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# INDOOR AUTONOMOUS ROBOT

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## Abstract

The elaboration of independent robotics has steered in a new period of intelligent machines able of operating singly in colorful surroundings. This design explores the design and perpetration of an inner independent robot that leverages the ESP32 microcontroller in confluence with ultrasonic detectors to descry and avoid obstacles. By integrating essential tackle factors and acclimatized software routines, this robot demonstrates a cohesive system able of navigating inner spaces efficiently and without mortal intervention. The use of ultrasonic detectors allows the robot to continuously measure the distance to near objects, helping it avoid collisions in real- time. At the heart of the system lies the ESP32 microcontroller, a important binarycore processor with erected- in Wi- Fi and Bluetooth capabilities. The ESP32 enables fast data processing, detector integration, and real- time decision-making without the need for external computing coffers. This ensures that the robot operates autonomously, replying incontinently to environmental changes and implicit pitfalls. The ESP32's capability to handle multitasking allows for the contemporaneous operation of detector data accession, motor control, and wireless communication, laying the foundation for unborn advancements similar as pall connectivity or mobile app integration.


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## Introduction

The progression of robotic technologies has brought autonomous systems to the forefront of embedded computing, AI, and modern automation practices. As businesses, healthcare institutions, and service providers look for intelligent tools to streamline their operations, the interest in robots capable of performing independently within structured indoor areas has intensified. These robots are increasingly used in locations such as homes, hospitals, offices, and storage facilities, where they offer consistent performance without the need for human input. Their key strengths lie in the ability to recognize obstacles, assess environments in real time, and carry out specific tasks reliably and repetitively.

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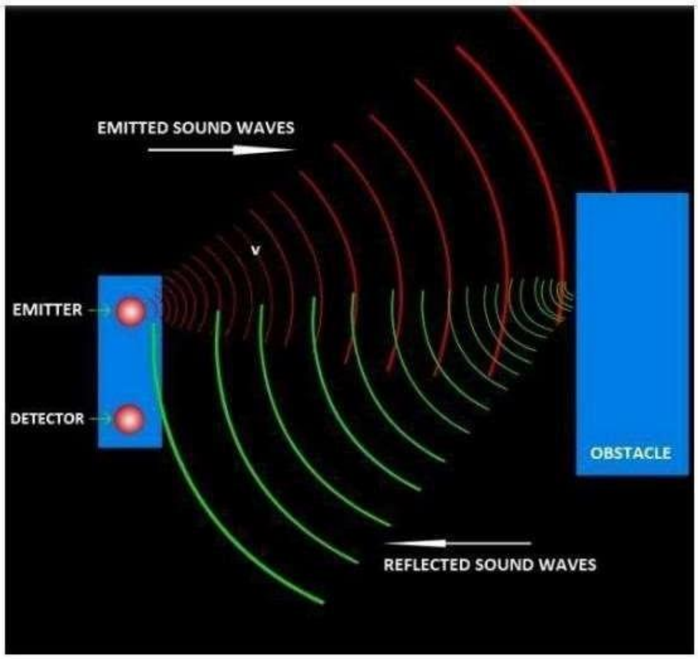


Fig 1 Ultrasonic Distance Sensor work

At the core of this project lies the ESP32—a compact, high-performance microcontroller known for its affordability and versatility. This board features a dual-core processor, onboard wireless communication modules, and a large number of input/output pins suitable for connecting a range of peripherals. Its compatibility with the Arduino programming environment and support from a wide open-source community make it an ideal choice for real-time robotic applications. Within this robotic system, the ESP32 acts as the decision-making hub, processing sensor readings and directing motor behavior accordingly.

To enable spatial awareness, the robot uses ultrasonic sensors, with the HC-SR04 being a commonly selected model due to its accuracy and simplicity. These devices function by sending ultrasonic pulses and measuring the time taken for the reflected signal to return. This feedback is used to calculate the distance between the sensor and any object in its path. With sensors positioned at key points on the robot's chassis, it can perceive objects on multiple sides and adjust its trajectory in real time, thereby avoiding collisions. This sensory feedback forms the basis of the robot's ability to move through environments autonomously.

