

Integrated V2V Communication System

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Abstract - Road accidents continue to rise due to delayed driver response, limited visibility, and lack of coordination between vehicles. Vehicle-to-Vehicle (V2V) communication enhances road safety by enabling cooperative awareness through real-time data exchange. This paper presents a low-cost Integrated V2V Communication System using ESP32 microcontrollers and the ESP-NOW protocol for collision avoidance and driver assistance. The system integrates ultrasonic and IR sensors for obstacle detection, GPS for vehicle localization, and multi-modal alert mechanisms including voice alerts, buzzer, LED indicators, and display modules. Vehicles directly broadcast safety-critical information to nearby vehicles without relying on external infrastructure or cloud connectivity. Experimental results show low communication latency, timely alert generation, and improved driver response, demonstrating the effectiveness of the proposed approach for intelligent transportation systems. *Keywords*—Vehicle-to-Vehicle Communication, ESP32, ESP-NOW, Collision Avoidance, Voice Alerts.

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INTRODUCTION

Rapid urbanization and the continuous growth in vehicle usage have significantly increased road congestion and accident rates. Traditional vehicle safety mechanisms primarily depend on driver attention and isolated in-vehicle sensors, which are often insufficient in dynamic and unpredictable traffic scenarios. Human limitations such as delayed reaction time, restricted visibility, and cognitive overload further contribute to road accidents, especially in high-speed highways and dense urban environments.

Vehicle-to-Vehicle (V2V) communication introduces a

cooperative approach to road safety by enabling vehicles to exchange real-time information including speed, location, braking status, and obstacle alerts. By sharing this data directly between nearby vehicles, potential hazards can be detected earlier than human perception allows. Recent advancements in embedded systems, wireless communication, and intelligent sensing technologies have made practical V2V implementations feasible and affordable. The proposed system focuses on the design and implementation of an Integrated V2V Communication System that combines real-time wireless communication, multi-sensor data acquisition, and intelligent voice-based alerts. The system aims to improve driver awareness, support proactive decision-making, and reduce collision probability through cooperative vehicular interaction.

1. RELATED WORK

Vehicle-to-Vehicle communication has been widely studied as a key enabler of intelligent transportation systems. Existing research highlights the effectiveness of V2V communication in reducing rear-end collisions, improving traffic efficiency, and enhancing driver awareness. Technologies such as DSRC and C-V2X have been explored for vehicular data exchange, while recent studies focus on AI-assisted driver support and cooperative safety mechanisms. Many vehicle-following control strategies based on V2V communication have been discussed in the literature, yet several of these systems rely on complex hardware platforms or lack formal validation. In this work, the authors propose a V2V-based vehicle-following control model using a Model-Based Design (MBD) methodology implemented in MATLAB/Simulink. Their prototype integrates SIMO communication architecture with formal verification tools, enabling reliable message transfer between vehicles even in dense urban environments. The study demonstrates that the proposed control approach significantly improves following stability and response accuracy, offering practical advantages for real-world V2V

deployments[1].

Several V2V communication systems suffer from vulnerabilities due to the open and dynamic nature of vehicular networks. This work introduces a secure V2V communication framework that employs AI-based anomaly detection combined with robust message validation techniques. The system is designed to prevent malicious data injection, spoofing attacks, and inconsistent message patterns commonly found in unsecured vehicular environments. The authors show that integrating AI-driven models increases reliability while maintaining low-latency communication, ultimately creating a trusted and secure V2V communication environment suitable for large-scale intelligent transportation systems [2].

Most legacy vehicles lack built-in communication modules, making it difficult to deploy V2V functionality without costly system upgrades. The authors address this by proposing an IoT-based V2V communication model using ESP32 microcontrollers and ESP-NOW protocol. Their prototype features a complete hardware implementation composed of ESP32 boards and sensors for vehicle-status monitoring. This architecture provides a low-cost and energy-efficient solution that enables seamless integration with older vehicles. The study demonstrates that the system achieves stable communication performance, establishing its suitability for scalable V2V adoption among non-smart vehicles[3].

