Ultrasonic Sensor based Obstacle detection and avoidance WMR

PROJECT REPORT

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May 9, 2025

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A Project Report submitted in partial fulfillment of the requirements for the degree of

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Under the guidance of

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1. Certificate

This is to certify that the Project entitled **Ultrasonic Sensor based Obstacle detection and avoidance WMR** has been carried out by **Bibhu Ashis Panda** (2201209613), **M.Flora** (2201209648), **Ayushh Raj** (2201209607), **Ommprasad Sundaray** (220109777) and **Bidisha Sonusaumya** (2201209614) under my guidance and supervision and is accepted in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electronics and Communication Engineering under Silicon University, Bhubaneswar.

Dr. Manoranjan Praharaj	**Dr.Biranchi Narayan Rath**	**Dr.Sudhansu Kumar Pati**
Assistant Professor	Project Coordinator	H.O.D, Dept. of ECE

2. Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included. We have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/sources in our submission. We understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

3. Acknowledgement

First of all we would like to express our sincere gratitude to our project supervisor, Dr Manoranjan Praharaj, for his constant guidance and encouragement throughout the course of our study. We are greatly indebted to him for allowing us to carry out our project work under his guidance. We would like to thank Dr.Sudhansu Kumar Pati (HOD, ECE) and Dr.Biranchi Kumar Rath (Project Coordinator) for providing lab facility and sincere assistance for the completion of our project work.

Words fail to express our deep sense of gratitude especially towards our parents for their patient love, moral encouragement and support which enabled us to complete this course. We thank all our batch mates who have extended their cooperation and suggestions by way of discussion at various steps in completion of this thesis.

Finally we would like to thank all whose direct and indirect support helped me to complete our project work.

4. Department Vision, Mission and PEOs

Vision...

To be recognized as a beacon of quality education and research in the field of Electronics and Communication Engineering

Mission...

- Continually improve the standard of our graduates by having high caliber motivated faculty members together with quality educational programs and facilities in-line with the rapid technological advancements in the field of Electronics and Communication Engineering (Knowledge, Skill and Quality).
- Provide a balanced regime of quality education that incorporates theoretical and practical education, innovation and creativity as well as freedom of thought and research with emphasis on professionalism and ethical behavior (Professionalism and Ethics).
- Promote and support research activities over a broad range of academic interests among students and staff for growth of individual knowledge and prepares for continuous learning (Research and Life-long Learning).

PEOs of the Program

- PEO1. Fundamental Knowledge and Core Competence: To provide knowledge of science and engineering fundamental for an electronics and communication engineer and equip with proficiency of mathematical foundations and inculcate competent problem solving ability.
- PEO2. Competency for Real World: To design, optimize and maintain electronics and communication systems in tune with community needs and environmental concerns.
- PEO3. Professionalism and Social Responsibility: To exhibit leadership capability,triggering social and economic commitment, fostering community service, and promoting environmental protection.
- PEO4. Life-long Learning: To pursue higher studies or engage in a technical or managerial role in diverse teams, grow professionally in their career through continued education and training of technical and management skills.

Contents

REPORT

Ultrasonic Sensor based Obstacle Detection and Avoidance WMR

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Dr.Manoranjan Praharaj

Abstract—This project is all about an obstacle avoidance robot that is interfaced with ultrasonic sensor. The robot uses ultrasonic sensor and it is controlled by ESP-32 micro controller. The ESP-32 board was selected as the micro controller platform and its software counterpart,arduino software, was used to carry out the programming.The obstacle detection is primary requirement of autonomous robot. The sensor gets the data from surrounding area through sensors fixed on the robot. The sensor senses the obstacle and gets deviate its path to choose an obstacle free path.The hardware used in this project is widely available and inexpensive which makes the robot easily replicable.

Keywords—*ESP-32, Ultrasonic sensor, WMR, Obstacle Avoidance*

5. Introduction

There have been a number of successful attempts in designing obstacle-avoiding robots. These works differ by sensor selection, path mapping process, and algorithms applied to set operational parameters. In this paper, we present a low-cost ultrasonic distance sensor for obstacle avoidance for mobile robot navigation. The system is implemented using micro controller *DOIT ESP-32 DEVKIT*,*L289N motor driver* which interfaced the robot with the geared dc motors. The system showed good performance under various types of **smooth surfaces**. Experimental results with varied positions of obstacle show the flexibility of the robot to avoid it and have shown a decent performance in our laboratory. Two ultrasonic sensors mounted on the top of the vehicle to detect obstacles and provide information to detour the obstacle;the sensing element system is extremely low-cost as a result of it solely uses one distance sensing element.

