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Development of a Low-Cost Autonomous Robot for Obstacle Avoidance Using Ultrasonic Sensing

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Abstract

In the evolving landscape of automation, autonomous mobile robots are becoming critical for performing tasks with minimal human intervention. This project presents the design and development of a cost-effective, small-scale obstacle-avoiding robot using an Arduino microcontroller and an ultrasonic sensor. The robot operates by scanning its surroundings, identifying nearby obstacles, and navigating by altering its path in real time. Through intelligent programming and sensor integration, the system achieves smooth, collision-free movement. This work highlights a practical application of embedded systems and serves as a foundational step for advancing autonomous navigation research. The robot operates by continuously scanning its surroundings with the ultrasonic sensor, which measures the distance to nearby objects by sending and receiving sound waves. When an object is detected within a predetermined threshold distance, the robot automatically stops, makes a quick decision to turn either left or right, and then proceeds forward again once the path is clear. This behavior ensures smooth, collision-free movement without the need for remote control or manual supervision. The robot's logic is implemented through simple yet effective programming on the Arduino platform, providing a clear example of real-time sensor processing, motor control, and reactive decision-making in embedded systems. Throughout this project, careful attention was given to the selection and integration of hardware components, the design of the control algorithm, and the assembly of a stable mechanical structure. We also documented the challenges encountered, such as sensor inaccuracies, motor performance issues due to battery limitations, and occasional difficulties in obstacle detection under certain environmental conditions. Additionally, extensive testing was conducted in a variety of scenarios involving different obstacle types and arrangements to evaluate the robot's performance, reliability, and limitations. Beyond just building a working prototype, this project serves as a foundational step for exploring more advanced topics in robotics, such as path planning, Simultaneous Localization and Mapping (SLAM), and artificial intelligence-driven navigation. Future enhancements could involve adding multiple sensors for better environmental awareness, implementing more sophisticated algorithms for decision-making, and improving power management for longer operational life. Ultimately, this project highlights how fundamental concepts in robotics and embedded systems can be taught, explored, and expanded upon using accessible technology, encouraging further innovation and learning in the field of autonomous mobile robots.

Keywords: Ultrasonic sensor, DC motor, Arduino Uno R3, servo motor, embedded systems

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INTRODUCTION

Robots that can move independently without requiring human control are becoming an important part of modern technology. Whether it is delivering packages, exploring unknown environments, or helping at home, the ability of a robot to navigate and avoid obstacles is essential. Without this, robots can easily crash into objects, making them unreliable and even dangerous in real-world settings. Obstacle avoidance is one of the most basic and necessary skills that any mobile robot must have before it can perform more complex tasks [1–5].

This project focuses on designing and building a simple, small-scale obstacle-avoiding robot using an Arduino Uno microcontroller, an HC-SR04 ultrasonic sensor, and an L298N motor driver module. The robot was designed to move forward as long as the path ahead was clear. However, when it detects an obstacle within a certain distance, it automatically stops, determines a new direction, and moves around the obstacle before continuing its journey [6–11].

By working on this project, we aim to gain a deeper understanding of how sensors, actuators, and microcontrollers can be combined to create intelligent behavior. We also learn how real-world challenges, such as imperfect sensors, unpredictable environments, and limited power, can impact a robot's performance, and how thoughtful design and programming can overcome these challenges [12–17].

In short, this project provides a solid foundation for the key concepts of autonomous navigation, embedded systems, and robotics, and prepares us for even larger innovations in the future.

PROBLEM STATEMENT

In the field of robotics and automation, enabling machines to move independently without human control is no longer a luxury—it has become a necessity [18–22]. Whether robots are used for delivering goods, assisting in healthcare, cleaning homes, or exploring dangerous environments, they must be able to safely and efficiently navigate spaces filled with obstacles. A robot that cannot detect and avoid objects in its path will not only fail at its task but also cause accidents or damage to itself and its surroundings [23–27].

Despite significant advancements in robotics, creating a fully autonomous system that can successfully sense, process, and react to real-world environments still presents several challenges. Many robotic systems rely on expensive and complex hardware, making them inaccessible to students, hobbyists, and small-scale developers who wish to explore the field of autonomous robotics. There is a need for a simpler, low-cost, and easy-to-build solution that can effectively demonstrate the fundamental concept of obstacle avoidance, without the need for sophisticated equipment or heavy computational power [28–33].