A wide variety of communication standards, including Dedicated Short-Range Communication (DSRC) and Cellular-V2X (C-V2X), have been developed for V2V systems, yet challenges still remain regarding interoperability and deployment feasibility. In this survey, the authors present an extensive review of existing V2V communication architectures and protocols. Their analysis highlights significant issues such as high implementation cost, compatibility limitations across regions, and performance variations under different driving conditions. The work emphasizes the necessity for flexible, low-cost communication frameworks that ensure consistent operation across diverse vehicular platforms [4].

The authors conduct a comparative study on DSRC and C-V2X protocols, focusing on their benefits, drawbacks, and safety applications within V2V environments. While both technologies offer reliable short-range communication, the study reveals critical differences in latency, scalability, and infrastructure requirements. The analysis highlights that low-cost and

energy-efficient communication models are essential for supporting intelligent transportation applications such as collision avoidance and cooperative maneuvering. The authors conclude that hybrid architectures may be required to fully address the communication challenges observed in highly dynamic road conditions [5].

To address lane-keeping instability and collision risks under dynamic road scenarios, the authors propose a V2V-based risk assessment and control system utilizing a Model Predictive Control (MPC) framework. Their prototype exchanges real-time vehicle parameters such as speed, position, and steering dynamics between neighboring vehicles to enhance cooperative driving accuracy. The system efficiently maintains lane alignment and prevents potential collisions through predictive adjustments. The results highlight that integrating V2V data with MPC significantly improves decision-making and responsiveness, particularly in complex traffic environments[6].

The reviewed literature highlights the significant role of Vehicle-to-Vehicle (V2V) communication in improving road safety through cooperative awareness and real-time information exchange. Existing studies demonstrate the effectiveness of sensor-based collision detection, vehicular ad hoc networks, and intelligent driver assistance systems, while also revealing challenges related to high implementation cost, infrastructure dependency, communication latency, and limited real-world deployment. Building upon these findings, the proposed system focuses on a low-cost, ESP32-based V2V communication framework utilizing the ESP-NOW protocol for direct, infrastructure-free data exchange. By integrating real-time sensor data, GPS-based positioning, and multi-modal alert mechanisms including voice alerts, visual indicators, and buzzers, the system aims to enhance driver awareness, reduce reaction time, and improve overall collision avoidance reliability in practical vehicular environments.

2. EXISTING SYSTEM

Current vehicle safety systems primarily rely on onboard sensors and driver assistance technologies such as adaptive cruise control, parking assistance, and collision warning systems. These systems monitor the immediate surroundings of a vehicle and generate alerts based on local sensor readings. While effective in isolated scenarios, such systems lack cooperative awareness and are unable to share critical information with nearby vehicles. As a result, potential hazards

beyond the sensor range or line of sight cannot be predicted in advance.

A. Limitations of the existing system

1. Vehicles operate independently without inter-vehicle communication

In existing vehicle safety systems, each vehicle functions as an isolated unit and relies solely on its onboard sensors and driver inputs. There is no mechanism for sharing critical information such as sudden braking, obstacle presence, or accident alerts with nearby vehicles. As a result, drivers are often unaware of potential hazards occurring beyond their immediate field of view, leading to delayed reactions and increased accident probability, especially in high-speed or congested traffic conditions.

2. Sensor-based detection has limited range and visibility

Most conventional safety systems depend on sensors such as ultrasonic sensors, cameras, or radar to detect obstacles. While effective within a short range, these sensors have limitations in terms of distance, angle, and environmental conditions. Factors such as sharp curves, blind spots, poor lighting, fog, or heavy rain significantly reduce detection accuracy. This limited sensing capability restricts early hazard identification and compromises overall safety.

3. Delayed driver response increases collision risk

Even when warning systems are present, the effectiveness of accident prevention largely depends on the driver's reaction time. Human response is often delayed due to fatigue, distraction, stress, or cognitive overload in complex traffic situations. A delay of even a few milliseconds can lead to rear-end collisions or multi-vehicle accidents. Existing systems lack proactive communication mechanisms to provide early warnings before a hazardous situation fully develops.

