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Original Paper

Multi-Sensor Intelligent Robot designed for Mentally Challenged

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ABSTRACT

The proposed intelligent obstacle avoidance design of an autonomous mobile robot based on multi-sensor information fusion seems to address the limitations of existing ultrasonic-based obstacle avoidance systems by incorporating visual information from road signs and adding an infrared ranging sensor for avoiding pits. Overall, this design aims to enhance obstacle avoidance capabilities by integrating visual information from road signs and incorporating an infrared ranging sensor. By fusing data from multiple sensors and employing intelligent logic, the robot can autonomously navigate through a multi-obstruction environment, avoiding obstacles and pits effectively. This model involves Road Sign Detection, Multi-Sensor Information Fusion, Path Planning, Obstacle Avoidance Logic, Control System, and Feasibility Verification. The design's feasibility is verified through analysis and experimentation. The acquired distances from the ultrasonic sensor and infrared distance measuring sensors are analysed to ensure they provide accurate and reliable information. Additionally, the trained road sign detection model is evaluated to assess its performance. Finally, experiments are conducted in manually constructed complex environments to validate the effectiveness of the proposed design.

KEYWORDS

Intelligent robot; multi sensor; Adaboost; obstacle avoidance; object detection

1. INTRODUCTION

Obstacle avoidance of a multi-sensor intelligent robot based on road sign detection involves using various sensors and algorithms to detect road signs and navigate the robot safely through its environment [1, 2, 3, 4]. Here's a general overview of how such a system might work:
Sensor Integration: The robot is equipped with multiple sensors such as cameras, LiDAR (Light Detection and Ranging), and/or ultrasonic sensors. These sensors provide different types of information about the environment.
Road Sign Detection: The robot's cameras are used to capture images or video frames of the robot's surroundings. Computer vision algorithms are then applied to detect and recognize road signs in the captured data. This can involve techniques such as image segmentation, feature extraction, and machine learning algorithms for classification.
Road Sign Classification: Once the road signs are detected, the system needs to classify them to understand their meaning. This can be done using machine learning techniques, where a model is trained on a labelled dataset of road sign images. The model can then predict the type of road sign based on the detected features.

Obstacle Mapping: In parallel with road sign detection, other sensors like LiDAR or ultrasonic sensors can be used to create a 3D map of the environment. This map helps identify obstacles, such as pedestrians, vehicles, or other objects that may obstruct the robot's path.
Path Planning: Based on the detected road signs and the obstacle map, a path planning algorithm determines a safe and efficient route for the robot to navigate. The algorithm considers the detected road signs and the position, size, and movement of obstacles to plan a collision-free path.
Control and Navigation: The planned path is then used to generate control signals for the robot's actuators, such as motors or steering mechanisms. The robot follows the planned path while continuously monitoring the environment for any changes or new obstacles.
Real-Time Adaptation: The system should be capable of real-time adaptation to handle dynamic environments. It should continuously update the road sign detection, obstacle mapping, and path planning based on the latest sensor inputs, allowing the robot to respond to changes in real-time.

2. Related Works

The modern era is witnessing mobile robots in various applications and emphasizing the importance of an effective perception system for achieving autonomous motion control [5, 6, 7, 8, 9, 10]. There are various needs for different types of sensors, such as proprioceptive and exteroceptive sensors, to gather information about the robot's surroundings. Sensing technologies for mobile robots includes passive sensing using cameras, stereo vision, and infrared cameras, as well as active sensing using lidar and sonar sensors for real-time obstacle detection [12, 13]. Laser ranging is also used for analysing wheel skid, and other visual methods for target tracking of wheeled mobile robots. Regarding obstacle avoidance and path planning, early methods that used infrared sensors to detect stickers on the ground for navigation were limited to known environments. Here's a general overview of how such a system might work:

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- Real-Time Adaptation: The system should be capable of real-time adaptation to handle dynamic environments. It should continuously update the road sign detection, obstacle mapping, and path planning based on the latest sensor inputs, allowing the robot to respond to changes in real-time. Various studies have been conducted that employed ultrasonic sensors to capture relative information and identify parking spaces. Mapping the surrounding environment and establishing the shape of obstacles using multiple ultrasonic sensors are used. But limited research on mobile robots encountering pits during automatic travel has been proposed. Here in this paper we propose a solution by fusing information from ultrasonic sensors, infrared distance measuring sensors, and cameras. Additionally, the paper introduces road sign recognition to enable accurate movement based on traffic sign information. There is a research gap in addressing pits during automatic travel and proposes a solution that incorporates road sign recognition.