Moreover, the real-world environments are unpredictable. Obstacles can vary in shape, size, and material, and conditions such as lighting, surface texture, and sensor noise can affect the ability of a robot to detect and react correctly. Therefore, designing a reliable and affordable robot that can handle these basic challenges in a variety of settings remains an important educational and engineering problem [34–39].

This project specifically addresses the need for a simple, affordable, and practical obstacle-avoiding robot that uses commonly available components, such as an Arduino Uno microcontroller and ultrasonic sensors. By focusing on basic but crucial functionality, detecting obstacles, and making navigation decisions, the project aims to create a robot that demonstrates the principles of autonomous movement in an understandable and hands-on way [40–46].

In summary, the core problem of this project is: how can we design and build a low-cost, small-scale mobile robot that can intelligently detect and avoid obstacles in its environment using simple electronic components and straightforward programming techniques?

By solving this problem, we not only build a functioning robot but also lay the groundwork for understanding more complex autonomous systems and inspiring future innovations in the field of mobile robotics [47–51].

Objectives

The primary goal of this project is to design, build, and implement a small-scale, autonomous obstacle-avoiding robot using an Arduino Uno microcontroller, HC-SR04 ultrasonic sensor, and motor driver. This project aims to demonstrate the fundamental concept of autonomous navigation, where the robot is capable of detecting obstacles in its path and making decisions to avoid collisions [52–57]. The key objectives of this project are as follows.

1. *To design and develop a mobile robot capable of autonomous obstacle avoidance*, the robot should be able to move forward when the path is clear and autonomously detect and avoid obstacles when encountered. This task should be performed without manual intervention or complex external control systems [58–60]. The behavior of the robot should be driven by the real-time data gathered from its ultrasonic sensor.
2. *To use affordable and widely available components*, the robot will be built using low-cost, widely available hardware such as the Arduino Uno microcontroller, HC-SR04 ultrasonic sensor, and basic DC motors. Using these components, the project aims to demonstrate how even simple, accessible materials can be used to create an effective robotic system.
3. *To implement a simple yet effective control algorithm*, the robot is programmed to detect obstacles and react accordingly by stopping, moving backward, and turning either left or right to avoid a collision. The control algorithm is designed to operate in real time, with the robot making quick decisions based on the proximity to obstacles. The focus will be on simplicity, ensuring that the robot can navigate and avoid obstacles effectively without the need for complex path planning or mapping [61–64].
4. *To explore sensor integration and motor control*, this project will provide a hands-on learning experience in sensor integration, where the ultrasonic sensor will be used to measure distances and provide feedback to the system. It also demonstrates motor control through the use of the L298N motor driver, which controls the direction and speed of the robot's movement.
5. *To test and evaluate the robot's performance in different real-world conditions*, the robot will undergo various testing scenarios to ensure that it performs reliably in typical environments with different types of obstacles. These tests will help identify limitations or issues such as sensor accuracy, motor performance, and power consumption. Based on the results, improvements or adjustments will be made to enhance the performance [65–67].
6. *To address and solve practical challenges in robotics*: Throughout the project, we aim to identify and tackle common challenges faced in robotics, such as sensor limitations (e.g., detecting small or thin obstacles), battery power issues, and dealing with environmental factors, such as lighting and surface texture. By addressing these challenges, this project will serve as a valuable learning experience for solving practical problems in robotics.
7. *To provide a foundation for future robotics projects*: By successfully building a simple obstacle-avoiding robot, this project will lay the groundwork for more advanced robotics. Future improvements could include adding multiple sensors for better obstacle detection, incorporating machine learning algorithms for smarter navigation, and improving power efficiency by using better battery solutions [68–70].

In summary, the objectives of this project are to create a simple, low-cost, and functional autonomous robot that can avoid obstacles in real-world environments, while also providing a platform for learning about robotics, sensor integration, motor control, and embedded system programming. This project not only demonstrates the basics of autonomous navigation but also serves as a stepping stone for more advanced exploration in the field of robotics [71–74].

Scope for the Study

The scope of this study extends to the design, development, and implementation of an autonomous obstacle-avoiding robot that operates using basic components, such as an Arduino Uno microcontroller and an HC-SR04 ultrasonic sensor. The project aims to demonstrate the core concepts of mobile robotics, such as autonomous navigation, real-time sensor processing, and basic decision-making algorithms, while addressing the practical challenges in creating a functional robotic system. The following points outline the specific areas and boundaries of this study.

