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**Original Research Article**

# Digital Wireless Caution Sign System: Enhancing Highway Safety

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**ABSTRACT**

*Road obstructions on highways present significant hazards to road users, resulting in accidents and traffic congestion. Conventional methods, such as road signs, have proven ineffective, particularly in countries like Nigeria and other African countries. Motorists frequently neglect to display caution signs (triangular signs) when their vehicles break down on highways, impeding the ability of other drivers to promptly identify and respond to stationary vehicles. To address this issue, a digital wireless caution sign system is proposed. The system combines a flashing caution light with wireless signal transmission to notify oncoming vehicles of obstructions, including parked or broken-down vehicles, along the road. The system consists of two units: the transmitter unit and the receiver unit. The transmitter unit incorporates an AT89s51 microcontroller, LEDs, and TWS-434 module, while the receiver unit comprises an AT89s51 microcontroller, TWR-434 radio, LCD, and buzzer. When a vehicular obstruction is detected, information is transmitted via the TWS-434 module to the receiver unit. This triggers a beep every ten seconds while simultaneously displaying details about the obstructing vehicle on an LCD screen. This real-time notification system enhances road safety by proactively alerting drivers to potential obstructions. The effectiveness of the proposed system lies in its ability to provide timely and accurate notifications, enabling drivers to make informed decisions and mitigate the risk of accidents. By equipping vehicles with the receiver system, drivers can receive proactive notifications about road obstructions, allowing them to adjust their driving behavior and ensure safer journeys.*

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## 1. INTRODUCTION

Throughout the history of motor vehicles, prioritizing road user safety has consistently remained a fundamental objective for governments, manufacturers, and other key stakeholders. (Smithsonian, 2017; Ekwonwune *et al.*, 2018). The global attention given to road safety is due to the significant impact of road accidents and fatalities (Mohammed *et al.*, 2019; Chang *et al.*, 2020; Khan *et al.*, 2020). Notably, road obstructions such as potholes, debris, and broken-down vehicles contribute substantially to accidents and traffic congestion (Khan *et al.*, 2020), resulting in significant economic and social consequences (Khan *et al.*, 2020; Afolabi and Gbadamosi, 2017).

Interestingly, there are opportunities to enhance emergency roadside assistance methods to further improve road safety outcomes and reduce incidences of road accidents. Some promising directions include developing systems that can automatically detect vehicle issues and communicate warnings to nearby traffic in real-time. Such system should offer timely and accurate notifications regarding obstructions, diversions, and road blockages (Glukhikh *et al.*, 2020; Mateen *et al.*, 2022).

To address these challenges, this study proposes a digital wireless caution sign system with wireless notification for packed vehicles on highways. The primary objective of this system is to enhance road safety by providing timely and accurate notifications to oncoming drivers about vehicular obstructions. By leveraging wireless radio transmitter and receiver technology, the system enables the transmission of crucial information about vehicular obstructions to drivers equipped with the receiver system, empowering them to take appropriate actions, such as reducing speed and exercising caution. This study will contribute to the field of road safety by presenting a practical solution to the challenges posed by road obstructions. Specifically, the proposed system provides timely and accurate notifications to drivers, enabling them to make informed decisions, ultimately minimizing accidents and improving traffic flow.

Enhancing road safety is a global imperative as traffic accidents remain a leading cause of fatalities and injuries (Hagan *et al.*, 2021; Ahmed *et al.*, 2023). To address this pressing issue, researchers and practitioners have been exploring various approaches and technologies (Zheng *et al.*, 2021; Ali *et al.*, 2021). In this study, we delve into the field's relevant studies and developments, specifically focusing on the use of real-time information dissemination systems and their potential impact on road safety improvement. Real-time information systems have gained significant attention in recent years due to their ability to provide drivers with timely and accurate information, enabling them to make informed decisions while on the road (Fu *et al.*, 2021; Torbaghan *et al.*, 2022). These systems leverage advancements in communication technologies and sensor networks to collect and disseminate information regarding road conditions, hazards, and traffic flow. By enhancing drivers' situational awareness and facilitating proactive responses to potential risks, they aim to enhance overall road safety.