3. Methodology

The control system of the mobile robot consists of several modules that work together to ensure the robot's functionality. Power Module is responsible for supplying energy to the entire system. As different modules may require different voltages, an up/down module is used to regulate and provide the appropriate voltage to each module. Main Controller, in this case, is an Arduino Mega 2560. It is responsible for processing the environment information received from the detection module and making decisions based on that information. The main controller acts as the central processing unit of the system. Industrial Personal Computer (IPC) is connected to the camera and is involved in processing camera data. The camera data is first sent to the IPC for processing, and then the processed information is fed back to the main controller. The IPC assists in image processing tasks and enhances the capabilities of the detection module. Detection Module consists of an ultrasonic sensor, an infrared distance measuring sensor, and a camera. This module is primarily responsible for detecting the surrounding environment. The ultrasonic sensor and the infrared distance measuring sensor provide distance information, while the camera captures visual data. The detected environment information is fed back to the main controller for further processing. The drive module comprises a motor driver and an encoder motor. The motor driver controls the speed of the encoder motor, which drives the movement of the robot. The motor encoder detects the motor speed and provides feedback to the driver, enabling closed-loop control of the motor. The system detection module detects the environment using the ultrasonic sensor, infrared distance measuring sensor, and camera. The detected data is then transmitted to the main controller. The main controller processes this information, taking into account the environment data, and makes decisions regarding the movement and attitude of the robot. The drive module receives the control signals from the main controller and adjusts the motor speed and direction accordingly, allowing the robot to avoid obstacles within its range of activity.

