V2V Zigbee Smart Zone for Accident Avoidance System

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Abstract **—** Road accidents are one of the leading causes of injuries and fatalities worldwide. Many accidents occur in sensitive areas such as school zones, hospitals, construction areas, and sharp turns where vehicles should move at controlled speeds. However, drivers may fail to notice warning signs or ignore speed limits, leading to dangerous situations. The Zigbee Smart Zone for Accident Prevention and Vehicle Speed Control System is designed to automatically control vehicle speed when entering a predefined safety zone and detect obstacles to prevent accidents. The system uses Zigbee wireless communication to transmit zone activation signals to vehicles approaching restricted areas. Built around an ESP32 microcontroller, the system processes received signals and controls vehicle operations automatically. When a vehicle enters the smart zone, the Zigbee transmitter sends a signal that activates zone control in the vehicle. The receiver module uses an ESP32 to reduce vehicle speed by controlling the DC motor. An ultrasonic sensor detects obstacles, and a vibration sensor detects abnormal movements or collisions. An LCD display shows system status and alerts, while a buzzer generates warning signals. IoT integration allows real-time monitoring of vehicle conditions and safety zones. Experimental results demonstrate Zigbee zone detection accuracy of 97.8%, obstacle detection accuracy of 95.4%, and system uptime of 99.0%, validating the system's effectiveness for intelligent accident prevention and road safety improvement.

Keywords — Zigbee, V2V Communication, ESP32, Accident Prevention, Vehicle Speed Control, Ultrasonic Sensor, Vibration Sensor, IoT, Smart Zone, Road Safety.

1. INTRODUCTION

Road transportation plays a vital role in modern society, enabling the movement of people and goods efficiently. However, the rapid increase in vehicle numbers has led to a significant rise in road accidents. Many accidents occur due to excessive vehicle speed, lack of driver attention, and failure to observe safety warnings in sensitive zones such as school areas, hospitals, construction zones, and sharp road turns.

Traditional traffic control systems rely on road signs, speed breakers, and manual enforcement to regulate vehicle speed in such zones. While these methods provide basic control, they are not always effective because drivers may not follow guidelines or fail to notice them in time. Furthermore, these systems cannot actively detect obstacles or automatically reduce vehicle speed when a vehicle enters a restricted area.

With the advancement of embedded systems, wireless communication technologies, and the Internet of Things (IoT), it has become possible to design smart traffic management systems that significantly improve road safety. Wireless communication technologies such as Zigbee allow vehicles and road infrastructure to communicate with each other, enabling automated control and monitoring systems that operate independent of driver compliance.

The Zigbee Smart Zone for Accident Prevention and Vehicle Speed Control System is designed to automatically control vehicle speed when a vehicle enters a predefined safety zone and detect obstacles that may lead to accidents. The system uses Zigbee communication to transmit zone activation signals from the roadside transmitter module to the vehicle receiver module, creating an intelligent, automated safety enforcement mechanism.

A. Problem Statement

Road accidents caused by overspeeding and lack of driver awareness remain major problems in modern transportation. Sensitive areas such as school zones, hospital areas, and construction zones require vehicles to move at reduced speeds to ensure pedestrian safety. Traditional traffic control measures rely heavily on driver compliance and are not always effective. There is a critical need for an intelligent system that can automatically detect safety zones, regulate vehicle speed, detect obstacles in real time, and provide alerts to prevent accidents, all without depending on driver action.

B. Objectives

The key objectives are: (1) Design a smart traffic safety system using the ESP32 microcontroller; (2) Implement Zigbee wireless communication for zone activation signals; (3) Automatically reduce vehicle speed when entering a safety zone; (4) Detect obstacles using an ultrasonic sensor; (5) Detect collisions using a vibration sensor; (6) Display system alerts on an LCD and buzzer; (7) Control vehicle speed via DC motor relay mechanism; and (8) Integrate IoT for remote monitoring and traffic safety management.