Over the years, road safety has been the subject of extensive research, with continuous efforts in this field. A particularly noteworthy aspect of road safety systems research revolves around the integration of wireless communication technologies (Ahangar *et al.*, 2021; Fu *et al.*, 2021). The utilization of this technology has emerged as a promising approach to augment road safety and facilitate the seamless flow of information to drivers during their interactions with road networks. By harnessing wireless communication technologies, it becomes possible to establish efficient and timely communication channels that can deliver critical information to drivers in real time. This proactive dissemination of information empowers drivers with heightened situational awareness, enabling them to make well-informed decisions while navigating the roadways (Kandris *et al.*, 2020).

Notably, various studies have examined the utilization of different wireless communication protocols, including Wi-Fi, Bluetooth, and cellular networks, to establish reliable and efficient communication channels. For instance, Li and Yu (2022) introduced a vehicle-approaching reminder device and anticollision warning system that leverages ZigBee wireless technology to enhance road safety. This system consists of a transmitter and receiver installed on the approaching and target vehicles, respectively. Once the approaching vehicle reaches a predetermined distance, the transmitter sends a signal to the receiver, triggering an alarm to alert the driver of the target vehicle (Li and Yu, 2022). This innovative device holds promise for mitigating accidents caused by driver inattention. However, it requires further refinement and testing, considering factors such as network quality, compatibility with other technologies, and ethical/legal challenges.

Continuing the exploration of road safety advancements through technology, Surugiu and Stăncel (2019) proposed a monitoring and warning system based on roadside sensors in a vehicular ad hoc network (VANET). Their system aims to provide drivers with crucial real-time information concerning road conditions, traffic congestion, accidents, and warnings, particularly in complex extra-urban areas. By utilizing wireless sensor networks and adopting a minimalistic approach to facilitate efficient inter-vehicular communication, the system shows potential in enhancing road safety by equipping drivers with the knowledge required to navigate safely and anticipate potential hazards. However, the study acknowledges certain limitations, including network security, congestion, scalability, evaluation, and comparisons with other solutions, which necessitate careful consideration for comprehensive system optimization and broader implementation (Surugiu and Stăncel, 2019).

Expanding on the preceding discussions, Simeonov *et al.*, (2021) evaluated an advanced curve speed warning system (CSWS) tailored specifically for fire trucks. The CSWS effectively alerted drivers when approaching curves at unsafe speeds during emergency driving, resulting in reduced speeds, decreased instances of severe braking, and improved overall response time. The positive feedback from drivers underscored the assistance, effectiveness, and usefulness of the CSWS. The study concludes that the CSWS holds the potential in enhancing fire truck safety without compromising emergency response. However, addressing limitations related to simulation validity, comparisons with alternative systems, long-term effects, and driver behavior is crucial for a comprehensive understanding and optimization of the CSWS (Simeonov *et al.*, 2021).

Building upon these findings, the integration of real-time information dissemination systems with existing road infrastructure emerges as a promising avenue for enhancing road safety. This integration involves connecting the system to traffic lights, road signs, and other traffic management systems, establishing a comprehensive and interconnected network. Several studies have examined the effectiveness of integrating real-time information systems with traffic signal control systems to optimize traffic flow and alleviate congestion. Toh *et al.*, (2019) contribute to this field by envisioning a future where wireless digital traffic signs play a central role in transmitting traffic sign information to road users, particularly in smart cities. The authors propose an innovative traffic sign architecture that utilizes various wireless communication technologies, such as RFID, NFC, Bluetooth, Wi-Fi, and 5G, to display crucial information about traffic conditions, road closures, and other relevant details. While acknowledging limitations such as technical feasibility, user acceptance, comparisons with alternative solutions, and potential environmental impacts, the study highlights the transformative potential of wireless digital traffic signs in revolutionizing road communication and enhancing overall traffic management efforts.

The literature review demonstrates the increasing research and development efforts in real-time information dissemination systems for improving road safety. These studies have explored various aspects, including wireless communication technologies, sensor technologies, and integration with existing road infrastructure. These advancements provide valuable insights and serve as the foundation for the development and implementation of effective road safety systems. Building upon this existing knowledge, the present study aims to contribute by developing and testing a system that leverages real-time information dissemination to enhance road safety.

## 2. METHODOLOGY

The methodology employed in this design encompasses a series of systematic steps to ensure the successful implementation of the proposed system. These steps include system design, system and software implementation.