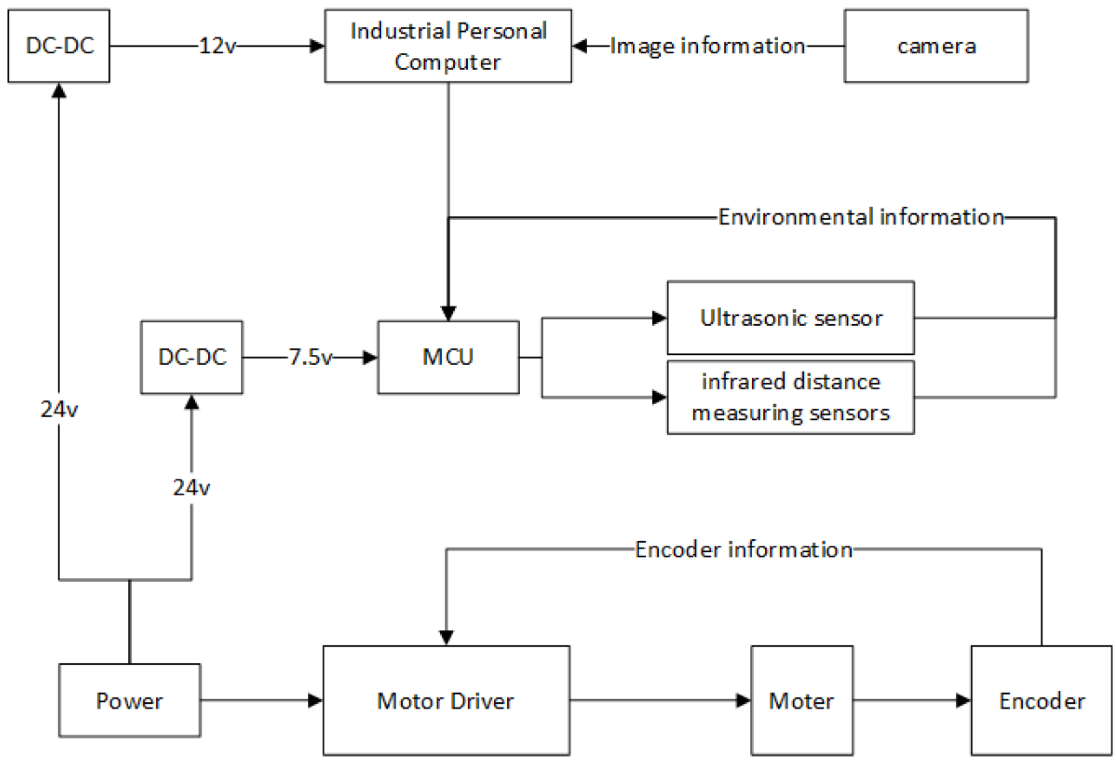

Figure 1 : Diagrammatic representation of the System of Mobile Robot

Figure 1 illustrates the composition of the mobile robot's system, showcasing the interconnection between the different modules and their roles in the overall control system. In the research paper on obstacle avoidance for the mobile robot, the processing of surrounding environment information is crucial, considering the dynamic and unknown nature of real-life environments. Additionally, there are situations where signs indicate specific directions for the robot to move. Therefore, selecting appropriate sensors to collect and analyse environmental information becomes essential to enable safe navigation in complex locations. For this design, the HC-SR04 ultrasonic sensor, GP2YA02 infrared distance measuring sensor, and a USB driver-free camera were chosen as components for the detection system. Nine ultrasonic sensors were installed on the robot to detect obstacle information in the surrounding area. These sensors are positioned to capture data about any bulges or objects that might obstruct the robot's path. Two infrared distance measuring sensors were placed between the two wheels at the front of the bottom wheel assembly. These sensors are specifically used to detect ground pits. By measuring the distance to the ground, the robot can avoid falling into pits or uneven terrain. A USB camera is used to capture road sign information. The camera is positioned to detect and analyse the road signs present in the environment. The information obtained from the camera is transmitted to the main controller for further processing. The data collected by these sensors is then processed by the main controller, which generates appropriate commands for the motor driver to control the robot's movement accordingly. This enables the robot to respond to the detected obstacles, avoid pits, and move safely towards its destination.