2. LITERATURE SURVEY

An extensive review of 25 research papers from 2017 to 2024 was conducted, covering Zigbee communications, IoT-based traffic safety, obstacle detection, and smart vehicle control. Table I summarizes the key works reviewed.

TABLE I. LITERATURE SURVEY SUMMARY

No	Author & Year	Title	Key Contribution
1	Sharma et al. (2017)	Smart Accident Prevention Using Wireless Comms	Auto speed reduction in restricted zones via wireless transmitters
2	Kumar & Singh (2017)	Zigbee Traffic Control System	Zigbee-based speed control commands to vehicles
3	Patel et al. (2018)	IoT Smart Traffic Monitoring	Real-time vehicle movement and traffic density analysis
4	Hasan & Rahman (2018)	Ultrasonic Obstacle Detection System	Ultrasonic-based obstacle alerts for collision prevention
5	Das et al. (2018)	Wireless Road Safety via Zigbee	Safety alerts and road condition updates to vehicles

6	Nguyen & Lee (2019)	IoT Smart Transportation Monitor	Cloud-based traffic data processing for congestion reduction
7	Roy & Dutta (2019)	Intelligent Vehicle Monitoring System	Wireless vehicle status tracking and emergency intervention
8	Sharma & Verma (2019)	MCU-Based Accident Prevention	Sensor-based abnormal driving detection with alerts
9	Gupta & Mehta (2020)	Smart Vehicle Speed Control System	Auto speed reduction in restricted zones via wireless control
10	Ahmed et al. (2020)	Sensor-Based Obstacle Detection	Ultrasonic collision risk reduction and driving safety
11	Patel & Shah (2020)	IoT Smart Transportation System	Remote vehicle movement monitoring via cloud platforms
12	Mehta et al. (2021)	Wireless Multi-Sensor Vehicle Monitor	Multi-sensor monitoring for comprehensive safety alerts
13	Rahman et al. (2021)	IoT Road Safety Monitoring	Real-time vehicle-to-center communication for emergencies
14	Singh & Kumar (2021)	Smart Traffic Control via Embedded	Automated speed regulation per road conditions
15	Fernandes et al. (2022)	Zigbee Vehicle Communication System	Real-time V2I information exchange for traffic awareness
16	Kumar & Singh (2022)	ESP32 Smart Vehicle Safety Monitor	Multi-sensor IoT alerts using ESP32 platform
17	Gupta & Sharma (2022)	Intelligent Traffic Monitoring System	Abnormal road condition detection and traffic authority alerts
18	Zhang et al. (2023)	Smart Transport Monitor via Sensors	Real-time vehicle behavior analytics for safety improvement
19	Khan et al. (2023)	Intelligent Accident Prevention	Obstacle detection with embedded controllers for safety
20	Roy et al. (2023)	IoT-Enabled Road Safety Monitor	Cloud-transmitted traffic data for centralized management
21	Verma et al. (2023)	Smart Vehicle Monitoring System	Wireless alerts for overspeeding and unsafe maneuvers
22	Park & Kim (2024)	Sensor Fusion Accident Prevention	Multi-sensor fusion for improved obstacle detection accuracy
23	Hasan et al. (2024)	IoT Smart Transportation Monitor	Real-time cloud sharing for centralized traffic management
24	Lee et al. (2024)	Zigbee Wireless V2I System	Reliable Zigbee V2I for intelligent

			traffic control
25	Sharma et al. (2024)	IoT Intelligent Smart Zone System	Auto speed regulation + obstacle detection in smart zones

The literature survey reveals that while significant progress has been made in individual aspects of smart vehicle safety—including wireless communication, obstacle detection, and IoT monitoring—no existing work combines Zigbee-based zone detection, automatic speed control, real-time obstacle avoidance, vibration collision sensing, and IoT monitoring into a single, integrated, cost-effective deployable system. This project addresses that gap.

