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V2V Collision Avoidance and Automatic Braking System based on IoT

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Abstract—The steady increase in vehicular traffic has led to a rise in road accidents, with rear-end collisions being one of the most frequent types. These accidents are often caused by delayed driver reaction and the absence of timely communication between vehicles. To address this issue, this paper presents a low-cost Vehicle-to-Vehicle (V2V) collision warning and automatic braking system based on Internet of Things (IoT) technology. The pro-posed system employs an ESP32 microcontroller and ultrasonic sensors to continuously monitor inter-vehicle distance and iden-tify unsafe proximity conditions. When a potential collision or sudden braking event is detected, warning information is shared with nearby vehicles through an IoT communication framework, enabling early awareness beyond the sensing range of individual vehicles. Based on the received alerts, an automatic braking mechanism is activated to reduce collision risk and prevent chain accidents. The system is designed to operate without dependence on dedicated roadside infrastructure, making it suitable for cost-effective and scalable deployment. Experimental validation using a hardware prototype demonstrates improved reaction time, enhanced situational awareness, and reliable collision mitigation, demonstrating the practical feasibility of the proposed approach for future intelligent transportation and V2X systems.

Index Terms—Vehicle-to-Vehicle Communication, Internet of Things, Collision Avoidance, Automatic Braking, ESP32, Ultra-sonic.

I. INTRODUCTION

With the growing number of vehicles, traffic safety is a major concern. Due to delayed human response, a large number of road accidents, particularly rear-end collisions, have occurred [1], [2]. Increased traffic density with no quick response, leading to sudden braking, results in a chain collision. Traditional safety mechanisms rely totally on driver assistance. Current technologies, such as parking sensors, rear-view cameras, and braking assistance, have improved personal safety, but they operate autonomously and are limited by line-of-sight [2], [3]. The present system helps to provide early warnings occurring out of the driver's vision, particularly in heavy traffic regions. Many vehicle-to-vehicle (V2V) communication solutions have surfaced to exchange real-time information, namely speed, location, and braking status, between vehicles [4], [5].

V2V communication systems help predict potential collision risks and enable timely preventive actions. Studies have shown that using V2V communication has helped reduce the likelihood of collisions and also improved reaction time. Particularly for the conditions that require sudden braking [6], [7]. Advancements in the Internet of Things(IoT) technology have improved the practicality of V2V-based safety systems. With the help of IoT V2V architectures, support low-cost hardware, cloud-based communication, and scalable deployment without the need for costly roadside infrastructure [8]–[10].

Additionally, new advancing communication technology such as LTE-Vehicle-to-everything (V2X), 5G-V2X, and future 6G-based systems aspire to achieve ultra-low latency and high reliability, making them suitable for safety-critical vehicular applications [11]–[13]. Despite these Technological advancements, many V2V communication systems focus on the transmission of a warning message, then apply intelligent braking control [14], [15].

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These constraints emphasise the need for practical, low-cost, infrastructure-independent V2V collision avoidance solutions that incorporate real-time sensing, communication, and automatic braking. Motivated by these challenges, this paper presents an IoT-based V2V collision avoidance and automatic braking system. It is designed to enhance road safety by reducing driver reaction time and preventing rear-end collisions. The proposed system integrates ultrasonic distance sensing, cloud-assisted V2V communication, and automated braking using low-cost components. Hardware-based experimental evaluation demonstrates the effectiveness of the system in improving situational awareness and lessening collision risks, providing a foundation for future intelligent transportation and V2X systems.

II. RELATED WORK

V2V communication has been broadly known as an essential technology for road safety. Therefore, enhancing road safety through the real-time exchange of information among vehicles. Prior study by Talukder et al. [1] suggests an IoT-enabled Vehicular Ad-Hoc Network (VANET) V2V framework for collision detection and prevention. The approach illustrated in the paper has reduced the response time using inter-vehicle communication. Though the system was not assessed during heavy traffic situations. A V2V system proposed by Sugayadevi et al. for accident prevention, which focuses on early warning transmission. The system illustrates a functional possibility. However, it fails to provide a report on communication delay and reliability [2]. An intelligent IoT-based collision avoidance system proposed by Yadav and Goyal [3], which showed improved response time in small-scale testing. However, communication loss and large-scale performance were not addressed. Demonstration done by Haider et al. [4], a cross-layer, direction-aware V2V architecture for cooperative collision avoidance, also reduces decision delay. Although it failed to analyse scalability and congestion effects. The convergence of IoT and V2X technologies was presented by Hejazi and Bokar [5]. It illustrates models and utilises cases for a cooperative Intelligent Transportation System (ITS). However, it fails to compare system performance metrics across different deployment strategies.