1. *Design and development of a basic autonomous robot*: The primary scope of this study is the design of a mobile robot that can autonomously detect and avoid obstacles. This study focuses on the use of accessible low-cost hardware components that are easy to source and integrate. By using the Arduino Uno and HC-SR04 ultrasonic sensors, the project provides a foundation for understanding how to build and program a simple robot capable of navigating real-world environments.
2. *Implementation of obstacle avoidance behavior*: A key aspect of this study is the development of an algorithm that enables the robot to avoid obstacles in its path. The robot uses an ultrasonic sensor to measure the distance to nearby objects and make real-time decisions based on this data. This included stopping, reversing, and randomly choosing a new direction (left or right) to avoid obstacles. The study will not delve into complex navigation strategies, such as path planning, but rather focus on the fundamentals of reactive obstacle avoidance.
3. *Sensor integration and real-time processing:* This project will explore how an ultrasonic sensor can be integrated with a robot to enable real-time data collection and processing. The scope of this study involves the basic use of an HC-SR04 sensor to detect obstacles within a specified range. The robot will not use advanced sensor fusion or multiple types of sensors (such as infrared or cameras), but rather focus on a single, cost-effective sensor to achieve obstacle detection.
4. *Evaluation and testing in controlled environments:* The robot will undergo testing in controlled environments with different obstacles such as boxes, walls, and furniture. The scope of this study was limited to indoor environments with clear paths and static obstacles. Although the robot's obstacle avoidance functionality will be tested and evaluated for performance, it will not be tested in outdoor or highly dynamic environments where moving objects, complex terrains, or unpredictable conditions might affect its behavior.
5. *Practical challenges and limitations*: This study identifies and explores the common challenges encountered in the development of autonomous robots, including limitations in sensor accuracy, power consumption, and the ability of robots to handle narrow or irregular obstacles. However, the study did not address more advanced challenges, such as optimizing sensor placement, enhancing motor efficiency, or implementing long-range navigation techniques. It focuses primarily on understanding the basics of mobile robot behavior and sensor integration.
6. *Focus on educational value*: One of the central goals of this study was to provide educational value for students and hobbyists interested in learning about robotics, embedded systems, and automation.

Proposed Architecture

Block Diagram

The architecture of the proposed obstacle-avoiding robot was designed to be both simple and effective, using basic components that can easily be integrated to form a fully functional autonomous system (Figure 1). The design focuses on allowing the robot to navigate its environment without human intervention by detecting obstacles and making decisions in real time based on sensor feedback. Below is a detailed explanation of the proposed architecture, which includes the key hardware components, their roles, and how they interact within the system.

System Overview

The architecture of the robot can be broken down into several main subsystems:

- *Sensing subsystem*: This subsystem is responsible for detecting obstacles in the environment using an ultrasonic sensor.
- *Processing subsystem*: The heart of the robot, where all decisions are made. It consists of an Arduino Uno microcontroller that processes sensor data and controls the movement of the robot.
- *Actuation subsystem*: This subsystem includes the motors and motor driver, which physically move the robot based on commands received from the microcontroller.
- *Power supply*: Provides the necessary energy for all components to function efficiently.