6. Related Work

A majority of work on obstacle detection uses active sensors.

In [1], discusses the obstacle avoidance algorithm used for a mobile robot. Since the algorithm depends heavily on the performance of the ultrasonic range finders, these sensors and the effect of their limitations on the obstacle avoidance algorithm were discussed as well.

To reduce the shortcoming of Ultrasonic sensor [2] has discussed to represent obstacles with the certainty grid method. This method of obstacle representation allows adding and retrieving data on the fly and enables easy integration of multiple sensors.

In [3], an obstacle avoidance mobile robotic system using ultrasonic sensor was developed. The robot moves left, right, forward and backward movement to avoid the obstacle, either autonomously or using the control application. The accuracy recorded from several testing trials, showed that the robot performed excellently scoring 87.5 percent, considering the scope under which it was examined.

In [4], The robot tracks a global trajectory and, if an obstacle is detected, a local trajectory is generated and followed until the obstacle is cleared and the initial trajectory is resumed. Both trajectories are followed using the same discrete-time sliding mode controller. An increase of the errors in the trajectory tracking is caused by switching from the global and local trajectories, but the robot can still follow the trajectory with satisfactory precision.

The paper [5] proposed an algorithm how to track the path of mobile robot using the ultrasonic sensors. The ultrasonic sensor is used to detect and maintain the distance between mobile robot and object. The position control results of obstacle avoiding robot by using PID controller are proposed

A real-time obstacle avoidance approach was presented in [6]. The approach permits the detection of any obstacles on the path of the mobile robot to avoid collision. Ultrasonic sensor was used to accurately control the movement of the robot. The navigation algorithm employed in the work also takes into account the behavioral effect of a fast mobile robot and also solved the local minimum trap problem. The result of the experiment using a mobile robot running at a maximum speed of 0.78m/s confirm the effectiveness of the proposed algorithm.

In[7], work on an obstacle avoidance mobile robotic system using ultrasonic sensor was developed for the physically disabled. It was showed that when the ultrasonic range finder transmit a sound wave, one part of the wavefront emitted towards the surface of an obstacle and not all the waves are reflected back to the sensor as some of the waves is scattered in other directions. This has a major setback with its usage of the ultrasonic range finder whose principle of operation and commonly used wavelength are the major constraint. Thus, the amount of reflected sound energy reflected back depend on the surface structure of the obstacle.

In[8] ultrasonic sensors were also employed in the development of an autonomous floor-cleaning robot. The sensor was used to detect any object and send the input to the Arduino controller that controls the robot autonomous movement. The zig-zag movements of the robot if compared with ours make our system easy to operate

