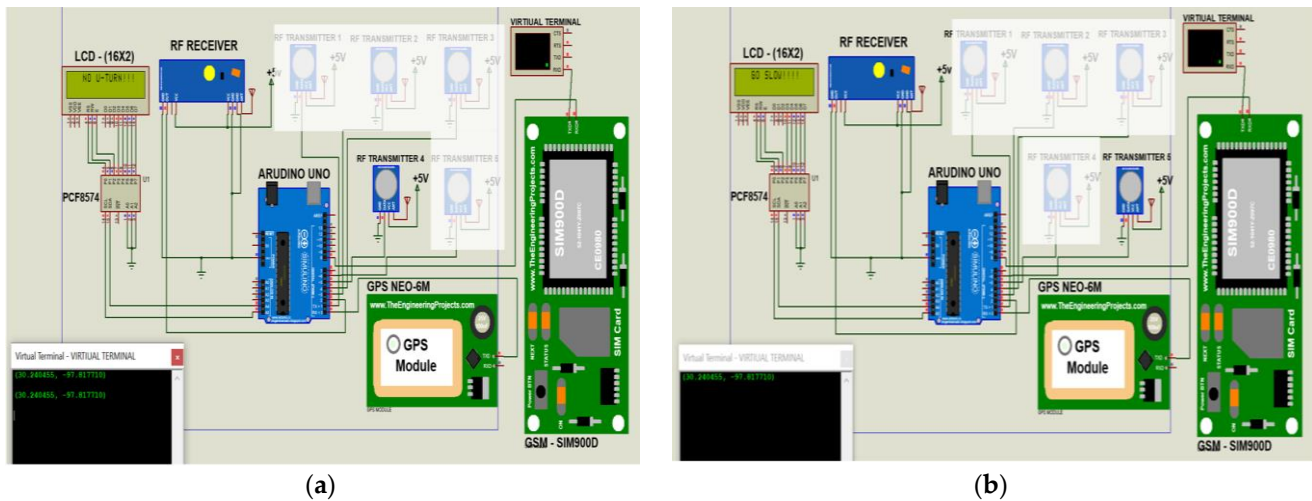


Figure 5. (a) Simulation result for no U-turn signboard; (b) Simulation result for go slow signboard.

4. Hardware Setup for the Proposed System and Real-World Testing

A scaled down prototype of the proposed system is depicted in Figure 6; it is presented with its integration of RFID technology with IoT enhanced GPS and GSM modules for sensing and alerting the driver about the road signs in real time. The RC522 reader module was replaced with M7E-TERA-CB RFID during real-world testing; this is a passive UHF RFID reader, which scans with passive UHF RFID tags integrated into road safety signboards. It has a claimed operating frequency of 865–928 MHz with maximum read range of up to 7 m and is suitable for high-speed applications.

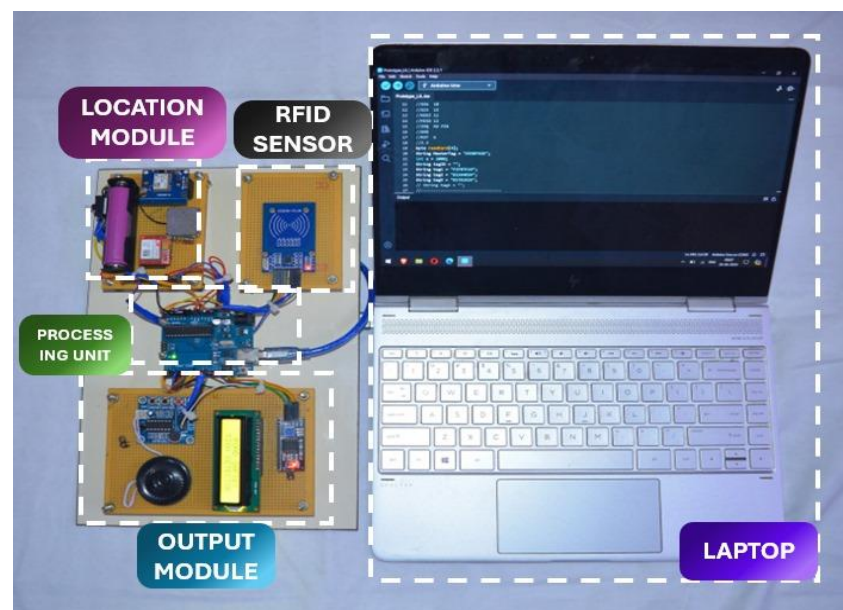


Figure 6. Scaled down prototype of the proposed invention.