4. High implementation cost restricts widespread adoption

Advanced driver assistance and collision avoidance systems typically require expensive hardware such as high-resolution cameras, radar units, and complex processing modules. This creates a safety gap where only premium vehicles benefit from advanced protection, leaving a large number of vehicles without effective safety mechanisms.

5. Lack of cooperative alerts leads to chain collisions in dense traffic

In dense traffic environments, accidents often occur in a chain reaction where a single sudden event triggers multiple collisions. Existing systems do not support cooperative alerts between vehicles, meaning that warnings are not shared beyond the affected vehicle. Without real-time cooperative communication, following vehicles receive alerts too late, increasing the likelihood of multi-vehicle pileups. This highlights the need for a coordinated V2V alert mechanism.

B. PROPOSED SYSTEM

The proposed system introduces an integrated Vehicle-to-Vehicle (V2V) communication framework aimed at enhancing road safety through cooperative awareness and real-time alert generation. Unlike conventional vehicle safety systems that function independently, the proposed approach enables direct communication between nearby vehicles to share safety-critical information such as obstacle presence, vehicle position, sudden braking, and emergency conditions. Each vehicle is equipped with an ESP32 microcontroller that acts as the central processing and communication unit. The system continuously collects data from multiple sensors to monitor the vehicle's surroundings and motion status. When a potential hazard is detected, the vehicle immediately generates alerts for the driver and broadcasts warning messages to neighboring vehicles using the ESP-NOW wireless protocol. This direct, infrastructure-free communication ensures minimal latency and reliable data exchange, which is crucial for time-sensitive collision avoidance applications. To enhance driver interaction and reduce response time, the system employs multi-modal alert mechanisms including voice alerts, buzzer signals, LED indicators, and display messages. Additionally, cloud-based monitoring through the Blynk IoT platform enables real-time visualization of vehicle parameters, supporting system evaluation and future scalability.

C. Advantages of the proposed system

1. Real-Time cooperative awareness among vehicles

The system enables vehicles to share safety-critical information such as obstacle detection, sudden braking, and emergency conditions in real time. By exchanging this information directly with nearby vehicles, drivers gain awareness of potential hazards beyond their immediate field of view. This cooperative awareness allows vehicles to respond proactively rather than

reactively, significantly reducing the chances of unexpected collisions in dynamic traffic environments.

2. Low-cost and scalable hardware design

The system is designed using affordable and easily available components such as the ESP32 microcontroller and basic proximity sensors. This low-cost hardware architecture makes the system economically viable for large-scale deployment across different vehicle categories. Additionally, the modular design allows easy scalability, enabling more vehicles to be added to the network without complex configuration or infrastructure upgrades.

3. Infrastructure-free communication using ESP-NOW

Unlike conventional vehicular communication systems that depend on roadside units or cellular networks, the proposed system uses the ESP-NOW protocol for direct device-to-device communication. This infrastructure-free approach ensures reliable operation even in remote or network-limited areas. The low-latency communication provided by ESP-NOW is particularly suitable for time-critical safety applications such as collision avoidance.

4. Enhanced driver interaction through voice alert

To minimize driver distraction and reduce reaction time, the system incorporates voice-based alerts along with visual and audible indicators. Voice alerts provide clear and intuitive warnings, allowing drivers to understand the situation without diverting their attention from the road. This human-centric alert mechanism improves driver response, especially in high-speed congested traffic conditions.

5. Improved collision avoidance and road safety

By combining real-time sensing, cooperative V2V communication, and multi-modal alerts, the proposed system significantly enhances collision avoidance capabilities. Early detection of hazards and timely dissemination of warnings enable drivers to take preventive actions well in advance. As a result, the system contributes to overall road safety by reducing accident probability, minimizing chain collisions, and promoting safer driving behavior.

D. METHODOLOGY

The methodology of the proposed Vehicle-to-Vehicle (V2V) communication system focuses on real-time data acquisition, processing, wireless communication, and driver alert generation. The system follows a modular and decentralized approach where each vehicle independently collects sensor data, processes potential hazards, and cooperatively shares safety information with nearby vehicles. This ensures timely collision avoidance and enhanced situational awareness.