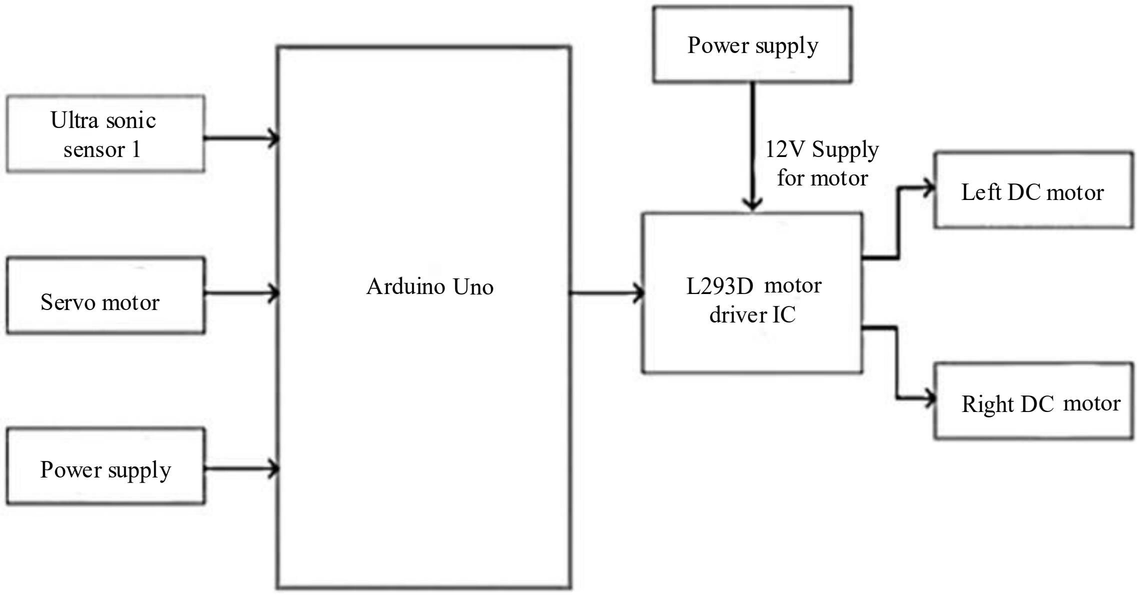

Figure 1. Block diagram of the obstacle-avoiding robot system.

These subsystems work together to form a cohesive system that allows the robot to avoid obstacles while navigating the environment.

DETAILED BREAKDOWN OF COMPONENTS

Microcontroller (Arduino Uno)

The Arduino Uno microcontroller was the central processing unit of the robot. It acts as the brain, interprets data from the ultrasonic sensor, and controls the motors to ensure smooth and intelligent movement. The microcontroller is programmed with an algorithm that dictates how the robot responds to the sensor data (i.e., when to stop, turn, or reverse). It communicates with all the other components and coordinates their actions to achieve autonomous navigation of the robot.

Ultrasonic Sensor (HC-SR04)

An HC-SR04 ultrasonic sensor was used to detect obstacles along the path of the robot. It emits a sound wave through its Trigger (TRIG) pin, which then bounces off objects and returns to the sensor through the ECHO pin. The microcontroller calculates the distance to the nearest object based on the time taken for the sound wave to return. If an obstacle is detected within a certain range (e.g., 20 cm), the microcontroller activates the appropriate response, such as stopping or changing direction.

Motor Driver (L298N)

The L298N motor driver was used to control the direction and speed of the DC motors that drove the robot. It receives signals from the microcontroller and activates the motors in a manner that allows the robot to move forward, backward, and turn. The motor driver can control two motors simultaneously: one for the left wheel and one for the right wheel. This enables the robot to move in different directions, such as forward, backward, and turn left or right, based on an obstacle avoidance algorithm.

DC Motors

The robot used two DC motors to drive its wheels. Each motor was controlled by a motor driver and was responsible for moving the robot forward or backward. The motors can be independently controlled, allowing the robot to turn by driving one motor forward and the other backward or varying the speed of the motors. The motors were powered by a battery pack that provided the energy required for movement.

Power Supply

A 9 V battery pack was used to power the entire system, including the Arduino, ultrasonic sensor, motor driver, and motors. The power supply was designed to provide a stable voltage to ensure that the system ran reliably. The motor driver receives its power separately to ensure that the motor receives sufficient current to function properly, whereas the Arduino and other components are powered through the motor driver or directly from the battery pack.

SYSTEM WORKFLOW

The system operates in a loop, where the ultrasonic sensor continuously scans the environment, and the microcontroller processes the data to determine the robot's next move. The system operates as follows:

1. *Obstacle detection*: The ultrasonic sensor emits a pulse through the TRIG pin and waits for the echo to return through the ECHO pin. Arduino calculates the distance to the nearest object based on the time it takes for the echo to return.
2. *Decision-making*: The microcontroller evaluates the distance received from the sensor. If the distance to the nearest object is greater than a set threshold (e.g., 20 cm), then the robot continues to move forward. If the distance is less than the threshold, the robot must avoid the obstacles.
3. *Obstacle avoidance:* When an obstacle is detected within a specified range, the microcontroller sends a signal to the motor driver to stop the motor. It then commands the robot to move backward over a short distance, followed by a random turn (either left or right) to find a clear path. After turning, the robot moved forward again, continuously scanning for obstacles.
4. *Continuous operation:* This process repeats continuously, with the robot making decisions and adjusting its path in real time based on data from the ultrasonic sensor. The robot reacts autonomously to obstacles without requiring any external control.

