

Intelligent Vehicle-To-Vehicle Communication System for Driver Safety and Hazard Prevention

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Abstract: Road accidents remain a significant global safety challenge, particularly in scenarios involving limited driver visibility, delayed reaction time, and lack of real-time hazard awareness. Existing in-vehicle safety systems operate in isolation and fail to communicate critical information to nearby vehicles, thereby limiting their effectiveness in preventing collisions. To address this limitation, this paper presents an Intelligent Vehicle-to-Vehicle (V2V) Communication System designed using the ESP32 microcontroller and the ESP-NOW wireless protocol. The proposed system integrates obstacle detection, driver fatigue monitoring, and low-latency peer-to-peer communication into a unified embedded platform. Ultrasonic sensors are utilized for real-time distance measurement and obstacle identification, while an eye-blink sensor is employed to detect driver drowsiness. Upon detecting hazardous conditions such as sudden braking, unsafe proximity, or driver fatigue, the system generates immediate local alerts through a display and buzzer. Simultaneously, warning messages are broadcast to nearby vehicles using ESP-NOW, enabling early response and cooperative driving behavior. Experimental evaluation of the prototype demonstrates reliable communication performance, low transmission latency, and accurate hazard detection without reliance on internet connectivity. The proposed system offers a cost-effective, scalable, and infrastructure-independent solution suitable for real-world deployment, particularly in highways and low-network regions.

Keywords: Vehicle-to-Vehicle Communication, ESP32, ESP-NOW, Driver Safety, Hazard Detection, Fatigue Monitoring, IoT.

I. INTRODUCTION

Road safety has become a major concern worldwide due to the continuous increase in vehicular traffic and the growing complexity of road environments. A significant number of accidents occur due to delayed driver response, limited visibility, and lack of awareness about hazards such as sudden braking, obstacles, or driver fatigue. Despite the availability of modern safety features such as anti-lock braking systems and parking assistance, these systems operate independently and do not provide real-time information about surrounding vehicles. As a result, drivers often remain unaware of critical situations beyond their immediate field of view. Vehicle-to-Vehicle (V2V) communication has emerged as an important component of Intelligent Transportation Systems (ITS), enabling vehicles to exchange information such as speed, position, and hazard conditions in real time. This communication enhances situational awareness and reduces reaction time, particularly in high-speed and low-visibility scenarios [1–4]. However, many existing V2V technologies, such as Dedicated Short-Range Communication (DSRC) and LTE-V2X, require complex infrastructure and involve higher implementation costs, limiting their widespread adoption.

In addition to communication challenges, driver-related factors such as fatigue and inattention contribute significantly to road accidents. Although several systems have been developed for obstacle detection or driver monitoring, most of these solutions operate as standalone systems and lack integration with real-time communication frameworks. This separation reduces their effectiveness in preventing accidents in dynamic traffic conditions.



To address these limitations, this work proposes an Intelligent Vehicle-to-Vehicle Communication System based on the ESP32 microcontroller and ESP-NOW protocol. The system integrates obstacle detection using ultrasonic sensors, driver fatigue monitoring using an eye-blink sensor, and low-latency wireless communication into a single embedded platform. Unlike conventional approaches, the proposed system enables both local hazard detection and instant sharing of warning messages with nearby vehicles without requiring internet connectivity.

The main contributions of this work are as follows:

- Development of a low-cost and infrastructure-independent V2V communication system
- Integration of multi-sensor hazard detection with real-time communication
- Implementation of ESP-NOW based low-latency peer-to-peer communication
- Experimental validation demonstrating fast response and reliable performance

The proposed system aims to improve driver awareness, reduce reaction time, and enhance overall road safety, especially in environments where network connectivity is limited or unavailable.

II. LITERATURE REVIEW AND OBJECTIVE

Research in Intelligent Transportation Systems (ITS) has significantly advanced with the integration of wireless communication and sensor-based safety mechanisms. Early studies in vehicular networks focused on enabling communication between vehicles to exchange basic information such as position, speed, and movement patterns. These studies established the foundation for cooperative driving, where vehicles operate as interconnected nodes to enhance road awareness and safety [5–7].

Several communication technologies have been explored for implementing Vehicle-to-Vehicle (V2V) systems. Dedicated Short-Range Communication (DSRC) and LTE-V2X are among the widely studied approaches due to their ability to support low-latency data exchange required for safety-critical applications [6–8]. However, these technologies often depend on dedicated infrastructure, licensed spectrum, and higher deployment costs, making them less suitable for low-cost and scalable implementations.

