

Design and Implementation of IoT-Based Smart Vehicle with Obstacle Avoidance and GPS Navigation Using ESP32

N. Sarath Sai¹, K. Sunil Joshi¹, K. Uday Sreenu¹, M. Bala Manikanta¹, K. Swathi^{2,*}

Abstract

The development of autonomous and intelligent transportation systems has gained significant attention in recent years. This paper presents the design and implementation of an IoT-based smart vehicle capable of autonomous navigation and obstacle avoidance using the ESP32 microcontroller. The system integrates an ultrasonic sensor for real-time obstacle detection, a GPS module for location tracking and navigation, and IoT connectivity using the Blynk platform for remote monitoring and control. The vehicle operates in both manual and autonomous modes. In manual mode, users can control movement through a mobile application, while in GPS mode the vehicle navigates toward a predefined destination using real-time coordinate calculations. The proposed system was tested under different operating conditions to evaluate navigation accuracy, obstacle detection reliability, communication delay, and system stability. Experimental results show that the vehicle achieves obstacle detection accuracy within ± 1 cm and GPS navigation accuracy within 2–3 meters. Additionally, the system continues to operate steadily over long periods of time, demonstrating its actual deployment applicability. A scalable, economical, and successful solution for smart autonomous vehicle applications is demonstrated by the integration of sensing, navigation, and IoT technologies on a single platform. By offering a low-cost prototype that may be further developed with cutting-edge capabilities like computer vision, machine learning-based decision-making, and multi-sensor fusion for increased autonomy and safety, our study adds to the expanding field of intelligent transportation. The integration of sensing, navigation, and IoT technologies demonstrates a cost-effective solution for smart autonomous vehicle applications.

Keywords: IOT, ESP32, GPS navigation, obstacle avoidance, smart vehicle, ultrasonic sensor

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INTRODUCTION

The rapid evolution of the Internet of Things (IoT), embedded systems, and wireless communication has fundamentally redefined the landscape of robotics and intelligent transportation. Modern autonomous systems are increasingly required to perform complex tasks, such as real-time environmental sensing, precise navigation, and remote monitoring, with minimal human intervention. These capabilities are essential in diverse sectors, including industrial automation, search and rescue, surveillance, and smart delivery services. This project presents the design and implementation of a cost-effective IoT-based smart vehicle powered by an ESP32 microcontroller. The system is engineered to bridge the gap between

simple obstacle avoidance robots and expensive, high-end autonomous vehicles. By integrating an HC-SR04 ultrasonic sensor for real-time collision prevention and a GY-GPS6MV2 module for geographic tracking, the vehicle achieves a high degree of situational awareness and navigational autonomy. The key innovation of this system is its dual-mode operational capability. Users can exert full manual control through a user-friendly Blynk IoT mobile interface or activate an autonomous GPS-following mode. In the autonomous phase, the vehicle utilizes advanced algorithms to calculate heading differences and distances to a user-defined destination, adjusting its path dynamically while prioritizing safety by continuous environmental scanning. By leveraging dual-core processing and the built-in Wi-Fi of the ESP32, this project demonstrates a scalable framework for intelligent vehicular technology that is accessible and energy-efficient. The following sections detail the hardware architecture, software logic, and experimental results that validate the reliability of the system in real-world scenarios, as shown in Figure 1.

LITERATURE REVIEW

Several autonomous navigation systems have been proposed using different sensor technologies [1]. Ultrasonic sensors are commonly used for short-range obstacle detection because of their low cost and reliability [2, 3]. GPS-based navigation systems are widely used for outdoor positioning applications, such as vehicle tracking and robotic navigation [4]. Previous research has combined GPS modules with microcontrollers to enable location-based autonomous movement [5, 6, 7]. IoT platforms such as Blynk, MQTT, and cloud servers have been used to enable the remote control and monitoring of robotic systems [8, 9, 10]. However, many existing systems lack efficient integration of obstacle avoidance and navigation features. This study focuses on combining ultrasonic sensing, GPS navigation, and IoT connectivity on a single embedded platform using ESP32.

PROPOSED SYSTEM

The proposed smart vehicle system consists of the following hardware components.