7. Block Diagram

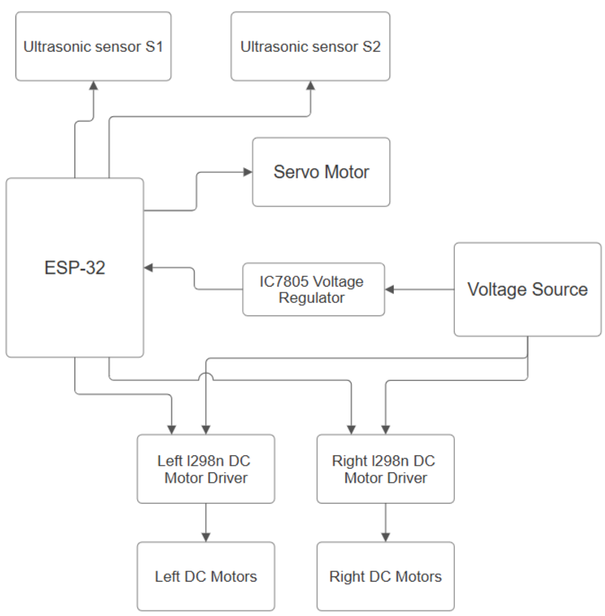

Figure 1. Block Diagram

8. Circuit Diagram and it's description

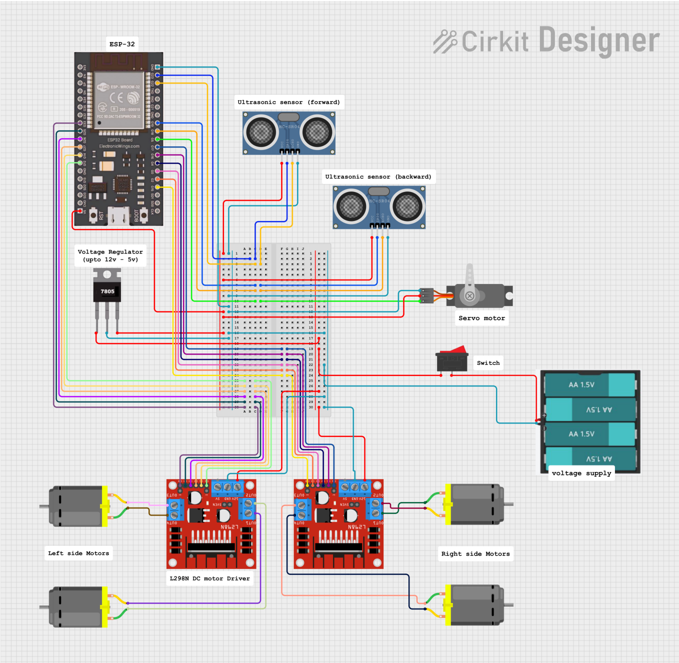

Figure 2. Circuit Diagram

This circuit diagram represents a robotic vehicle control system using an ESP32 microcontroller, designed for obstacle detection and avoidance. Below is a detailed description of the components and connections:

8.1. Main Components:

ESP32 Microcontroller

- Acts as the central processing unit of the robot.
- Interfaces with sensors, motor drivers, and other peripherals.

Ultrasonic Sensors (Forward and Backward)

- Used for distance measurement to detect obstacles.
- The forward sensor monitors objects in front of the vehicle, while the backward sensor checks behind.

Servo Motor

- Likely used to rotate the forward ultrasonic sensor for scanning the environment.
- Connected to one of the PWM-capable pins of the ESP32.

L298N DC Motor Drivers (2 Units)

- Controls the left and right side motors independently.
- Each driver is connected to two DC motors.
- IN1-IN4 pins are connected to ESP32 GPIOs for control.
- ENA and ENB pins control motor speed using PWM.

DC Motors (4 total: 2 on each side)

- These drive the robot's wheels.

Voltage Regulator (7805)

- Converts the battery voltage (up to 12V) to 5V for powering the ESP32 and sensors.

Power Supply (4 x AA 1.5V Batteries)

- Provides a total of 6V power to the circuit via a switch.

Breadboard and Wires

- Used for prototyping and interconnecting all the components.

Switch

- Used to turn the power supply on or off.

Connections Summary:

- Power:
  - The battery pack is connected through a switch to the voltage regulator.
  - The regulated 5V output powers the ESP32, ultrasonic sensors, and servo motor.
  - L298N modules get motor power (VCC) directly from the battery pack.
- Ultrasonic Sensors:
  - VCC, GND, Trig, and Echo pins are connected to the ESP32.
  - Each sensor has unique GPIO pins for Trig and Echo.
- Servo Motor:
  - Powered by the 5V line.
  - Signal pin connected to a PWM-enabled GPIO on the ESP32.
- DC Motors:
  - Connected in pairs to each L298N motor driver.
  - Control pins (IN1–IN4) and enable pins (ENA, ENB) connected to ESP32 GPIOs.

Functionality Overview:

- The robot uses ultrasonic sensors to detect obstacles.
- The ESP32 processes the data and controls: Ultrasonic Sensor is mounted over servo motor to scan the area.
- Motor drivers move or steer the robot by powering the appropriate wheels.
- The switch allows for manual power control.
- A regulated 5V supply ensures the safe operation of all low-voltage components.

9. Components

9.1. L289N 2A Motor Driver

Figure 3. L289N 2A Motor driver

L298N 2A Based Motor Driver is a high power motor driver perfect for driving DC Motors and Stepper Motors It uses the popular L298N motor driver IC and has an onboard 5V regulator which it can supply to an external circuit. It can control up to 4 DC motors, or 2 DC motors with directional and speed control. This motor driver is perfect for robotics and mechatronics projects and perfect for controlling motors from microcontrollers, switches, relays, etc. It is perfect for driving DC and Stepper motors for micro mouse, line following robots, robot arms, etc.

