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Vehicle-to-Vehicle (V2V) Communication: Design, Components, Benefits, Challenges, and Implementation Using Embedded Systems

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Abstract: Vehicle-to-Vehicle (V2V) communication is a key technology in Intelligent Transportation Systems (ITS), enabling vehicles to share real-time information such as speed, braking, and hazard warnings. Unlike conventional sensors limited by line-of-sight, V2V enhances cooperative awareness to reduce accidents, improve traffic flow, and optimize fuel efficiency. This paper presents the design of a low-cost prototype using Arduino Uno, ultrasonic sensors, tilt sensors, and HC-12 wireless modules, supported by an LCD, buzzer, and regulated power supply for driver alerts. The system detects obstacles, monitors driver attentiveness, and transmits warnings within a 1 km range. While the prototype shows feasibility for affordable deployment, challenges such as limited range, security, and standardization must be addressed. Future integration with 5G, C-V2X, and AI-based traffic management can further enhance safety and scalability.

Keywords— Vehicle-to-Vehicle (V2V), Intelligent Transportation Systems (ITS), Embedded Systems, Arduino, Ultrasonic Sensor, Tilt Sensor, HC-12 Wireless Module, Road Safety, Collision Avoidance, Cooperative Driving.

I. INTRODUCTION

The exponential growth of the global vehicle population has intensified concerns over traffic congestion, air pollution, and most critically, road accidents. According to the World Health Organization (WHO), approximately 1.3 million people die annually in road traffic accidents, with human error accounting for more than 90% of these fatalities. This alarming statistic highlights the urgent need for technologies that can assist drivers, reduce response delays, and enable cooperative decision-making between vehicles.

Fig. 1. What is Vehicle-to-Vehicle (V2V) communication.

Vehicle-to-Everything (V2X) communication has emerged as a promising solution, where vehicles communicate with infrastructure, pedestrians, and other vehicles. Within V2X, Vehicle-to-Vehicle (V2V) communication is particularly crucial, as it enables direct exchange of speed, braking, and positional data between vehicles without reliance on external infrastructure. Unlike conventional sensors such as cameras and radars, which are constrained by weather or line-of-sight limitations, V2V allows vehicles to develop cooperative awareness, making it more resilient in diverse driving conditions.

This study presents the development of a prototype V2V communication system built on embedded platforms to demonstrate real-time hazard detection and driver alertness monitoring. The proposed solution emphasizes affordability and scalability, making it a practical approach for enhancing road safety in regions where advanced Intelligent Transport System (ITS) infrastructure is limited.

This paper presents the design and implementation of a cost-effective V2V system using embedded hardware components. By integrating Arduino microcontrollers, ultrasonic and tilt sensors, and HC-12 wireless modules, the prototype demonstrates how affordable embedded platforms can deliver real-time hazard detection and driver assistance.

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Such solutions are especially valuable for developing nations where large-scale ITS infrastructure may not yet be feasible.

II. EXISTING SYSTEM

Dedicated Short-Range Communications (DSRC): This technology uses a dedicated frequency band (5.9 GHz) for short-range communication between vehicles, allowing them to exchange information like speed, location, and braking status.

Cellular Vehicle-to-Everything (Cellular V2X):This approach leverages existing cellular networks for vehicle-to-everything communication, enabling wider coverage and integration with other infrastructure and services.

Onboard Communication Units (OBUs):These devices are installed in vehicles to send and receive data, forming the core of the V2V communication infrastructure**.**

Sensors and GPS:Vehicles use onboard sensors and GPS to gather data about their position, speed, and other relevant information, which is then transmitted to other vehicles via V2V communication.

Cloud Integration : Some systems integrate with cloud infrastructure to provide centralized data processing and analysis, enabling features like traffic flow optimization and predictive safety alerts.

III. PROPOSED SYSTEM

Advanced Wireless Technologies: Research and development are exploring new wireless technologies, such as Li-Fi (Light Fidelity), which uses light signals for communication, and other advanced protocols for data exchange.