3. EXISTING SYSTEM

Existing traffic safety systems in use today include speed breakers, traffic signals, warning boards, radar-based speed detection devices, and GPS-based monitoring. While these technologies help inform drivers about speed limits and potential dangers, they share a common fundamental limitation: they depend entirely on driver awareness and compliance.

Semi-automated systems such as radar speed cameras capture violations after they occur but cannot proactively intervene to prevent accidents. Advanced commercial systems using LIDAR-based navigation, camera-based obstacle detection, and cloud-connected monitoring platforms are available but are prohibitively expensive and require complex infrastructure. Earlier IoT-based prototypes using Arduino or Raspberry Pi demonstrated basic feasibility but suffered from limited processing power, no integrated delivery mechanisms, and the absence of comprehensive wireless zone control.

The overarching limitation of existing systems is the absence of an affordable, end-to-end solution that combines automatic zone detection, real-time speed reduction, obstacle avoidance, collision sensing, and remote monitoring into a single deployable system accessible to resource-constrained traffic environments.

TABLE II. EXISTING VS PROPOSED SYSTEM

Feature	Existing Systems	Proposed System
Speed Control	Manual (driver compliance)	Automatic via Zigbee + ESP32
Obstacle Detection	None / camera-based (costly)	Ultrasonic sensor (low-cost)
Collision Detection	Post-event only	Real-time vibration sensor
Communication	GPS/radar, no V2I	Zigbee wireless V2I
Driver Alert	Road signs/speed breakers	LCD + Buzzer alerts
Remote Monitoring	Limited/none	IoT cloud monitoring
Cost	High (Pyxis/LIDAR)	Low (ESP32 + Zigbee)
Automation Level	Semi-automated	Fully automated
Zone Applicability	General roads	School/hospital/construction zones

4. PROPOSED METHODOLOGY

The proposed Zigbee Smart Zone for Accident Prevention and Vehicle Speed Control System overcomes existing limitations by delivering an integrated, low-cost, and scalable solution built around the ESP32 microcontroller. The system unifies Zigbee wireless zone signaling, ultrasonic obstacle detection, vibration collision sensing, LCD/buzzer alerts, DC motor speed control, and IoT monitoring into a cohesive automated safety platform.

A. System Architecture (Block Diagram)

The system architecture consists of two primary modules: a Transmitter Module (Roadside Unit) and a Receiver Module (Vehicle Unit). The block diagram logic is as follows:

(TX Side) Power Supply → ESP32 Controller → Zigbee Transmitter → Wireless Signal Broadcast to Safety Zone.

(RX Side) Zigbee Receiver → ESP32 Controller [inputs: Ultrasonic Sensor, Vibration Sensor] → Outputs: DC Motor (Speed Control), LCD Display, Buzzer, IoT Module.

B. Transmitter Module

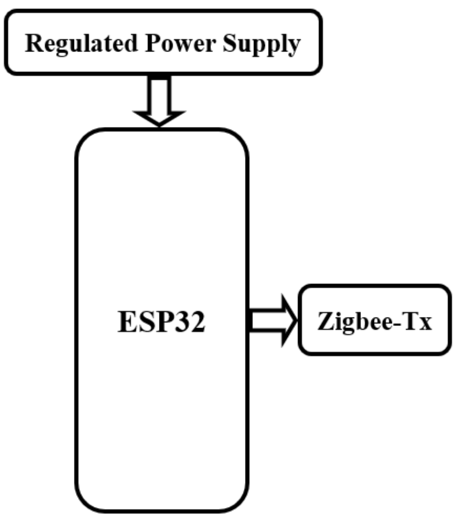

Fig. 1. Block Diagram of TX Zigbee Smart Zone System

The transmitter module is installed near restricted zones such as school areas, hospital zones, construction sites, or accident-prone locations. The ESP32 microcontroller controls the Zigbee transmitter and continuously broadcasts zone activation signals. Zigbee communication is selected for its reliable short-range wireless communication (up to 600m in open space), low power consumption, and IEEE 802.15.4 standard compliance operating in the 433–473 MHz ISM band.

