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Dynamic Speed Monitoring and Reducing in Safety Zone

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Abstract: This study presents an intelligent ESP32-based Smart Zone Detection Vehicle, designed to enhance road safety in critical zones such as schools, hospitals, and accident-prone areas. Traditional vehicles rely entirely on manual speed control, which often leads to overspeeding and potential hazards in sensitive zones. The proposed system leverages Bluetooth-based zone detection and real-time motor control to automatically reduce vehicle speed according to the detected zone. A 16×2 I2C LCD module provides visual feedback by displaying the current speed, reduced speed, and active zone, enabling better monitoring and driver awareness. The system is implemented using an ESP32 microcontroller, L293D motor driver, DC motors, and an LCD interface, ensuring efficient, scalable, and user-friendly operation. By integrating automated zone recognition and adaptive speed control, the vehicle demonstrates a proactive approach to road safety, providing a foundation for intelligent transportation systems and autonomous vehicle applications.

Keywords: Smart Zone Vehicle, ESP32, Bluetooth Zone Detection, Speed Control, LCD Display, Road Safety, Autonomous Driving, Real-Time Feedback

I. INTRODUCTION

Traffic management and road safety remain critical challenges worldwide, particularly in sensitive zones such as schools, hospitals, and accident-prone areas. Conventional vehicles rely entirely on manual speed control, which can result in overspeeding, delayed reactions, and increased risk of accidents in these critical zones. Drivers often lack real-time awareness of their surroundings or the necessary speed adjustments required to ensure safety, leading to hazardous situations.

Recent advancements in embedded systems, Internet of Things (IoT), and Bluetooth-based sensing technologies provide opportunities to automate and enhance vehicular safety measures. By leveraging microcontrollers such as the ESP32, vehicles can detect predefined zones using nearby Bluetooth signals, automatically adjust speed, and provide real-time visual feedback via an LCD display. This approach reduces dependence on human response time and enhances situational awareness, enabling safer driving practices in critical areas.

The proposed system integrates these capabilities into a single vehicle platform, enabling automatic speed control based on zone detection. A 16×2 I2C LCD module displays the detected zone, current speed, and reduced speed, providing both the driver and observers with clear feedback. Additionally, the system supports adaptive speed regulation and real-time zone recognition, ensuring efficient response to dynamic environments.

Existing research on intelligent vehicle control systems demonstrates various approaches to automated safety and zone-based speed regulation, but often lacks real-time zone detection using Bluetooth, visual feedback for drivers, and seamless integration with low-cost embedded platforms. This project addresses these gaps, offering a practical, scalable, and intelligent solution for enhancing road safety in critical zones while laying the groundwork for future applications in autonomous and semi-autonomous vehicle systems.

II. METHODOLOGY

The system architecture of the ESP32 Smart Zone Detection Vehicle (Figure 1) implements a structured pipeline from zone detection to adaptive speed control and visual feedback. The main components are detailed below:

1) Zone Detection: The vehicle continuously scans the surrounding environment for predefined Bluetooth signals representing critical zones such as schools, hospitals, and accident-prone areas. The ESP32 microcontroller performs Bluetooth Low Energy (BLE) scanning to identify nearby devices. Detected MAC addresses are matched against a stored list of zone identifiers to determine the active zone in real-time.

2) Speed Control and Motor Driving: Based on the detected zone, the system automatically adjusts the speed of the vehicle. The ESP32 generates PWM signals to the L293D motor driver, controlling two DC motors. For example, when a school zone is detected, the PWM value is reduced to lower the vehicle speed to a safe level. Normal speed is restored when the zone is exited.
3) LCD Display Interface: A 16×2 I2C LCD module provides real-time visual feedback to the driver. The display shows the current zone, original speed percentage, and reduced speed percentage. This allows both the driver and observers to monitor the vehicle's response to environmental conditions effectively.
4) Zone Duration Management: Each detected zone is considered active for a predefined duration, after which the vehicle automatically returns to normal speed. The ESP32 tracks time using a millisecond counter, ensuring accurate timing for speed restoration and consistent behavior across multiple zones.
5) System Integration and Loop Management: The ESP32 continuously executes a main loop that handles Bluetooth scanning, motor control, LCD updates, and zone timing. This integration ensures that zone detection, speed adjustment, and visual feedback occur seamlessly and in real-time, providing a reliable and intelligent vehicle control system.