### 2.1. System Design and Implementation

The proposed system comprises essential hardware components that work in tandem to achieve its objectives. Firstly, a wireless communication module is utilized to enable the wireless transmission of signals to the microcontroller. This module serves as a crucial link in facilitating real-time communication between the system and the drivers. Secondly, a microcontroller is employed to process the sensor data and provide drivers with timely notifications. The microcontroller acts as the central processing unit, executing the necessary operations to analyze the data received from the sensors and transmit appropriate notifications to drivers. In terms of software, the system's functionalities are implemented using Assembly language. The software encompasses several key functions, including the initialization of the microcontroller and hardware

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components, configuration of the ultrasonic sensors and wireless communication module, detection and measurement of road obstructions, processing of sensor data to determine the type of obstruction, and finally, the notification of drivers via the wireless communication module.

**2.1.1. System design**

The system design phase involved a meticulous process of identifying, selecting, gathering, and examining all the necessary components and modules essential for the successful implementation of the proposed system. To facilitate the design and simulation of the system, Proteus, a hardware simulation software, was employed.

Proteus is a powerful software tool widely used for designing electronic circuits and conducting simulations to observe the behavior of the designed circuit before actual implementation. It provides a platform to simulate the real-life operation of the system, detect errors, and identify any incorrect values of components or wiring discrepancies. Additionally, for programmable chips, Proteus allows the designer to program and observe the actual operation of the system. Throughout the simulation process, various adjustments and refinements were made to align the design with the system's objectives. These modifications ensured that the final implementation of the system met the desired goals. The design was carried out in a step-by-step manner, encompassing the power pack design, as well as the sensor, RF module, LCD module, Alarm unit, and microcontroller. A block diagram of the proposed system is shown in Figure 1. By utilizing Proteus for system design and simulation, we were able to thoroughly assess the functionality and performance of the system, making necessary adjustments to achieve the desired outcomes. This careful design approach laid a solid foundation for the subsequent stages of implementation and testing, ensuring a successful realization of the proposed system.

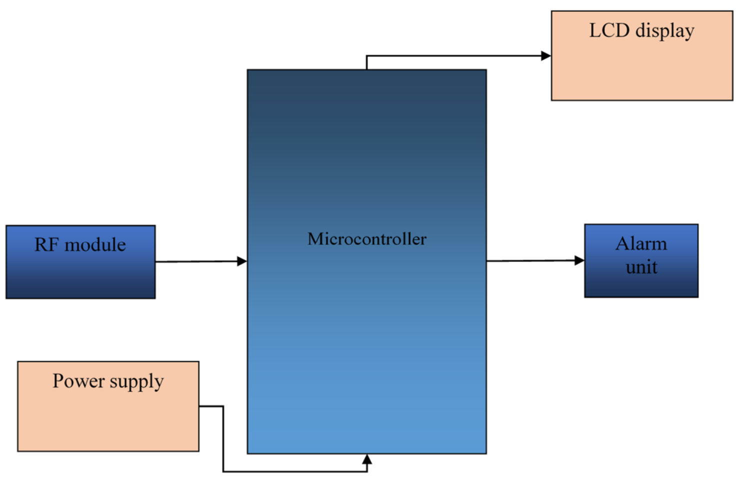


Figure 1: Block diagram of the system

**RF Module:** The RF module used in this system employs the amplitude shift keying (ASK) modulation technique and operates at a frequency of 434 MHz. At the transmitter, the input data is accepted serially and transmitted via radio frequency. The transmitted signals are then picked up by the receiver module placed at a certain distance (100 m). The communication between the two nodes in the system follows a point-to-point simplex configuration.

To facilitate communication, the RF module is used in conjunction with two integrated circuits (ICs), namely the encoder and decoder. Each IC is equipped with four dedicated ports, which are configured as input and output channels. The encoder IC, HT12E, converts parallel data from the four input switches into serial data. The serial data is then transmitted through pin 17, which is connected to the input data pin 2 of the transmitter module. The transmission of signals occurs serially through the RF transmitter's antenna. For transmission to be enabled, pin 14 of the encoder IC should be connected to an active low state.

The transmitted data is received by the receiver module and fed serially into the decoder IC, HT12D, through the data input pin 14. The decoder IC converts the serial data back into parallel data, which is then outputted through ports D0 to D3. The pin configuration of the decoder IC is illustrated in Figure 2, providing a detailed overview of the functions of each pin.