9.2. DC Motor

Figure 4. DC Motor

The metal gears have better wear and tear properties. The gearbox is sealed and lubricated with lithium grease and requires no maintenance.Although the motor gives 100 RPM at 12V, the motor runs smoothly from 4V to 12V and gives a wide range of RPM, and torque. The shaft has a hole for better coupling. Operating Voltage(V): 12 ; Rated Torque(kg-cm): 2.9 Stall Torque(kg-cm): 11.4

9.3. DOIT ESP-32 DEVKIT

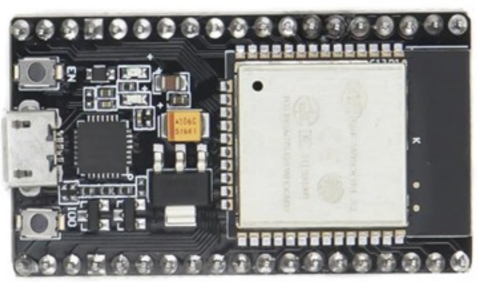

Figure 5. DOIT ESP-32 DEVKIT

This is ESP WROOM 32 MCU Module. ESP WROOM 32 is a powerful, generic WiFi-BT-BLE MCU module that targets a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks, such as voice encoding, music streaming, and MP3 decoding.There are 2 CPU cores that can be individually controlled or powered.The user may also power off the CPU and use the low-power coprocessor. ESP32S integrates a rich set of peripherals, ranging from capacitive touch sensors, Hall sensors, and low-noise sense amplifiers. In addition, this module can support data rates of up to 150 Mbps to allow for the widest physical range.

Table 1.
Technical Specifications of ESP32 Devkit

Specification	**Details**
Microcontroller	Tensilica Xtensa LX6 dual-core (32-bit)
Operating Voltage	3.0V to 3.6V (typically 3.3V)
Input Voltage (recommended)	5V (via USB)
Digital I/O Pins	30
Analog Input Pins (ADC)	15 (12-bit ADC)
Analog Output Pins (DAC)	2 (8-bit DAC)
Communication Interfaces	UART, SPI, I2C, I2S, CAN
Wi-Fi	802.11 b/g/n
Bluetooth	Bluetooth v4.2 BR/EDR and BLE
Flash Memory	4 MB (can vary by module)
SRAM	520 KB
Clock Speed	Up to 240 MHz
GPIO Current Drive	12 mA per pin
Power Consumption	Low power modes available (Deep Sleep: 10 µA)
Dimensions	Approx. 50mm x 25mm

9.4. Tower Pro SG90 Servo Motor

Figure 6. Servo Motor

Tower Pro Servo Motors are optimum quality and affordable cost servos.They are suitable for a wide range of applications, including RC aircraft, automobiles, and robotics. They have high resolution with accurate positioning along with fast control response. RED - Positive, Brown - Negative, Orange - signal

9.5. Ultrasonic Sensor

Figure 7. Ultrasonic Sensor

This HC-SR04-Ultrasonic Range Finder is a very popular sensor that is found in many applications where it requires measuring distance and detecting objects.The module has two eyes like projects in the front which forms the Ultrasonic transmitter and Receiver. The HC-SR04 ultrasonic sensor uses sonar to determine the distance to an object like bats or dolphins do.It has very handy and compact construction. It offers excellent range accuracy and stable readings in an easy-to-use package. The Trigger and the Echo pins are the I/O pins of this module and hence they can be connected to the I/O pins of the micro controller Arduino.

10. Our Approach

The mobility of the obstacle avoiding robot is obtained with four DC geared motors which are attached to the wheels of the car. Control for the four motors in the system is carried out by using dual L298N integrated circuit. The driving signals are generated by the microcontroller which produces appropriate PWM according the position of the robot. Sensor arrangement for object detection, two ultrasonic sensors are used and the arrangement in which is placed at the top centre of the robot. This arrangement is used for accurate detection of obstacle within the range. To make the robot turn to the left or right, the motors of one side will rotate forward and another side will rotate backward. Turn is achieved as the direction difference of both side motors. This results in robot spinning in its own place. The brain of the robot is a DOIT ESP-32 DEVKIT V1 30 MCU, Bidirectional motor speed control is achieved by using two L289N motor driver circuit. The power applied to the motor is varied by using PWM generated by the microcontroller. Ultrasonic sensor is used to detect and maintain a specific distance from the object. Ultrasonic sensor generates high frequency sound waves and evaluates the echo which is received back by the sensor. The ultrasonic sensor accurately works within a range of 4 meters. Obstacle avoidance is implemented using ultrasonic sensors due to limitations in the mobile robot's computing hardware. In the current setup, the detection of moving obstacles relies solely on these ultrasonic sensors. These sensors measure the distance to objects in near real-time using the pulse-echo technique. However, Ultrasonic Sensors cannot inherently differentiate between moving and stationary obstacles. Their effectiveness depends on several factors, including the orientation, reflectivity, and curvature of the obstacle's surface relative to the sensor, as well as the detection threshold set for received echoes. The view angle of the ultrasonic sensor system shown in Fig. 8 and Fig.9