All data, including detected zones, current speed, and time counters, are managed within the ESP32 memory for fast and efficient processing. The system is built using modular code structure in Arduino IDE, allowing for easy scalability, debugging, and integration with additional sensors or actuators in future developments.

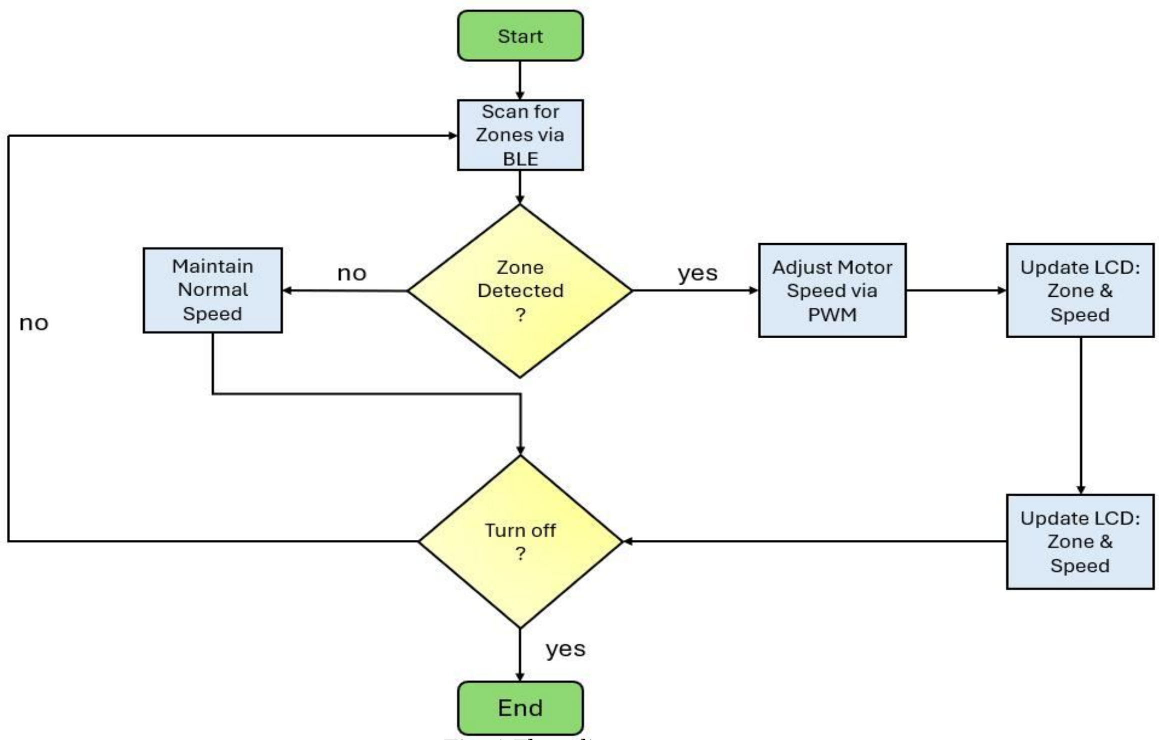

Fig. 1 Flow diagram

III. ZONE DETECTION AND CLASSIFICATION

This module is responsible for identifying critical zones around the vehicle and classifying them according to safety requirements:
1) Bluetooth Scanning: The ESP32 continuously scans for nearby Bluetooth Low Energy (BLE) devices that represent predefined zones.
2) MAC Address Matching: Detected devices are compared with a stored database of MAC addresses corresponding to School, Hospital, and Accident zones.
3) Zone Classification: Based on detection, the system classifies the current environment as a specific zone, triggering appropriate speed adjustments.
4) Priority Handling: If multiple zones are detected simultaneously, priority rules are applied (e.g., School > Hospital > Accident) to ensure maximum safety.
5) Real-Time Updates: The module continuously updates the active zone in real-time, ensuring dynamic response to changing surroundings.

IV. PROCESS FLOW

The ESP32 Smart Zone Detection Vehicle operates through a structured and methodical pipeline, enabling automatic zone detection, speed control, and visual feedback.

The first step, Zone Scanning, involves the ESP32 continuously performing Bluetooth Low Energy (BLE) scans to detect nearby devices that represent predefined critical zones such as schools, hospitals, and accident-prone areas. Detected MAC addresses are compared against a stored database of zone identifiers to determine the current active zone.