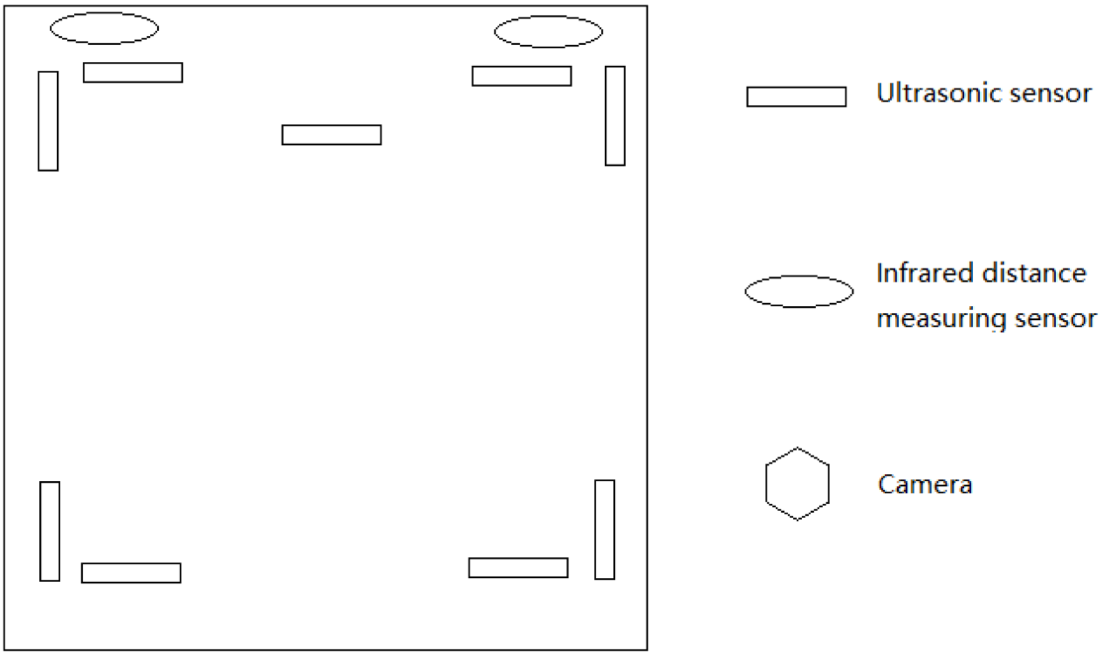

Figure 2 : Diagrammatic represents of Sensor layout

Figure 2 illustrates the sensor layout of the mobile robot, indicating the placement of the ultrasonic sensors, infrared distance measuring sensors, and the USB camera on the robot body.2

Target Detection Based on Adaboost Algorithm

The Adaboost algorithm is utilized for target detection, specifically for detecting road signs. The process involves sample pretreatment, where the training samples are prepared for the algorithm. The training samples are divided into positive and negative samples. Positive samples consist of road sign images, while negative samples are any other images that do not contain road signs. For this research, 1000 positive samples and 2000 negative samples were selected. The selected samples undergo preprocessing steps. Firstly, the samples are converted to grayscale. Then, they are normalized to a standardized size of 128x72 pixels in grayscale. This normalization step ensures that all samples have the same dimensions, preventing variations in feature calculations due to image size differences.

The preprocessed positive and negative samples form the training sample set. This set is used to train the Adaboost algorithm. By using a standardized sample size, the algorithm can calculate features consistently across all samples. Sample Examples of road sign samples that are part of the positive training sample set. These samples represent the road signs to be trained and detected. By preparing the training samples through these pretreatment steps, the Adaboost algorithm can effectively learn and identify the features associated with road signs, distinguishing them from other objects or backgrounds. These samples serve as the basis for training the algorithm to perform road sign detection in subsequent stages of the research. In the study, the obstacle avoidance strategy for mobile robots focuses on two specific situations: ground bulging obstacles and ground sag obstacles. The schematic diagram of the obstacles and the corresponding obstacle avoidance routes are shown in Figure 5. The following assumptions are made about these obstacles:

- Ground Raised Obstacles: These are obstacles that protrude from the ground
- Ground Sag Obstacles: These are depressions or pits in the ground. The assumption is that ground raised obstacles and ground pits do not appear simultaneously.
- Road Sign on Raised Obstacle: It is assumed that a road sign is present on a raised obstacle. This means that the robot needs to take into account the information from the road sign while avoiding the obstacle.
- Width of Ground Pit: The width of the ground pit is assumed to be less than the wheel spacing of the robot. This ensures that the robot can successfully navigate around the pit without falling into it.
- Stop Road Sign: It is assumed that there is a stop road sign at the destination, indicating the need for the robot to come to a stop.

These assumptions provide a basis for designing the obstacle avoidance strategy in the study. The mobile robot takes into account these factors while navigating through the environment, ensuring safe and effective obstacle avoidance in the presence of ground bulging and sagging obstacles. During the operation of the intelligent vehicle, the following obstacle avoidance strategy is implemented:

1. Initialization: The data is initialized, and the vehicle is given an initial forward speed.
2. Sensor Activation: The ultrasonic sensor in front and the infrared distance measuring sensors are activated to start detecting the surrounding environment.
3. Obstacle Detection: If the ultrasonic sensor detects an obstacle within a distance of 60 cm, the robot stops and activates the camera to check for the presence of a road sign indication.
4. Road Sign Detection: If a road sign is detected by the camera, the robot avoids the obstacle according to the direction indicated by the road sign. The specific avoidance movement is determined by the type of road sign detected.
5. Autonomous Obstacle Avoidance: If no road sign is detected, the robot autonomously avoids the obstacle using a built-in program. The exact avoidance movement is predefined based on the robot's design and capabilities.
6. Ground Pit Detection: If the infrared distance measuring sensors detect a ground pit with a distance less than 8 cm, the robot performs the corresponding movement to avoid the pit. If pits are detected on both sides, the vehicle stops and waits for manual intervention.
7. Safe Distance Consideration: The robot maintains a safe distance of 60 cm from obstacles to ensure safe turning. The deviation in the robot's rotation is accounted for by setting the safe distance to 60 cm instead of the maximum distance of 50 cm.
8. Camera Usage: The camera is only used when obstacles are detected because road signs are fixed to the surface of obstacles on the ground. The cameras cannot determine the distance of road signs once they are detected. Therefore, the ultrasonic sensor detects the obstacle and determines its distance, and then the camera is used to detect the presence and location of road signs.