ESP32 Microcontroller

A powerful Wi-Fi-enabled microcontroller that coordinates all system activities. It processes sensor inputs, calculates distances, executes obstacle avoidance logic, manages motor speed and direction via PWM, and maintains the IoT connection.

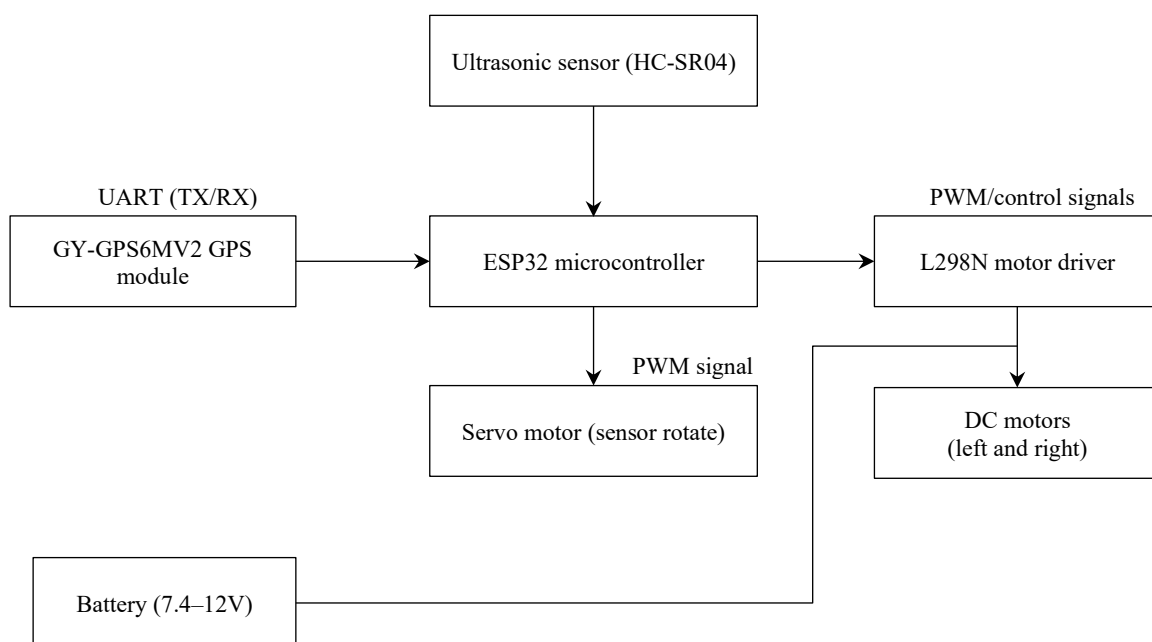


Figure 1. Block diagram of the proposed smart vehicle system.

The ESP32 microcontroller serves as the central processing unit (CPU) and primary “brain” of the proposed smart vehicle system. It is a highly advanced, low-power system-on-chip (SoC) that is equipped with robust processing capabilities and built-in Wi-Fi connectivity. In the context of IoT-enabled robotics, the ESP32 was chosen over traditional microcontrollers because of its superior processing speed and native Internet communication abilities. This allows the microcontroller to effortlessly coordinate all system activities and handle complex computational tasks locally while simultaneously maintaining a stable, real-time connection to cloud platforms without experiencing lag, as shown in Figure 2.

HC-SR04 Ultrasonic Sensor

The ultrasonic sensor continuously measures the distance to nearby obstacles. If an object is detected within a predefined threshold distance, the vehicle automatically changes direction to avoid collision.

The HC-SR04 ultrasonic sensor acts as the primary environmental perception tool for smart vehicles. It is responsible for continuously measuring the physical distance between the vehicle and any nearby obstacles in the forward path. During real-world operation, the sensor achieved a highly reliable detection accuracy of ± 1 cm. The system’s avoidance logic was programmed with a predefined safety threshold distance of 25 cm. If an object is detected within this critical range, the vehicle’s automated system immediately reacts and changes direction to prevent a collision, as shown in Figure 3.

GY-GPS6MV2 GPS Module

The GPS module provides latitude and longitude coordinates. The ESP32 calculates the distance and direction toward the destination and adjusts the motor movement accordingly.