A. System Architecture

The system architecture consists of several interconnected functional modules integrated within each vehicle. These modules work collaboratively to sense the environment, communicate with nearby vehicles, and alert the driver during hazardous conditions.

1. Data Acquisition Module

The data acquisition module is responsible for collecting real-time information from the vehicle's surroundings and motion state. Ultrasonic and IR sensors are used to detect obstacles and measure the distance between the vehicle and nearby objects. These sensors continuously monitor the road environment and provide accurate proximity data. Additionally, a GPS module is used to obtain real-time vehicle location, enabling position-based alert sharing among vehicles.

2. Processing and Decision-Making Module

The ESP32 microcontroller acts as the central processing unit of the system. It receives raw data from the sensors and processes it to determine potential risk conditions. Threshold-based logic is applied to identify critical events such as obstacle proximity, sudden deceleration, or unsafe distance. Based on the analyzed data, the ESP32 decides whether an alert needs to be generated locally or transmitted to nearby vehicles. This real-time decision-making capability is essential for rapid collision avoidance.

3. Vehicle-to-Vehicle Communication Module

For inter-vehicle communication, the system employs the ESP-NOW protocol, which enables direct wireless communication between ESP32 devices without requiring internet connectivity or centralized infrastructure. Each vehicle broadcasts safety messages containing essential information such as hazard type,

vehicle position, and alert status. Nearby vehicles receive and process these messages to enhance cooperative awareness. The low-latency nature of ESP-NOW ensures fast and reliable alert dissemination in time-critical situations.

4. Alert and Driver Assistance Module

Once a hazardous condition is detected either locally or through received V2V messages, the alert module is activated. The system generates multi-modal alerts using voice notifications, buzzer signals, LED indicators, and display messages. Voice alerts provide clear and immediate warnings to the driver, reducing cognitive load and response time. Visual and audible alerts act as supporting indicators to ensure effective notification even in noisy or distracted driving conditions.

5. Monitoring and Visualization Module

To support real-time monitoring and performance evaluation, the system integrates with the Blynk IoT platform. Vehicle parameters such as sensor readings, alert status, and GPS location are transmitted to the cloud for visualization. This module helps in analyzing system behavior, validating performance, and enabling future enhancements such as remote diagnostics and data logging.

A. Data flow Processing

The system follows a continuous data flow model where sensor data is periodically collected and analyzed by the ESP32. When a potential hazard is detected, alert messages are generated and simultaneously broadcast to nearby vehicles using ESP-NOW. Incoming messages from other vehicles are validated and combined with local sensor data to improve situational awareness. Based on this combined information, appropriate alerts are issued to the driver in real time.

B. Operational Workflow

- Sensors mounted on the vehicle continuously collect real-time environmental and vehicle-related data such as obstacle distance and proximity.
- The collected sensor data is transmitted to the ESP32 microcontroller for processing and analysis.
- The ESP32 evaluates the incoming data using predefined threshold conditions to identify potential hazards or unsafe situations.

- When a hazardous condition is detected, safety alerts are generated locally within the vehicle.
- The system broadcasts warning messages to nearby vehicles using the ESP-NOW Vehicle-to-Vehicle communication protocol.
- At the same time, the system receives alert messages from other vehicles in the vicinity.
- Received alerts are analyzed and combined with local sensor data to enhance cooperative awareness of surrounding traffic conditions.
- Based on the processed information, multi-modal alerts such as voice notifications, buzzer signals, LED indicators, and display messages are generated.
- These alerts notify the driver in real time, enabling timely and appropriate preventive action to avoid collisions.

D. Key Methodological Features

1. Decentralized and infrastructure-free communication

The proposed system follows a decentralized communication approach where each vehicle operates independently while cooperatively exchanging safety information with nearby vehicles. By using the ESP-NOW protocol, direct Vehicle-to-Vehicle communication is achieved without relying on external infrastructure such as cellular networks, roadside units, or cloud servers. This infrastructure-free design ensures reliable system operation even in remote or network-constrained areas and eliminates single points of failure, making the system more robust and practical for real-world deployment.