9. Turning and Forward Movement: When avoiding raised obstacles, the robot turns left or right based on the difference in distances measured by the left and right ultrasonic sensors. The speed of the wheels is adjusted accordingly to perform the turning movement. After successful turning, the robot drives forward until it is out of the range of the obstacle. The robot then turns in the opposite direction and continues driving to completely avoid the obstacle.
10. Leaving Obstacle Range: Once the robot is out of the obstacle range, the detection value of the ultrasonic sensor on the side of the robot is greater than 60 cm, indicating that it has successfully navigated around the obstacle.
11. Manual Intervention for Both Side Pits: If pits are detected on both sides, the vehicle stops and waits for manual movement, as it may not be possible to autonomously navigate through such a scenario.

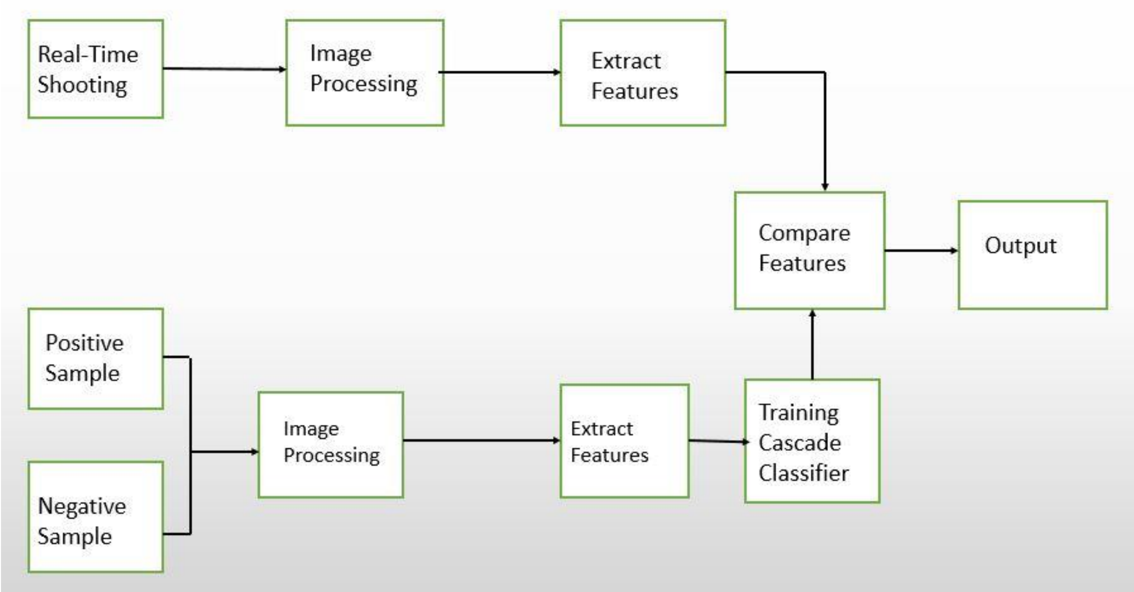

Figure 3 : Workflow Diagram of the model

Figure 3, workflow diagram of the model. By following this obstacle avoidance strategy, the intelligent mobile robot can effectively navigate through complex environments, avoiding both raised obstacles and ground pits, while taking into account road sign indications when present