A V2V-based collision avoidance decision strategy for autonomous vehicles interacting with pedestrians was presented by Zou et al. [6]. It verified the improved safety through proportional braking, but communication reliability during heavy traffic conditions was not verified. A V2V-based automatic braking system was developed by Sowyna et al. [7] for chain accident prevention, establishing a reduced stopping distance. However, the effects of packet loss and delayed message reception have not been proven. However, the study does not evaluate the difference between the security overhead and real-time communication latency. Chauhan et al. suggested an IoT-based vehicular emergency communication system using V2V alert. Though it lacked a quantitative analysis of the packet delivery framework for diverse vehicle densities [8]. An IoT-based system was introduced by Ashwini et al. [9] V2V communication system for accident alert transmission. The system was not verified for its scalability analysis and packet delivery. Vandana and Ramya introduced a V2V framework based on fog-computing to reduce communication latency [10]. Although the energy efficiency and deployment operability were not considered.

A comprehensive survey conducted by Annu and Rajalaxami on the 6th generation(6G) V2X sidelink communication, focusing on resource allocation strategies. The mathematical formulations aspired to achieve ultra-low latency. The paper just remains a conceptual insight; it lacks a theoretical illustration [11]. Similarly, Rahim et al. analysed the enabling technology’s performance targets for 6G-based V2X communication. The paper emphasises the 1 sub-millisecond latency. It fails to demonstrate practical implementation challenges [12]. Evaluation by Zorkany et al. of the extent and complexities of V2V communication. It emphasises the issues related to latency, scalability, and security. The study provides direction for further research; however, it does not offer a quantitative performance analysis [13]. Algorithmic coordination strategies for V2V communication were introduced by Radman et al. [14]. However, no real-world demonstration is provided. Gupta and Nayal [15] surveyed security requirements in a publish-subscribe-based V2V communication system, and distinguished key security properties. It doesn’t analyse latency-security trade-offs.

Overall, the literature indicates that while significant progress has been made in V2V communication and collision avoidance, many existing systems remain limited by infrastructure dependence, lack of real-world validation, and insufficient integration of automatic braking mechanisms. These gaps motivate the development of a low-cost, real-time, and infrastructure-independent IoT-based V2V collision avoidance system, as proposed in this work.

III. PROPOSED SYSTEM OVERVIEW

A. Overall System Architecture

The proposed system is an IoT-based V2V collision warning and automatic braking system that was developed to enhance road safety by decreasing the number of rear-end and chain collisions. Each vehicle (car) in the system is outfitted with sensing, processing, communication, and braking modules. The inter-vehicle distance is continuously monitored. It detects unsafe conditions and issues warning information to neighbouring vehicles using cloud-assisted V2V communication. Once a potential collision scenario is detected, the system initiates braking to reduce vehicle speed and prevent accidents. The system is designed to operate independently of roadside units, making it relevant