Figure 2. ESP32 microcontroller board.



Figure 3. Ultrasonic sensor (HC-SR04).

The GY-GPS6MV2 GPS module served as the primary navigation instrument for the autonomous operation mode of the vehicle. By establishing communication with global satellite networks, the module continuously acquires real-time geospatial data, specifically providing the vehicle's current latitude and longitude coordinates. This constant stream of precise location data is essential for enabling smart vehicles to navigate autonomously toward a user-defined destination without requiring manual steering input, as shown in Figure 4.

L298N Motor Driver

The L298N motor driver is a critical high-power module that functions as an electromechanical bridge between the logic-level control signals of the ESP32 microcontroller and the physical DC motors. Because microcontrollers cannot safely supply the high electrical current required to drive the mechanical wheels, the L298N acts as an essential intermediary. By receiving specialized pulse width modulation (PWM) and directional control signals from the ESP32, the L298N efficiently regulates both the speed and rotational direction of the vehicle wheels without overloading the delicate processing unit, as shown in Figure 5.

DC Motors

This module independently drives the left and right DC motors, enabling the vehicle to execute precise Forward, Backward, Left, and Right movements. This differential drive mechanism is fundamental to the operation of smart vehicles in both of their primary modes. In manual mode, it ensures smooth and responsive steering based on the user's remote input from the mobile application. In autonomous mode, it provides the rapid and independent wheel control necessary for the vehicle to pivot and immediately alter its trajectory when the ultrasonic sensor detects an obstacle blocking the path.

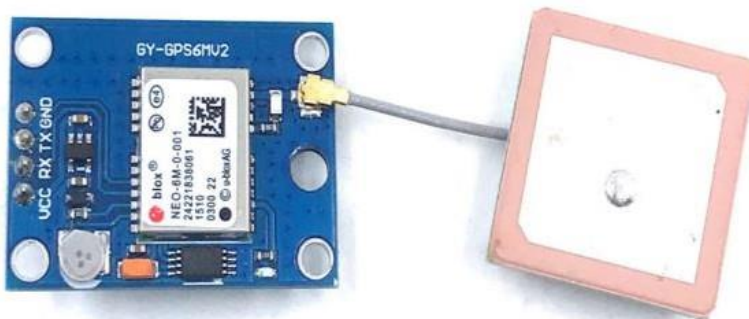


Figure 4. GPS Module (GY-GPS6MV2).

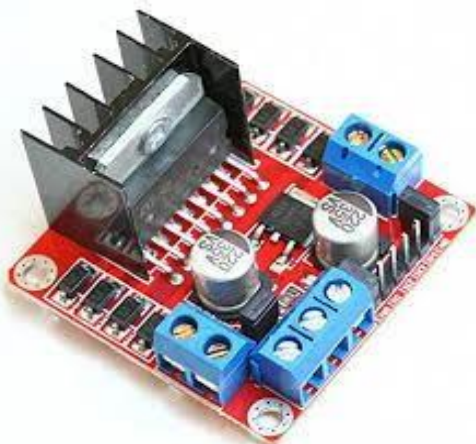


Figure 5. L298N motor driver module.

Servo Motor

To complement the continuous movement of the vehicle, a highly precise servomotor was integrated into the forward sensor array. This motor was used to securely mount and physically rotate the HC-SR04 ultrasonic sensor across 180° arcs. By leveraging this rotational capability, the system can dynamically “scan” the surrounding environment to the left and right to identify a clear, unobstructed path whenever an impediment is encountered. This targeted scanning approach significantly improved the efficiency of the obstacle avoidance logic, allowing the vehicle to “look around” without having to turn its entire chassis, as shown in Figure 6.

Lithium-Ion Battery

Lithium-ion batteries serve as the primary and central power sources for smart vehicle systems. It is a highly efficient, rechargeable energy storage unit that is specifically selected to supply the voltage and current required to drive all onboard electronic and electromechanical components. A reliable power supply is critical in an autonomous system, as the vehicle houses a complex array of hardware with varying electrical demands, ranging from the low-power logic circuits of the ESP32 microcontroller and sensors to the high-power requirements of motor drivers, as shown in Figure 7.