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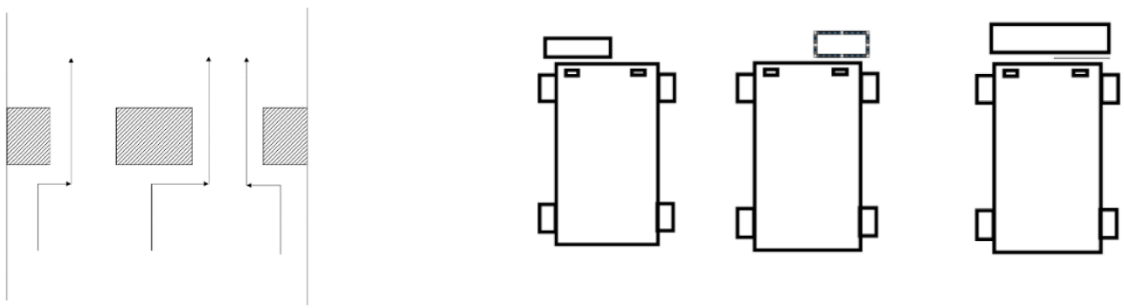
4. Experiment and Result Analysis

The prototype of the mobile robot consists of four main components: the vehicle body, drive assembly, detection assembly, and control assembly. Vehicle Body is the main structure of the robot that provides support and houses all the other components. It is designed to accommodate the drive assembly, detection assembly, and control assembly. The drive assembly is responsible for propelling the robot and controlling its movement. It includes a drive member, such as a motor or motor assembly, which drives the rotation of the wheels relative to the vehicle body. The wheels are connected to the drive member and enable the robot to move in different directions. The detection assembly comprises various sensors that are used to gather information about the robot's surroundings. Ultrasonic Sensors are used to detect obstacles in the vicinity of the robot. They emit ultrasonic waves and measure the time it takes for the waves to bounce back after hitting an object. By analysing the reflected waves, the robot can determine the presence and distance of obstacles. Infrared Sensors are positioned at the lower end of the robot body and are used to detect obstacles on the ground, such as pits. They work by emitting infrared light and measuring the reflection or absence of the reflected light to identify the presence of obstacles. The cameras are part of the detection assembly and are used to capture visual information. They are primarily utilized for detecting road sign information. The camera data is processed by the control assembly to identify road signs and make appropriate navigation decisions. The control assembly is responsible for processing the signals received from the detection assembly and controlling the drive assembly accordingly. It receives signals from the detection assembly, which include information about obstacles and road signs. Based on this information, the control assembly determines the appropriate actions to be taken to avoid obstacles and follow road sign indications. It sends commands to the drive assembly to control the rotation of the wheels, enabling the robot to maneuver and navigate through its environment. By integrating these components, the mobile robot prototype can effectively detect obstacles using various sensors and autonomously navigate by controlling its drive assembly based on the signals received from the detection assembly.



(a) (b)

Figure 4 : Diagrammatic representation of Obstacles avoidance

Figure 4 is the diagrammatic representation of obstacle avoidance. The HC-SR04 ultrasonic ranging module is a commonly used sensor for distance measurement in mobile robot applications. It utilizes ultrasonic waves to measure distances and provides non-contact ranging functionality. The Ultrasonic Transmitter emits ultrasonic waves, which are high-frequency sound waves that are beyond the range of human hearing. The transmitter generates short pulses of ultrasonic waves that propagate through the air. Ultrasonic Receiver is designed to detect the ultrasonic waves that bounce back after hitting an object. It receives the reflected waves and converts them into electrical signals. Control circuit manages the timing and synchronization of the ultrasonic pulses and the reception of the reflected waves. It ensures accurate distance measurements by controlling the timing intervals and processing the received signals.