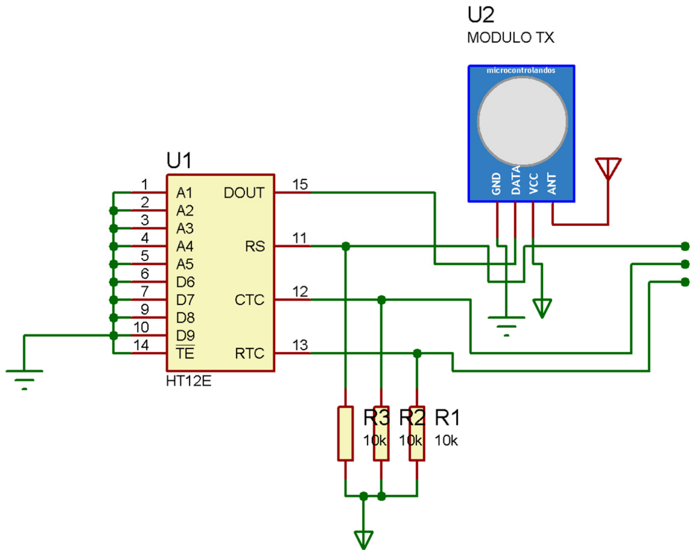


Figure 2: RF decoder for the transmitter

In the system's setup, pins 10 to 14 of the decoder IC are connected to port 1 of the microcontroller. External pull-up resistors are added to ensure a default high signal. Additionally, a 1 Mohm resistance is required between the OSC1 and OSC2 pins. The Transmitter Enable (TE) pin of the decoder IC is connected to the microcontroller, and it is permanently set to a low logic state to keep the transistor enabled at all times. The output serial data, DOUT, is directly fed to the RF Transmitter Module. By utilizing the RF module in conjunction with the encoder and decoder ICs, the system enables reliable wireless communication, allowing for the transmission and reception of data between the transmitter and receiver units.

**2.1.2. System implementation**

Following the completion of the design, program development, and simulation phases, the system implementation process was initiated. This involved assembling the various components and modules used in the circuit diagrams design, such as the LCD, RF module, and Microcontroller. The components were carefully soldered together to ensure proper connections and functionality.

To facilitate the integration of the components, a Printed Circuit Board (PCB) shown in Figure 3 was designed using PCB design software. The designed PCB was then printed and etched using chemicals to create the necessary circuitry. The PCB provided a platform for placing and soldering the components. After completing the soldering process, the system was powered on gradually to verify its operational capability. Finally, all the components were assembled and powered on as a complete system.

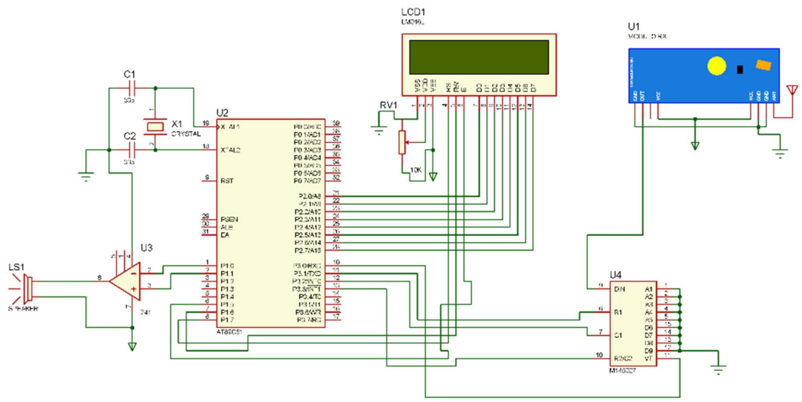


Figure 3: Circuit diagram of the system

## 2.2. Software Implementation

In terms of software, assembly language was utilized for this design. Assembly language was chosen due to its reliability, speed, and memory efficiency. Once the software was developed, it was assembled using MIDE - ASMS1. Any identified errors were corrected, and the final hex code was generated. To transfer the hex code to the microcontroller, an EPROM programmer was employed. After programming, the microcontroller was powered on, allowing the software to run on the system. The successful implementation of the system, both in terms of hardware and software, lays the foundation for its functionality and operation in real-world scenarios. The next phase of the project involved conducting thorough testing and evaluation to assess the system's performance and ensure it meets the intended objectives and requirements.

## 3. RESULTS AND DISCUSSION

The system underwent rigorous testing to assess its performance efficiency and reliability. The findings from the tests are presented and thoroughly discussed in this section.

