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A Review on Sensor Technologies and Control Methods for Mobile Robot with Obstacle Detection System

Ang Jia He, Min Thu Soe*

***Abstract* – Obstacle detection system is a system that reacts to the object in the path and perform action such as stopping robot movement and collision prevention according to the design of algorithm which enhance the safety level of robot. This paper examines the overview of sensor technology that associates with obstacle detection system and car-like robot. This review summarizes the effectiveness and weakness of common type of sensors such as lidar, radar, ultrasonic sensor, infrared sensor, computer vision, sensor fusion and sensor array. This paper will also discuss on control methods for car-like robot that includes hand gestures, voice control, infrared remote control, Android based Bluetooth mobile control, and Wi-Fi based mobile control, outlining the effectiveness and limitation of each control method.**

Keywords—Sensor Technologies, Obstacle Detection, Control Methods, Mobile Robot, Safety System.

I. Introduction

In the recent year of technologies advancement, the demands for integrating car-like robot, automated guided vehicle (AGV), autonomous vehicles, robotics, and smart technologies in various applications are increasing rapidly since they are becoming more cost-effective and able to be easily source as a result of the development and growth of technology and science. The evolvement of this technology resulted in the increasing of paramount of the sensing and obstacle detection technologies. As robotics, industrial automation, and autonomous navigation systems mainly rely on obstacle detection and for a range of applications that enhance the safety and productivity, it is essential to provide accurate and reliable obstacle detection to the environment around it. The emergence of autonomous, unmanned aerial vehicle (UAV), car-like robots, and intelligent robotic systems has required the need for robust obstacle detection algorithms by reacting to the information gathered from the sensor in order to achieve high safety in navigation though complex environments. The technology used for obstacle detection can be traced back to the use of proximity sensor to cameras that used the technique of image processing to perform obstacle and obstacle [1]. In the process of designing obstacle detection systems, choosing the most suitable sensor technology for an application is an essential decision. A number of sensor technologies can be used for obstacle detection, including LiDAR, radar, infrared sensors, ultrasonic sensors, cameras and etc., have been investigated for this purpose. Each type of technology has its own set of benefits and drawbacks, making it challenging for researchers and engineers to find the most effective solution that fulfils the application's different requirements. The literature review

*Corresponding author. Email: stmin@mmu.edu.my

Ang Jia He is with the Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia (email: jhang3123@gmail.com)

Min Thu Soe is with the Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia (email: stmin@mmu.edu.my)

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will concentrate on research in obstacle detection systems, compare the strengths and weaknesses, and justify the type of sensor and method utilized for obstacle detection systems with comparison, and also the application type of robot will the system to be installed to prove the algorithm and working principle.

II. Literature review

A. *Method and Sensor to Perform Obstacle Detection*

Obstacle detection can be defined as the detection and recognition of obstacles in the way and avoiding collisions between them by reacting to the signals received from the sensors [2]. According to the study of [3] used an ultrasonic sensor array to perform obstacle estimation. In their research, an ultrasonic sensor array is vertically arranged against the detecting plane to generate a fan-shaped, broad-directional beam that detects a wide range of obstacles with a single output and also multilateration arranged in horizontal receiver array on the detection plane to receive the signal from the vertical plane, as shown in Figure 1 by using probability density function (PDF) distribution to estimate the obstacle. But due to the receiver array's limited width in this case, the distribution along the x-axis is more prone to spreading due to range errors because of their ultrasonic array configuration. The objective of their system is to identify obstacles within 15 metres of the device in 0.1 seconds, provided that the equipment is moving in a 20 km/h environment. In a dynamic environment, an experiment was carried out to detect and estimate the position of a car and a human approaching the device. As a result, the system is able to detect obstacles correctly at low speed with minimal 1-to-2-meter error.

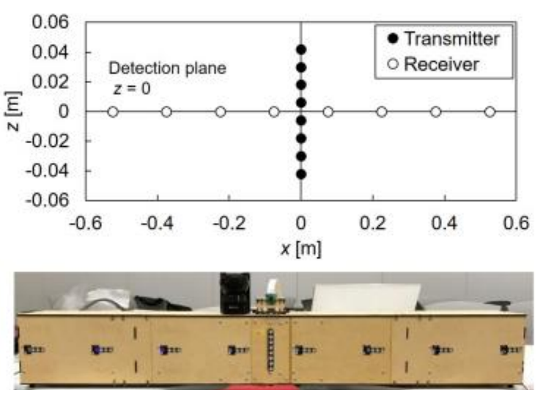

FIGURE 1. Ultrasonic sensor array configuration and measurement device used by [2].