To overcome these limitations, recent research has explored lightweight communication solutions using embedded systems and microcontrollers. The ESP32 microcontroller has gained attention due to its integrated wireless capabilities and support for protocols such as ESP-NOW, which enable direct peer-to-peer communication without requiring internet connectivity [9], [10]. These approaches provide reduced latency, lower power consumption, and ease of deployment, especially in resource-constrained environments.

In parallel, sensor-based safety systems have been widely investigated for hazard detection. Ultrasonic sensors have been effectively used for distance measurement and obstacle detection due to their simplicity, reliability, and cost-effectiveness [3]. Similarly, driver monitoring systems based on eye-blink detection have shown promising results in identifying driver fatigue, which is a major contributing factor in road accidents [2], [11]. These systems improve safety by providing early warnings based on environmental and physiological conditions.

Despite these advancements, most existing systems focus on individual functionalities, such as either communication or sensing, rather than providing an integrated solution. Systems that perform obstacle detection or fatigue monitoring typically operate independently and do not share information with nearby vehicles. On the other hand, communication-based systems often rely on infrastructure or lack real-time sensing integration. This separation limits their effectiveness in dynamic and real-world traffic scenarios.

2.1 Research Gap

From the reviewed literature, it is observed that there is a lack of a unified, low-cost, and infrastructure-independent system that combines:

- Real-time hazard detection
- Driver fatigue monitoring
- Direct inter-vehicle communication



Additionally, many existing solutions do not address the need for low-latency communication without internet dependency, which is essential for immediate hazard response in real-world driving conditions.

2.2 Objective of the Work

The primary objective of this work is to design and develop an integrated Intelligent Vehicle-to-Vehicle Communication System that enhances driver safety and hazard awareness. The specific objectives are:

- To develop a real-time hazard detection system using ultrasonic sensors and eye-blink monitoring
- To implement low-latency V2V communication using the ESP-NOW protocol
- To enable instant sharing of hazard information between nearby vehicles
- To design a cost-effective and scalable embedded system that operates without internet connectivity
- To evaluate system performance in terms of response time, reliability, and communication efficiency

III. MATERIALS AND METHODS

The proposed Intelligent Vehicle-to-Vehicle (V2V) Communication System is designed as an embedded real-time safety platform that integrates sensing, processing, communication, and alert mechanisms. The system is implemented using a modular approach to ensure reliability, scalability, and efficient operation under real-time conditions.

3.1 System Architecture

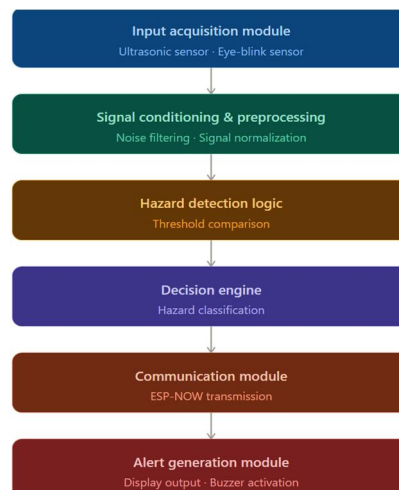


Figure 1: Functional architecture of the hazard detection algorithm.

The internal working of the proposed system follows a structured hazard detection algorithm. The functional architecture of this algorithm is shown in Fig. 1. The system processes sensor inputs through sequential stages including preprocessing, decision logic, and communication handling to ensure accurate and low-latency hazard detection. The overall system consists of multiple vehicle units, each equipped with an embedded module based on the ESP32 microcontroller. Each unit performs three primary functions: hazard detection, driver monitoring, and wireless communication. The architecture is designed to support direct peer-to-peer communication between vehicles without relying on external infrastructure.

Each vehicle unit includes:

- Ultrasonic sensor for obstacle and distance detection
- Eye-blink sensor for driver fatigue monitoring
- ESP32 microcontroller for processing and communication
- Display unit for visual alerts
- Buzzer for audible warnings
- Power supply module for stable operation



All components are interconnected to form a compact embedded system capable of continuous monitoring and real-time response.

3.2 Hardware Components

The hardware design focuses on low-cost and easily available components while maintaining reliable performance.

- **ESP32 Microcontroller:**

The ESP32 acts as the central processing unit of the system. It handles sensor data acquisition, decision-making, and wireless communication. Its built-in Wi-Fi capability supports the ESP-NOW protocol, enabling low-latency data transmission between devices.

