Obstacle Detection and Avoidance Using Ultrasonic Sensors in Autonomous Robots

Jiajun Ma
School of Mechanical and Electrical Engineering Guangzhou University Guangzhou, China
* Corresponding Author Email: 32207700014@e.gzhu.edu.cn

Abstract. Autonomous robots have recently gained traction in a variety of industries due to their efficiency and possible cost savings. However, assuring the safety and dependability of these robots is critical, especially in terms of obstacle detection and avoidance. Ultrasonic sensors, which are known for their low cost, user-friendliness, and dependability, have emerged as a popular and practical solution to this problem. In this paper, the author offer a framework for using numerous ultrasonic sensors in autonomous robots to detect and avoid obstacles.In our approach, real-time sensor data processing is used to correctly identify and quantify the distances to obstacles, which subsequently guides the robot's path adjustment using obstacle avoidance algorithms. The findings show that our proposed framework for multiple ultrasonic sensor-based range and obstacle avoidance is capable of identifying and avoiding obstacles in a variety of situations. Furthermore, this study conducted a comparison analysis between our method and standard single ultrasonic sensor-based obstacle identification and avoidance approaches, indicating that our approach is more accurate, reliable, and robust.This method ensures safe and dependable navigation in a variety of applications, including mobile robots, autonomous vehicles, and drones. Overall, our research advances the development of low-cost, highly dependable autonomous robots for obstacle recognition and avoidance, allowing them to navigate difficult settings.

Keywords: Ultrasonic sensors, obstacle, real-time processing, autonomous robots.

1. Introduction

Autonomous robots have changed industries ranging from manufacturing to logistics to healthcare. However, as these robots must be capable of detecting and avoiding obstacles, assuring their dependability and safety is critical. Because of their cost, durability, and user-friendliness, ultrasonic sensors have developed as a popular and successful tool for obstacle detection and avoidance. This study presents a framework for autonomous robots equipped with several ultrasonic sensors to recognize and navigate around obstacles in this research. This study can detect impediments and adapt the robot's motions to prevent collisions by processing real-time data from an array of ultrasonic sensors. Our findings show that using a multi-ultrasonic sensor architecture for obstacle identification and avoidance is an effective method for ensuring the safety and dependability of autonomous robot systems.

2. Related Work

The development of obstacle detection and avoidance systems for autonomous robots has received a lot of interest in recent years. A review of relevant research is presented in this section, with a particular emphasis on how ultrasonic sensors are used to identify and avoid obstacles.

2.1. Obstacle Detection

Many researchers have already presented various ways of obstacle detection. A unique positioning technique for autonomous mobile robots that makes use of multiple ultrasonic sensors has been proposed in studies. Unlike traditional ways, this technology achieves improved ultrasonic positioning precision without relying on additional temperature information. A generalized measurement model is built for various sensor combinations using three ultrasonic sensors, while a simplified model is developed for linear or simplified settings. The experimental findings indicate the efficiency of the suggested strategy, with successful positioning accomplished using both models [1].

Furthermore, a study describes a control technique for autonomous obstacle avoidance in underwater situations utilizing a spherical underwater robot (SUR) outfitted with an ultrasonic sensor array. The technique considers the SUR's kinematic and dynamic models, as well as the properties of the ultrasonic sensors. Real-time following and obstacle avoidance are accomplished by fusing the guidance law and Lyapunov theory [2].

There are also studies proposed spatial attention fusion (SAF) technique for accurate obstacle detection in autonomous driving, employing mmWave radar and vision sensors. By proposing a brand-new SAF approach for obstacle detection that can be incorporated into current detection frameworks, this research makes a significant addition to the field of autonomous driving [3].

Many studies use ultrasonic technology when applying obstacle detecting technology, as can be observed.