In a study conducted in article [4] and [5] with the use of a single ultrasonic sensor, they utilised an ultrasonic sensor to perform obstacle detection and avoidance on a line following mobile robot with the sensor only facing the front of the robot. From the study of [6], a similar setup from the studies of [4] and [5] was being utilised, but using one ultrasonic sensor and an infrared sensor paired with a temperature sensor to perform obstacle detection for an unmanned aerial vehicle (UAV). In their project, the robot uses an ultrasonic sensor to acts as input to the system and the signal is sent to the microprocessor to identify and stop or manoeuvre away from any obstacles on its route. There are two openings on the front of the sensor. One of the opening 'Trig' which is responsible of triggering the ultrasonic sensor, while the other opening 'Echo' receives the signal back to the ultrasonic sensor. After receiving the bounce back of ultrasonic signal after hitting an object, the distance between the robot and the obstacle can be determined. Due to the facts that it only utilised a single ultrasonic sensor, the outcome result will not be ideal as ultrasonic has a very narrow beam angle and low accuracy and resolution. The result of the experiment shows that when utilising ultrasonic with a temperature sensor, it is 99.4% while without the temperature sensor is only 90% when the distance is at 50cm away.

According to the study conducted by [7], they utilised 3 units of HC-SR04 ultrasonic sensor to create an array of ultrasonic sensor for object detection and distance measurement on a walking stick for visually impaired people. The setup of the 3 ultrasonic sensors is separated by 90 degrees, which include a front, left, and right-facing ultrasonic sensor shown in figure 2. The basic working principle of the array of ultrasonic sensor is similar to the one mentioned in previous [4] and [5] articles. The differences between an ultrasonic sensor and ultrasonic array are the ultrasonic array has a wider coverage to detect the obstacle at the side of the robot depending on how the multiple ultrasonic is being setup. In the study of [7], it used a speech warning message to react to the direction in which the object lies.

FIGURE 2. Ultrasonic sensor array setup by [7].

In the study by [8], also implemented a similar setup on a robotic arm to perform obstacle detection, the ultrasonic sensor is mounted at both side and front of the robot arm gripper to form an array of ultrasonic sensor as shown in Figure 3. All object within the radius of the robotic arm gripper could be detected, allowing the arm to identify how close surrounding objects are. Then the data will be processed by the system for the robotic arm to be stopped if an obstacle of any type is detected near the arm until the obstacle is removed. Both models developed by [7] and [8] have great precision, and the result were promising for how the sensor reacted to the obstacles detected by the array of ultrasonic sensor.

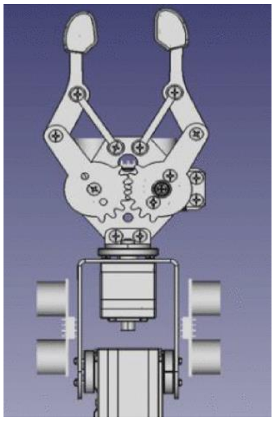

FIGURE 3. Ultrasonic sensor array setup by [8].

Based on the method conducted by [9] used 8 HC-SR04 ultrasonic sensor were used to form an ultrasonic array shown in Figure 5 surrounding the body of the frame. In their research of the implementation on an ultrasonic sensor array, noise is identified from the ultrasonic sensor. For them to eliminate the noises, Savitzky-Golay filter is being used rather than the Kalman filter to process the signal received from the ultrasonic sensor before the obstacle detection. The Savitzky-Golay filter is similar to moving average as it does linear least squares fit with any nth-degree polynomial across data of size n, and it also provides a much lighter computation work while still providing accurate obstacle detection results. The experiment result of the ultrasonic sensor can be seen in Figure 4.