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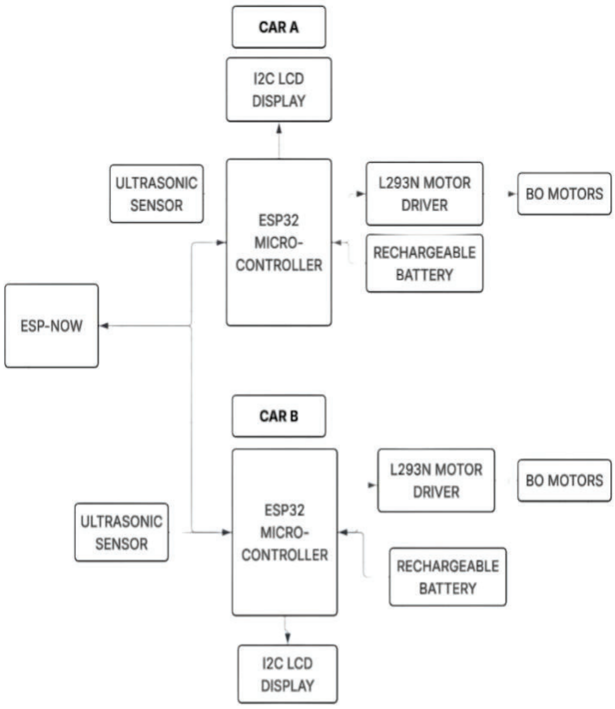

Fig. 1. Proposed System

for cost-effective and scalable deployment.

1. Sen r integration: Ultrasonic sensors are used for real-time obstacle and distance detection. The sensor operates by transmitting ultrasonic pulses and calculating the time-of-flight of the reflected signal to estimate distance. The effective sensing range of the sensor is approximately 2 cm to 400 cm, with an average measurement accuracy of ±3 mm. The sensor continuously monitors the frontal region of the vehicle at a sampling rate of approximately 10–15 readings per second, ensuring timely detection of unsafe proximity. When the measured distance falls below a predefined safety threshold (typically 20–30 cm for prototype validation), the system flags a potential collision condition.

2. Data processing unit: The data processing unit is implemented using an ESP32 microcontroller, which serves as the central control module of the system. The ESP32 processes distance measurements in real time and compares them against predefined safety thresholds to determine collision risk. Due to its dual-core architecture and integrated Wi-Fi capability, the ESP32 supports fast decision-making with minimal latency, typically under 50 ms for local processing. Based on the sensor input and received V2V alerts, the controller generates warning signals, controls the braking mechanism, and updates system status on the display module.

3. Collisio detection and avoidance system: The collision detection logic is based on continuous evaluation of inter-vehicle distance and received warning messages from other vehicles. If the detected distance drops below the safety threshold or a braking alert is received from a preceding vehicle, the system classifies the situation as hazardous. The avoidance strategy prioritises early detection and timely response to reduce dependency on driver reaction. In such scenarios, the system generates a collision warning and immediately triggers the automatic braking process to decelerate the vehicle in a controlled manner.

4. Vehicle-to- hicle communication: Vehicle-to-vehicle communication is achieved using Wi-Fi-based connectivity. Each vehicle periodically sends its status information, including distance measurements and braking alerts, to the surrounding vehicles using ESP-NOW. This cooperative communication mechanism allows vehicles beyond direct sensor range or line-of-sight to receive early warnings, thereby improving overall situational awareness.
ESP-NOW is a lightweight wireless communication protocol developed by Espressif Systems for microcontroller platforms such as the ESP32 and ESP8266. It enables efficient, low-latency communication between devices without requiring a traditional Wi-Fi infrastructure such as a router or access point. ESP-NOW operates using a peer-to-peer (P2P) communication mechanism, where devices communicate directly with each other using their unique MAC addresses for identification and data transmission. The protocol supports the exchange of small data packets with a maximum payload size of approximately 250 bytes, making it suitable for applications that require rapid transmission of sensor readings, control signals, or status information. Communication using ESP-NOW can be configured in either one-way or two-way modes. ESP-NOW primarily operates at the data-link layer of the OSI(Open System Interconnection) model, which contributes to its fast response time and minimal communication overhead. Under ideal environmental conditions, the protocol can achieve a communication range of approximately 220 meters; however, the actual range may vary depending on factors such as signal interference, physical obstacles, and antenna design. ESP-NOW is particularly suitable for real-time embedded systems and V2V communication applications due to its low latency and lightweight architecture.