Movement is achieved using a pair of geared DC motors, which provide the torque and direction control necessary for indoor mobility. The motors are managed via an L298N motor controller, which interprets instructions from the ESP32 and converts them into electrical signals for speed and directional control. This setup allows the robot to change direction quickly and smoothly in response to its surroundings. Coordination between the controller and the microcontroller ensures that motion remains stable and precise, even in challenging layouts such as narrow hallways or cluttered rooms.

## Related Work

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The landscape of indoor autonomous robotics has undergone significant transformation with the evolution of smarter, more adaptable navigation systems. Research efforts have concentrated on optimizing how robots detect obstacles, interpret sensor input, and respond to varying environmental conditions. Microcontrollers such as the ESP32 have emerged as preferred hardware platforms, due to their processing speed, integrated wireless

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modules, and low power consumption. These features make ESP32-based systems especially suitable for robotics applications that demand both real-time responsiveness and scalability. Within this context, numerous studies have contributed foundational work that informs the development of this project.

In their 2023 publication, A. Kumar et al. designed an obstacle-avoiding robot using an Arduino board in combination with HC-SR04 ultrasonic sensors. Their prototype proved effective in navigating simple environments and demonstrated how affordable components could be leveraged to build autonomous mobile platforms. However, the absence of Wi-Fi or Bluetooth connectivity limited the robot's potential for remote access or system expansion. Additionally, the system lacked GPS integration, which restricted its usability to confined spaces. Despite these limitations, their work provided a strong starting point for understanding the basic dynamics of ultrasonic-based obstacle detection in embedded systems.

A more advanced approach was taken by P. Sharma and R. Verma in 2022, who integrated Raspberry Pi with machine learning algorithms for visual object recognition. Their robot combined ultrasonic sensors with a camera, enabling it to differentiate between static and dynamic obstacles using OpenCV libraries. This enhancement expanded the robot's environmental perception but required significantly more computational power and higher-cost components. Their findings were influential in highlighting the trade-off between intelligent sensing and hardware complexity—a key consideration in the design of the present project, which aims to maintain balance between affordability and advanced capability.

The study by M. Lee and D. Santos in 2021 explored modularity by designing a robot based on NodeMCU and infrared sensors for home environments. While infrared sensors are sensitive to lighting conditions and were found to be unreliable in fluctuating ambient light, the project introduced valuable architectural concepts such as hardware modularity and ease of upgrades. Their work demonstrated how a robot's functionality can be expanded or adapted through a flexible design approach. This concept strongly influenced the modular architecture adopted in this current system, allowing components such as sensors or communication modules to be added or replaced without major system redesign.

In 2020, S. Bose et al. developed a similar ESP32-based robot that utilized ultrasonic sensors for obstacle avoidance. Their design emphasized quick processing of sensor inputs and effective control of DC motors via the Arduino IDE. However, the study acknowledged limitations in corner detection and highlighted that the system lacked long-range positioning due to the absence of GPS. These constraints directly informed improvements made in this project, including the inclusion of GPS for future integration and better handling of tight spatial navigation using sensor triads.

## Problem Statement

Indoor service robots are steadily gaining traction across various domains, including healthcare, logistics, and personal assistance. While these systems offer automation benefits, their widespread adoption is hindered by issues such as high development costs, limited flexibility, and suboptimal obstacle detection. Entry-level robotic models frequently lack adaptability or advanced control mechanisms, while sophisticated alternatives often require significant financial and technical resources. Bridging this divide calls for a practical, scalable solution that prioritizes ease of assembly, intelligent behavior, and room for future growth.

One of the persistent challenges in this space is effective object detection. Many older systems rely on basic contact sensors or infrared technology, both of which have drawbacks in terms of accuracy or consistency.