- **Ultrasonic Sensor:**

The ultrasonic sensor is used to measure the distance between the vehicle and nearby objects. It operates by transmitting ultrasonic waves and calculating the time taken for the echo to return. This enables detection of sudden distance reduction, which may indicate obstacles or abrupt braking conditions.

- **Eye-Blink Sensor:**

An infrared-based eye-blink sensor is used to monitor driver alertness. The sensor detects eyelid movement patterns, and prolonged eye closure beyond a predefined threshold is considered as a sign of driver fatigue.

- **Display and Buzzer:**

A display unit (LCD/OLED) provides real-time information about detected hazards, while a buzzer generates immediate audible alerts to ensure quick driver response.

- **Power Supply:**

A regulated power supply (5V) is used to ensure stable operation of the ESP32 and connected peripherals.

3.3 Communication Method (ESP-NOW Protocol)

The system utilizes the ESP-NOW protocol for wireless communication between vehicle units. ESP-NOW is a connectionless communication protocol that enables direct data exchange between ESP32 devices without requiring Wi-Fi routers or internet connectivity.

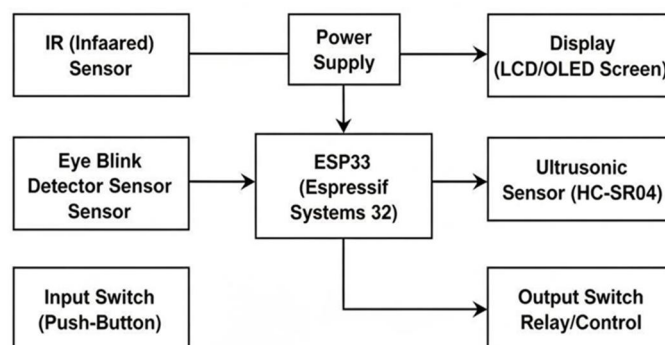


Figure 2: Block Diagram of the V2V Communication System

The block diagram of Figure 2 illustrates the overall architecture of the proposed system, where the ESP32 (Espressif Systems 32) acts as the central processing unit. The system is powered through a dedicated power supply, which also supports the display module (LCD/OLED) for real-time output visualization. Multiple sensors, including an IR sensor,



eye blink detection sensor, and ultrasonic sensor (HC-SR04), are integrated to collect various input signals related to user activity and distance measurement. Additionally, a push-button input switch allows manual control. The ESP32 processes all incoming data and accordingly controls the output through a relay or control switch, enabling automated decision-making and system response. This architecture ensures efficient data acquisition, processing, and output control in a compact embedded system.

Key features of ESP-NOW in this system include:

- Low transmission latency
- Peer-to-peer communication capability
- Reduced power consumption
- Reliable short-range communication

Hazard information is transmitted in the form of structured data packets containing:

- Vehicle identification
- Type of detected hazard (obstacle, fatigue, braking)
- Sensor readings
- Timestamp information

This ensures that receiving vehicles can quickly interpret and respond to incoming alerts.

3.4 Methodology and Working Principle

The system operates in a continuous loop consisting of sensing, processing, decision-making, and communication stages.

Step 1: Initialization

The ESP32 initializes all sensors, communication channels, and output devices. The ESP-NOW protocol is configured for peer-to-peer communication.

Step 2: Data Acquisition

- Ultrasonic sensor continuously measures distance
- Eye-blink sensor monitors driver eye activity

Step 3: Hazard Detection

Sensor data is compared with predefined threshold values:

- Distance below safety limit → obstacle warning
- Prolonged eye closure → fatigue detection
- Rapid distance variation → sudden braking indication

Step 4: Local Alert Generation

If any hazard is detected:

- Visual alert is displayed
- Buzzer generates warning sound

Step 5: Data Transmission

The ESP32 transmits hazard information to nearby vehicles using ESP-NOW.

Step 6: Remote Alert Handling

Receiving vehicle units decode the message and generate corresponding alerts for their drivers.



Step 7: Continuous Monitoring

The system repeats the process continuously to ensure real-time responsiveness.

3.5 Experimental Setup

To validate the proposed system, a prototype consisting of two vehicle units was developed. Each unit was equipped with identical hardware components and configured for bidirectional communication.