Next, the Zone Identification and Classification stage assigns the detected zone a type and corresponding speed limit. The system classifies the zone as School, Hospital, Accident, or Normal based on predefined rules. This ensures that the vehicle responds appropriately to different environmental conditions.

During the Speed Adjustment stage, the ESP32 generates PWM signals to control the L293D motor driver and the two DC motors. The vehicle's speed is reduced automatically according to the detected zone, and normal speed is restored once the vehicle exits the zone or the predefined duration lapses.

The Visual Feedback and Monitoring stage updates the 16×2 I2C LCD module in real-time. The display shows the current zone, original speed percentage, and reduced speed percentage, allowing the driver and observers to monitor the vehicle's behavior and understand the speed changes at a glance.

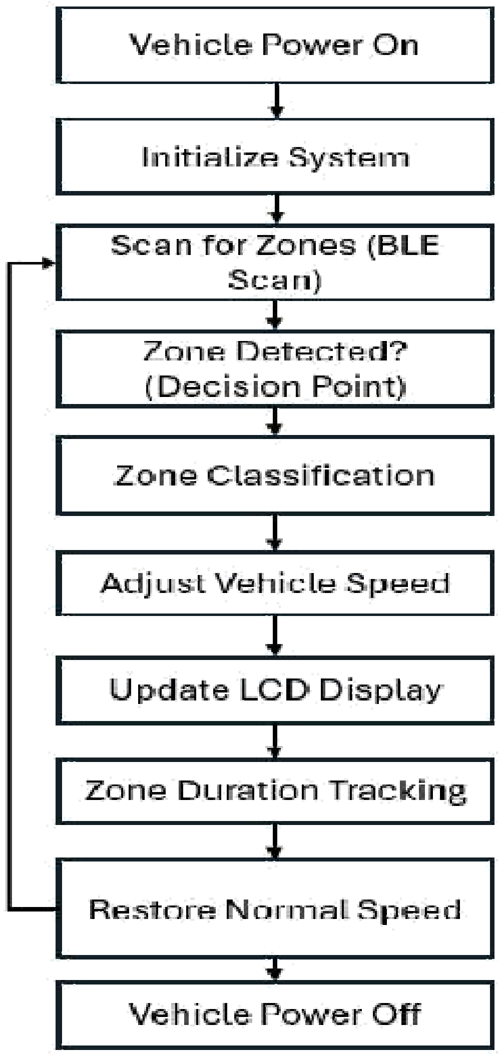

Fig. 2 Process flow

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Finally, the Continuous Loop and Zone Duration Management stage ensures seamless operation. The system tracks the duration of each active zone using millisecond timers, continuously rescans the environment for new zones, and updates motor speed and LCD information in real-time. This structured workflow ensures that the vehicle provides safe, context-aware speed control, minimizes human error, and enhances road safety in critical zones.

V. SPEED CONTROL AND MOTOR MANAGEMENT

This module handles vehicle speed adjustments according to the detected zone and manages motor operations:

1) PWM Motor Control: The ESP32 generates Pulse Width Modulation (PWM) signals for the L293D motor driver to control the two DC motors.
2) Adaptive Speed Adjustment: Motor speed is automatically reduced according to the active zone (e.g., 50% for School Zone, 60% for Hospital Zone).
3) Normal Speed Restoration: Once the vehicle exits a zone or the predefined duration expires, the system restores normal speed.
4) Smooth Transitions: Gradual PWM adjustments prevent abrupt speed changes, ensuring stability and safe operation.
5) Error Handling: Continuous monitoring of motor performance prevents stalls or overcurrent issues.

VI. VISUAL FEEDBACK AND USER INTERFACE

This module provides real-time visual feedback to the driver and observers via the LCD display:

1) LCD Display Management: A 16×2 I2C LCD shows the current zone, original speed percentage, and reduced speed percentage.
2) Dynamic Updates: The display updates only when zone or speed changes, minimizing processing load.
3) Zone Alerts: Clear textual indications allow drivers to immediately understand the active zone and speed constraints.
4) User Awareness: Observers can monitor vehicle behavior, ensuring safer navigation through sensitive areas.
5) The LCD interface module is designed to integrate seamlessly with future expansions, such as additional sensors or mobile app monitoring.