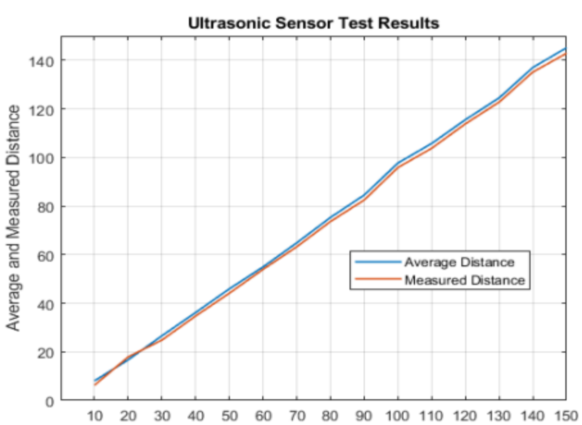

FIGURE 4. Ultrasonic test result perform by [9]

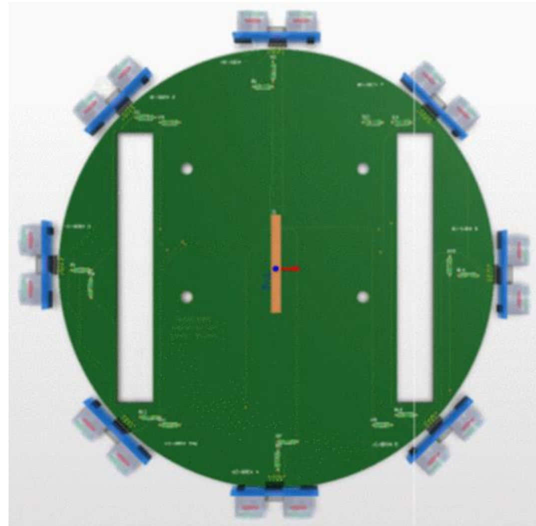

FIGURE 5. Ultrasonic sensor array setup by [9].

According to the study of [10], the system is installed on an electric wheelchair with the use of a sensor fusion of low-cost ultrasonic and infrared sensors. Infrared sensors emit a focused patterned beam of light and determine distance using simple triangulation of the reflected beam. They work by detecting a very precise wavelength in the range above 760nm generated by a light-emitting diode. Ultrasonic sensors, measure the distance between objects by measuring the time it takes from the emission of ultrasound to the receiving of the echo created by various objects. Ultrasonic sensors give accurate readings and a quick response, but it has poor detection at angles higher than 45° or when the reflected surface is small in size. Light pulses are emitted by infrared sensors, which is a drawback when sensing transparent or very absorbent materials. Taking into account the benefits and limits of each technology employed in the ultrasonic and infrared sensors, they developed the system by combining of the two sensors to reduce the error rate. However, integrating two separate sensor types involves sensor synchronisation and integration, which may raise system complexity.

Based on the study conducted by [11], an obstacle detection system for electric wheelchairs based on computer vision was presented. The obstacle detection system involves a smartphone as the camera to record videos and export the frame to measure the distance between the wheelchair and the obstacle for obstacle detection using the YOLOv3 algorithm or Canny edge detection if the obstacle cannot be recognised by the YOLOv3 approach. YOLOv3 is a real-time object detection technique that uses a deep convolutional neural network to recognise particular items in video, live feeds, or photos. It used vertical and horizontal lines as a threshold for alerting, as shown in Figure 6. The result of obstacle detection has a high success rate of 90% but due to the high processing power and computation capability is required by the YOLOv3, the cost to obtain the required processing hardware will not be affordable.

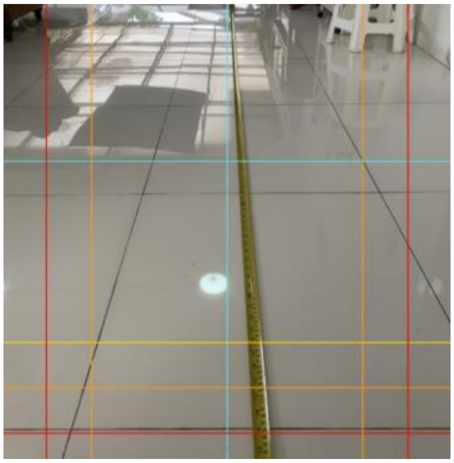

FIGURE 6. Vertical and horizontal threshold lines used by YOLOv3 algorithm by [11].

Another study conducted by [12] to perform obstacle detection also used a similar approach with a rear-view camera, but they utilised an easier algorithm by comparing the differences between regions of interest (ROI) of frames from the video recorded by the camera which reduced the load of computation and hardware requirements. However, camera is affected by the lighting conditions of the environment as they are prone to being noisy and suffering from reduced image quality under low lighting environment conditions which affects the accuracy and performance of the obstacle detection system.

According to the research by [13], they utilised radar to perform an obstacle detection system that is installed on an unmanned surface vehicle (USV). The usage of radar involved radar processing, Electronic Navigational Chart (ENC) processing, ENC, and a grid map-based obstacle detection system. They are able to perform obstacle detection using radar to detect fixed surrounding terrain and object, as well as moving vessel as dynamic obstacles. However, from their study, the radar has a slow update cycle, which results in not being able to detect fast moving obstacle that are too close to the device.