Enhanced Data Sharing:Future systems are expected to support more comprehensive data sharing, including real-time traffic conditions, road hazards, and even driver behavior data, to enable more proactive and safer driving.

Autonomous Vehicle Integration: V2V communication is seen as crucial for the development of autonomous vehicles, allowing them to communicate with each other and with infrastructure to ensure safe and efficient operation.

IV. VEHICLE TO A VEHICLE COMMUNICATION SYSTEM

Research on Vehicle-to-Vehicle (V2V) communication began in 2003 under the Vehicle Infrastructure Integration (VII) program, though its foundations can be traced back to automated highway initiatives of the early 1990s. V2V communication leverages Internet of Things (IoT) principles and modern computing technologies to enable vehicles to exchange real-time data regarding traffic conditions, braking events, and potential hazards through ad hoc mesh networks. Depending on the vehicle's system design, drivers may receive early warning messages about accidents or congestion, or autonomous functions may automatically adjust speed, reroute, or stop the vehicle to ensure safety. Studies indicate that up to 60% of road accidents could be prevented if drivers were provided with timely warnings.

The effectiveness of V2V communication depends on robust protocols and secure data exchange. Dedicated ShortRange Communication (DSRC) standards have been developed to minimize delays in broadcasting safety messages and to support both public safety and private vehicular applications. Typically, V2V-enabled vehicles broadcast messages up to ten times per second within a range of approximately 300 meters, providing information about speed, position, weather, and terrain . Combined with sensors such as radars and cameras, these systems enhance situational awareness, reduce collisions, and support cooperative driving. However, the reliability of such systems is strongly tied to network performance; communication delays, signal loss, or misrouted messages can increase risks rather than mitigate them.

Fig. 2. Vehicle collision.

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This technology also uses radars and cameras to detect and avoid collisions of vehicles. It not only helps drivers and automatic vehicles to survive from dangerous threats but also avoid creating crashes. Vehicle to vehicle communication protocols can be used by any vehicle like cars, buses, trucks to enhance their visibility. This communication protocol ensures the confidentiality of the driver's information while sending and receiving warning messages. The vehicletovehicle communication protocol system increases the performance of the security system of vehicles and saves the lives of many. Every year millions of people die and get injures in road accidents, which can be avoided using this vehicle-to-vehicle communication protocol technology.

A. components of vehicle to vehicle communication

1. **ArduinoUno**: A microcontroller board based on the ATmega328P, widely used for embedded applications. It serves as the central processing unit, handling sensor inputs, communication data, and control outputs in real time.
2. **TiltSensor:** A mercury-based tilt sensor used to detect driver head movement or inclination, enabling drowsiness detection and generating alerts in case of inattentiveness.
3. **HC-12WirelessModule:**
   A serial communication module that supports multi-channel wireless data transmission. Operating in the 433–473 MHz band, it provides a communication range of up to 1 km between vehicles.
4. **UltrasonicSensor(HC-SR04):**
   A sensor that measures distance by transmitting and receiving ultrasonic waves. It is used for obstacle detection, collision avoidance, and proximity monitoring.
5. **Liquid Crystal Display(LCD16×2):** A display module with command and data registers used to provide realtime alerts and messages to the driver, such as obstacle warnings or driver attentiveness notifications.