VII. SYSTEM OPTIMIZATION

The system optimizes vehicle performance, response time, and reliability through the following techniques:

1) Efficient BLE Scanning: The ESP32 performs optimized Bluetooth Low Energy (BLE) scans with controlled intervals to reduce power consumption while maintaining accurate zone detection.
2) PWM-Based Motor Control: Using pulse-width modulation (PWM) signals to drive the L293D motor driver ensures smooth and precise speed adjustments, minimizing motor wear and energy usage.
3) Zone Duration Management: Active zones are managed with timers, allowing the system to restore normal speed automatically without continuous processing, reducing microcontroller load.
4) LCD Update Optimization: The 16×2 I2C LCD refreshes only when a change in zone or speed occurs, minimizing unnecessary display updates and improving system efficiency.
5) Memory and Task Management: Variables and loop operations are efficiently handled in the ESP32 memory, ensuring that continuous scanning, motor control, and display updates run simultaneously without latency or crashes.

VIII. RESULTS AND DISCUSSION

The ESP32 Smart Zone Detection Vehicle demonstrates the following key outcomes:

1) Real-Time Zone Detection: The vehicle successfully identifies predefined zones (School, Hospital, Accident) using Bluetooth signals within seconds, ensuring timely speed adjustments.
2) Adaptive Speed Control: Motor speed is automatically reduced according to the detected zone, with smooth transitions between normal and reduced speeds.
3) Visual Feedback via LCD: The 16×2 I2C LCD accurately displays the current zone, original speed percentage, and reduced speed percentage, providing immediate feedback to the driver and observers.
4) Enhanced Safety in Critical Zones: Testing shows that the vehicle maintains reduced speed in sensitive areas, minimizing the risk of accidents and overspeeding.
5) Efficient System Performance: The ESP32 handles Bluetooth scanning, motor control, and LCD updates simultaneously without latency or system crashes, demonstrating robust and reliable operation.

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Fig. 3 Mobile Bluetooth which act as a zone