2. Low-latency real-time alert dissemination

Timely delivery of safety alerts is critical for effective collision avoidance. The proposed methodology ensures low-latency communication by using ESP-NOW, which enables fast data transmission between vehicles with minimal overhead. Sensor data is processed locally by the ESP32 microcontroller, and alerts are generated and broadcast immediately upon hazard detection. This real-time alert dissemination significantly reduces response time and allows drivers to take preventive action before a hazardous situation escalates.

3. Human-centric alert mechanisms

To improve driver response and reduce cognitive load, the system incorporates human-centric alert mechanisms that combine voice alerts with visual and

audible indicators. Voice notifications provide clear and intuitive warnings, allowing drivers to understand the nature of the hazard without diverting attention from the road. Supporting alerts such as buzzers, LEDs, and display messages ensure that warnings are noticeable under various driving conditions, enhancing overall system effectiveness and usability.

4. Scalable and cost-effective system design

The system is designed using low-cost, readily available hardware components such as the ESP32 microcontroller and basic sensors, making it economically viable for large-scale deployment. The modular architecture allows easy integration of additional vehicles without complex configuration or infrastructure expansion. This scalability ensures that the system can be extended to larger vehicular networks while maintaining cost efficiency, supporting future adoption in intelligent transportation systems.

E. Tools and Technologies Used

The proposed Vehicle-to-Vehicle (V2V) communication system is implemented using reliable hardware and software technologies to ensure real-time performance, low latency, and scalability:

- **Microcontroller Platform:** ESP32 (core processing, sensing, and wireless communication)
- **Sensors and Modules:** Ultrasonic sensor, IR sensor, MPU6050 (motion and orientation), GPS module
- **Communication Technology:** ESP-NOW protocol (low-latency, infrastructure-free V2V communication)
- **Alert and Interface Devices:** Buzzer, LEDs, OLED display, voice alert module
- **Development Environment:** Arduino IDE (programming and debugging)
- **Monitoring and Visualization:** Blynk IoT platform (real-time data visualization and system monitoring)

F. Training and Testing Process

Training and testing were conducted to ensure reliable and accurate system performance. Sensors were calibrated and validated to obtain precise distance, motion, and location data. Individual modules were tested separately to verify correct operation. ESP-NOW communication was evaluated



between multiple ESP32 nodes to ensure low-latency and reliable data exchange. Integrated testing was performed under simulated driving scenarios such as obstacle detection and emergency alerts. System response time and alert accuracy were monitored using onboard displays and the Blynk platform.

E. OUTPUT AND RESULT

This section presents the experimental results obtained from the implementation and testing of the Vehicle-to-Vehicle (V2V) communication system. The system was evaluated using a working prototype under simulated driving conditions to assess sensor accuracy, communication reliability, alert effectiveness, and overall system performance. Output images from the implementation are included to demonstrate system functionality.

A. Sensor Interfacing and Vehicle Data Acquisition

The sensor interfacing module successfully acquired real-time vehicle and environmental data during system operation. Ultrasonic and IR sensors accurately measured the distance between vehicles and nearby obstacles, enabling early detection of unsafe proximity. The MPU6050 sensor reliably captured vehicle motion parameters such as acceleration, tilt, and sudden braking, while the GPS module provided continuous location updates. The collected data remained stable and responsive under different test scenarios, confirming effective real-time vehicle data acquisition.