Figure 6. Servo motor.

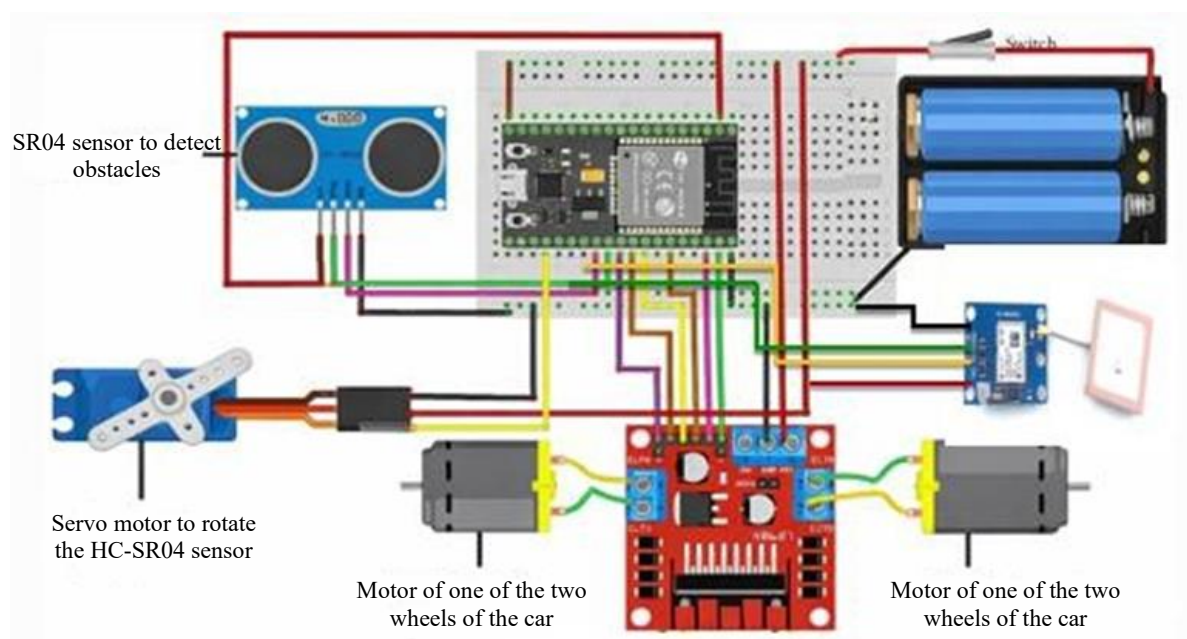


Figure 7. Circuit diagram of the smart vehicle system.

SYSTEM OPERATION

The smart vehicle is designed to operate seamlessly in two distinct modes, providing users with flexible control options depending on the environment and task requirements, as shown in Figure 8.

Manual Mode

In manual mode, the vehicle was directly controlled by the user through the Blynk mobile application over a Wi-Fi connection. This IoT-based interface acts as a remote control, allowing the operator to send real-time commands to steer the vehicle forward, backward, leftward, and rightward. To ensure smooth and precise movement across different surfaces, the motor speed of the vehicle was dynamically regulated using pulse-width modulation (PWM) signals generated by the ESP32 microcontroller. This mode is highly effective in situations that require careful human supervision, manual parking, or navigation through highly complex, unpredictable environments where automated logic might struggle, as shown in Figure 8.

Autonomous GPS Mode

In autonomous GPS mode, the vehicle shifts to self-navigation, requiring minimal human intervention. The operation begins when the user inputs the specific coordinates (latitude and longitude) of their desired destination into the system. Utilizing the onboard GPS module, the microcontroller continuously tracks the current position and calculates the real-time distance and directional heading required to reach the target location. A dedicated navigation algorithm then translates these data into motor commands to guide the vehicle along the correct path. Crucially, the obstacle avoidance mechanism remains fully active during autonomous transit. If an impediment is detected by the ultrasonic sensor while the vehicle is driving to its waypoint, it will automatically pause, scan the area, and maneuver around the object to avoid a collision before resuming its journey toward the final destination, as shown in Figure 9.