The processing unit is the Arduino UNO, which has the Atmega328p microcontroller, which is interfaced with the RFID reader, GPS, 3G, etc. It has a flash memory of 32 Kilo BITS and runs at 16 MHz of clock speed; hence, it achieves real-time data processing and communication of functional units. With the GPS module, we receive real-time vehicle location updates, and the GSM module makes cloud connectivity possible for dynamic updates and alerts. The key in enabling the functionality of the system under diverse environments lies in these modules. To alert the driver, the system integrates an LCD display and speaker. The audio output is universal and multi-lingual, and the visual

display improves driver awareness. Power is provided from a 5V DC power supply either from the auxiliary battery or engine. The installation of solar panels exists to boost energy efficiency and sustainability. Figure 7 illustrates the flowchart of the system of the proposed invention. Figure 8 demonstrates the component description of the scaled down prototype, and the components are listed in Table 2.

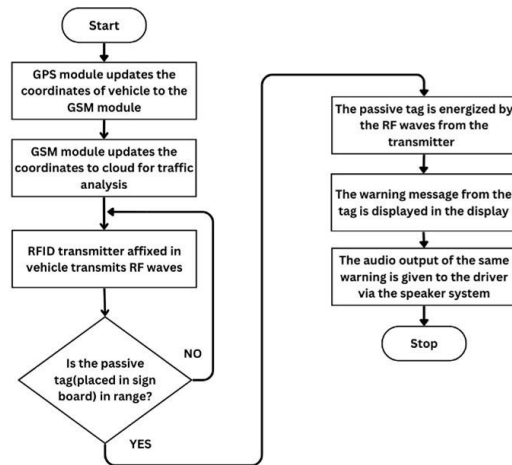


Figure 7. Flowchart for the proposed invention.

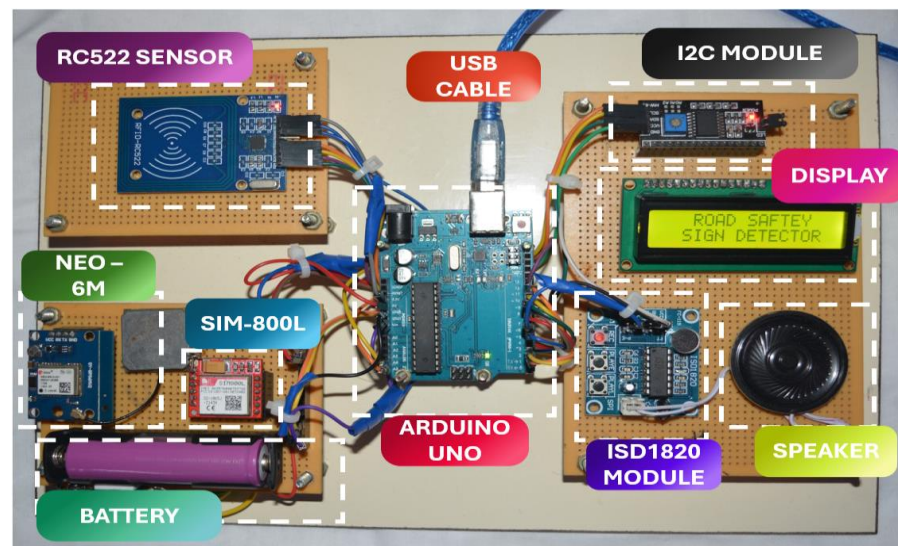


Figure 8. Component description of the scaled down prototype.

Table 2. Component description of hardware.