## 3.1. System Testing

To validate the functionality of the different sub-systems, a comprehensive test plan was implemented. The testing was conducted on a module-by-module basis, ensuring that each sub-system operated smoothly before proceeding with the assembly. The successful operation of the power supply, RF module, and microcontroller in the individual testing phases lays a solid foundation for the overall system's functionality and effectiveness. The power supply's consistent delivery of 5 volts ensures a stable and reliable operation, minimizing the risk of disruptions that could hinder the system's ability to transmit crucial information to drivers. The RF 433 MHz module's capability to transmit signals to the receiver module demonstrates its reliability in wireless communication. This feature allows the system to promptly relay real-time information about road conditions to approaching vehicles, empowering drivers with accurate and timely updates. This wireless technology significantly enhances drivers' situational awareness and enables them to make informed decisions while on the road, ultimately contributing to improved road safety. The microcontroller, serving as the control unit, showcases its compatibility with the program and its ability to provide accurate output. This emphasizes the microcontroller's reliability and efficiency in processing sensor data and transmitting relevant information to the receiver system. Its seamless integration within the system architecture ensures smooth operations and plays a vital role in the overall functionality of the system. By conducting meticulous testing of each unit, potential errors or malfunctions were identified and addressed before proceeding with the system integration and general testing phases. This approach mitigates the risk of encountering critical issues during later stages and underscores the commitment to delivering a robust and reliable system.

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### 3.2. System Operation

Upon activation, the system seamlessly executes the instructions programmed within the 89s52 microcontroller and the RF module. Every 5 seconds, the transmitter sends out a signal that can be received by vehicles within a 100-meter radius. This signal carries essential information about the surrounding conditions at the system's location. As the signal reaches the receiver system, it is displayed on the LCD screen, accompanied by a warning beep that immediately captures the attention of drivers. This smooth and reliable operation ensures that drivers are promptly informed about the specific conditions they will encounter, significantly enhancing road safety and enabling them to make informed decisions while driving. The system operation is shown in Figure 4a, 4b, and 4c.


(a) (b) (c)

Figure 4: System operation and display

The results obtained during the system testing phase validate the functionality and performance of the individual components and sub-systems. The system's ability to effectively transmit information and operate as intended confirms the practicality and effectiveness of the proposed solution. These findings reinforce the system's potential to address the challenges associated with road safety and contribute to the overall improvement of traffic conditions and accident prevention. The successful implementation and operation of the system provide valuable insights into its capabilities and highlight its potential impact on road safety. By delivering timely and accurate information to drivers, the system empowers them to proactively respond to road conditions, reducing the likelihood of accidents and promoting smoother traffic flow. Moreover, the seamless integration of the various components, such as the microcontroller and RF module, underscores the reliability and efficiency of the system as a whole.

### 3.3. Detailed Analysis and Discussion of Findings

The findings derived from the systematic testing phase shed light on the capabilities and potential impact of the proposed system on road safety. The meticulous module-by-module testing approach ensured the efficient functioning of each sub-system, thereby contributing to the overall system's effectiveness.

The operational mechanism of the system involves the regular transmission of signals every 5 seconds from the transmitter end. This frequent transmission interval guarantees that the information remains up-to-date and readily accessible to vehicles within a 100-meter radius. The incorporation of a warning beep, coupled with the message displayed on the LCD screen, serves to capture drivers' attention and alert them to potential hazards or prevailing road conditions. This multi-faceted approach significantly enhances the system's ability to effectively convey critical information and proactively engage drivers. The potential impact of the proposed system on road safety is substantial. By providing real-time information about road conditions, such as obstacles or hazardous situations, the system empowers drivers to take proactive measures and make informed decisions accordingly. This proactive approach to road safety holds immense potential for mitigating the risk of accidents and optimizing overall traffic flow. Furthermore, the system's wireless communication capability and reliable transmission range ensure the timely dissemination of vital information to drivers, even in areas with limited infrastructure or challenging road conditions. This becomes particularly crucial in regions where conventional road signs may be insufficient or where compliance with traditional safety measures is lacking. The system fills the gap by delivering crucial information directly to drivers, enabling them to navigate through potential hazards and make informed choices to ensure their safety.

The integration of the system within vehicles presents a practical and accessible solution for enhancing road safety. Equipping vehicles with the receiver system empowers drivers with real-time notifications, thereby enhancing their situational awareness and facilitating informed decision-making on the road. The system acts as an additional layer of safety, complementing existing road signage and manual safety practices, thus augmenting overall road safety measures.

### 3.4. Limitations and Recommendations

The proposed system has effectively showcased its capacity to improve overall road safety by promptly alerting drivers to potential parked vehicles ahead. However, it is essential to acknowledge that the system does have certain limitations. This section provides appropriate recommendations to address these limitations and further enhance the system's performance.