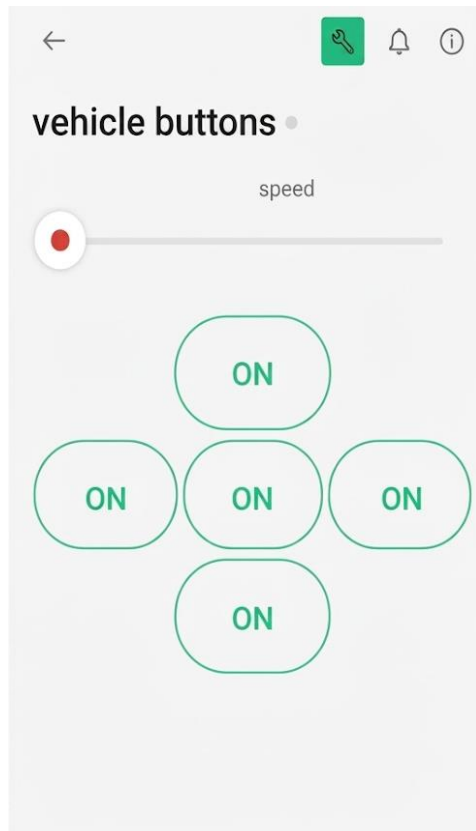


Figure 8. Smart vehicle mobile control panel.

