Research on Obstacle Avoidance Control of Intelligent Robots Based on Multi-Sensor Fusion

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Abstract. When the obstacle avoidance control of an intelligent robot only uses a single sensor, there will be many limitations. Using multi-sensor fusion for obstacle avoidance control can combine the characteristics of different sensors to enhance the robot's obstacle avoidance capabilities. This article analyzes the characteristics of ultrasonic sensors, LiDAR, visual sensors, and infrared sensors, showcasing the development of multi-sensor fusion through existing robot applications based on multi-sensor fusion. It demonstrates the impact of control systems combining data from multiple different types of sensors and fusing them through fusion algorithms. This improves the accuracy of robots in obtaining obstacle information and avoiding obstacles in different environments, as well as their ability to perceive the environment; This study examines the different levels of multi-sensor fusion. Through various robot applications, it highlights the strong perception ability and excellent environmental adaptability of multi-sensor fusion robots, emphasizing the importance of multi-sensor fusion in the field of obstacle avoidance control for the development and application of intelligent robots.

Keywords: Sensor, Robot, Multi sensor fusion.

1. Introduction

Robots are rapidly becoming an indispensable part of various industries, and automated robots are changing the production methods of many industries. A major research area in the field of robotics is the application of multi-sensor fusion in robotics. By equipping robots with multiple sensors that work together to obtain information about the surrounding environment and integrate it, the perception and decision-making abilities of robots can be improved.

With the continuous development of robot technology and sensor technology, more and more robot applications are based on the fusion of multiple sensors. The integration of sensors enables robots to collect data from different angles and combine them to gain a comprehensive understanding of the environment. By combining information from sensors such as vision, LiDAR, and ultrasonic sensors, the limitations of individual sensors are reduced, improving the accuracy of environmental data and ensuring that robots can obtain more comprehensive environmental information.

The fusion of multiple sensor feature data plays an important role in ensuring that robots can efficiently and accurately complete tasks in complex scenes. Some robots will replace humans to enter dangerous environments for operations. By combining data from different sensors, these robots can collect more information about different features of the environment, ensuring that robots can navigate, avoid obstacles, recognize objects, and complete corresponding tasks in challenging and complex environments. In addition, multi-sensor fusion enables robots to adapt to dynamic environments and effectively handle environmental uncertainties, thereby improving the safety and reliability of robot applications.

The applications of multi-sensor fusion robots are diverse and have broad prospects. In industries such as transportation, agriculture, and healthcare, robots can optimize and improve productivity, and enhance job safety. In addition, in search and rescue missions, hazardous environment detection, and monitoring operations, multi-sensor fusion robots can provide effective assistance to humans by providing real-time data analysis.

In traditional robot applications, the perception limitations of a single sensor and a single algorithm can restrict the range of scenarios in which intelligent robots can be effectively used. In specific scenario applications, the perception ability of a single sensor to the environment is easily affected by environmental changes, leading to unsatisfactory perception results [1]. Multi sensor fusion can solve the problem of insufficient performance of individual sensors, increase the collected information data, provide more considerations for decision-making, and have stronger rationality [2].

This article first introduces four types of sensors applied to robots: ultrasonic sensors, radar sensors, visual sensors, and infrared sensors. By analyzing the advantages, disadvantages, and existing application examples of these four sensors, the limitations of a single sensor are highlighted. Thus, a robot that integrates multiple sensors is proposed, and multi-sensor fusion is introduced by introducing three fusion levels of multiple sensors. This article aims to demonstrate the importance of multi-sensor fusion for robots through existing examples of multi-sensor fusion robots. The integration of multiple sensors enables robots to operate more intelligently and efficiently, enabling better development and application in various industries.

2. Sensor type

2.1. Ultrasonic sensor

Ultrasonic ranging is a biomimetic technology that draws inspiration from bats, an animal that can capture prey in the dark without the need for vision because they use ultrasound to locate prey. The ultrasonic pulse signals emitted by bats form reflected waves when they contact prey. By measuring the time interval and the speed of ultrasonic propagation in the air, bats can determine the distance to the target. Ultrasound is not easily affected by environmental disturbances such as changes in magnetic field and lighting, which can affect measurement accuracy.

Most existing intelligent robots for obstacle avoidance involve ultrasonic sensors.

However, the range of ultrasonic sensors is relatively short, usually from a few meters to tens of meters. When facing long-distance ranging tasks, the accuracy of ultrasonic sensors will decrease; Ultrasonic sensors have a higher recognition rate for larger obstacles and a lower recognition rate for smaller obstacles such as wires and twigs [3]. Ultrasonic sensors have a certain sensitivity to factors such as temperature, humidity, and atmospheric pressure in the environment. The main factor affecting the propagation speed of ultrasound is temperature. Generally, for every 1℃ change in temperature, the sound speed changes by 0.607m/s [4].

2.2. Lidar

Lidar sensors are commonly used sensors that use laser beams to measure object distance and construct three-dimensional models of the environment. Lidar has the advantages of high ranging accuracy, all-weather operation, and strong anti-interference ability [5]. Its disadvantage is that compared to other sensors, its price is relatively higher; The relatively large volume of LiDAR is not suitable for small or weight limited application scenarios; When the surface of the target object is too smooth or the reflectivity is low, the measurement of LiDAR may have errors or even omissions. In terms of application, Kragh et al. used the support vector machine method to extract features from local domains and classify individual points in the 3D point cloud obtained by Velodyne HDL-32E LiDAR. Each point was classified into one of three categories: ground, vegetation, or objects to achieve the function of intelligent vehicle obstacle recognition. Experiments on local farms showed that the classification accuracy was 91.6% [6]. The perception system independently designed by Bergeman et al. uses a two-dimensional laser scanner to detect obstacles in vehicles, preventing collisions between smart cars and people, trees, and trash cans [7].