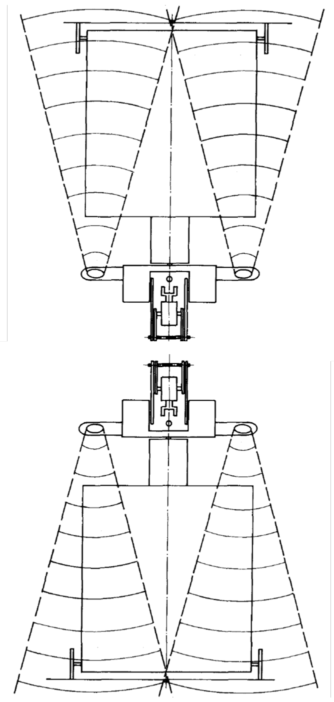

Figure 8. Detection area of the ultrasonic sensor

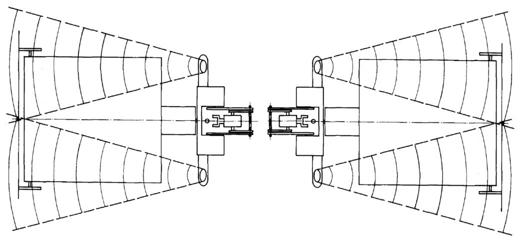

Figure 9. Detection area of the ultrasonic sensor

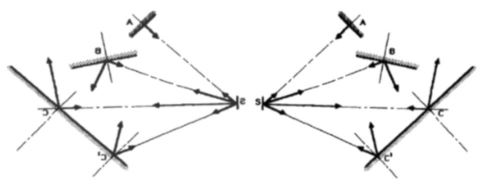

Figure 10. Scan field for two transducers mounted on "Servo Motor" of robot

10.1. Flow Chart

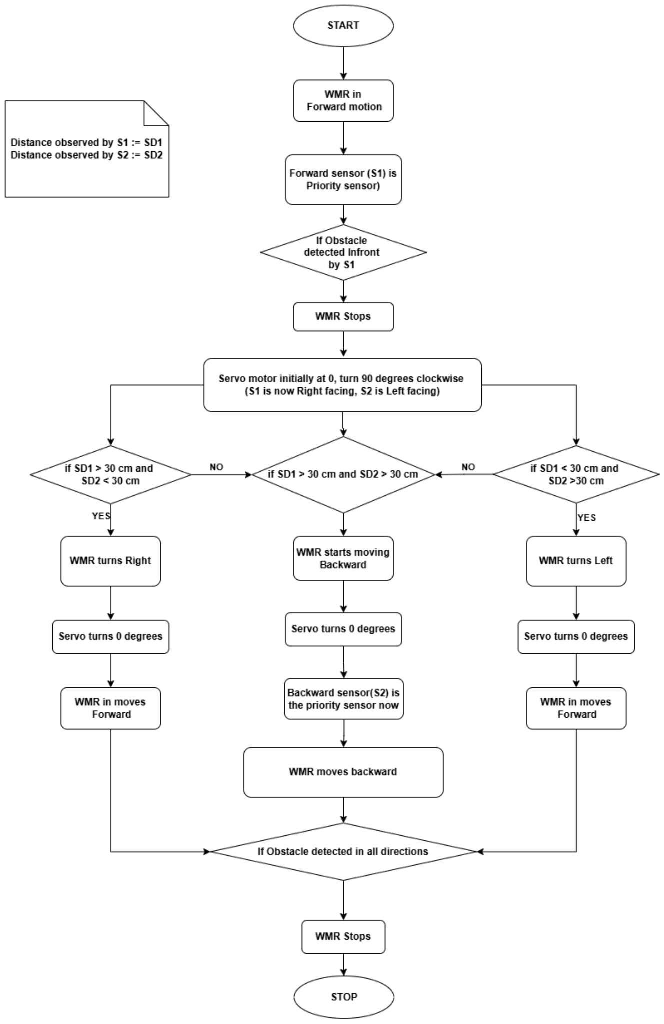

Figure 11. Flow Chart

10.2. Algorithm

Step 1: Initialization

- The robot begins by moving in the forward direction.
- Both the left and right DC motors are engaged to move the robot forward.
- The servo motors are initially set to 0 degrees:
  - **Ultrasonic Sensor-1:** is oriented to face forward.
  - **Ultrasonic Sensor-2:** is oriented to face backward.

Step 2: Obstacle Detection (Forward Motion)

- While moving forward, Sensor-1 continuously monitors for obstacles.
- If an obstacle is detected by Sensor-1 at a distance of less than 30 cm, the following sequence is executed:
  - The robot halts immediately.
  - A delay of 1 second is observed.
  - The servo motor rotates to 90 degrees:
  - **Sensor-1:** now faces the right side.
  - **Sensor-2:** now faces the left side.
- The robot evaluates both sides:
  - **If Sensor-1 (right) < 30 cm and Sensor-2 (left) > 30 cm:**
    - $\rightarrow$ The robot turns left by rotating in place (left motor forward, right motor backward).
  - **If Sensor-1 (right) > 30 cm and Sensor-2 (left) < 30 cm:**
    - $\rightarrow$ The robot turns right by rotating in place (left motor backward, right motor forward).
- If both sensors detect obstacles < 30 cm:
  - $\rightarrow$ The robot cannot proceed left or right. It waits for 1 second, reorients the servo motor back to 0 degrees, and transitions to backward motion.
- After turning (left or right), a delay of 1 second is observed.
- The servo motor is returned to 0 degrees, and the robot resumes forward motion in the new direction.