Interaction Between Subsystems

- The Arduino receives the input from the ultrasonic sensor and processes it to determine the next action of the robot.
- The Arduino then sends control signals to the motor driver to adjust the movement of the DC motors, thereby allowing the robot to avoid obstacles and navigate smoothly.
- The motor driver provides the necessary power to the motors, enabling them to turn their wheels in the desired direction.
- The power supply ensures that all the components are powered consistently, enabling the robot to function reliably over time.

Flowchart of the System

To visualize the proposed architecture, a simple flow chart showing how the robot operates

- Start → Sensor detects obstacle → Is the obstacle too close (within 20 cm)?
  - If no, continue moving forward.
  - If yes, stop → move backward → randomly turn → move forward → repeat the loop.

This loop is constantly running as long as the robot is powered, ensuring continuous and intelligent behavior based on real-time obstacle detection and decision making.

CONCLUSIONS

This project successfully demonstrated how an affordable and simple robotic platform can be used to develop an autonomous obstacle avoidance system. Utilizing an ultrasonic sensor and Arduino-based control logic, the robot efficiently navigated through various scenarios without external input. The implementation provided practical insights into sensor limitations, battery dependencies, and algorithm design for real-time control. Future improvements may include the addition of advanced sensors, integration of wireless communication, and exploration of AI-based decision-making. This project offers significant educational value and provides a solid foundation for further innovation in mobile robotics.

The main goal of the project was to design a robot that could move independently, detect obstacles in its path, and take quick actions to avoid collisions without any human control. After a series of design iterations, testing, and fine-tuning, the robot successfully achieved these goals. It can reliably navigate its environment, move forward when the path is clear, stop when it encounters an obstacle, and either turn left or right to find a new path forward. The simplicity of the behavior may seem basic but achieving such reactive and autonomous behavior requires a strong understanding of the sensors, microcontrollers, motor control, and programming logic.

Several key observations have emerged throughout development. One of the most important lessons was the critical role that sensors played in robot autonomy. The ultrasonic sensor proved to be a practical and cost-effective choice for basic obstacle detection, although it has limitations in detecting very narrow or soft objects, such as table legs or cloth curtains. These challenges highlight the importance of choosing appropriate sensing technologies based on the specific environment and application requirements.

Another important takeaway is the need for efficient power management. The performance of the robot was highly dependent on battery health and voltage levels. As the battery voltage decreased, the motors became weaker, and the response time of the robot decreased. This suggests that for future development, the use of a more robust power source, such as rechargeable lithium-ion batteries, would be highly beneficial.

One interesting design choice is to implement random left or right turns when an obstacle is detected. This simple “randomness” helped prevent the robot from becoming stuck in loops or tight corners, which often occurs with more rigid obstacle avoidance algorithms. Although the method is basic, it adds a surprising level of natural behavior and adaptability to the robot’s movements.

Despite some minor issues, such as occasionally struggling with very narrow passages or soft obstacles, the robot performed consistently well in various indoor testing environments. Most of the time, it navigated around books, boxes, and furniture with ease. It showed that even with limited hardware and straightforward programming, reliable and efficient obstacle-avoiding behavior can be achieved.

Furthermore, this project provides a solid foundation for understanding how embedded, real-time programming, and robotic control systems work together. This demonstrates that hands-on projects are an excellent way to bridge the gap between theoretical learning and real-world application. The experience gained from building this robot will be invaluable for moving on to more complex robotics projects in the future.

There are countless ways to expand and enhance this project. For example:

- The addition of more sensors (ultrasonic, infrared, or even camera modules) would make obstacle detection more robust.
- Implementing more sophisticated algorithms, such as mapping, simultaneous localization and mapping (SLAM), or AI-based navigation, could allow the robot to plan its movements instead of reacting purely on the fly.
- Improving the chassis design and using more powerful motors could allow the robot to operate in a tougher outdoor environment.
- Integrating wireless communication (Bluetooth and Wi-Fi) can allow remote monitoring or even remote control when needed.

In conclusion, this project not only achieved its initial objectives but also opened the door to numerous new possibilities in robotics development. It was a strong reminder that even the simplest robots can teach valuable lessons about design, integration, and problem-solving in the world of automation. This obstacle-avoiding robot project represents a first but important step towards building smarter, more capable autonomous machines in the future.

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