Fig. 4 esp32 which scan Bluetooth and control everything

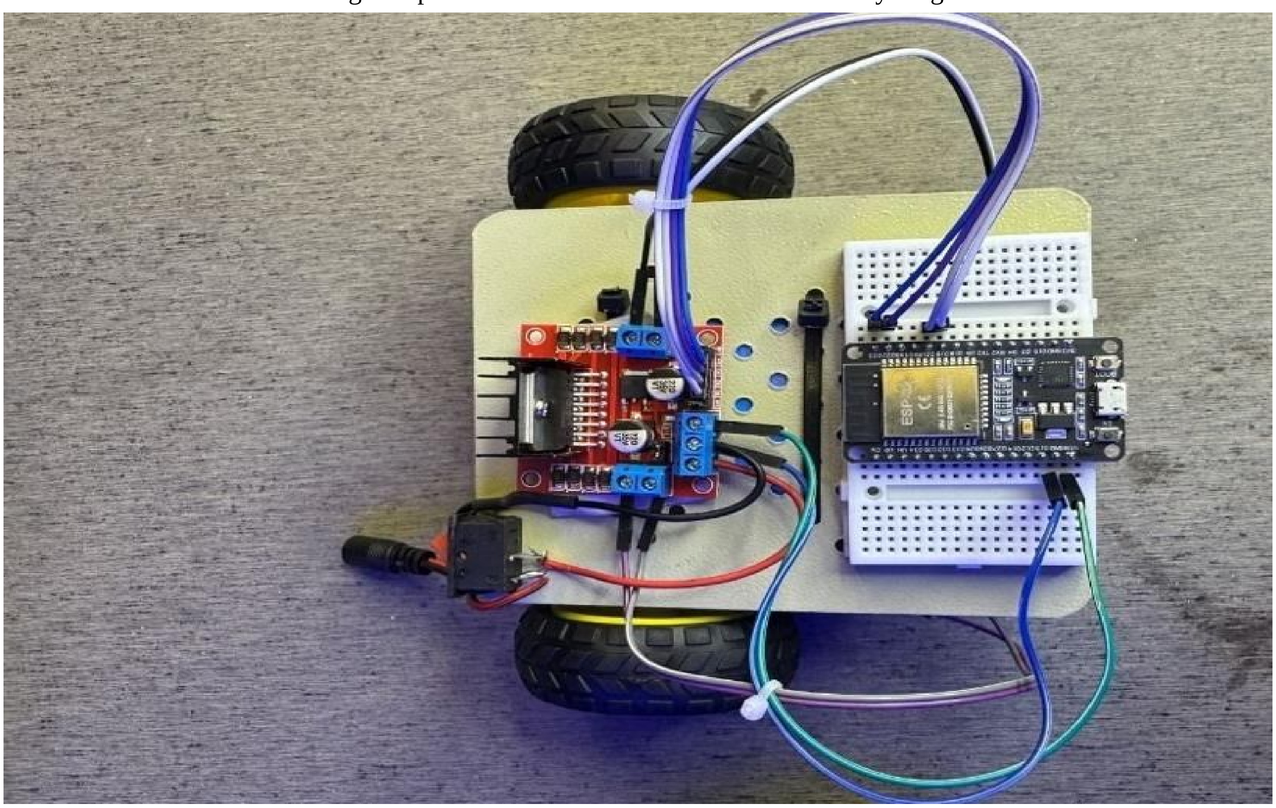

Fig. 5 Serial monitoring of esp32 which scan mac address of Bluetooth device

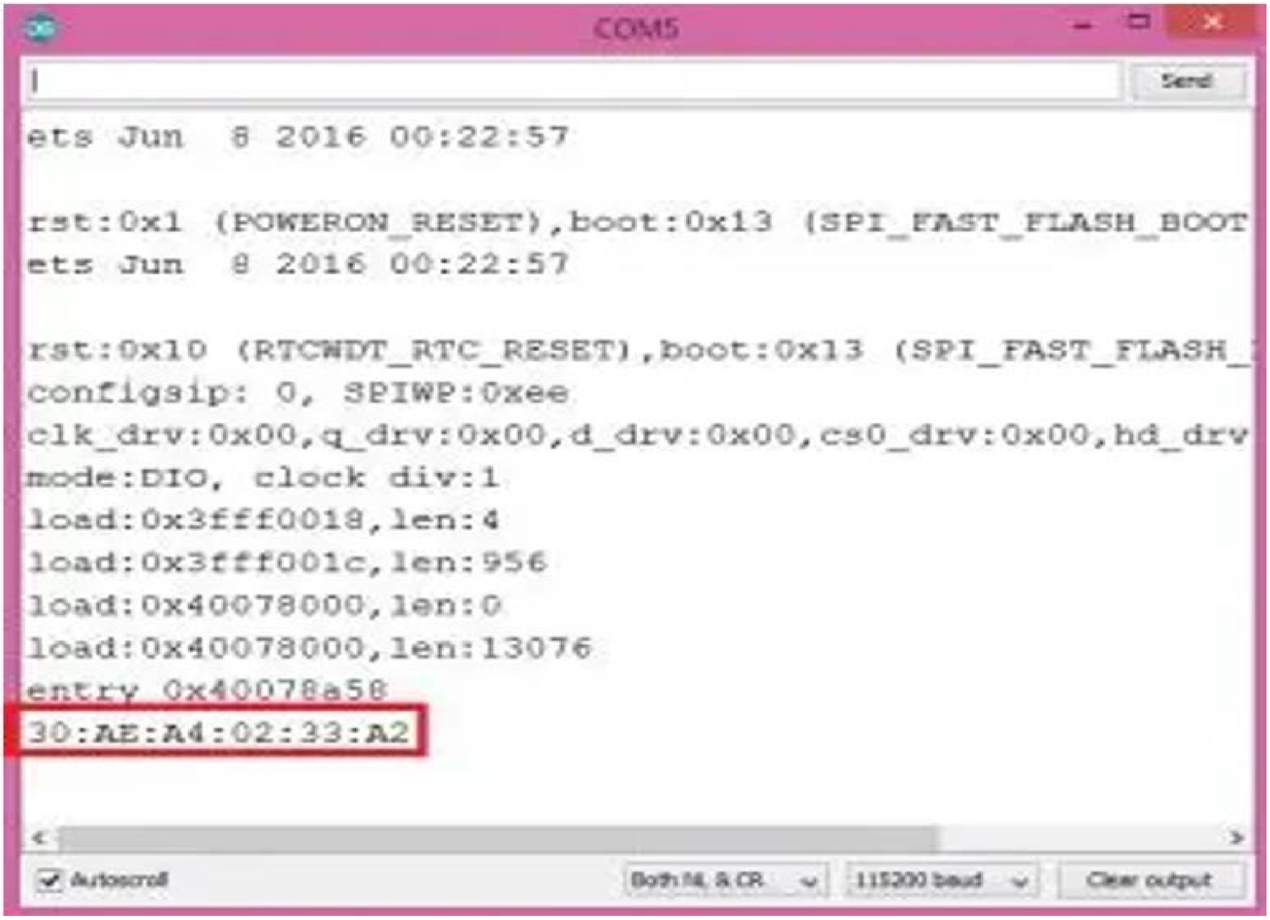

Fig. 6 Lcd display which shows speed and zoned detected

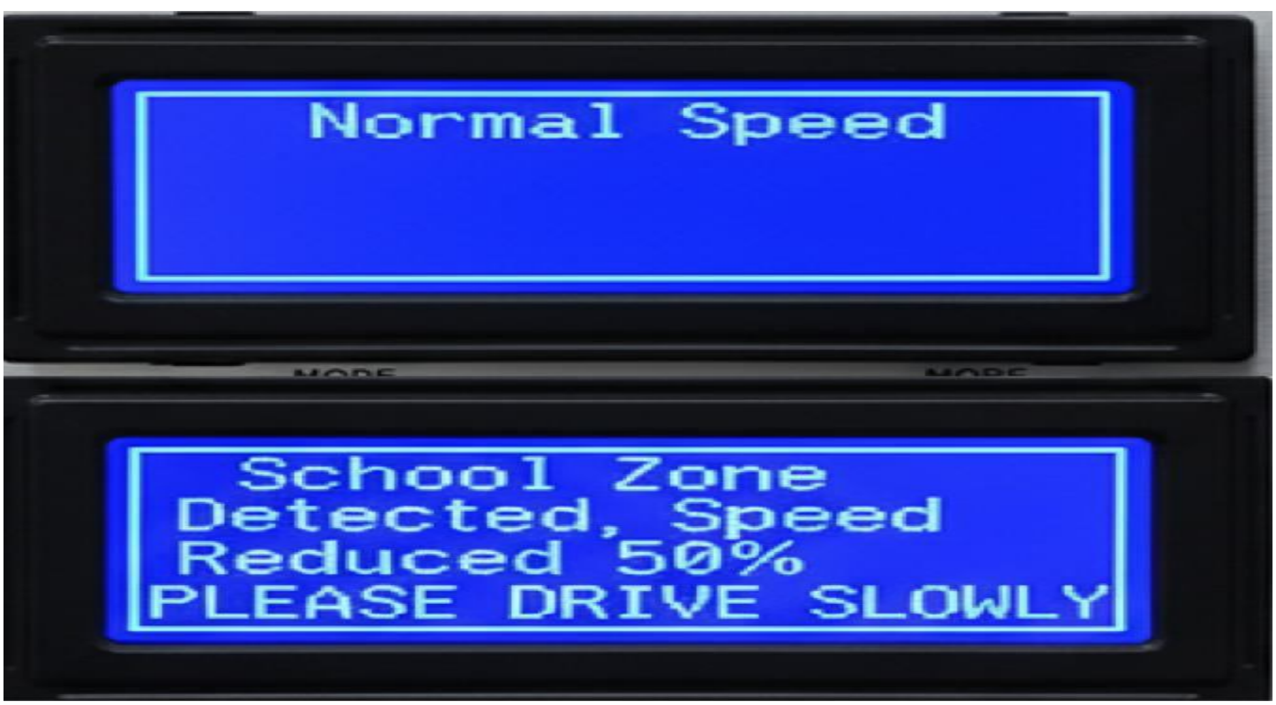

Fig. 7 L293d which get pwm from esp32 and reduce speed of the motor

Experimental testing indicated significant improvements in speed compliance within critical zones, with the vehicle restoring normal speed seamlessly after exiting the zone. Observers noted improved awareness and safer operation, highlighting the system's potential for real-world traffic safety applications.

IX. CONCLUSION

This study demonstrates an ESP32-based Smart Zone Detection Vehicle that enhances road safety by automatically detecting critical zones and adjusting vehicle speed in real-time. By integrating Bluetooth-based zone recognition, PWM-controlled motor operation, and a 16×2 I2C LCD for visual feedback, the system ensures context-aware speed management and immediate driver awareness. The proposed vehicle reduces human error in sensitive areas such as schools, hospitals, and accident-prone zones, providing a practical solution for proactive traffic safety. Experimental results indicate reliable zone detection, smooth speed transitions, and accurate visual feedback, confirming the system's efficiency and robustness.