Step 3: Obstacle Detection (Backward Motion)

- If no path is available in the forward direction, the robot begins to move backward.
- In this state:
  - **Sensor-2:** becomes active to detect rear obstacles.
  - **Sensor-1:**remains idle.
- If Sensor-2 detects an obstacle at less than 30 cm, the following sequence is executed:
  - The robot stops immediately.
  - A delay of 1 second is observed.
  - The servo motor rotates to 90 degrees:
    - Sensor-1 now faces the **right** side.
    - Sensor-2 now faces the **left** side.
- The robot evaluates both sides using the same logic as in forward motion:
  - Obstacle on right, left is clear $\rightarrow$ Turn left.
  - Obstacle on left, right is clear $\rightarrow$ Turn right.
  - Obstacles on both sides $\rightarrow$ Proceed to Step 4.
- After turning, a delay of 1 second is observed.
- Servo motor returns to 0 degrees, and the robot resumes backward motion.

Step 4: Directional Decision When Both Sides Are Clear

- If both left and right distances are greater than 30 cm:
  - The robot compares the two values.
  - Turns toward the side with greater distance.
  - Introduces a 2-second delay for motion stabilization.
- If no significant difference is found or uncertainty exists:
  - The robot stops
  - Waits for 2 seconds, and returns control to main navigation logic.

Step 5: No Path Available

- If the robot encounters obstacles on all four sides (front, back, left, and right), it concludes that no path is currently available.
- The robot:
  - Stops completely.
  - Waits for 5 seconds.

11. Result and Analysis

- The robot effectively avoided obstacles across various floor surfaces during laboratory testing.
- The dual sensor arrangement ensured smooth maneuvering around obstacles, confirming system reliability.
- The motor driver demonstrated consistent performance, even under varying load conditions.