5. Autom ic braking and actuation: The automatic braking module is activated when a collision risk is detected locally or through V2V communication. Instead of abrupt braking, the system applies controlled deceleration by modulating motor speed in multiple stages. This progressive braking approach helps maintain vehicle stability and reduces passenger discomfort. In critical situations, full braking is applied automatically to prevent impact. The braking status is continuously monitored and updated in real time to ensure reliable system operation.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

TABLE I
OVERVIEW OF THE PROPOSED IOT-BASED V2V COLLISION WARNING AND BRAKING SYSTEM

Aspect	Description
System objective	Early collision warning and automatic braking using V2V communication
Core hardware platform	ESP32 microcontroller integrated with ultrasonic distance sensors
Sensing approach	Short-range distance measurement for unsafe proximity detection
Communication mechanism	ESP NOW platform for inter-vehicle message exchange
Decision logic	Threshold-based collision risk assessment
Braking strategy	Automatic brake activation upon violation of safety distance
Operating environment	Prototype evaluated under controlled experimental conditions
Intended application	Low-cost experimental validation of V2V safety concepts
Key limitation	Dependent on network latency and sensor line-of-sight conditions

6. Real-Tim monitoring and user interface: The system is embedded with an LCD to provide real-time feedback to the driver. It displays key information such as obstacle distance, braking status, and received V2V alerts. The distance value is displayed in centimetres.

This section consists of the proposed system. Table I presents an overview of the key design aspects, operational characteristics, and validation scope of the IoT-based V2V collision warning and braking prototype. This overview highlights the system objectives, core components, and inherent limitations identified during prototype-level evaluation.

IV. SETTING PARAMETERS OF THE PROPOSED SYSTEM

This section describes the main parameters used in the proposed IoT-based Vehicle-to-Vehicle (V2V) collision avoidance system. These parameters determine how the system measures the distance between vehicles, evaluates potential collision risks, and activates automatic braking to ensure safe operation.

A. Distance Measurement Using Ultrasonic Sensor

Accurate distance estimation is essential for detecting poten-tial collision risks between vehicles. In the proposed system, the distance between vehicles is measured using an ultrasonic sensor.

Ultrasonic sensors operate on the time-of-flight principle: a high-frequency sound wave is transmitted toward an object, and the time for the reflected echo to return is measured.

The distance between the sensor and the obstacle can be calculated as:

$$d = \frac{v_s \times t}{2} \tag{1}$$

where

- d = distance between vehicles (m)
- v_s = speed of sound in air (approximately 343 m/s)
- t = round-trip travel time of the ultrasonic pulse (s)

Ultrasonic sensing is widely used in intelligent transportation and collision detection systems due to its low cost, short-range accuracy, and ease of integration with embedded platforms.

B. Braking Distance

Braking distance refers to the distance a vehicle travels after braking begins until it comes to a complete stop. Even when braking is activated immediately, the vehicle cannot stop instantly due to its forward momentum.

The total stopping distance of a vehicle can be expressed as:

$$d_{stop} = d_{reaction} + d_{brake} \tag{2}$$

where

- $d_{reaction}$ = distance travelled during system reaction time
- d_{brake} = distance required for the vehicle to stop after braking begins

1) Factors Affecting Braking Distance: The braking distance mainly depends on several factors.

Vehicle Speed: Higher vehicle speed increases the kinetic energy of the vehicle, which leads to a longer stopping distance.

Braking Capability: The braking mechanism and motor control determine how quickly the vehicle can decelerate.

Surface Conditions: Road conditions influence braking efficiency. Slippery surfaces increase braking distance, while dry surfaces allow faster stopping.

C. Stopping Threshold

To prevent collisions, the system must determine the distance at which braking should begin. This distance is called the stopping threshold.

In the proposed system, the stopping threshold is defined as:

$$d_{stop} = 0.25m \tag{3}$$

When the measured distance between vehicles becomes less than or equal to this threshold, the system activates emergency braking.

1) Justification of the Selected Threshold: The stopping threshold was determined based on system reaction delay, motor braking distance, and sensor measurement uncertainty.