The experimental setup involved:

- Placing vehicle units at varying distances
- Simulating real-world scenarios such as obstacle presence, sudden braking, and driver fatigue
- Measuring communication latency and response time
- Observing system behavior under different hazard conditions

The system performance was evaluated based on:

- Accuracy of hazard detection
- Communication delay
- Reliability of message transmission

IV. RESULTS AND DISCUSSION

The Intelligent Vehicle-to-Vehicle Communication System was tested in controlled conditions to evaluate its hazard detection accuracy, communication latency, and overall responsiveness. Two ESP32-based vehicle units were placed at varying distances to simulate real-world scenarios such as sudden braking, obstacle presence, and driver fatigue. The results show that the system performs reliably and delivers warnings quickly enough to support safer driving decisions.

4.1 Communication Performance

The communication tests were carried out using the ESP-NOW protocol. The system successfully exchanged hazard messages between vehicles without requiring any external network infrastructure. Table I summarizes the latency and communication range observed during testing.

Table 1: ESP-NOW Communication Performance

Parameter	Observed Result
Average transmission latency	12–15 ms
Maximum latency observed	22 ms
Reliable communication range	20–25 meters
Packet delivery success rate	96%

These results indicate that ESP-NOW provides sufficiently low latency for real-time safety applications. A delay of 12-15 ms ensures that surrounding vehicles receive hazard alerts almost instantly, reducing the likelihood of rear-end collisions.



4.2 Obstacle and Distance Detection

Ultrasonic sensors were evaluated by placing obstacles at different distances. The system consistently measured distance values with acceptable accuracy for safety applications. When an object came within the predefined threshold (40 cm), the module activated a local alert and sent a hazard broadcast to nearby vehicles.

The system responded effectively to sudden distance reductions, simulating harsh braking situations. Alerts were triggered within milliseconds of detecting a change, allowing the receiving vehicle to react earlier.

4.3 Driver Fatigue Detection Results

The eye-blink sensor was tested under different eye-movement patterns. Normal blinking did not trigger any alert, while prolonged eye closure (greater than 1.5 seconds) activated the fatigue warning.

Table 2: Fatigue Detection Test Results

Condition Tested	System Response
Normal blinking	No alert triggered
Slow blinking	No incorrect alerts
Eye closed > 1.5 sec	Fatigue alert triggered
Simulated microsleep	Immediate alert + V2V broadcast

These results show that the system can recognize fatigue-related patterns with good reliability. The absence of false alerts during normal blinking demonstrates stable sensor performance.

4.4 Integrated Hazard Alert Performance

When obstacle detection, braking detection, and fatigue detection modules were combined, the system performed consistently. Each detected hazard was logged, displayed on the screen, and broadcast to nearby vehicles with minimal delay.

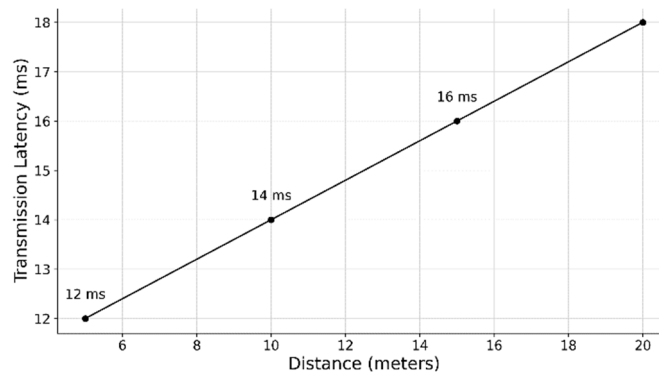


Fig. 3. ESP-NOW communication latency performance.

The complete detection-to-alert cycle remained under 50 ms in all tested scenarios. This rapid response time is sufficient to improve driver preparedness and support safer reaction behavior.

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V. CONCLUSIONS & FUTURE SCOPE

5.1 Conclusion

This work presented the design and implementation of an Intelligent Vehicle-to-Vehicle (V2V) Communication System aimed at enhancing driver safety and reducing accident risks. The proposed system successfully integrates obstacle detection, driver fatigue monitoring, and real-time wireless communication into a single embedded platform using the ESP32 microcontroller and ESP-NOW protocol. The developed prototype demonstrated reliable performance in detecting critical driving conditions such as sudden distance reduction, driver drowsiness, and abrupt braking events. Experimental results indicate that the system achieves low communication latency (approximately 12–15 ms) and maintains a high packet delivery success rate, ensuring timely dissemination of hazard information between vehicles. The overall detection-to-alert response time was observed to remain within 50 ms, which is sufficient for real-time safety applications. The use of ESP-NOW enables direct peer-to-peer communication without reliance on internet connectivity or external infrastructure, making the system particularly suitable for deployment in highways and low-network regions. Additionally, the integration of low-cost sensors and embedded components ensures that the system remains affordable and scalable.