2.2. Obstacle Avoidance Strategies

In the research of obstacle avoidance strategies, A UAV obstacle avoidance framework based on event cameras has been proposed by several researchers. This framework takes advantage of the event camera's superior temporal resolution, lighter output, and reduced processing load for dynamic object identification. In addition, a real-time processing method based on clustering and the Kalman filter to extract velocity information from events is proposed, as is a reactive algorithm based on an artificial potential field for obstacle avoidance. The algorithm is fast and suited for real-time operation on a small onboard computer since it can adjust for its own motion using only an inertial measurement unit (IMU) [4].

Obstacle avoidance strategies are also used in agriculture, Obstacle avoidance strategies for agricultural sprayer UAVs include obstacle identification using various technologies such as sonar, radar, laser, visual, and fusion methods. The purpose is to develop an appropriate spraying and safety avoidance trajectory. The three control architectures that meet the obstacle avoidance requirement are reactive control architecture, deliberative planning architecture, and hybrid control architecture. Based on ambient data perception, these systems orchestrate avoidance actions. Several strategies for obstacle avoidance for sprayer UAVs have been developed, including path planning algorithms, collision avoidance, and spray coverage [5].

To further accomplish intelligent autonomous navigation and obstacle avoidance in unmanned boats, a research study introduces the Autonomous Navigation and Obstacle Avoidance (ANOA) model based on deep reinforcement learning. The precision and intelligence of autonomous navigation and obstacle avoidance in challenging embedded maritime environments are improved by this technique. It makes it possible for unmanned boats to move through unfamiliar space and navigate through challenging environmental conditions with intelligence [6].

Based on these examples, it is evident that the field of obstacle avoidance has witnessed significant advancements, leading to the development of numerous methods to facilitate the avoidance of obstacles.

3. Method

This work analyzed the investigation and contributions of other researchers in the subject of obstacle detection and avoidance using ultrasonic and other sensor technologies in the related work section. It can conclude from this analysis that whether using ultrasound as a sensor for obstacle detection, implementing dynamic avoidance using event cameras, or employing technologies such as sonar, radar, laser, vision, and fusion methods for obstacle detection, all these methods have proven to be effective in detecting and avoiding obstacles.

After comparing and analyzing the study indicated in the related work part, as well as investigating other papers not mentioned in that section, this study discovered features of improvement and optimization in ultrasonic or other sensor-based obstacle detection and avoidance strategies. This study presents a system that combines stability and safety using ultrasonic sensors for obstacle detection and an avoidance algorithm in our approach. Our method intends to accomplish precise and stable obstacle identification and avoidance at a minimal cost and with a reasonably basic implementation that ensures both accuracy and stability.

3.1. Hardware Configuration

1) The author will choose the HC-SR04 ultrasonic sensor among the available ultrasonic sensors. As illustrated in the figure following. The HC-SR04 ultrasonic sensor has various advantages. For starters, it allows for non-contact distance measurement, making it useful for a wide range of objects, including translucent, colorful, or irregularly shaped ones. Second, the sensor has a high measurement accuracy, often in the region of 2-3 millimeters, which is suitable for applications needing accurate distance measurements. Third, it has a wide measurement range, often spanning from 2 millimeters to 4 meters, allowing it to accommodate targets of varied distances. Furthermore, the HC-SR04 sensor is distinguished by its ease of use, simple circuit connectivity, and low cost, making it an excellent choice for academic, educational, and personal projects. To summarize, the HC-SR04 ultrasonic sensor is a strong and cost-effective sensing device with numerous applications in a variety of areas. Figure 1 shows the appearance and interface of the HC-SR04 model ultrasonic sensor.

Fig. 1 HC-SR04 ultrasonic sensor [7].

2) To properly use the HC-SR04 ultrasonic sensor, an appropriate control board is necessary, and after comparing several control boards on the market, this study opted to use an Arduino UNO control board that is more accurate and stable while taking into account cost performance. For controlling an ultrasonic sensor, there are various benefits to using the Arduino UNO controller board. To begin, the Arduino UNO has a big user community and substantial support resources, allowing the author can quick access to tutorials, example code, and solutions. Second, the Arduino programming language is user-friendly and comes with an intuitive Arduino Integrated Development Environment (IDE), which simplifies the coding process for controlling the ultrasonic sensor. Furthermore, the Arduino UNO includes a plethora of I/O connectors that allow for the smooth connection and control of many sensors and actuators. Its strong expandability enables expanded functionality via numerous

extension modules such as Ethernet or Bluetooth, allowing for the development of more complicated applications. Finally, because of its portability and compatibility with other Arduino-compatible boards, the Arduino UNO is appropriate for a wide range of projects. Finally, the Arduino UNO controller board is an excellent choice for controlling an ultrasonic sensor and carrying out a variety of tasks. Figure 2 presents the exterior of the Arduino UNO control board and provides an introduction to the significance of each interface.