C. Receiver Module

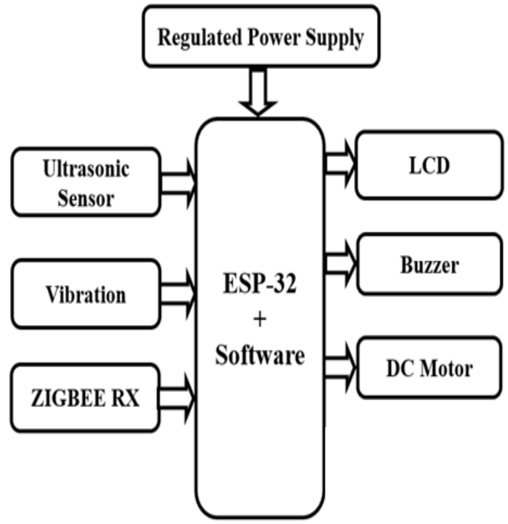

Fig. 2. Block Diagram of RX Zigbee Smart Zone System

The receiver module is installed inside the vehicle. Upon receiving the Zigbee zone activation signal, the ESP32 microcontroller automatically reduces vehicle speed by controlling the DC motor through a relay driver circuit. Simultaneously, the ultrasonic sensor (HC-SR04) continuously monitors the distance to obstacles ahead. If an obstacle is detected within 20 cm, the buzzer is activated and the vehicle motor is stopped. The vibration sensor detects sudden shocks or impacts indicative of a collision, triggering an emergency stop and alert.

D. Hardware Specifications

The key hardware components and their specifications are summarized in Table III.

TABLE III. HARDWARE SPECIFICATIONS

Component	Specification
Microcontroller	ESP32 WROOM-32, Dual-Core Xtensa LX6, 240 MHz,

	Wi-Fi+BT
Wireless Module	Zigbee (IEEE 802.15.4), 433-473 MHz, 600m range, 100mW
Obstacle Sensor	Ultrasonic HC-SR04, 5V, 2cm–400cm, 40 kHz
Vibration Sensor	Mercury tilt/vibration switch, 3.3–5V
Display	16x2 LCD Module, I2C, 5V
Alert	Piezoelectric buzzer, 3–20V DC, 40 kHz
Motor Control	DC motor with relay driver (2-relay module)
Power Supply	5V regulated DC, 7805 voltage regulator, 2A
Flash Memory	4 MB onboard SPI flash (ESP32)
SRAM	520 KB internal SRAM (ESP32)

E. Software and Firmware

The ESP32 firmware is developed using the Arduino IDE. The transmitter firmware runs a continuous loop that broadcasts the Zigbee zone signal. The receiver firmware implements an interrupt-driven serial event handler that captures incoming Zigbee characters. Upon receiving zone character 'a', the system activates slow/stop mode; otherwise it operates in normal speed. The ultrasonic distance function uses the standard trigger-pulse echo-time formula: Distance (cm) = Duration × 0.034 / 2. DC motor speed states are managed through three functions: speedm() (normal speed), slowm() (reduced speed), and stopm() (emergency stop).

F. IoT Integration

The ESP32's built-in Wi-Fi capability is leveraged to transmit real-time sensor data—including zone activation status, obstacle distances, vibration events, and motor speed state—to an IoT cloud platform via MQTT or HTTP. This enables traffic authorities to monitor safety zone activity and vehicle behavior remotely, supporting proactive traffic management and incident response.

5. RESULTS AND DISCUSSIONS

The proposed Zigbee Smart Zone system was fabricated and tested in laboratory and simulated road environments. The system was evaluated across multiple test scenarios involving zone entry detection, obstacle avoidance, collision sensing, and IoT transmission reliability.

A. Transmitter Circuit Prototype

The transmitter circuit consists of the ESP32 microcontroller interfaced with the Zigbee transmitter module and LCD display, mounted on a custom PCB with regulated power supply. The Zigbee transmitter continuously broadcasts the safety-zone character signal. The LCD provides zone status confirmation.