Motor Braking Distance

After braking begins, the motors require a short distance to stop the vehicle completely. Experimental testing shows that the braking distance of the prototype vehicle is approximately:

$$d_{brake} \approx 0.1 - 0.12m \tag{4}$$

Sensor Safety Margin

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Vol. 15 Issue 05 , May - 2026

Ultrasonic sensors may experience small measurement variations due to environmental noise, surface reflections, or signal delays. Therefore, a safety margin is added:

$$d_{margin} \approx 0.03 - 0.05m \tag{5}$$

Total Safe Stopping Distance

The total safe stopping distance can therefore be estimated as:

$$d_{total} = d_{reaction} + d_{brake} + d_{margin} \tag{6}$$

$$d_{total} \approx 0.23 - 0.27m \tag{7}$$

Based on this analysis, a threshold value of 0.25 m is selected as the braking trigger distance. This ensures that the vehicle begins braking before reaching the obstacle while maintaining reliable sensor detection performance.

TABLE II
PARAMETERS USED FOR STOPPING THRESHOLD SELECTION

Parameter	Value Used in Prototype	Explanation
Vehicle speed	0.4–0.6 m/s	Speed of prototype vehicle
System reaction time	~0.2 s	Time required to detect and process sensor data
Reaction distance	~0.1 m	Distance travelled during reaction delay
Motor braking distance	~0.1–0.12 m	Distance required for motors to stop Compensation
Sensor safety margin	~0.03–0.05 m	for sensor measurement error Estimated safe
Total stopping distance	~0.23–0.27 m	stopping distance Final braking trigger distance
Selected stopping threshold	0.25 m	tance

D. raking Logic

The braking logic determines how the system responds when the distance between vehicles changes.

Two operational states are defined as:

$$B = \begin{cases} 0 & \text{Normal driving} \\ 1 & \text{Emergency braking} \end{cases} \tag{8}$$

The braking decision depends on the measured distance d relative to the stopping threshold d_{stop}:

$$B = \begin{cases} 0 & d > d_{stop} \ 1 \\ & d \leq d_{stop} \end{cases} \tag{9}$$

If the measured distance remains greater than the threshold, the vehicle continues normal operation. However, when the distance becomes smaller than or equal to the threshold, the system immediately activates emergency braking.

V. M HODOLOGY

This section describes the operational workflow of the proposed system introduced in Section III.

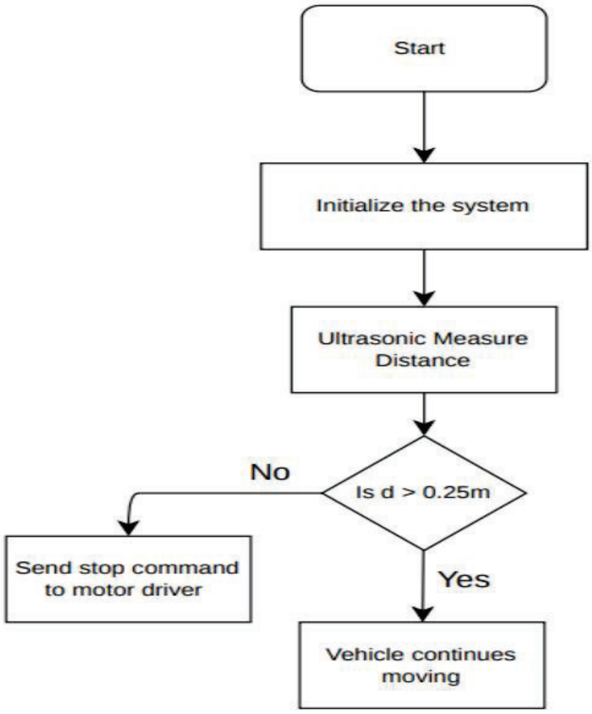

Fig. 2. Braking Logic

A. Sys m workflow

This segment describes the operational workflow of the proposed V2V collision-warning and automatic-braking systems. The operations performed by the system, from real-time sensing to cooperative braking action, are through V2V communication.

1. ontinual monitoring:
The ultrasonic sensors are used for the detection of obstacles and the distance of the vehicle from the obstacle. The ultrasonic is mounted in the front of the vehicle and continuously measures the distance between the vehicle and the obstacle. The measured distances are updated in real-time.