#### 3.4.1. Limitations

Despite the promising results and potential impact of the proposed system, some notable limitations of the proposed system are acknowledged:

a. Range limitation: The current system operates within a maximum range of 100 meters. While this range is suitable for certain scenarios, it may not be sufficient for larger areas or highways. Future enhancements should focus on extending the transmission range to ensure comprehensive coverage.

b. Environmental factors: The system's performance may be affected by environmental conditions such as interference from other wireless devices, weather conditions, and physical obstacles. Further investigations should be conducted to assess the system's robustness under various environmental conditions and identify potential solutions to mitigate these limitations.

c. Power dependency: The system relies on a stable power supply to operate effectively. In regions with unreliable or limited power infrastructure, ensuring continuous power supply to the system may pose a challenge. Exploring alternative power sources or implementing power backup mechanisms can help address this limitation.

d. Integration challenges: Integrating the system into existing vehicles may present technical and logistical challenges. The compatibility of the receiver system with different vehicle models and the installation process should be further examined to streamline integration and ensure widespread adoption.

e. Detection of road obstructions: One of the limitations of the system is its inability to detect all types of road obstructions, including small objects or debris. The current design primarily focuses on notifying drivers of potential parked vehicles on the highway that pose a significant risk to motorists. While the system performs well in identifying and alerting drivers about parked vehicles, it may not provide the same level of accuracy or sensitivity when it comes to smaller objects.

#### 3.4.2. Recommendations

Based on the identified limitations, the following recommendations are made to enhance the system's effectiveness and address potential challenges:

a. Range extension: To expand the system's coverage, future research should focus on improving the transmission range. Investigating advanced wireless communication technologies or exploring the integration of satellite-based systems can enhance the system's reach and effectiveness, especially in larger areas and highways.

b. Environmental adaptability: Conducting comprehensive field tests under diverse environmental conditions will provide valuable insights into the system's performance and identify potential interference sources. Based on these findings, adaptive algorithms and signal-processing techniques can be developed to mitigate the impact of environmental factors and ensure reliable communication.

c. Power management strategies: Developing energy-efficient designs and exploring alternative power sources, such as solar energy or energy harvesting technologies, can reduce the system's power dependency. Additionally, implementing power backup mechanisms, such as rechargeable batteries, can provide a reliable power supply in regions with intermittent power availability.

d. Collaboration with vehicle manufacturers: Collaborating with vehicle manufacturers and industry stakeholders is crucial to streamline the integration process. Establishing standardized protocols and guidelines for incorporating the receiver system into different vehicle models will facilitate widespread adoption and ensure seamless compatibility.

e. Integration with Smart Infrastructure: Exploring opportunities for integrating the system with smart infrastructure, such as intelligent traffic systems or smart city initiatives, can amplify its impact on road safety. By leveraging existing infrastructure and data networks, the system can enhance its capabilities and reach a broader user base.

## 4. CONCLUSION

In this study, we have successfully developed and tested a system designed to improve road safety by providing real-time information to drivers and engaging them proactively. Through comprehensive testing and analysis, we have confirmed the functionality and compatibility of the system's sub-systems, gaining valuable insights into its capabilities and potential impact on road safety. The system operated seamlessly, transmitting signals at regular intervals and effectively delivering crucial information to drivers within a 100-meter range. By incorporating a warning beep and displaying messages on an LCD screen, we were able to capture drivers' attention, ensuring timely awareness of road conditions ahead. This multi-modal approach proved highly effective in enhancing drivers' situational awareness and enabling informed decision-making while on the road. The potential impact of our proposed system on road safety is significant. By providing real-time information about obstacles, hazards, and overall road conditions, drivers can take proactive measures to avoid accidents and navigate safely. The system's wireless communication capability and reliable transmission range ensure that vital information reaches drivers, even in areas with limited infrastructure or challenging road conditions. This aspect is particularly important in regions where traditional road signage is insufficient or compliance with safety measures is lacking. The integration of our system within vehicles offers a practical and accessible solution for enhancing road safety. Equipping vehicles with the receiver system empowers drivers with real-time notifications, augmenting their situational awareness and facilitating well-informed decision-making. Our system acts as an additional layer of safety, complementing existing road signage and manual safety practices. Lastly, continued research and development in this area will further refine the system and contribute to the ongoing efforts to make roads safer for all users.

## 5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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