Ultrasonic range finders have improved reliability by enabling proximity sensing without physical contact. However, even these are sometimes poorly integrated, resulting in inconsistent behavior in cluttered or dynamic layouts. A more refined strategy for interpreting range data in real time is needed to enhance safe and efficient navigation.

Another critical issue involves computational resources. Low-cost microcontrollers frequently reach their limits when handling multiple sensor inputs alongside motor control and logic execution. Devices with limited memory or single-threaded architectures may introduce latency or fail under load. To address this, the design outlined here employs a dual-core board that supports simultaneous data acquisition and control outputs. This hardware platform also brings in wireless communication as a secondary benefit, enabling remote monitoring or updates.

Motion accuracy is another essential requirement. Uncoordinated wheel control can cause skidding, zigzag paths, or collisions. Stable and responsive motion depends on a well-designed feedback system that links environmental sensing with motor actuation. The robot in this work uses a motor driver module that facilitates two-way motor control and supports real-time speed adjustments. For even more refined handling, feedbackbased corrections are implemented through logic that simulates proportional control systems.

A further limitation found in existing designs is rigidity. Many robots are built for single-use demonstrations or fixed applications, with no easy path to add new features. This inflexibility makes it difficult to keep pace with changing use cases or experimental needs. The present robot avoids this issue by enabling users to swap components or connect new ones—such as location tracking units or environmental sensors—without reconfiguring the entire system.

## Methodology

This robotic system was developed by combining customized hardware with embedded software to create a fully independent mobile unit capable of navigating interior spaces. The physical structure comprises a lightweight base outfitted with a pair of DC gear motors, enabling motion in all cardinal directions. Power for the robot is drawn from a rechargeable lithium-ion cell, regulated to maintain a constant voltage level across all connected devices. A modular approach was followed, enabling individual units such as sensors, motor controllers, or communication modules to be independently added or upgraded without interfering with overall functionality. This flexibility is key for experimental setups and future feature integration.

The project's core computational power is provided by the ESP32 development board, which is equipped with a dual-core processor, Wi-Fi and Bluetooth modules, and a rich set of general-purpose I/O interfaces. The firmware is written using the Arduino development environment, chosen for its simplicity and compatibility with ESP32 libraries. Through this setup, the microcontroller can gather distance measurements, interpret obstacle patterns, and activate motion commands in near real time. The built-in serial output tools facilitate runtime diagnostics, assisting in performance tuning and debugging during iterative development phases.

To perceive its environment, the robot employs three ultrasonic ranging modules—positioned to monitor the front and both sides of the chassis. These modules operate by emitting high-frequency audio pulses and measuring the time delay before the returning signal is detected. Using the captured delay values, the software estimates the spatial distance to objects nearby. These estimates are compared against a predefined safe range to determine whether the robot must change direction, pause, or reverse to avoid contact with an object or boundary.

Motor actuation is controlled through an L298N dual-channel motor driver, which functions as an intermediary between the ESP32 and the motors. Speed variation is achieved using pulse-modulated control signals, while directional switching is handled through digital logic lines. The driver supports two motors independently, which is crucial for maneuvering in tight areas and executing turns with precision. Its current-handling capacity makes it well-suited for the compact DC motors used in this platform.

**System Architecture**

The design of the robot is structured around a modular and hierarchical system that emphasizes scalability, ease of debugging, and reliable performance. The central processing component is the ESP32 microcontroller, which

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orchestrates input processing and output control. The architecture begins with sensor data acquisition—primarily from ultrasonic range finders and, optionally, a GPS module. Data from these inputs is processed by the ESP32, which then sends commands to the motion control system. Each element of the system—sensors, actuators, and communication interfaces—is independently connected via digital I/O or serial lines, ensuring a clean and modular signal structure.