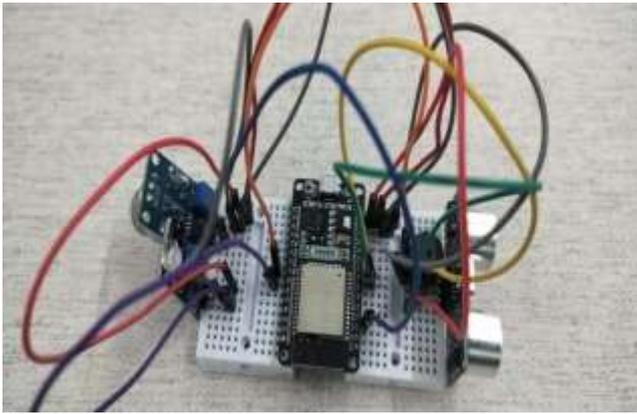


Fig 1.1 Sensor Interfacing with ESP32

B. Vehicle-to-Vehicle Communication Performance

This module demonstrated reliable Vehicle-to-Vehicle communication using the ESP-NOW protocol. Multiple ESP32-based vehicle units successfully established peer-to-peer connections and exchanged safety-related messages without relying on internet connectivity or external infrastructure. Alert messages were transmitted and received with minimal delay, ensuring timely information sharing between vehicles. The results validate the effectiveness of infrastructure-free, low-latency V2V communication.



Fig 1.2. ESP-NOW Communication

C. Collision Detection and Driver Alert Mechanism

The collision detection module effectively identified hazardous situations by analyzing sensor data against predefined safety thresholds. When unsafe distance, sudden braking, or abnormal motion was detected, the system immediately generated alerts. Multi-modal driver notifications including voice alerts, buzzer sounds, LED indicators, and display messages were activated in real time. These alerts

provided clear and timely warnings, improving driver awareness and response during critical situations.

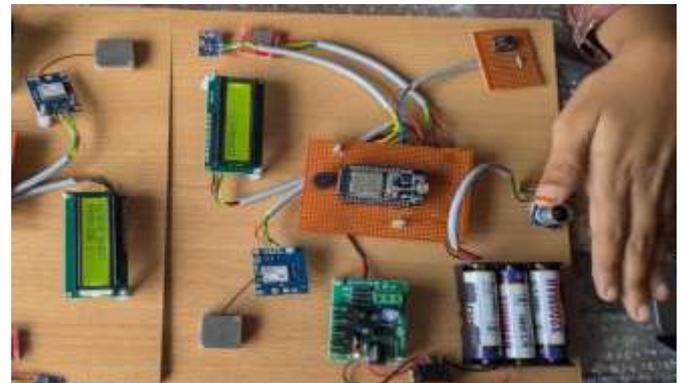


Fig No. 1.3. Obstacle detection using ultrasonic sensor

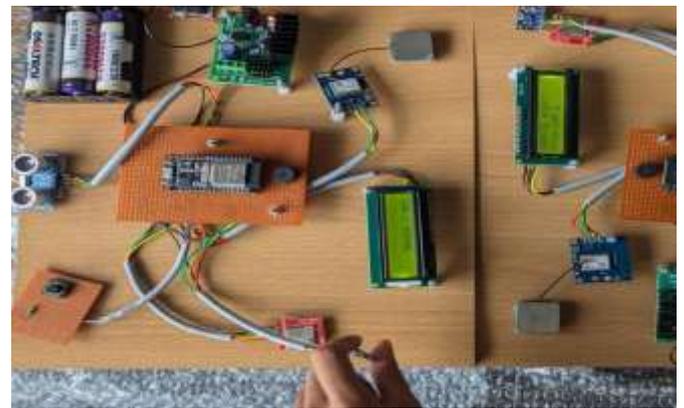


Fig 1.4 Lane Change Detection using MPU6050

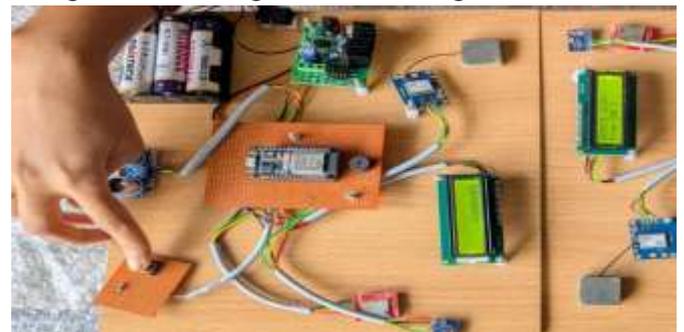


Fig 1.5 SOS Button for Emergency

D. Decision-Making, Vehicle Control, and Emergency Response

The decision-making module successfully evaluated both locally detected hazards and alerts received from nearby vehicles. Based on the severity of the detected event, appropriate emergency responses were initiated, including priority alert generation and continuous warning signals. This

module enhanced cooperative awareness by enabling vehicles to react proactively to potential risks beyond their immediate sensing range. The results confirm effective decision-making support for safer vehicle operation.