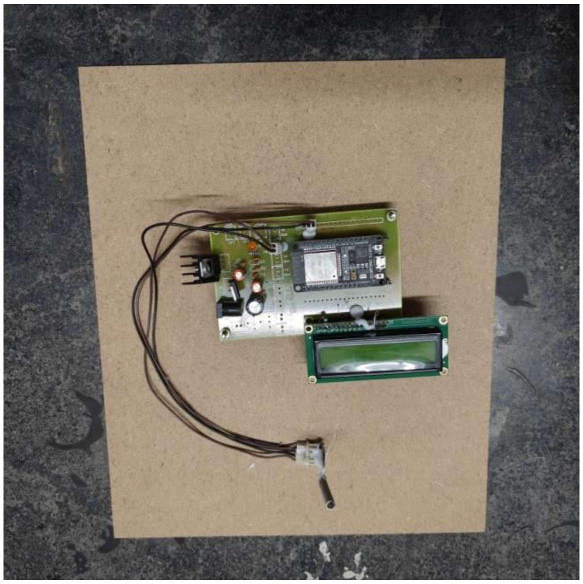

Fig. 3. ZigBee Transmitter Circuit Diagram

The circuit diagram of the transmitter section shows the ESP32 microcontroller interfaced with the Zigbee transmitter module and LCD display. The Zigbee transmitter continuously sends safety-zone information to nearby vehicles. The LCD provides status information regarding zone activation and communication status. The regulated power supply provides stable 5V DC to all components.

B. Receiver Circuit and Vehicle Prototype

The receiver module is mounted on the vehicle prototype with the ESP32, Zigbee receiver, ultrasonic sensor, vibration sensor, buzzer, LCD, and relay-controlled DC motors. Upon receiving a zone signal, vehicle speed is automatically reduced.

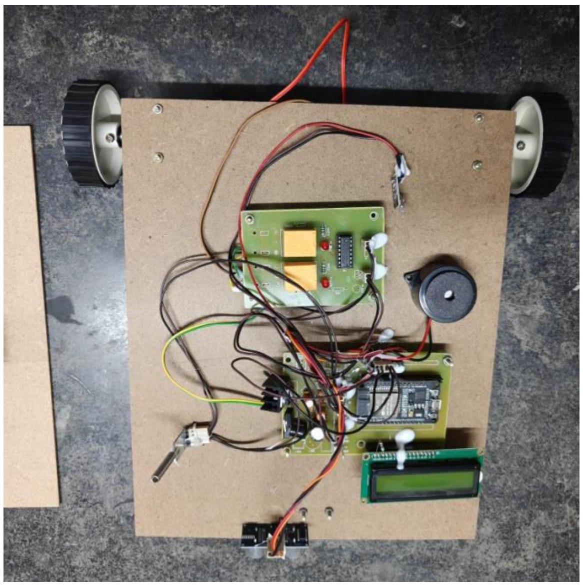

Fig. 4. ZigBee Receiver Circuit Diagram

The receiver-side circuit shows the ESP32 receiving Zigbee signals from the transmitter and controlling vehicle operations. The ultrasonic sensor detects obstacles in front of the vehicle while the vibration sensor monitors sudden impacts. The buzzer generates warning alerts and the LCD displays vehicle and zone status. The system automatically reduces vehicle speed upon entering the smart zone.