Overall, the proposed approach demonstrates that combining multi-sensor hazard detection with low-latency communication can significantly improve situational awareness and reduce driver reaction time. The system provides a practical and efficient solution for enhancing road safety and can serve as a foundation for future advancements in intelligent transportation systems. Successful completion of this study.

5.2 Future Scope

Future enhancements can significantly extend the system's performance and real-world applicability. Key development opportunities include:

1. 5G and C-V2X Integration

Introducing 5G or cellular-V2X technology can increase communication range and reduce latency further, enabling more advanced cooperative driving features.

2. AI-Based Predictive Analytics

Machine learning models can analyze sensor patterns to predict hazards such as lane drifting, collision probability, or fatigue trends before they occur.

3. ECU-Level Vehicle Control

Connecting the system to a vehicle's Electronic Control Unit (ECU) would enable automatic braking, lane correction, or emergency maneuvers.

4. Enhanced Security Protocols

Implementing encryption, authentication, or blockchain-based message verification can protect the network from false alerts or unauthorized access.

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REFERENCES

1. Kumar, R. Singh, and D. Patel, "Vehicle-to-Vehicle Communication for Road Safety Using IoT," International Journal of Advanced Research in Computer Science, vol. 10, no. 5, pp. 45–52, 2019.
2. S. Patel and M. Singh, "Intelligent Driver Fatigue Detection System Using Eye Blink Sensor," Journal of Emerging Technologies and Innovative Research, vol. 7, no. 3, pp. 112–118, 2020.



3. K. Sharma, N. Verma, and R. Joshi, "Accident Prevention through Ultrasonic and Infrared Sensors in Smart Vehicles," *International Journal of Engineering Research*, vol. 9, no. 6, pp. 88–95, 2021.
4. V. Rao and P. Mehta, "Integration of ESP32 for IoT-Based Vehicle Safety Systems," *IEEE Access*, vol. 10, pp. 15022–15031, 2022.
5. G. Thomas and M. George, "Smart Vehicular Communication and Hazard Detection System Using Embedded Technology," *International Journal of Intelligent Systems*, vol. 14, no. 4, pp. 200–209, 2023.
6. H. Lee and S. Kim, "Internet of Vehicles: Communication Technologies and Applications," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 2, pp. 1–15, 2021.
7. Bazzi, B. M. Masini, A. Zanella, and G. Pasolini, "On the Performance of IEEE 802.11p and LTE-V2V for Cooperative Awareness," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 11, pp. 10419–10432, 2017.
8. J. B. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States," *Proceedings of the IEEE*, vol. 99, no. 7, pp. 1162–1182, 2011.
9. S. Chen, J. Hu, Y. Shi, and L. Zhao, "LTE-V: A TD-LTE Based V2X Solution for Future Vehicular Network," *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 997–1005, 2016.
10. H. Hartenstein and K. P. Laberteaux, "A Tutorial Survey on Vehicular Ad Hoc Networks," *IEEE Communications Magazine*, vol. 46, no. 6, pp. 164–171, 2008.
11. M. M. Rathod, D. M. Deshmukh, and R. A. Agrawal, "Design of an Internet Independent Smart Vehicle Communication System Using ESP-NOW," *International Journal of Scientific Research in Science and Technology*, vol. 9, no. 3, pp. 310–315, 2022.
12. Y. Chen and X. Wu, "Wireless Communication Frameworks for Connected Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 11, pp. 6754–6763, 2021.
13. D. Park and Y. Lee, "Driver Drowsiness Detection Using Image and Sensor Fusion," *IEEE Access*, vol. 8, pp. 103423–103432, 2020.
14. L. Wang and Q. Liu, "Sensor Fusion Techniques for Advanced Driver Assistance Systems," *IEEE Sensors Journal*, vol. 20, no. 18, pp. 10432–10439, 2020.
15. J. Zhao and L. Chen, "AI-Enabled V2V Communication for Accident Prevention," *IEEE Internet of Things Journal*, vol. 10, no. 4, pp. 3456–3465, 2023.