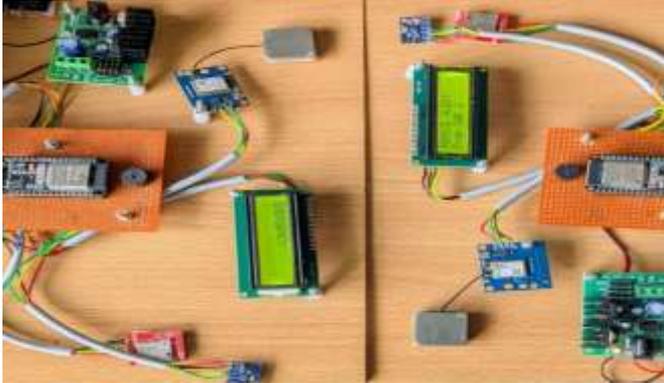


Fig 1.6 Vehicle control and Emergence Response

E. Data Visualization, System Testing, and Performance Evaluation

Real-time data visualization was achieved using the Blynk IoT platform, displaying sensor readings, alert status, and vehicle location during system operation. The dashboard accurately reflected real-time system behavior and supported continuous monitoring during testing. Performance evaluation showed stable system operation, low communication latency, accurate hazard detection, and reliable alert delivery. Overall testing results confirm that the system performs effectively under simulated traffic conditions.



Fig no. 1.7 Data visualization using Blynk

F. Overall Outcome

The overall outcome of the Vehicle-to-Vehicle communication system demonstrates effective integration of real-time sensing, low-latency inter-vehicle communication, and intelligent alert mechanisms to enhance road safety. The system

successfully detected potential collision scenarios, shared safety alerts between nearby vehicles, and notified drivers through multi-modal alerts in a timely manner. Infrastructure-free communication ensured reliable operation without external dependencies, while real-time visualization supported continuous monitoring and performance evaluation. These results confirm that the system provides a practical, scalable, and cost-effective solution for cooperative collision avoidance in intelligent transportation environments.

F. CONCLUSION

This work presents the design and implementation of a Vehicle-to-Vehicle communication system focused on improving road safety through cooperative awareness and real-time information sharing. The system integrates sensing, communication, and alert mechanisms to detect hazardous driving conditions and support timely driver response. By enabling direct communication between vehicles, the system addresses limitations of conventional sensor-only safety approaches and enhances overall situational awareness. The system effectively combines ultrasonic, motion, and location sensors to continuously monitor vehicle behavior and surrounding conditions. Sensor data is processed locally to identify unsafe proximity, sudden braking, and abnormal vehicle movement. These detected events are shared with nearby vehicles using ESP-NOW based communication, allowing vehicles to anticipate potential risks beyond their direct sensing range without relying on internet connectivity or roadside infrastructure.

Multi-modal alert mechanisms, including voice alerts, buzzer signals, LED indicators, and display messages, play a crucial role in improving driver awareness. These alerts provide clear and immediate notifications during critical situations, reducing driver reaction time and supporting safer driving decisions. The decentralized decision-making process ensures low-latency response and reliable operation even in dense traffic environments.

Experimental results confirm that the system operates reliably with low communication delay, accurate hazard detection, and stable performance under simulated traffic scenarios. The cost-effective and scalable design makes the system suitable for practical deployment in intelligent transportation systems. Overall, the developed V2V communication framework demonstrates strong potential to enhance collision avoidance capabilities and serve as a foundation for

future advancements in connected and autonomous vehicle technologies.

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