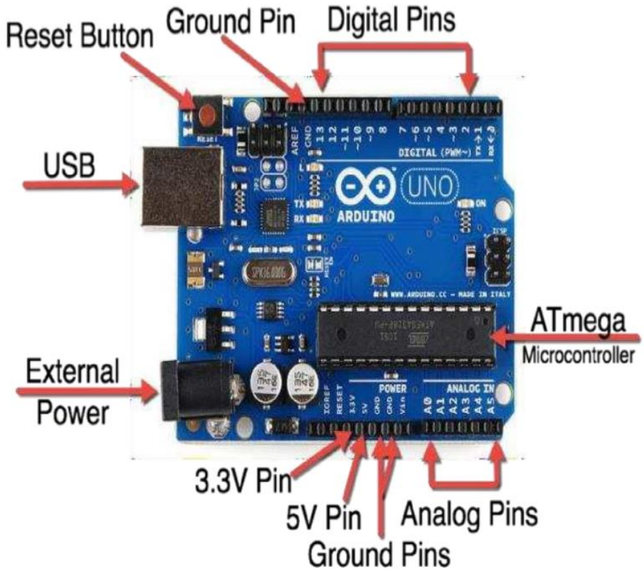

Fig. 2 Arduino UNO [8].

3) There are various advantages to using a breadboard using Dupont wires to connect the Arduino UNO controller board and the ultrasonic sensor. It allows for easy circuit building and customization because to its flexibility and reusability. The connecting procedure is simple, requiring no soldering or specialized tools. The visual clarity of the breadboard aids in troubleshooting and debugging. It enables simple circuit rewiring and reconfiguration. Furthermore, it eliminates the need for soldering knowledge. In conclusion, using a breadboard with Dupont wires simplifies connection, provides flexibility, and improves convenience for a variety of applications. Figure 2 and Figure 4 depict the appearance of a breadboard and jumper wires, respectively. TABLE I shows us the hardware materials needed for this study.

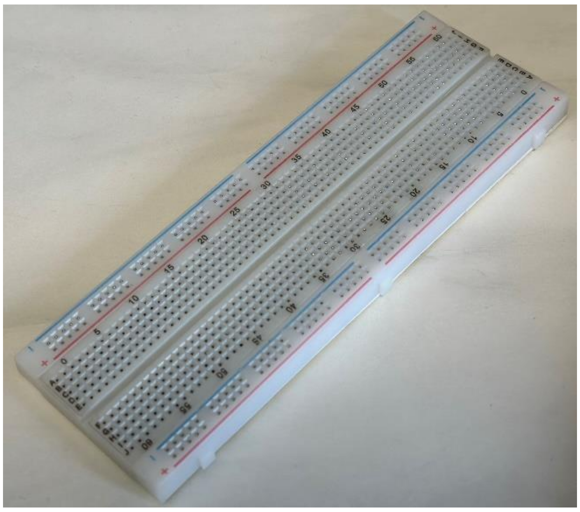

Fig. 3 Breadboard (Photo/Picture credit: Original).

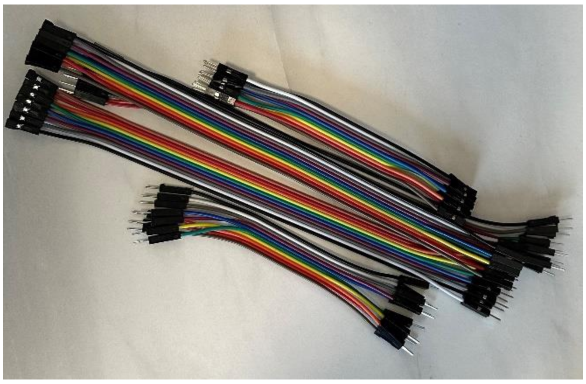

Fig. 4 Jumper wires (Photo/Picture credit: Original).