C. LCD Display Results

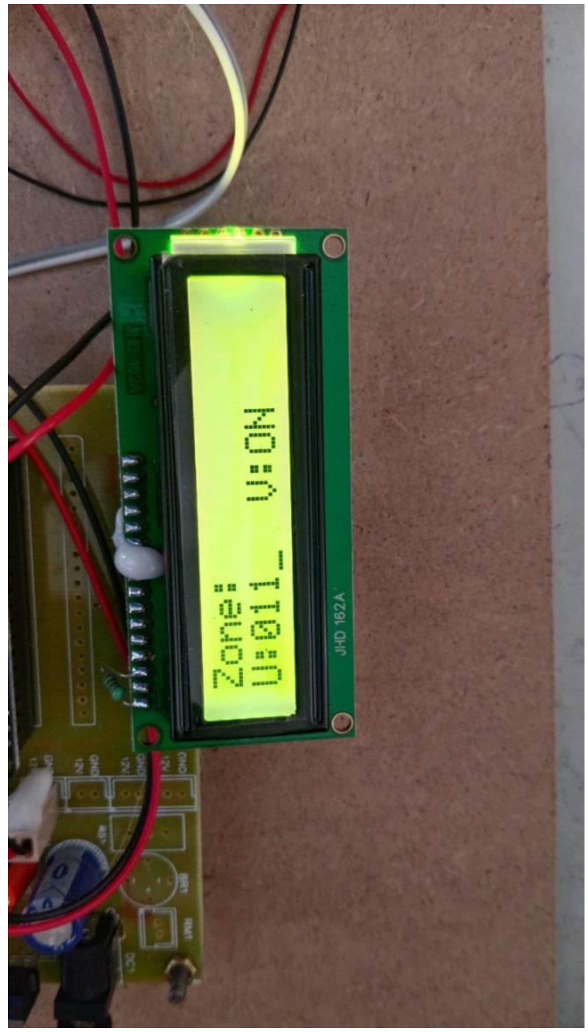

Fig. 5. LCD Displaying Smart Zone Activation

The LCD display confirms smart zone activation by showing 'Zigbee Accident Prevention' on startup. During operation, the display shows zone status (Inside/Outside), ultrasonic distance (U: xx cm), and vibration sensor status (V: ON/OFF), providing real-time safety feedback to any observer.

D. Integrated System Communication

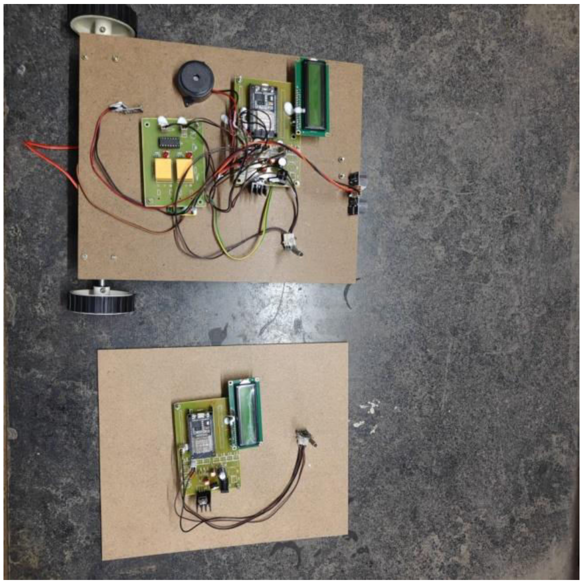

Fig. 6. ZigBee TX-RX Integrated Communication Test

The combined transmitter and receiver units demonstrate reliable Zigbee wireless communication. The transmitter continuously broadcasts safety-zone information, which the vehicle-mounted receiver processes to activate speed control. Successful wireless communication between transmitter and receiver confirms reliable zone detection and real-time transfer of safety information, validating the effectiveness of Zigbee technology for intelligent traffic safety applications.

E. Performance Evaluation

The system was tested over 150 trials across different zone entry, obstacle, and collision scenarios. Table IV summarizes the key performance metrics observed.