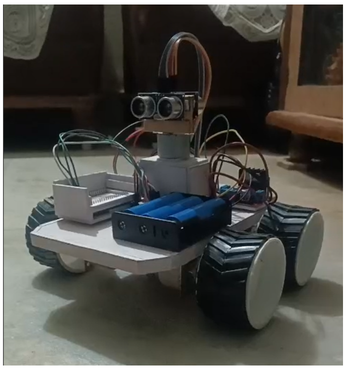

Figure 12. Robot Construction

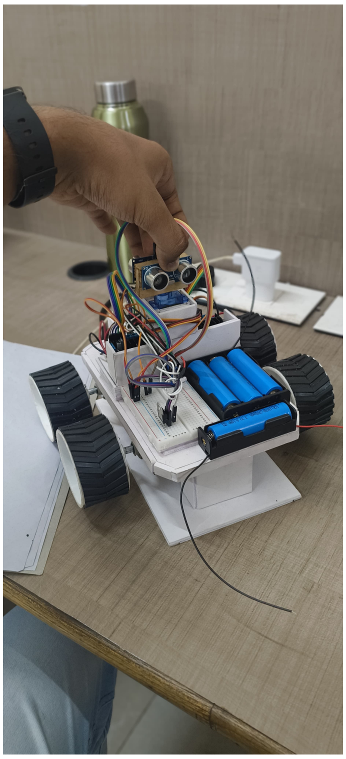

Figure 13. Construction of Robot

- Sensor readings remained accurate within the robot's operational range, ensuring precise obstacle detection.
- The simple design facilitated easy hardware troubleshooting and repair, reducing downtime.
- The robot exhibited effective obstacle avoidance capabilities under stress tests, confirming robustness.
- Stable movement was maintained, with no significant drift during operations.
- System latency between obstacle detection and motor response was minimal, ensuring prompt action.
- A cost analysis confirmed that the project was executed within an affordable budget.
- Demonstrations highlighted the robot's reliable performance, even during repeated trials.

12. Conclusion

The robot performed reliably under stress tests, effectively avoiding obstacles with quick response times and stable movement. It showed minimal noticeable drift during operation and maintained consistent behavior across repeated trials. The project was also completed within budget, making it both efficient and cost-effective.

13. Future Scope

The obstacle avoidance system developed in this paper cannot by itself perform a task such as to move in unknown environments while simultaneously keeping track of its location in an outdoor scenario. Implementing SLAM (Simultaneous Localization and Mapping) techniques can enable the robot to perform the mentioned scenario outdoors. Also the robot stops when multiple obstacles are detected at different angles,Using the built-in Wi-Fi and Bluetooth capabilities of the ESP32, real-time monitoring and remote control functionalities can be developed, making the robot suitable for surveillance, search and rescue, and industrial inspection tasks. Interfacing Additional sensors like infrared (IR) sensors, LIDAR, or vision-based systems (camera modules) can be combined with ultrasonic sensors to provide more accurate, robust, and reliable obstacle detection and environmental mapping.

14. The last chapter:Problems we faced

Ultrasonic range measurements face several fundamental limitations that restrict their effectiveness in mapping and other applications demanding high accuracy, particularly in domestic environments. These limitations are not tied to any specific manufacturer but are instead inherent to the operating principles and typical wavelengths employed by ultrasonic range finders.[7]

Even though ultrasonic ranging devices play a substantial role in many robotics applications [1]–[5], [8]

the amount of reflected sound energy depends strongly on the surface structure of the obstacle. To obtain a highly diffusive reflection from an obstacle, the size of the irregularities on the reflecting surface should be comparable to the wavelength of the incident sound-waves [7]

$$\lambda = \frac{v}{f} = \frac{340m/s}{5000Hz} = 6.8mm, \tag{1}$$

where
λ = wavelength,
v=340m/s velocity of sound waves in air at room temperature
f=50kHz frequency of the sound waves.

Unfortunately, the domestic environment comprises mostly much smoother surfaces, such as walls, polished wood, plastics, etc.Increasing the frequency (thereby decreasing the wavelength) of the sound waves is limited by the undesirable side effect of a higher energy dissipation.The directionality problem is partly accounted in our obstacle avoidance algorithm.

Also The SG90 Tower Pro micro servo rotated less than the intended 90° when commanded, leading to inaccurate positioning. To compensate for this deviation, an error margin of $\pm 5°$ was introduced. This workaround highlights the servo's inconsistency in achieving precise angular movement.

During the initial stages of the project, the absence of a 7805 voltage regulator IC resulted in unstable power supply to the ESP module. This led to frequent malfunctions and unreliable operation of the system. Without proper voltage regulation, the ESP was unable to function consistently, highlighting the critical importance of integrating a stable 5V power source in embedded hardware designs.

When multiple components like sensors, motors, and communication modules ESP32 are interfaced, using delay() for more than 2 seconds led to system lag and malfunction. The delay() function with more than 2 seconds of delay was blocking call, which halts all program execution—including sensor reading, data processing, and communication—during the delay period and to overcome the issue we kept all the delay time period less than or equal to 2 seconds.

15. References

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