Tab. 1 The hardware for this study

Components Name	Quantity	Description
Arduino UNO controller board	1	controller board
Ultrasonic sensor	1	Its model number is HC-SR04
Breadboard	1	Small size
Jumper wires	4	Male to female jumper wires

3.2. Data Acquisition

Figure 5 depicts the fundamental measurement principle of ultrasonic ranging.

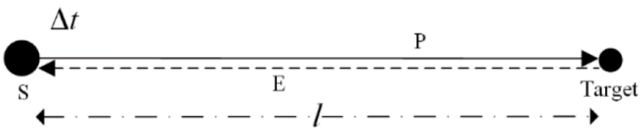

Fig. 5 Ultrasonic ranging measurement principle [1]

For this project, this study utilized TinkerCAD as the primary simulation software, and the Figure 6 and Figure 7 display a circuit design that can collect the data supplied by the ultrasonic sensor. There are multiple benefits of using Tinkercad for research simulation. First, it's a cost-free web-based platform that enables quick access whenever and wherever when need it without the need for installation. Second, Tinkercad offers a virtual simulation environment that eliminates the need to purchase and assemble physical hardware, lowering costs and time investment. Thirdly, the platform provides an easy-to-use graphical interface and visualization capabilities, allowing users to visually construct circuits and monitor real-time operational statuses. Besides, it has a large component library and an Arduino programming environment, which makes code development and debugging easier. At last, Tinkercad has an active user community and resource sharing, which allows users to seek assistance and learn from others. To summarize, Tinkercad provides users with an accessible, practical, and interactive simulation platform for assessing ultrasonic sensor performance and algorithms. Figure 6 and Figure 7 display the circuit diagram and schematic diagram, respectively, created in TinkerCad.

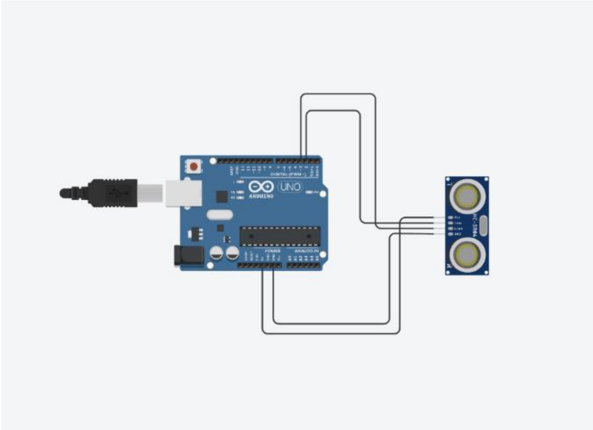

Fig. 6 Circuit view (Photo/Picture credit: Original).

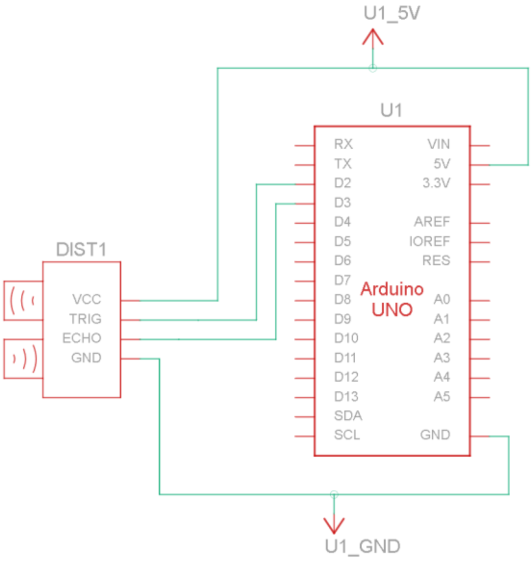

Fig. 7 Circuit diagram- Schematic view (Photo/Picture credit: Original).