According to the study by [14], they implemented obstacle detection by using a 2D Light Detection and Ranging (LiDAR) sensor on an autonomous vehicle with a robot operating system (ROS). They used the data collected by the LiDAR sensor to create a 2D mapping on Rviz and also reacting to the obstacle if the distance reading from the sensor reached a certain threshold. Tests were carried out for the LiDAR based obstacle detection to detect objects and moving pedestrians and identified that the LiDAR sensor does not respond well to reflective surfaces as the laser light from the LiDAR sensor may not deflected properly, resulting in varied measurement distance that only obtained an average accuracy of 85.92% from the Lidar sensor and actual distance, which also occurs in the research of [14], that utilised Braitenberg strategy, pedestrian detection shows the LiDAR data with higher fluctuation and performs poorer when compared to the ultrasonic sensor, which is likely due to the use of only single laser model for LiDAR measurements, and robot also cannot avoid transparent objects such as acrylic and polycarbonate bottles. The experiment result of [15] shows that the average accuracy during optimal conditions is 99.1%.

From the study of [16], they implemented an array of ultrasonic sensor for obstacle detection for the visually impaired using Arduino. The system component of obstacle detection is created using three ultrasonic sensors for detection, a GSM module, a buzzer, and two vibration motors to notify user, as shown in Figure 7, and it processes details about the environment using an ultrasonic signal with a frequency of 40kHz. They used three ultrasonic sensors in separate directions on the devices to enhance the angle of coverage and provide feedback via vibration. Testing was carried out for the device performance of the visually impaired, and positive feedback was received on the usage of the designed system to detect obstacles above waist level.

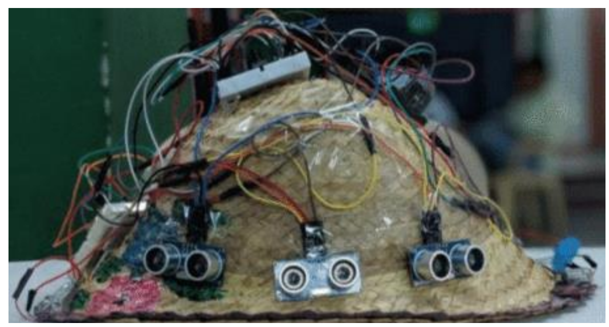

FIGURE 7. Ultrasonic sensor array setup by [16].

A similar approach has been done on a wearable support system to aid the visually impaired in independent mobilisation by the research of [17]. An array of ultrasonic sensor has been made out of 6 ultrasonic sensors instead of 3 sensors from article [16]. The angle of each ultrasonic sensor is an upward-facing sensor, 4 forward-facing sensor, and downward-facing sensor. The result of their obstacle detection system is that it can reliably detect static indoor obstacles with great 100% obstacles detection sensitivity and adequate obstacle detection performance of 100% for all object except for chair and table, which has minimal surface for the sensor to detect.

In the study of [18] and [19], infrared (IR) sensor was being implemented to perform obstacle detection, shown in Figure 8. The working principle of the infrared sensor is that the infrared light emitted by the transmitter LED is received by the receiver when it detects the reflection of an object as it is close to the IR and generates an alarm though a buzzer. An experiment has been carried out in their research and obtained a high degree of accuracy and a minimum probability of failure when applied on automated guided vehicles (AGV) and construction site vehicles. The usage of an obstacle detection system using an infrared sensor is able to perform as expected. However, the system cannot be applied in direct sunlight because it may interfere with IR radiation and also requires the aids and combination of different sensor to improve the reliability of the system.

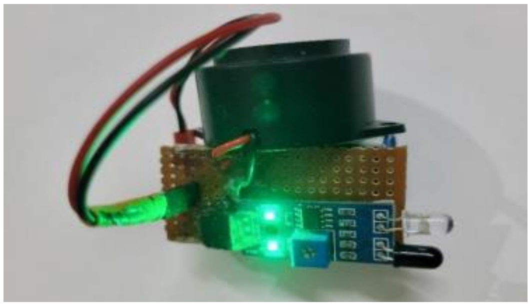

FIGURE 8. Infrared sensor obstacle detection system used by [19].