Power delivery is a crucial part of the system's reliability. The robot operates on a lithium-ion battery, which feeds power through a series of voltage regulators to maintain safe and stable outputs. Sensitive components like the ESP32 and sensors receive regulated 5V current, while higher-power devices such as motors draw directly through the L298N driver circuit. The driver board includes heat dissipation and protection mechanisms, such as heat sinks and diodes, to shield against reverse voltage or current surges. This deliberate separation of logic-level power and actuator-level power prevents signal interference and preserves overall stability during peak load conditions.

The primary sensors used in the system are three ultrasonic modules, positioned to cover the front and lateral areas of the robot. These sensors emit sound waves and capture reflected signals to measure distance to nearby obstacles. The central front sensor is responsible for detecting objects directly ahead, while the two side-mounted units assist in edge detection and help guide the robot around corners or narrow passages. The sensors interface with the microcontroller through specific I/O pins, configured for sending and receiving ultrasonic pulses. The ESP32 reads this data in near real time and interprets it to adjust the robot's trajectory accordingly.

Motion is controlled through the L298N motor controller, which operates two independent DC motors configured for differential drive. Control signals in the form of digital direction and PWM (Pulse Width Modulation) values are sent from the ESP32 to the driver, which adjusts the motors' behavior accordingly. The configuration enables complex movement patterns, including turning on the spot, reversing, or executing smooth arcs. Power to the L298N is supplied directly from the battery to ensure adequate current supply during demanding maneuvers, while control inputs from the microcontroller regulate motor speed and direction based on sensor inputs.

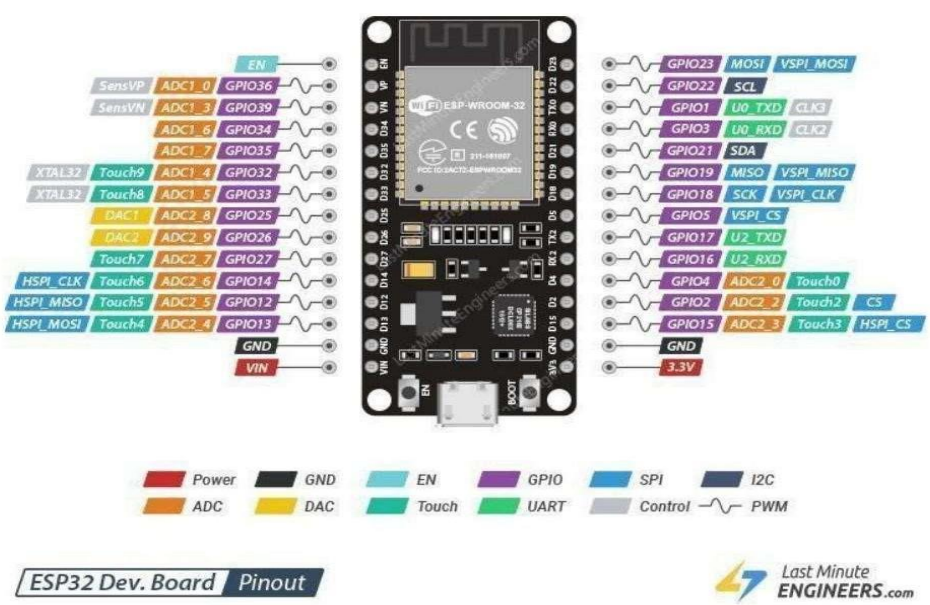

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Fig 2 The ESP32 DevKi

To support both programming and troubleshooting, the ESP32's onboard USB-to-serial converter enables direct communication with development tools such as the Arduino IDE. Through this interface, developers can upload new firmware, monitor sensor outputs, and verify system performance. Additional modules like GPS are also linked via UART serial connections, allowing for optional data logging or position tracking. While GPS functionality is limited indoors, it remains useful for mapping edge areas or for future enhancements where outdoor mobility may be required.

The software is developed in a modular format to mirror the system's hardware flexibility. Code is organized into discrete functions handling specific tasks like initializing sensors, processing distance readings, triggering obstacle responses, and executing movement commands. The main loop cycles through these modules repeatedly to maintain consistent awareness and reactivity. Time-sensitive events may use interrupt-driven processing, while other operations are controlled through timers and logical flags. The structure of the software promotes clarity, ease of testing, and future expansion without requiring significant codebase rework.