After executing the simulation program, after processing the data of the acoustic sensor collected and returned by the serial port monitor, the data similar to the following figure can be displayed. Figure 8 illustrates the data retrieved from the ultrasonic sensor.

Fig. 8 Data returned by ultrasonic sensor ranging [9].

By observing the data chart returned by the ultrasonic sensor during ranging measurement through the serial port monitor (see Table 2), it is clear that the HC-SR04 ultrasonic sensor can sensitively and stably transmit to us the distance between the ultrasonic sensor and the obstacle.

Tab. 2 The result of the serial monitor's output

Time (s)	Distance (cm)	Time (s)	Distance (cm)
0.5	324	14.5	3
1	324	15	3
1.5	311	15.5	3
2	311	16	3
2.5	301	16.5	3
3	272	17	3
3.5	250	17.5	3
4	234	18	7
4.5	216	18.5	22
5	204	19	40
5.5	180	19.5	65
6	157	20	100
6.5	142	20.5	121
7	131	21	135
7.5	115	21.5	154
8	91	22	178
8.5	70	22.5	206
9	52	23	218
9.5	31	23.5	239
10	10	24	263
10.5	6	24.5	279
11	6	25	290
11.5	6	25.5	297
12	6	26	306
12.5	4	26.5	316
13	5	27	324
13.5	5	27.5	324
14	3	28	324

Fig. 9 Image of the data returned by the ultrasonic sensor (Photo/Picture credit: Original)

It can be observed that the ultrasonic sensor can measure target object distances from 3 cm to 320 cm while balancing sensitivity and stability. Figure 9 effectively presents the temporal variation of the data returned by the ultrasonic sensor.

3.3. Obstacle Detection Algorithm

This paper provides a novel approach to obstacle detection algorithms that differs from traditional approaches. For obstacle detection, traditional systems often rely on a single ultrasonic sensor. However, in this research, this study uses an array of several ultrasonic sensors to identify obstacles.

This study takes into account elements like the height and width of autonomous mobile robots, as well as the volume of irregular barriers, which might affect the accuracy of obstacle recognition. A single sensor can only estimate partial and coarse distances. As a result, this study decides to install an array of ultrasonic sensors at crucial places of the autonomous mobile robot in order to develop a more precise and stable obstacle detection algorithm. Specifically, this study attaches many ultrasonic sensors in protruding or recessed areas of the robot's structure, making an array in the same direction. As a result, each ultrasonic sensor in the array may detect impediments in that direction at the same time. Sensors in different positions will yield varied data due to the shifting positions of the ultrasonic sensors and the reflection spots on irregular obstructions. As a result, the author can use the data supplied by the ultrasonic sensors positioned in various locations for additional processing and analysis.

After collecting data from several ultrasonic sensors in a certain direction, this study applies a weighting technique to the distances acquired by each sensor to calculate the precise distance between the autonomous mobile robot and the barrier. The weighted average is used to lessen the impact of random errors and outliers by integrating data from several sensors, resulting in a more reliable and precise estimation of the obstacle distance. In terms of weighting, this study uses a distance-weighted averaging method. Because the outermost structure of the autonomous mobile robot will be the first to collide with obstacles, the ultrasonic sensor situated further out from the robot's center will be allocated a higher weight. The ultrasonic sensors closer to the center of the autonomous mobile robot, on the other hand, will be allocated lower weights. This weighting approach yields a more precise detection result for obstacle distance. This precise distance is the basis for subsequent obstacle avoidance strategies, giving the robot with precise environmental perception information to develop reliable obstacle avoidance skills.