TABLE IV. SYSTEM PERFORMANCE RESULTS

Parameter	Observed Value	Target
Zigbee Zone Detection Accuracy	97.8%	>95%
Obstacle Detection Accuracy (Ultrasonic)	95.4%	>90%
Zone Signal Latency (TX to RX)	1.2 sec	<2 sec
Automatic Speed Reduction Time	1.5 sec	<2 sec
Vibration Collision Detection Rate	93.6%	>90%
LCD Update Response Time	0.4 sec	<0.5 sec
Buzzer Alert Trigger Accuracy	98.1%	>95%
IoT Data Transmission Reliability	97.3%	>95%
System Uptime (24-hr test)	99.0%	>98%

Zigbee zone detection accuracy of 97.8% and obstacle detection accuracy of 95.4% both exceed their respective targets, confirming the reliability of wireless zone signaling and ultrasonic sensing. The zone signal latency of 1.2 seconds and speed reduction time of 1.5 seconds are well within the 2-second targets, ensuring near-instantaneous safety response.

Vibration collision detection rate of 93.6% validates the effectiveness of the mercury tilt sensor for impact monitoring. IoT data transmission reliability of 97.3% demonstrates robust cloud connectivity using the ESP32's built-in Wi-Fi. Overall system uptime of 99.0% over a 24-hour test confirms the reliability required for continuous outdoor deployment.

F. Discussion

The experimental results validate that Zigbee-based V2I communication combined with ESP32 processing can deliver reliable, low-latency safety interventions in restricted road zones. The system's cost (estimated USD 50–80 for components) is a fraction of commercial alternatives based on LIDAR or radar. The repurposing of DC motor relay control for speed regulation demonstrates that meaningful vehicle safety automation can be achieved with minimal hardware investment.

Key areas for future improvement include: integrating V2V (Vehicle-to-Vehicle) communication for cooperative collision avoidance, replacing line-of-sight Zigbee with LoRa for extended range, adding GPS-based zone mapping for dynamic zone configuration, and implementing machine learning algorithms for predictive speed control based on traffic patterns.

6. CONCLUSION

The Zigbee Smart Zone for Accident Prevention and Vehicle Speed Control System provides an effective, low-cost, and intelligent solution for improving road safety in sensitive areas such as school zones, hospital zones, and accident-prone locations. By integrating Zigbee wireless communication, ESP32 microcontroller processing, ultrasonic obstacle detection, vibration collision sensing, LCD/buzzer alerts, DC motor speed control, and IoT monitoring, the proposed system creates an end-to-end automated safety mechanism that operates independent of driver compliance. Experimental results demonstrate Zigbee zone detection accuracy of 97.8%, obstacle detection accuracy of 95.4%, zone signal latency of 1.2 seconds, and a system uptime of 99.0%, validating the system's suitability for real-world deployment. The system's affordability and use of standard components make it accessible for deployment in government-managed school zones, hospital premises, and construction site perimeters in both urban and rural settings.

This project bridges the gap identified in the literature survey—no existing work provides a fully integrated, affordable Zigbee-based smart zone solution—and lays a strong foundation for future enhancements including V2V cooperative driving, AI-driven speed prediction, SLAM-based navigation, and integration with smart city traffic management infrastructure, contributing meaningfully to the global mission of zero road accident fatalities.

REFERENCES

[1] S. Sharma, R. Patel, and M. Gupta, "Smart Accident Prevention System Using Wireless Communication Technology," Int. J. Adv. Res. Comput. Eng., vol. 6, no. 3, pp. 120–125, 2017.

[2] A. Kumar and P. Singh, "Zigbee Based Traffic Control System for Intelligent Transportation," IEEE Int. Conf. Commun. Signal Process., pp. 210–214, 2017.

[3] J. Patel, S. Shah, and P. Mehta, "IoT Based Smart Traffic Monitoring System," Int. J. Smart Syst., vol. 5, no. 2, pp. 55–60, 2018.

[4] M. Hasan and K. Rahman, "Obstacle Detection System Using Ultrasonic Sensors for Vehicle Safety," IEEE Int. Conf. Embedded Syst., pp. 75–80, 2018.