The overall design of the robotic system follows a modular framework that prioritizes simplicity, scalability, and ease of debugging. Central to this structure is a programmable logic board that serves as the main control unit. This controller processes incoming data from multiple input sources, evaluates conditions based on coded logic, and issues control signals to output devices. The architecture is arranged in a pipeline fashion—beginning with environmental sensing, flowing through computational logic, and ending with mechanical response—allowing each module to function independently while maintaining synchronization across the system.

Power management is a key consideration in the system's design. A rechargeable energy source provides electricity to all modules. Circuits that regulate voltage ensure that the logic components receive consistent low-voltage power, while higher-demand parts, such as motors, are connected to power pathways that support greater current without introducing noise. Protective components are also included to shield sensitive electronics from power surges or electrical feedback. This power isolation ensures stable operation, especially during rapid changes in motor behavior.

The robot uses distance-sensing devices mounted on different sides of its body to assess its surroundings. These sensors operate by emitting acoustic signals and capturing the reflections that bounce off nearby objects. Based on the delay between signal emission and reception, the controller calculates approximate distances to physical barriers. This information is processed to help the robot decide whether to move forward, stop, or change direction. The sensor layout enables wide-angle perception, helping the machine navigate around corners and through narrow paths.

The movement system is driven by a pair of compact motors installed on either side of the base. These motors are controlled by an external interface module, which interprets signals from the central processor. Motor speed and direction are adjusted using timed electrical pulses and logic-level switching signals. The motor arrangement allows for individual control of each wheel, enabling the robot to spin in place or make tight turns. This configuration enhances mobility and makes it suitable for operating in limited indoor spaces.

For communication and development, the central controller connects to a personal computer through a standard serial interface. This connection allows engineers to upload control programs, receive diagnostic messages, and observe sensor outputs during testing. An optional location-tracking module is also connected through a serial communication port, which can record position data when signals are available. Although this tracking system is not essential for indoor use, it opens the door for integration with broader navigation systems in the future.

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Software is organized in a modular fashion to match the hardware layout. Each key task—such as reading sensor values, analyzing conditions, or activating motors—is assigned to its own function. These functions are called repeatedly in the main program loop, which allows the robot to respond to changes in its environment as they happen. Critical tasks that require precise timing are handled using interrupts, while slower processes rely on

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condition checks and timers. The separation of logic helps simplify debugging and supports future enhancements to the robot's behavior.

In summary, the architecture supports a well-organized interaction between sensing, processing, and movement. Every module, from the power supply to the movement system, is built to be replaceable and upgradeable. The system's layout and coding style are designed to support students, researchers, and developers who want to expand or modify the robot. Its flexibility, real-time responsiveness, and clean structure make it suitable for practical deployment, academic projects, or experimentation in the field of mobile automation.

## Results

Following the completion of both hardware assembly and software deployment, a series of practical evaluations were conducted to assess the robot's autonomous functionality. The unit was tested in various indoor setups that included tight corridors, open floor areas, and obstacle-dense paths to simulate realistic operational environments. During these evaluations, the ESP32 microcontroller demonstrated a high degree of responsiveness, processing inputs from sensors and issuing motor commands with negligible delay. These results confirmed that the system could adapt dynamically to environmental changes, validating the effectiveness of its navigation and avoidance algorithms.

The ultrasonic modules consistently identified nearby objects within a range of approximately 2 to 100 centimeters. Although slight variations in readings occurred—primarily due to glossy surfaces or irregular angles—overall performance remained stable. The configuration of three ultrasonic sensors, placed at the front and on either side of the chassis, enabled the robot to monitor multiple directions simultaneously. This setup enhanced spatial awareness and allowed the robot to anticipate and respond to corner obstacles or walls. The reliable detection and responsive adjustments indicated a strong sensor integration strategy.