2. Data quisition processing:
Sensor data acquired from the ultrasonic module is transmitted to the ESP32 microcontroller for processing. The microcontroller calculates the distance using the time-of-flight principle and compares the measured value against a predefined safety threshold. This processing is performed locally to minimise decision latency and enable rapid response to changing traffic conditions.

3. Ha rd identification:
When the measured inter-vehicle distance falls below the defined safety threshold, the system classifies the situation as a potential collision hazard. This hazard identification stage acts as the trigger point for subsequent warning

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

generation and braking decisions. The classification is based on a threshold-based logic suitable for real-time embedded implementation.

4. Alerts generati
Once a hazardous condition is identified, the system generates an alert that includes relevant safety information, such as obstacle distance and braking status. This alert is immediately transmitted via ESP-NOW to other car with ESP32.

5. Automa c application of braking mechanisms:
When a valid collision alert is received—either from local sensor detection or V2V communication—the automatic braking mechanism is activated. The ESP32 controller sends control signals to the motor driver to reduce vehicle speed or apply braking. This autonomous response minimises reliance on driver reaction time and reduces the likelihood of rear-end or chain collisions.

6. D ver notification and system feedback:
Real-time feedback is provided to the driver through an onboard LCD. The display shows key parameters such as obstacle distance, alert status, and braking activation messages. This feedback enhances driver awareness and provides transparency regarding system actions during normal and emergency scenarios.

VI. IM MENTATION

The implementation of the proposed IoT-based V2V collision warning and automatic braking system is carried out using low-cost embedded hardware and cloud-assisted software. This section describes the hardware components, software design, and operational workflow of the system.

A. Hardwa design

- ESP32 Microcontroller: Used as the central processing and communication unit.
- Ultrasonic Sensor: Used for real-time distance measurement.
- Motor Driver Module: Used to control vehicle speed and braking.
- DC Motors: Represent vehicle motion in the prototype. • LCD Display: Used for real-time system feedback.
- Power Supply Unit: Rechargeable battery pack.

The ultrasonic sensor fitted in front of the vehicle operates within the range of 2 cm to 400 cm. Ultrasonic measures the distance continuously between the vehicle and the obstacle ahead. On receiving the distance measurements, the ESP32 performs real-time processing. A motor driver interfaced with the ESP32 to regulate motor speed. According to the command generated the motor driver either reduces the speed gradually or applies a complete stop during emergency conditions. The LCD provides real-time alerts, obstacle