Component Name	Component Description
Arduino UNO	Processing unit
RC522 (3.3 V) and M7E-TERA-CB	RFID sensor
LCD 16X2	Liquid crystal display
I2C	I2C module
ISD1820	Speaker module
Speaker (0.5 Watt)	Audio output
NEO-6M	GPS module
SIM-800L	GSM module
Battery (7800 mAh)	Lithium-ion battery

Extensive real-world testing across a variety of weather conditions—from clear, rain, fog, and dense fog to speeds of 0–100 km/h across urban, rural, and tunnel

environments—was used to validate the system’s performance. Figure 9 represents the real-time testing of the proposed system with the M7E-TERA-CB sensor. All data was logged through a Raspberry Pi 4 taking in detection events, response times, and GPS coordinates. Tags were placed at 10 m intervals along prescribed routes, and each testing scenario is evaluated over 10 trials. In particular, the system obtained 98% accuracy under clear weather, with robust baseline performance. However, in moderate rain (25 mm/h), signal attenuation and a decrease in accuracy to 95% were observed; in dense fog (visibility < 50 m) accuracy decreased further to 85% as shown in Figure 10. The challenges encountered in fog included a 4.2% false positive rate (due to signal reflections) and a 10.8% missed detection rate due to signal degradation from the tags. Accuracy as a function of speed is shown in Figure 10 and decreases from 97% at 30 km/h to 88% at 100 km/h, though mostly due to read range limitations of less than 15 m. In rural environments, the accuracy achieved through environmental testing was 96%, while in urban zones (affected by RF interference from buildings), it was 92%, and in tunnels (GPS denied condition), 89%.



Figure 9. Real-time testing of the proposed system with the M7E-TERA-CB sensor.

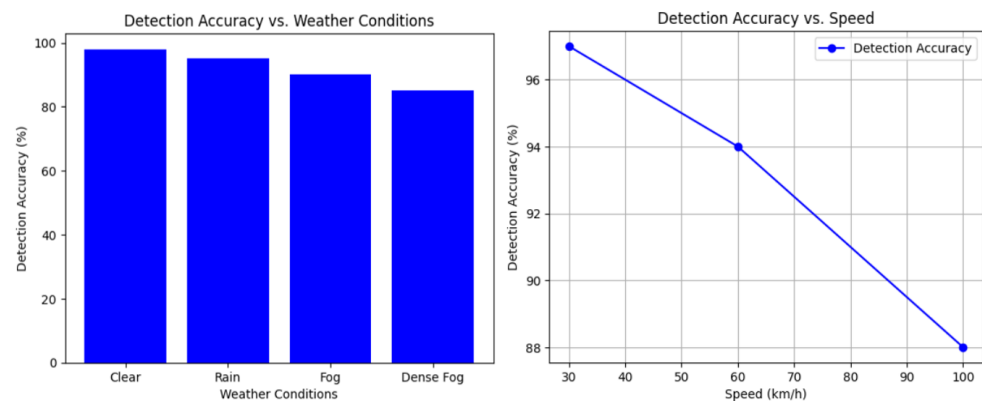


Figure 10. The accuracy rates for different weather conditions and different speeds.

Evaluation was also performed at various speeds. Figure 11 represents the response time for different weather conditions and different speeds. The detection accuracy dropped from 97% to 88% at 100 km/h, indicating that there was a need to reduce the system response time and increase the read range especially for high-speed applications. System performance was, however, affected by environmental factors. In rural areas, the system performed best, at 96%; it also faced difficulties in urban areas (92%) and in tunnels (89%). Finally, the results highlight the importance of interference and GPS-denied zones.

The system counters errors by incorporating redundancy through multi-lingual audio warnings and visual displays, ensuring timely driver alerts even when detection accuracy fluctuates. Dynamic power adjustments in fog conditions enhance the detection range by increasing transmit power from 1 W to 2 W, improving performance by 18%. While the RFID system outperforms AI-based methods like YOLO in low-visibility scenarios

such as fog and rain, achieving 85% accuracy compared to YOLO's 62%, it slightly lags in high-speed scenarios with 88% accuracy versus YOLO's 90% at 30 km/h. To address current limitations, advanced antenna designs and signal-filtering techniques are being implemented to mitigate urban RF interference, while inertial navigation systems are under development to supplement GPS in tunnels and other denied zones. Real-time latency, averaging 0.8 s, is being reduced through code optimization and edge computing to support speeds exceeding 120 km/h. Future work will integrate hybrid AI-RFID fusion, combining YOLO's high-speed precision with RFID's weather resilience, to further minimize false positives (4.2%) and missed detections (10.8%) in dense fog and high-speed scenarios. These refinements aim to create a unified solution for diverse conditions while maintaining the system's redundancy-driven safety guarantees.