B. Control Method of Car-Like Robot with Obstacle Detection

Car-like robot often have the issue of colliding to obstacles during the process of manoeuvring through spaces. The implementation of an obstacle detection system is required as a preventive measure method to protect the car-like robot from collisions and damage. In the study of [20], the implementation of robot car control has been done by using hand gesture control. An MPU-6050 gyroscope sensor is being utilised, and the communication between the MPU-6050 and Arduino UNO is being done by using a Wi-Fi module. The MPU-6050 is attached to a glove to perform the control of the car by rotating the hand in the Y-axis and X-axis, as shown in Figure 9. The roll and pitch motion of the hand can perform the control of the motor of the car-like robot to move in left, right, forward, and backward motion. The robot is powered by 4 DC motors and their car-like robot is also equipped with 2 infrared sensor modules as an obstacle detection system to detect obstacles and objects in front of the robot to prevent collisions. However, they found out that the technology is not mature enough to be applied in a virtual environment, and the gesture control is still far behind the dynamic gesture control algorithm which is a more advanced system.

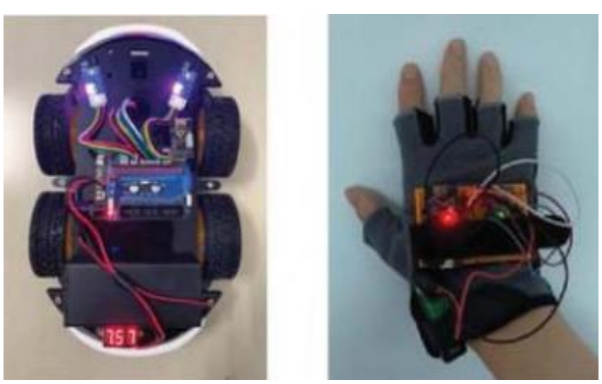

FIGURE 9. MPU-6050 attach to the glove done by [20].

A study was done by [21] to perform an Arduino based Bluetooth voice-controlled car with an obstacle detection feature, and the implementation of robot car control has been done by using voice commands. The hardware for the control movement of the car-like robot consists of an Android phone, motor driver, 4 DC motors, Arduino UNO, and HC-05 master slave Bluetooth module to allow communication between them. The Android phone is used as an input device that receives the command though an application named Google Speech Recognition that will convert the spoken speech into text, and the text will be transmit to the Arduino via Bluetooth module through serial communication. The voice command allows the robot to perform forward, backward, left, right, and stop instruction and is also able to react to the object obstructing the robot by using an ultrasonic sensor-based obstacle detection algorithm. The Android application used is shown in Figure 10. However, they discussed that adding multiple types of sensors is required in order to increase the performance of the obstacle detection system, and also the altering of the recognition of speech applications is required to improve the recognition of voice. Last but not least, this application is only compatible with Android based phone as it uses the HC-05 Bluetooth module rather than the BLE module. The accuracy of the overall function has achieved a percentage of 98.5% and stability of 98%.

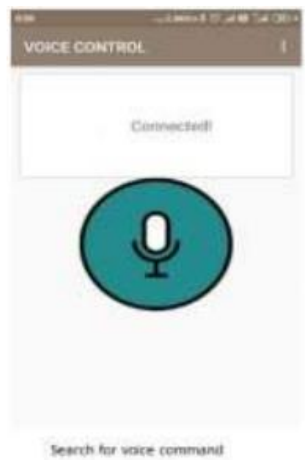

FIGURE 10. Android app with Google speech recognition used by [21].

In the study of [22], they designed a crawler mobile car robot with infrared remote control. They implemented the control of the robot by using infrared remote control, which the hardware consists of a STC 51 series single-chip microcomputer, motor driver, and 2 track driver motor wheel, photoelectric sensors, an IR remote control, and IR receiving module, as shown in Figure 11. The control of the robot depends on the button pressed on the IR remote control and send the command signal to the MCU to be processed and transmits a PWM signal to the motor driver to drive the DC motor of the track belt. The obstacle detection system is based on multiple photoelectric sensor that are installed around the chassis of the robot to detect for obstacles. Their study found that the range of the IR receiver can reach a maximum of 15 meter.

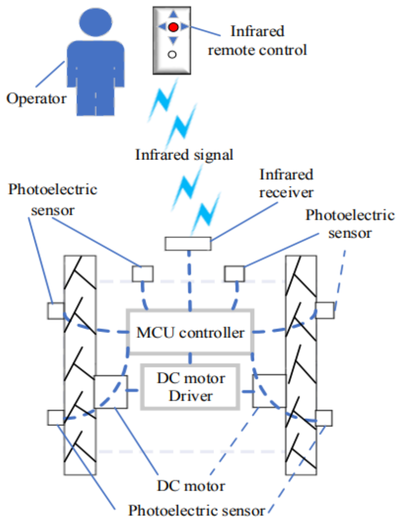

FIGURE 11. Hardware design of a car-like robot by [22].