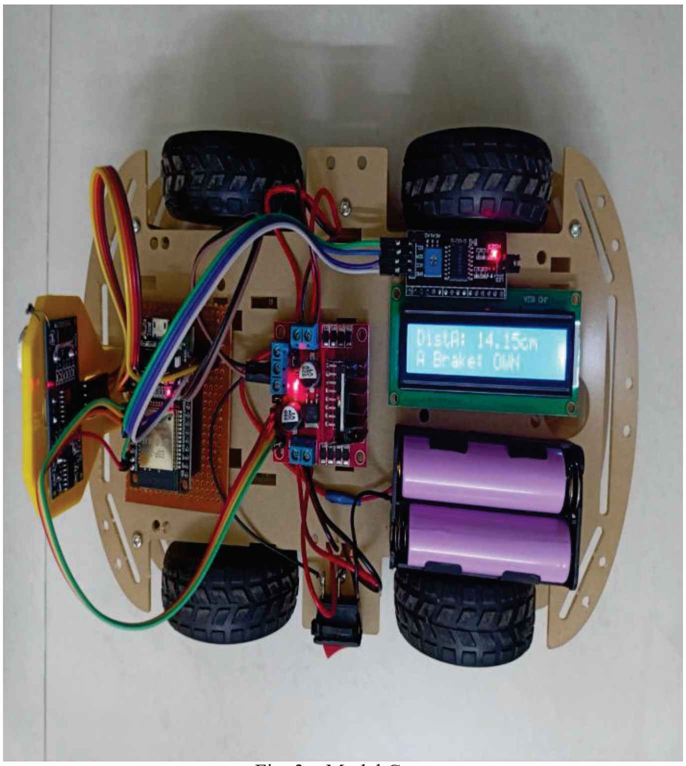

Fig. 3. Model Car

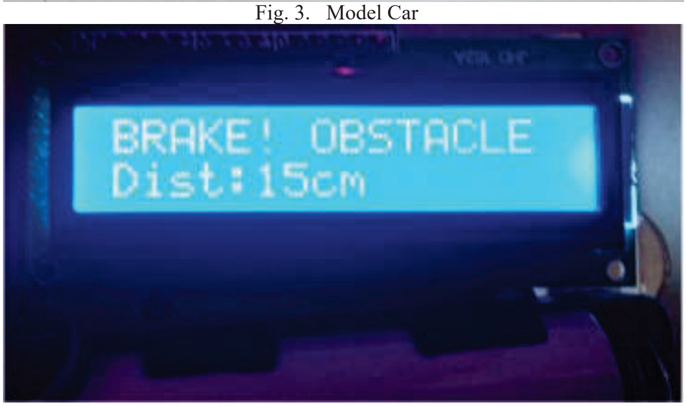

Fig. 4. Braking Alert

distance, and braking status.

B. Soft re design

The system firmware is developed using the Arduino IDE and programmed in embedded C/C++. The ESP32 software follows a continuous execution loop to ensure real-time operation.

At the initial state, the ESP32 establishes a Wi-Fi connection. Once connected. The distance values given by the ultrasonic sensor are continuously processed and compared against the predefined threshold values. If collision risk is detected, an alert status is updated to the ESP-NOW dashboard, and suitable signals are sent to the motor driver.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 05 , May - 2026

The alert status is updated on the LCD.

C. V2V co unication implementation

V2V communication is implemented using ESP-NOW. Each vehicle publishes its braking and alert status to an individual ESP-NOW dashboard. When a nearby vehicle receives the alert in near real time, and initiate a preventive braking response. This communication enables cooperative safety without requiring dedicated roadside infrastructure.

VII. ULT AND DISCUSSION

The proposed IoT-based V2V collision warning and automatic braking system was implemented using ESP32 microcontrollers, ultrasonic sensors, motor drivers, and LCDs integrated into prototype vehicles, as shown in Fig. 3. During experimental testing, the ultrasonic sensor successfully detected obstacles within its operating range of 2 to 400 cm and continuously transmitted distance measurements to the ESP32 controller. The measured values were processed in real time and displayed on the LCD interface, Fig. 4, confirming correct obstacle detection and system monitoring.

When the measured distance entered the predefined critical zone, the controller generated braking commands that reduced the vehicle's speed and automatically stopped the vehicle. The system also demonstrated successful V2V alert communication via ESP-NOW, allowing neighbouring vehicles to receive braking alerts and respond accordingly. The average system response time during the testing is significantly less than the typical human reaction time, allowing earlier braking activation and improved collision avoidance in the prototype system.

VIII. USION AND FUTURE SCOPE

This paper presented the design and implementation of a Vehicle-to-Vehicle (V2V) collision warning and automatic braking system aimed at reducing rear-end and chain collisions. The proposed system integrates real-time obstacle detection using ultrasonic sensors, cloud-assisted V2V communication, and automatic braking controlled by an ESP32 microcontroller. Experimental evaluation of the hardware prototype demonstrated reliable distance detection, timely alert dissemination, and effective braking response without driver intervention.

The results confirm that cooperative communication between vehicles significantly reduces reaction time compared to human response alone, thereby improving overall road safety. The use of low-cost hardware makes the proposed system affordable, scalable, and suitable for prototype-level validation. The successful implementation highlights the feasibility of developing infrastructure-independent V2V safety systems using IoT technology.

Future work may also include the integration of addi-tional sensors such as radar, LiDAR, and cameras to improve detection accuracy under adverse weather and low-visibility conditions. Machine learning algorithms can be incorporated to enable predictive collision analysis, adaptive braking, and driver behaviour monitoring. Furthermore, the system can be extended from a single-vehicle prototype to a fleet-level deployment for large-scale traffic safety applications. These enhancements would contribute toward the development of fully autonomous, intelligent transportation systems and next-generation V2X communication frameworks.

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