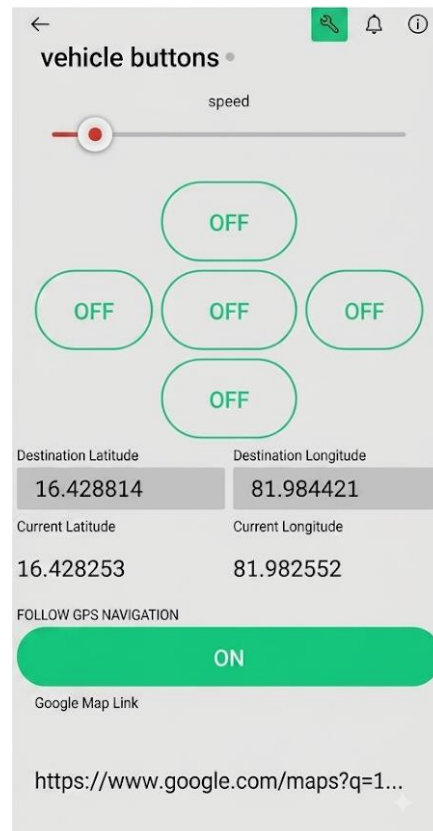


Figure 9. Mobile application interface for vehicle control and GPS navigation

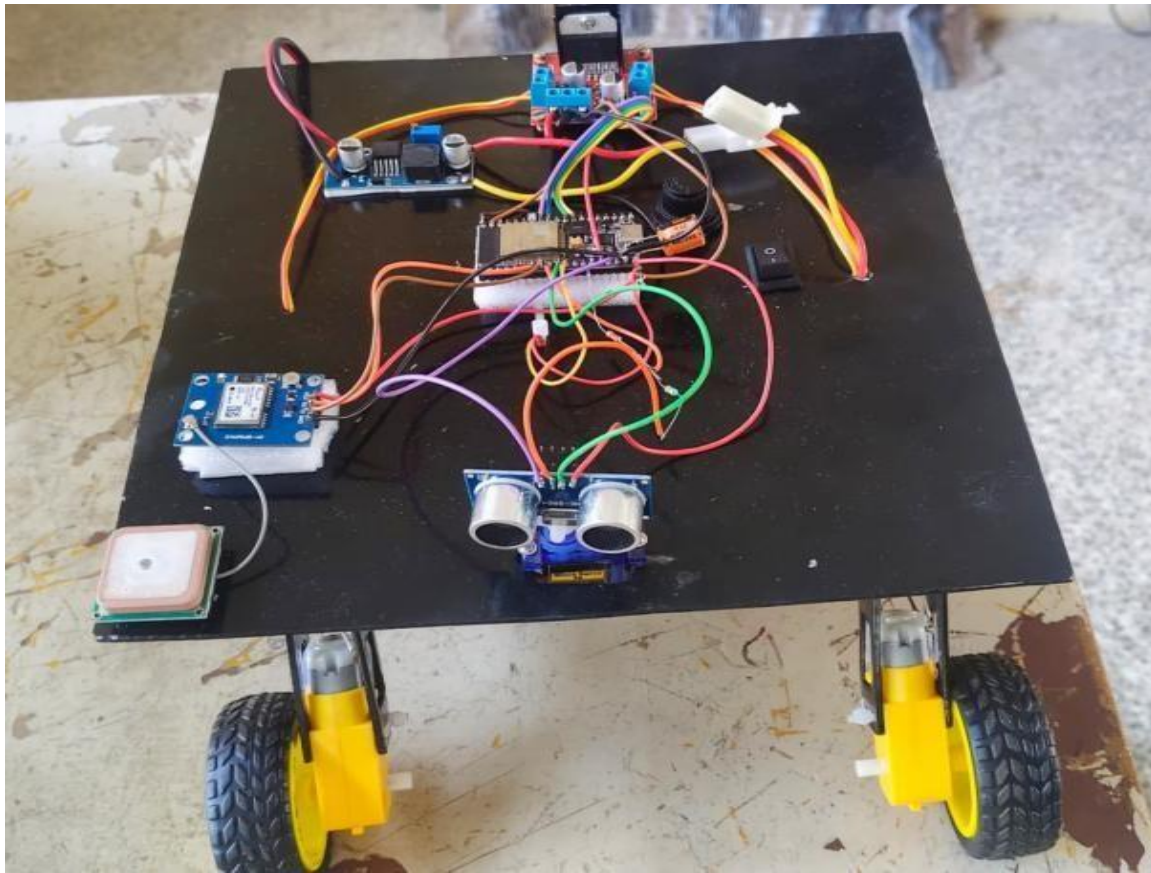


Figure 10. Hardware prototype of the IoT-based smart vehicle.

RESULTS AND PERFORMANCE ANALYSIS

The performance of the proposed smart vehicle was comprehensively evaluated through a series of practical tests conducted in both indoor and outdoor environments, as shown in Figure 10. A critical aspect of this evaluation was the assessment of the system's responsiveness and the reliability of its IoT communication network. During manual operation via the mobile application, the vehicle exhibited highly stable Wi-Fi and cloud connections. The system successfully achieved real-time GPS data transmission to the user interface, maintaining a minimal average communication and response delay ranging between 0.5 and 1 s. Furthermore, the integration of PWM signals was highly effective, allowing for smooth and precise directional control of the motors across various testing scenarios.

In the autonomous mode, the spatial awareness and self-navigation capabilities of the vehicle were rigorously tested to ensure safety and accuracy. The ultrasonic-sensor-based obstacle detection system demonstrated reliable collision avoidance, maintaining an impressive detection accuracy of ± 1 cm whenever objects appeared within the predefined safety threshold distance of 25 cm. For global positioning, the onboard GPS module required an initial lock time of 30–60 s to establish a stable connection with satellite networks. Once locked, the module maintained a continuous position update frequency of 1 Hz, which facilitated a commendable navigation accuracy of 2–3 m from the target destination. Overall, these experimental results validate the stability, precision, and practical reliability of the system under real-world conditions.

CONCLUSION AND FUTURE SCOPE

This study successfully presented the design and implementation of an IoT-based smart vehicle that integrates obstacle avoidance and GPS navigation using the ESP32 microcontroller. The experimental results confirmed that the system provides reliable real-time obstacle detection, acceptable GPS navigation accuracy, and stable wireless communication with cloud platforms. Overall, the proposed

architecture serves as a highly cost-effective and scalable solution for modern autonomous-vehicle applications.

The future scope of this project involves significantly enhancing the vehicle's environmental perception and decision-making capabilities. Future improvements may include the integration of AI-based navigation algorithms, LiDAR sensors, and camera-based object detection. These advanced additions allow vehicles to intelligently map their surroundings, recognize specific objects, and operate with greater autonomy in highly complex environments.

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