According to the study [23], they designed a wireless car control system based on Arduino UNO. They implemented the control system by using mobile control by Bluetooth technology, which the hardware consists of an Android based mobile device, Arduino UNO, motor driver, 4 DC motor, HC-05 Bluetooth module, and an ultrasonic sensor. The motor is driven by PWM signal from the Arduino when there is input command being received from the Bluetooth module that is sent from mobile device to perform turn left, right, forward, and backward motion. The obstacle detection system of their design is based on an ultrasonic sensor that will react to the distance measured and stop the operation of the car if the measured distance is over the threshold limit set in their algorithm. However, they found out that by utilising one ultrasonic sensor is not able to have high adaptability to the complex environment. The average accuracy of the test result is 97.14%.

Another similar approach has been designed and developed by [24] to perform mobile-controlled robot with obstacle detection and avoidance system. The hardware system used is almost identical to the study in article [23]. The difference is that their ultrasonic sensor is mounted on a servo motor that will perform left and right oscillation to check for obstacle at the side of the robot. The model created by [24] can be seen in Figure 12. By utilising this method, it only required a single unit of ultrasonic sensor to perform the obstacle detection system with wider angle of detection. The screenshot of control interface from the android application can been seen in Figure 13 to perform forward, backward, left, and right motions.

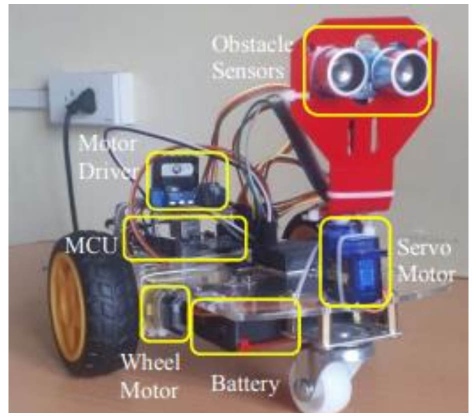

FIGURE 12. Robot model developed by [24].

FIGURE 13. Screenshot of control interface on Android used by [24].

According to the project done by [25], they implemented the control of the Arduino based robotic car by using the Wi-Fi technology of the NodeMCU. The interaction between the MCU and application is similar to the study of [23] and [24], but it utilises Wi-Fi technology rather than Bluetooth, which provides a more reliable and faster transmission of data between hardware and is also compatible with more types of devices. The obstacle detection system of their design is based on an ultrasonic sensor that will react to the distance measured, and stop the operation of the car if the measured distance is over the threshold limit, and send a notification to the user smartphone application to have real-time control with a camera to perform real-time monitoring.

III. Conclusion

The motivation behind this review paper is to explore the previous examples of work that discussed, summaries and highlight the various types of sensor technology for obstacle detection and control method for mobile robot. Every sensor technology has its limitations and strengths in different aspects. By combining the sensors into an array and performing sensor fusion techniques will have significantly improve in overcoming the effectiveness of the system technology will the limitation of the existing sensor technology.

Notably, the method of controlling the robot will depends on the area of usage. A hand gesture control may give a better control of the robot as it follows the motion of the hand with a hands-free experience which has better user engagement. While Wi-Fi is able to provide a longer range of control but the Bluetooth will stand out for the lower energy consumption. Identifying of the optimal type of sensors and control method for different type of applications is crucial for ensuring the suitability and stability of the system. Furthermore, application that requires precise distance measurement, the LiDAR will be preferred, whereas an ultrasonic sensor will perform better in proximity sensing at a much lower cost. While radar will be well suited for longer range of detection, a camera-based system can offer object recognition capabilities with machine vision but the performance will be affected by low lighting condition, where the infrared sensor and ultrasonic sensor will be excelled in that environment condition.

One significant gap will be the needs of additional research in the area of advanced sensor fusion approach, while the performance of sensor fusion approach is promising but a deeper research study is required to optimize this technique to meet the specific needs of application. Moreover, developing low energy consumption sensor and control method still remains a critical area of improvement as robot increasingly being utilized in various sector, identifying a control method and sensor that can balance between performance and energy efficient is important.

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