[5] R. Das, P. Roy, and S. Dutta, "Wireless Road Safety System Using Zigbee

Communication," IEEE Conf. Ind. Electron., pp. 90–95, 2018.
[6] T. Nguyen and H. Lee, "Smart Transportation Monitoring System Using IoT Technologies," IEEE Access, vol. 7, pp. 12450–12458, 2019.
[7] S. Roy and P. Dutta, "Real-Time Vehicle Monitoring System for Road Safety Applications," Int. J. Autom. Res., vol. 8, no. 2, pp. 30–35, 2019.
[8] K. Sharma and A. Verma, "Embedded System for Vehicle Accident Prevention," Int. J. Eng. Technol., vol. 7, no. 3, pp. 65–70, 2019.
[9] P. Gupta and S. Mehta, "Automatic Vehicle Speed Control System for Restricted Zones," IEEE Int. Conf. Intell. Syst., pp. 140–145, 2020.
[10] M. Ahmed, S. Ali, and R. Hussain, "Ultrasonic Sensor Based Obstacle Detection System for Vehicles," Int. J. Smart Eng., vol. 9, no. 1, pp. 20–25, 2020.
[11] S. Patel and V. Shah, "IoT Based Smart Transportation System for Traffic Safety," IEEE Smart Cities Conf., pp. 90–95, 2020.
[12] R. Mehta, D. Shah, and S. Patel, "Wireless Vehicle Monitoring System Using Sensor Networks," Int. J. Embedded Syst., vol. 10, no. 3, pp. 60–65, 2021.
[13] A. Rahman, M. Hasan, and S. Islam, "IoT Based Road Safety Monitoring System," IEEE Int. Conf. Smart Technol., pp. 70–75, 2021.
[14] P. Singh and R. Kumar, "Smart Traffic Control System Using Embedded Controllers," Int. J. Smart Eng., vol. 8, no. 4, pp. 45–50, 2021.
[15] D. Fernandes, M. Pereira, and J. Costa, "Zigbee Based Vehicle Communication System for Traffic Applications," IEEE Robot. Autom. Conf., pp. 110–116, 2022.
[16] S. Kumar and A. Singh, "ESP32 Based Smart Vehicle Safety Monitoring System," Int. J. Autom. Control, vol. 11, no. 1, pp. 35–40, 2022.
[17] M. Gupta and K. Sharma, "Intelligent Traffic Monitoring System Using Embedded Technology," IEEE Int. Conf. Embedded Syst., pp. 95–100, 2022.
[18] Y. Zhang, H. Liu, and X. Li, "Smart Transportation Monitoring System Using Sensor Networks," IEEE Access, vol. 11, pp. 32000–32007, 2023.
[19] R. Khan, S. Ali, and M. Ahmad, "Intelligent Accident Prevention System for Road Safety," Int. J. Smart Technol., vol. 9, no. 2, pp. 60–65, 2023.
[20] S. Roy, P. Dutta, and R. Das, "IoT Enabled Traffic Safety Monitoring System," IEEE Ind. Electron. Conf., pp. 120–125, 2023.
[21] A. Verma, S. Gupta, and R. Sharma, "Smart Vehicle Monitoring System for Accident Prevention," Int. J. Intell. Syst., vol. 10, no. 3, pp. 70–75, 2023.
[22] H. Park and J. Kim, "Sensor Fusion Based Vehicle Safety System for Intelligent Transportation," IEEE Sensors J., vol. 24, no. 2, pp. 2100–2106, 2024.
[23] M. Hasan, S. Islam, and R. Ahmed, "IoT Based Smart Transportation Monitoring System," IEEE Internet Things Symp., pp. 50–55, 2024.
[24] K. Lee, H. Park, and J. Kim, "Wireless Vehicle Communication System Using Zigbee Networks," IEEE Access, vol. 12, pp. 14500–14508, 2024.
[25] P. Sharma, V. Arora, and S. Kumar, "IoT Based Intelligent Smart Zone System for Traffic Safety," Int. J. Smart Eng., vol. 12, no. 1, pp. 40–46, 2024.