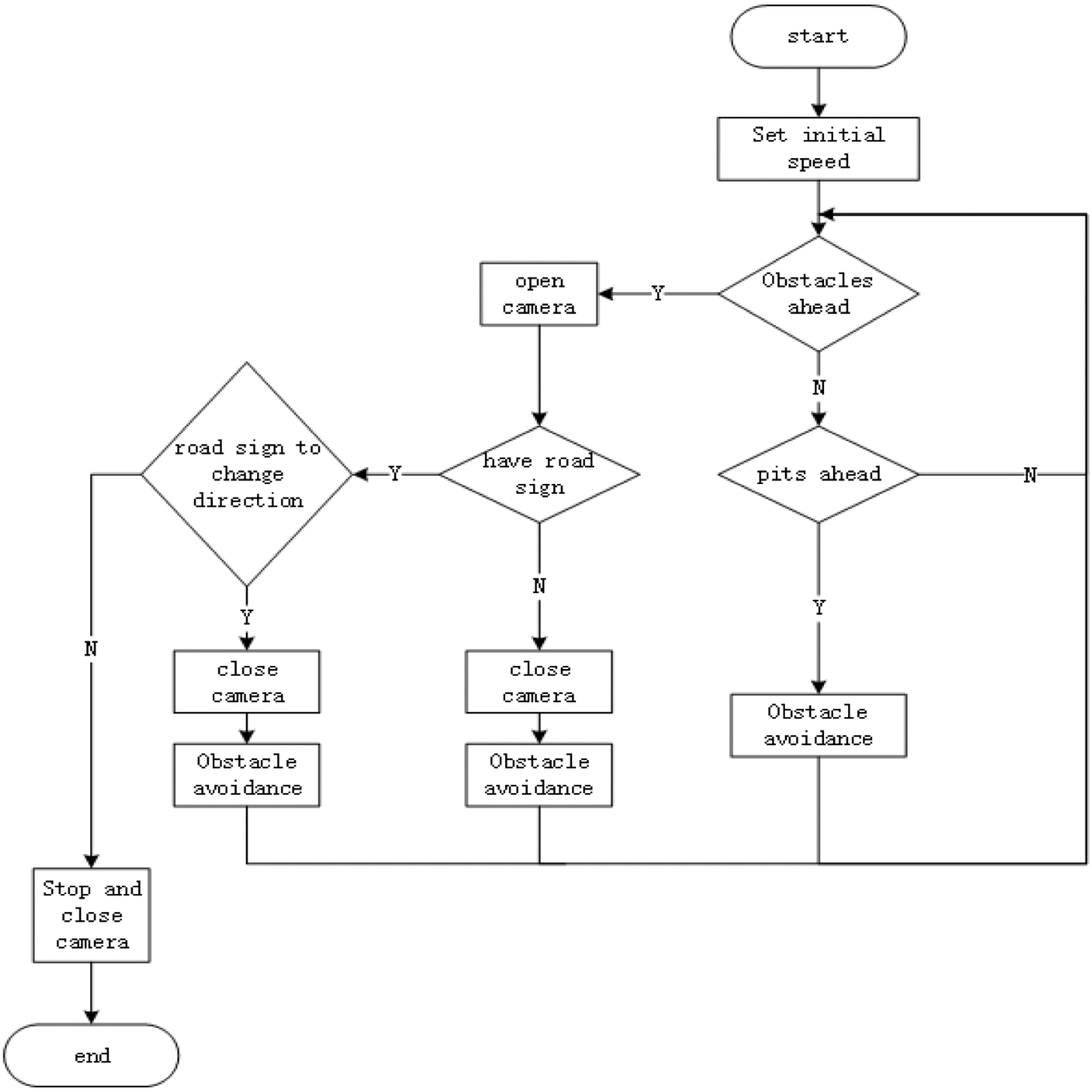


Figure 5 : Flowchart of the Mobile Robot

Figure 5 is the flowchart of the Mobile Robot. The HC-SR04 module is capable of measuring distances in the range of 2 cm to 450 cm with a high degree of accuracy. It can provide ranging accuracy up to 3 mm, which allows for precise distance measurements in various applications. To measure the distance using the HC-SR04 module, the transmitter sends out a short ultrasonic pulse, and the receiver detects the echo of the pulse when it bounces back from an object. By measuring the time it takes for the pulse to travel to the object and back, the module can calculate the distance based on the speed of sound. Overall, the HC-SR04 ultrasonic ranging module is a reliable and widely used sensor for obstacle detection, distance measurement, and navigation purposes in mobile robot systems. Its non-contact ranging capability and high accuracy make it suitable for a range of applications, including obstacle avoidance and localization. The ultrasonic module typically has four pins: Trig (control end), Echo (receiving end), GND, and VCC. The GND and VCC pins are connected to a 5V power supply to provide power to the module. The Trig pin is used to control the transmission of ultrasonic signals, and the Echo pin receives the reflected ultrasonic signals.