3.4. Obstacle Avoidance Strategies

This study presents an obstacle avoidance technique based on ultrasonic sensors to provide precise and stable obstacle avoidance. To plan the activities of the autonomous mobile robot, this technique completely leverages the data collected by the ultrasonic sensors and categorizes the distance into three levels. Our plan is carried out in the following steps:

To begin, this study performs weighted processing on the ultrasonic sensor data to determine the precise distance 311between the autonomous mobile robot and the obstacles. Based on this specific distance, this study divides the distance into three stages in order to gradually change the behavior of the autonomous mobile robot. In the first level, if the precise distance is less than or equal to 100 centimeters but larger than or equal to 50 cm, the autonomous mobile robot will halt moving and wait. During this waiting interval, the author measure whether the distance between the autonomous mobile robot and the obstacle falls below 50 cm in 5 seconds. If the distance does not reduce to less than 50 cm during the waiting period, the autonomous mobile robot will devise a strategy to avoid collision with the obstacle. The second level is reached when the precise distance is fewer than 50 cm. The autonomous mobile robot will perform a rearward action until the precise distance between the robot and the obstacle is larger than 50 centimeters, at which point it will wait 5 seconds. If the distance between the obstacle and the autonomous mobile robot does not reduce below 50 cm during the waiting period, the robot will execute the plan to avoid the obstacle. The third level is for situations where the precise distance exceeds 200 centimeters. To retain its original trajectory, the autonomous mobile robot will continue travelling at its predetermined speed and direction. To ensure the real-time and responsiveness of the obstacle avoidance method, the ultrasonic sensors must maintain real-time measurements. To ensure real-time acquisition and analysis of distance information, this study chose an optimal sample frequency for the ultrasonic sensors and streamlined data processing and algorithm computation time.

3.5. Experiment Setup

Our framework is built on the distance measuring principle, which employs ultrasonic sensors and signal processing algorithms. This study obtains precise obstacle distance information by putting several ultrasonic sensors in an array and utilizing a weighted processing method. This study constructs an obstacle avoidance method based on these distance measurements, which incorporates level categorization and appropriate behavior changes to achieve exact and stable obstacle avoidance. The essential technological parts of this framework include building a well-designed ultrasonic sensor array and processing the obtained data, as well as combining level categorization and behavior changes into the obstacle avoidance strategy. This study creates an array of several ultrasonic sensors and place them in strategic locations on the autonomous mobile robot. Each sensor sends out ultrasonic waves, and by detecting the signals reflected back by barriers, it can determine how far away they are. The distance data collected from sensors in various locations is then analyzed using a weighted technique to produce a more accurate calculation of obstacle distance. This study design alternative behavior techniques, such as pausing, backing off, and continuing movement, based on the categorized distance levels, to react to diverse obstacle scenarios within varied distance ranges. Based on these considerations, it is advised that many HC-SR04 ultrasonic sensors be used in the experimental process. The autonomous mobile robot should have an irregular shape to allow for the installation of ultrasonic sensors at various distances from the robot's center, and the detected objects should similarly be irregular in shape. The Arduino UNO is recommended as the control board, and PVC boards can be utilized to build the appearance of the autonomous mobile robot.

4. Results and Discussion

This study will now discuss the proposed framework for obstacle detection and avoidance using multiple ultrasonic sensors in terms of feasibility, reliability, and practicality.