Motor control was conducted through the L298N driver module, which received direction and speed inputs from the ESP32 based on sensory feedback. The robot maintained smooth motion along unobstructed paths and adjusted its route effectively when encountering barriers. It was capable of performing sharp maneuvers, such as pivoting or redirecting around objects, and then returning to its original path. The independent control of both motors allowed for precision in directional shifts and contributed to the robot's overall stability during navigation trials.

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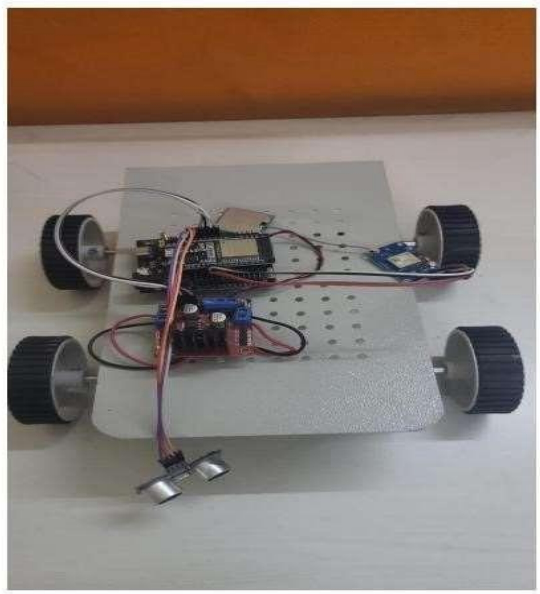

## Conclusion

The development of an autonomous robotic system for indoor navigation, built around the ESP32 platform and ultrasonic detection, has demonstrated effective integration of hardware and software components. This system successfully achieved its design objectives by offering a cost-efficient, responsive, and dependable solution for unmanned movement in enclosed spaces. Through its ability to interpret real-time spatial data and adjust motor behavior accordingly, the robot navigated various layouts—including narrow corridors and confined rooms—without human guidance.

Acting as the central controller, the ESP32 microcontroller executed multiple functions concurrently with a high level of efficiency. While the current implementation did not fully utilize its wireless features, these capabilities remain valuable for future upgrades such as remote interface access, cloud integration, or data streaming. Programming via the Arduino development environment allowed for rapid prototyping and simplified module integration, reinforcing the microcontroller's role as a versatile platform for both educational and applied robotics.

Real-time detection using ultrasonic range finders played a critical role in the robot's autonomy. These sensors enabled the unit to sense nearby objects and calculate safe paths with precision. Placing them at strategic angles allowed the robot to monitor a wide field of view and make dynamic decisions. The algorithm governing motion control responded quickly to sensor inputs, preventing collisions and maintaining smooth traversal. These outcomes confirmed the robustness of the sensory layout and the logic behind obstacle management.

Control over movement relied on the L298N motor driver, which provided reliable actuation and speed modulation across two motors configured for differential motion. This design supported both straight-line travel and agile turns. Where needed, fine-tuning of the system was carried out through logic enhancements, such as proportional control adjustments, contributing to consistent movement across varied terrain conditions. The alignment of mechanical structure and software timing produced effective motion behavior across all test scenarios.

Energy efficiency and structural integrity were additional strengths of the final system. A single battery cycle was sufficient to sustain prolonged use, and the electrical design ensured stable voltage for both sensor circuits and high-current motor lines. Even during demanding maneuvers, the robot maintained uninterrupted operation. The use of modular hardware further simplified part replacement and system expansion, offering flexibility for long-term maintenance or adaptation to new tasks.

Taken together, these design elements resulted in a compact and reliable indoor robotic platform. The combination of realtime responsiveness, scalable control systems, and straightforward programmability reflects a well-balanced solution to common problems in small-scale autonomous navigation. As it stands, the robot is suitable for a wide range of uses, from educational demos to light-duty automation in structured spaces.

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