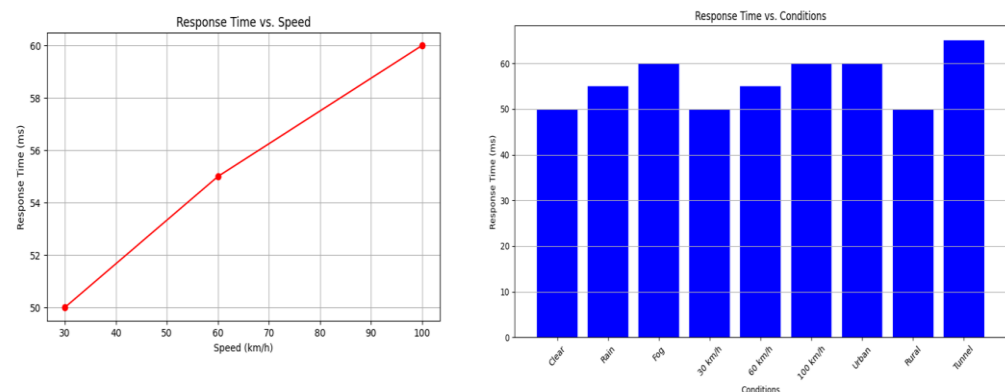


Figure 11. The response time in different weather conditions and at different speeds.

5. Conclusions and Future Scope

The proposed RFID system demonstrates significant potential to enhance road safety through real-time detection of road signs and multi-lingual driver alerts. Achieving 98% accuracy in clear weather, 95% in rain, and 85% in dense fog, the system outperforms AI-based methods like YOLO, which drops to 62% accuracy in fog, while maintaining competitive performance at high speeds with 88% accuracy at 100 km/h compared to YOLO's 90% at 30 km/h. Environmental testing reveals robust rural performance at 96% accuracy but also reveals challenges in urban areas and tunnels due to RF interference and GPS-denied conditions, yielding 92% and 89% accuracy, respectively. Unlike vision-dependent AI systems, RFID avoids occlusion issues in poor weather but faces read-range limitations at high speeds and susceptibility to urban signal noise. Deployment challenges include scalability due to infrastructure costs for large-scale RFID tag installation, interference mitigation in dense urban environments, and GPS dependency in tunnels requiring supplemental inertial navigation.

Multi-lingual audio alerts integrated with visual displays are provided to drivers in a timely manner; hence, they will be warned in time and in a way that they can comprehend, thereby preventing accidents due to drivers' poor visibility. Solar panels are utilized to enhance the system's energy efficiency and environmental sustainability. Additionally, the system includes GPS and GSM modules for real-time updates and maps, thereby utilizing modern transportation systems. Hence, the use of M7E-TERA-CB has proven to be efficient with speeds up to 100 km/h with response times being less than 50 ms on average. This system brings improvements to road safety by combining RFID with IoT-enabled GPS and GSM modules in such a way that it not only enhances safety on the road but also creates a platform for intelligent transportation systems capable of adapting road environments and reducing accidents caused by bad visibility.

Overall, the proposed system looks to resolve three critical elements in road safety, which are poor visibility because of fog, rain, and high-speed roads, with a cost effective and scalable solution. The results verify the usefulness of the system and point to a real-world deployment of the system.

The proposed system can be further improved by integrating AI-based (YOLO or CNN) techniques with RFID technology to enhance detection accuracy and response time especially when the systems are run at high speed and low visibility. Such optimization for adverse weather is to bring in robust performance in all environments. Large scale implementation will be evaluated in terms of feasibility with a detailed cost analysis and scalability assessment, along with strategies to mitigate signal interference in urban areas for more reliable performance. Furthermore, the RFID system would be compared with existing AI-based systems. Government and industry stakeholders will work together to adopt the system for integration into modern transportation networks that are safer and more sustainable. In the future, the potential interference in high-traffic areas can be mitigated by signal prioritization methodology and channel allocation algorithms.

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