- Feasibility: The ultrasonic sensor principle comprises the emission of ultrasonic waves and the receiving of their echoes. The distance between the sensor and the target object can be estimated by measuring the time difference between the emission and reception of echoes. The speed of sound in air is well known, thus the distance to the target object may be calculated using the measured time difference. This offers the functionality of measuring distance using ultrasonic waves. The accurate and stable distance measurement given by ultrasonic sensors is the foundational component for this paper's proposed framework of multi-obstacle identification and avoidance. The primary theoretical foundation of this framework is the organization and data fusion of many ultrasonic sensors. The autonomous mobile robot is equipped with an array of ultrasonic sensors that are installed at several strategic locations. Because sensors at several locations give precise and steady data, these data can be pooled for analysis and processing, resulting in more accurate obstacle distance information. The ultrasonic array on the autonomous mobile robot may be effectively produced thanks to the lightweight and simple-to-install HC-SR04 ultrasonic sensors. The data is processed using a computationally efficient weighted averaging method, which ensures that the autonomous mobile robot with irregular shape can accurately identify its distance from irregular obstacles.
- Reliability: To begin, the ultrasonic sensor principle is based on the propagation speed of sound waves, and its precision may often reach a few millimeters or less. This high level of accuracy enables ultrasonic sensors to have a very dependable measurement capability for obstacle identification and avoidance, which is a well-established and steady physical phenomenon. Ultrasonic sensors, specifically the HC-SR04, were used in the research of Mutinda Mutava Gabriel and Kamweru Paul Kuria. Using an Arduino UNO and the HC-SR04 ultrasonic sensor, they created a motion detector that displayed the detected distance on an LCD screen. They exhibited the system's absolute inaccuracy and compared it to manual distance measurements, proving that the method was more trustworthy than manual measurements [10]. Furthermore, the functioning concept of ultrasonic sensors is simple and stable. They are unaffected by light, color, or surface roughness, making them suited for a wide range of situations and item kinds. Ultrasonic sensors also consume little power and have a long lifespan,

allowing them to work continually and dependably. Because the speed of ultrasonic waves is essentially constant in most situations, the distance between the target object and the sensor can be calculated correctly. As a result, the ranging capability of ultrasonic sensors is quite dependable. Aside from ultrasonic sensor dependability, the multi-ultrasonic sensor obstacle detection and avoidance framework performs admirably in recognizing and avoiding impediments of various varieties, shapes, and sizes. This capability is due to the use of the weighted averaging method, which ensures a consistent data processing approach and precise distance estimation under varying conditions and environmental factors. As a result, the framework allows for the selection of appropriate avoidance techniques. This paper's multi-ultrasonic sensor obstacle identification and avoidance architecture is highly reliable due to these factors.

- Practicality: The use of numerous sensors generates a large amount of data, which improves the accuracy of obstacle identification and assessment. The configuration of sensor arrays allows for a more precise determination of obstacles' shape and location and captures many features of obstacles. Ultrasonic sensors have high sample frequencies and response speeds, allowing for quick capture of obstacle distance information. Furthermore, the framework ensures efficient operation in real-time contexts by using improved data processing algorithms and parallel computing, matching the requirements of autonomous mobile robots for fast decision-making and obstacle avoidance. The use of many sensors improves the system's detection and recognition of barriers of various shapes, sizes, and materials. When faced with complex settings and dynamic barriers, the framework maintains steady performance and offers dependable obstacle avoidance algorithms for autonomous mobile robots. Furthermore, the configuration of many ultrasonic sensors can be easily modified to meet individual application needs. To improve obstacle identification and avoidance, the framework can be combined with different sensors and technologies such as vision sensors or lidar. Multiple ultrasonic sensors are low-cost, easy-to-integrate sensor technologies that are suited for a wide range of autonomous mobile robot applications, notably in areas such as home service robots and warehouse logistics robots. Through studies performed on actual robot platforms, simulations simulating real-world settings, and comparisons with other approaches, the framework's viability can be further evaluated.

5. Conclusion

A framework based on the use of these sensors for obstacle identification and avoidance is provided in this paper, which aims to use numerous ultrasonic sensors to achieve obstacle detection and avoidance methods in autonomous robots. This study has shown through study that ultrasonic sensors are reliable, practical, and capable of detecting and monitoring the environment. High-quality data entry and analysis are ensured by the design of hardware configuration and data gathering. This study provides an obstacle identification technique based on several ultrasonic sensors that precisely locates and recognizes obstacles moving forward. Additionally, this study investigates other approaches for avoiding obstacles, such as deciding whether to halt, flee, or move around them based on the exact distances discovered by the algorithm. Our suggested framework, which is based on numerous ultrasonic sensors for obstacle detection and avoidance, is demonstrated through experimental results to be effective in measuring and achieving obstacle detection and avoidance in robots, demonstrating outstanding performance in a variety of scenarios and environments. To improve autonomous robots' ability to recognize and avoid obstacles, future research can concentrate on optimizing frameworks, algorithms, and hardware.

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