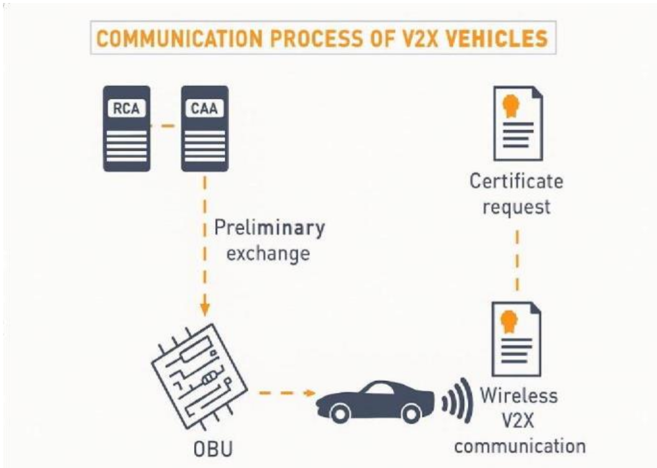

Fig3. Public key infrastructure for V2X

V. BENEFITS OF V2V COMMUNICATION

Vehicle-to-Vehicle (V2V) communication protocols provide a wide range of benefits that directly address the challenges of modern transportation systems. One of the most significant advantages is **collision avoidance**, as vehicles continuously share speed, position, and braking data to warn drivers of potential hazards. This cooperative awareness reduces human reaction time delays and prevents crashes in high-risk areas such as intersections, highways, and blind spots. It also helps to consume fuel effectively by the truck's platoons. Truck platoons are a group of trucks that follow each other. The leading truck will show the route that enables the other trucks to consume less fuel to reach the destination.

The vehicle-to-vehicle communication protocol systems in vehicles will help to optimize the routes by giving exact location and less time-consuming route map to the drivers . Another benefit is **traffic efficiency**, as vehicles equipped with V2V systems can coordinate movements, reduce unnecessary braking, and optimize lane changes. This leads to smoother traffic flow, reduced congestion, and improved fuel economy, particularly when combined with vehicle platooning strategies. In addition, **environmental benefits** arise from lower emissions due to reduced idling and more efficient driving patterns.
Lastly, the protocol plays a crucial role in the **transition to autonomous vehicles**. By providing a reliable data

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exchange platform, V2V supports cooperative adaptive cruise control, lane merging, and coordinated decision-making among autonomous fleets. This not only improves safety but also accelerates the adoption of connected and autonomous vehicle ecosystems.

Fig 4. vehicle communication

VI. LIMITATION OF VEHICLE-TO-VEHICLE COMMUNICATION

Vehicle-to-Vehicle (V2V) communication protocols and security frameworks face significant limitations that make real-time implementation challenging. Some of the key issues are :

Frequency Bandwidth: The spectrum allocated for V2V is limited and cannot effectively support communication when a large number of vehicles operate in the same area.

Protocol and Security Issues: Real-time operation introduces interoperability concerns and security vulnerabilities that affect reliability and raise public safety risks.
Cyber-Attacks: Vehicles using Dedicated ShortRange Communication (DSRC) may be exposed to hacking.

In such cases, attackers could take control of the vehicle, create large-scale disruptions, or exploit the system for criminal or terrorist purposes.

Data Privacy Risks: V2V systems store sensitive information such as vehicle location, identification, and driver details. Unauthorized access, for example through automated license plate readers, could lead to identity theft or misuse of vehicle data.

The Vehicle-to-vehicle communication protocol and security systems at present need .

Lack of Regulations: Since V2V is still a developing technology, legal frameworks and government regulations remain insufficient. In cases of miscommunication leading to accidents, liability issues may fall unfairly on vehicle owners.

Human Intervention: Current systems still rely on human monitoring for safety. If the driver is inattentive or misinterprets a warning, accidents may still occur despite the technology.

- **Vehicle Dependency:** Implementation depends on the vehicle model and system complexity, meaning not all vehicles can be uniformly equipped with V2V technology.

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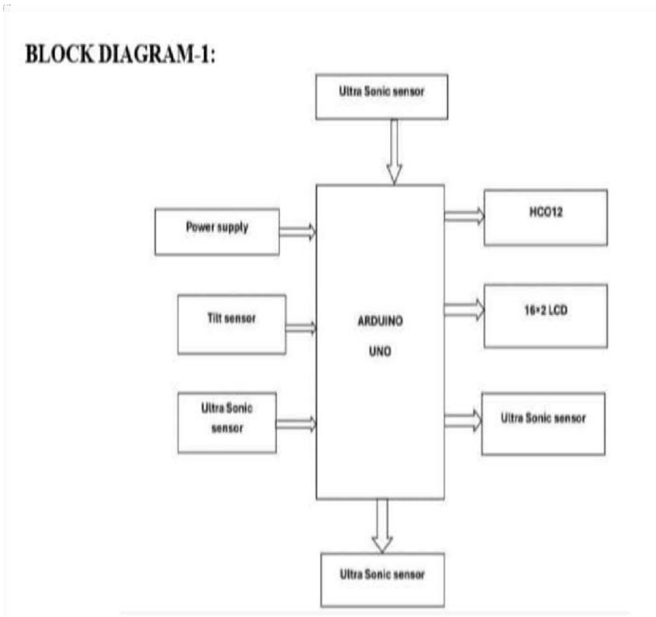