The principle of ultrasonic ranging is based on the reflection characteristics of ultrasonic waves. When the ultrasonic module is triggered, it emits a beam of ultrasonic waves and starts timing. The ultrasonic waves travel through the air and bounce back when they encounter obstacles. The receiving end of the module detects the reflected ultrasonic waves and stops the timing. By recording the time it took for the ultrasonic waves to travel to the obstacle and back, the distance between the module and the obstacle can be calculated using the formula $S = 340t/2$, where S is the distance and t is the time. To ensure accurate measurements, the module requires a pulse trigger signal of more than 10 microseconds. The module emits ultrasonic waves at a frequency of 40 kHz for 8 cycles and then waits for the echo signal to be detected. The pulse width of the echo signal is proportional to the measured distance. By measuring the time interval between the transmitted signal and the received echo signal, the distance can be calculated using the formula: distance = high level time * sound speed/2. The measurement period is typically set to be above 60 ms to avoid interference from the transmitted signal on the echo signal. In this study, an ultrasonic sensor was used to measure the distance from objects. The obtained distance values can be used in conjunction with a neuron-based intelligent PID motor drive module. This motor drive module has a built-in controller capable of performing PID computation, trapezoidal control, and driving DC motors using the built-in drive circuit on the circuit board. By sending command signals through the serial port, the module can control the forward and backward movement of the dual motor. The motor speed curve after PID adjustment, demonstrates the effectiveness of the PID control. The curve shows a small overshoot and quickly reaches dynamic equilibrium when the motor speed increases from 0 to the maximum speed. This indicates that the PID control algorithm effectively adjusts the motor speed and maintains stability during acceleration.

3. CONCLUSIONS

The physical prototype experiment demonstrates the successful implementation and functionality of the designed mobile robot system. The robot is able to navigate through narrow gaps between obstacles in a stable and safe manner. It correctly interprets the road sign indications and effectively avoids obstacles based on the detected information. The experimental results validate the feasibility of the overall design and the accuracy of the road sign detection and obstacle avoidance capabilities. By utilizing multiple sensors and fusing their information, the system can compensate for the limitations and errors of individual sensors. This allows the robot to sense and respond to obstacles from various directions and types, enabling effective obstacle avoidance. The method of sensor information fusion not only enhances the reliability and accuracy of obstacle detection and avoidance but also expands the robot's perception capabilities. By integrating data from different sensors, the robot can gather comprehensive information about its surroundings and make informed decisions. This approach has broad applications in various mobile robot systems where accurate obstacle avoidance is crucial. Overall, the successful outcomes of the physical prototype experiment support the effectiveness and potential applicability of the designed mobile robot system, showcasing the benefits of sensor fusion and highlighting its importance in enhancing the capabilities of mobile robots.

ACKNOWLEDGEMENTS

We would like to express my sincere appreciation for the paper titled "Multi-Sensor Intelligent Robot designed for Mentally Challenged." The authors have presented a valuable and innovative contribution to the field of assistive technology for individuals with mental challenges. Their work on designing a multi-sensor intelligent robot that caters to the specific needs of this community is commendable.

The paper's detailed description of the robot's design, sensor integration, and the underlying technology provides valuable insights for researchers, engineers, and practitioners working in the field of robotics and assistive devices. The thoroughness and clarity of the paper are highly appreciated, as it aids in understanding the design principles and functionalities of the robot.

This research offers a promising avenue for improving the lives of individuals with mental challenges and paves the way for further advancements in the field. The authors' dedication to addressing the needs of this underserved population is truly inspiring, and their work will undoubtedly have a positive impact.

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