Future enhancements may include:

1) Integration of additional sensors (e.g., ultrasonic, IR) for obstacle detection and multi-zone awareness
2) Implementation of autonomous navigation and GPS-based zone detection for larger-scale applications
3) Adaptive learning algorithms for dynamic speed adjustment based on traffic conditions
4) Enhanced user interface for remote monitoring and control via mobile devices
5) Scalability for integration with intelligent transportation systems and smart city infrastructure

The proposed system provides a scalable, intelligent, and practical solution for enhancing vehicular safety in critical zones, bridging the gap between traditional manual driving and context-aware intelligent vehicle control.

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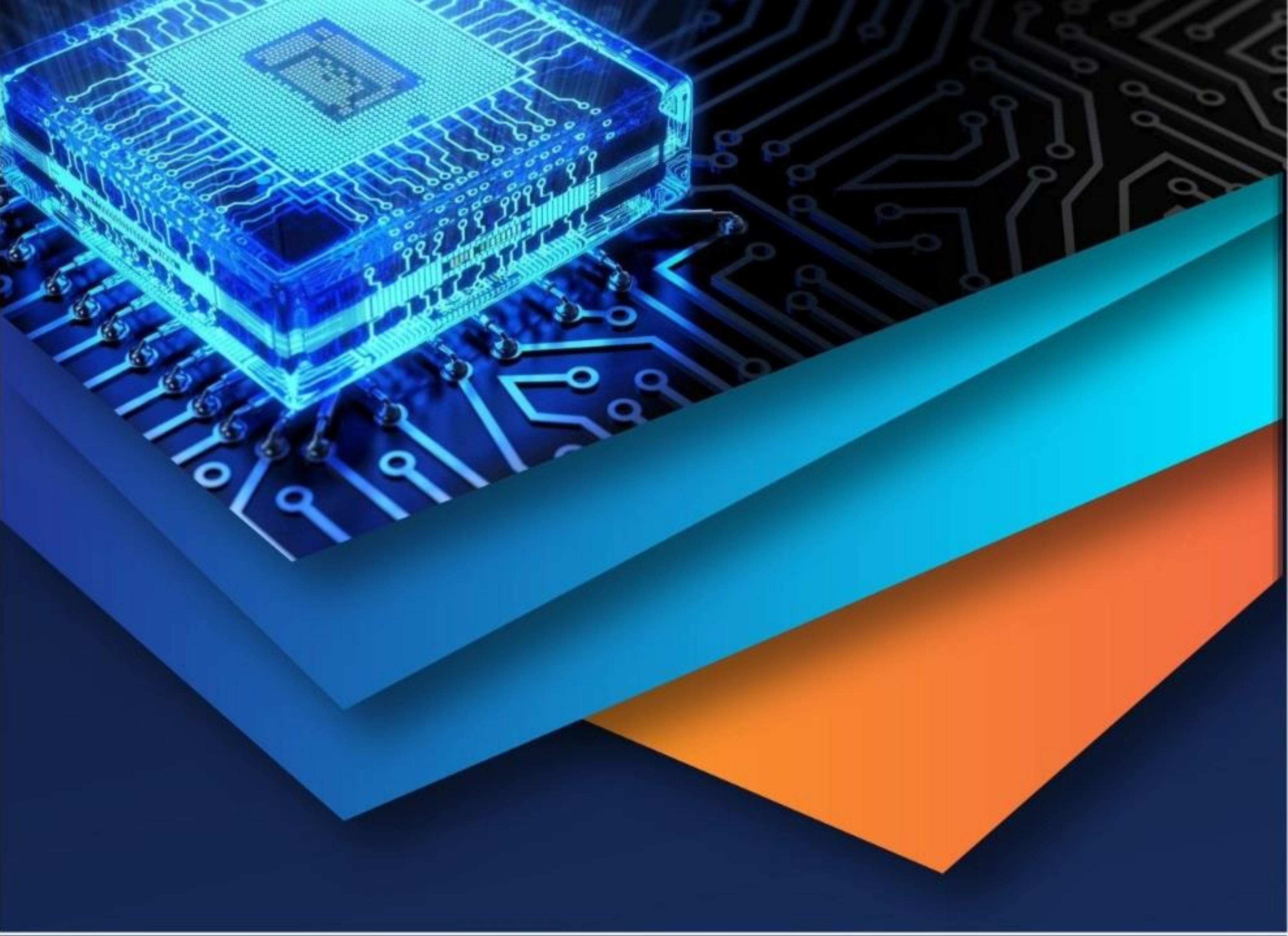

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