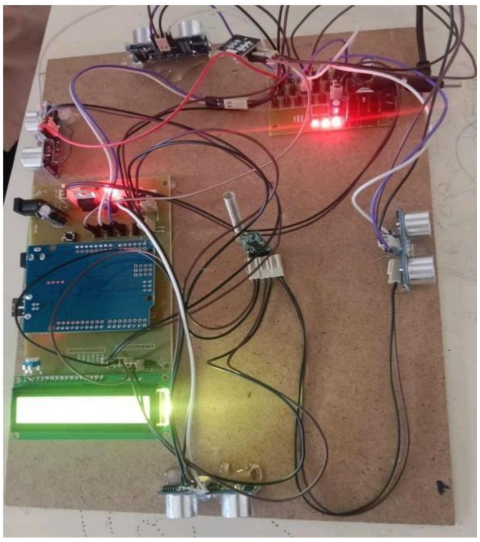
Fig 5. Block diagram

VII. APPLICATIONS OF -VEHICLE - TO-VEHICLE COMMUNICATION SYSTEMS

Vehicle-to-Vehicle (V2V) communication systems enable vehicles to exchange real-time information that improves safety, reduces accidents, and enhances overall traffic efficiency. By allowing vehicles to share data such as speed, braking, and positional information, V2V applications play a crucial role in driver assistance, cooperative awareness, and intelligent transport systems Key applications of V2V communication include: 1)**Collision Avoidance:** Vehicles exchange speed and distance information to provide early warnings of potential rear-end or head-on collisions. **2)Intersection Safety:** Alerts drivers when it is unsafe to enter intersections, helping to prevent crashes with crossing traffic.

3)Lane Change Assistance: Detects vehicles in blind spots or adjacent lanes and issues timely alerts to prevent unsafe lane changes. **4)Emergency Vehicle Notification:** Allows ambulances, police, or fire services to broadcast priority messages so nearby vehicles can yield the way. **5)Adaptive Cruise and Platooning:** Enables multiple vehicles to maintain coordinated speeds and safe distances, improving fuel efficiency and traffic flow. **6)Traffic Flow Optimization:** Shares real-time traffic and congestion data among vehicles to reroute trips and reduce delays. **7)Driver Condition Monitoring:** Works with onboard sensors to detect driver fatigue or inattention, providing alerts to both the driver and surrounding vehicles.

VIII. RESULT



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Vehicle to vehicle communication system (V2V) can send and receive the vehicle information by wireless communication, and can use as a safety driving assist for driver. Currently, it is investigated to clarify an appropriate activation timing for collision information, caution and warning. This study focused on the activation timing of collision information (Provide objective information for safe driving to the driver) on V2V, and an effective activation timing of collision information, and the relationship between the activation timing and the accuracy of the vehicle position.

IX. CONCLUSION

Vehicle-to-Vehicle (V2V) communication stands as a cornerstone of next-generation Intelligent Transport Systems, offering the potential to significantly reduce road accidents, improve traffic flow, and enhance driver awareness. This work presented the design and implementation of a low-cost V2V prototype using embedded components such as Arduino Uno, ultrasonic sensors, tilt sensors, and HC-12 wireless modules. Experimental evaluation confirmed that the system can successfully detect obstacles, monitor driver attentiveness, and transmit hazard alerts in real time, demonstrating its feasibility as a practical safety solution.

While the prototype validates the effectiveness of embedded systems for cooperative communication, challenges related to security, interoperability, and large-scale deployment remain. These must be addressed through strong encryption protocols, universal communication standards, and supportive regulatory frameworks.

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