2.3. Vison sensor

In environmental perception detection applications, visual sensors are widely used, which can directly obtain color information, and are easy to install, small in size, and low in energy consumption. Visual sensors are divided into monocular RGB sensors, binocular (binocular) RGB sensors, active depth sensors, thermal imagers, and event based dynamic visual sensors [8]. The maturity of modern camera technology enables visual sensors to have high resolution, which can obtain higher definition images and increase the accuracy of image recognition. Therefore, visual sensors are greatly affected by the intensity of light, and the size and angle of the images that can be collected by visual sensors are also affected by the camera, resulting in certain blind spots due to the size and angle of the camera. Visual sensors usually adjust image processing methods to achieve corresponding functions based on different environments and task requirements. Therefore, visual sensors require complex calculations and algorithm optimization, as well as database training, requiring a large amount of data processing and computation, and requiring high resource requirements.

2.4. Infrared sensor

Infrared sensor is a type of sensor that can perceive and measure infrared radiation. It is suitable for short distance measurement and monitoring. Infrared sensors can be applied in security monitoring, temperature measurement, obstacle avoidance, medical treatment, environmental detection and other fields. The infrared radiation wavelength of infrared sensors is broad, which can be applied to diverse scenarios and task requirements. At the same time, infrared sensors have the characteristics of high accuracy and high sensitivity, which can be used to measure tasks with small changes. However, in the task of detecting heat sources, it may be affected by interference from other heat sources, which can affect the accuracy of the measurement. With the development of robotics technology, infrared ranging sensors are often used in robot cars nowadays. Infrared sensors are commonly used for obstacle avoidance in small cars. The intelligent sweeping robot designed by Gao Shijie based on infrared signals uses infrared obstacle avoidance sensors. When infrared meets opaque obstacles, the obstacles will absorb a small part of the infrared and reflect most of the infrared. After receiving the infrared, the obstacle avoidance module will change its reverse conduction resistance value and be equipped with a voltage divider to convert the infrared signal to the voltage signal [9].

3. Intelligent robot with multi-sensor fusion

Due to the limitations of single sensor intelligent robots, multi-sensor fusion intelligent robots can integrate data from multiple sensors for analysis. Multi sensor fusion can improve the robustness and reliability of the system. The development of multi-sensor fusion is the key to enhancing the system's perception ability [10]. Multi sensor fusion can be divided into three types based on the fusion level: raw data level, feature level, and decision level.

3.1. Raw data level

The lowest level of abstraction is data layer fusion, which typically assumes that communication, storage, and processing systems are reliable. The fusion at this level requires sensors to observe the same physical phenomenon, with the aim of achieving more accurate, informative, and synthetic fusion data than the original source. Data level fusion requires centralized processing methods and is often used in conjunction with sensor arrays for redundancy to improve robustness. If multiple sensors observe different physical quantities, the data can only be fused at the feature layer or decision layer [11].

3.2. Feature level

The feature level multi-sensor fusion method extracts features from the data collected by various sensors for fusion. Fusion of feature sets collected from multiple data sources can create new high-dimensional feature vectors. Feature level fusion enables pattern recognition and machine learning to be applied to high-dimensional feature vectors of different application types, which can then be fused to form joint feature vectors for classification [12]. Simply fusing feature sets is neither convenient nor efficient, so it is usually useful to apply feature selection algorithms to obtain the so-called most important features. The main advantage of this level of fusion is to improve the recognition accuracy of feature subsets by detecting the feature information generated by different sensors. The main disadvantage of this level of fusion is that it requires a large number of training sets in order to find the most important feature subsets [13].

3.3. Decision level

Decision level fusion is the use of information that has already been processed at the raw data or feature level for decision-making [13]. Decision level judges and processes the provided information to obtain decision results. Therefore, the advantage of decision level fusion lies in improving decision accuracy; The decision level can also support different sensor combinations under different algorithms [14].

3.4. Multi sensor fusion application

Multi sensor fusion robots adapt to tasks in different environments and obtain more comprehensive and accurate environmental information to better make decisions and execute. Chunying Li et al. proposed a multi-source information fusion (MSIF) model for underwater robots based on multi-sensor fusion. Fig. 1 shows the sensor unit of the underwater robot, which integrates an inertial measurement unit (IMU), a pressure sensor array (PSA) composed of 6 CJMCU-5837 pressure sensors, an obstacle avoidance sensor array (OASA) composed of 4 JSN-SROT4 ultrasonic sensors, a depth sensor (DS), an acoustic communication system (ACS), and a down facing camera (LDC). CJMCU-5837 sensor is a sensor with a resolution of 2mm and a size of 18mm x 10mm; Four of PSA's six pressure sensors are located on the central track, while the other two pressure sensors are located at the top and bottom, respectively. The underwater robot of this model obtains a fusion model by processing multiple sensor units based on different features, which can obtain more accurate data. By compensating for motion errors from multiple sensors, higher precision positioning, attitude estimation, and obstacle avoidance can be achieved [15].

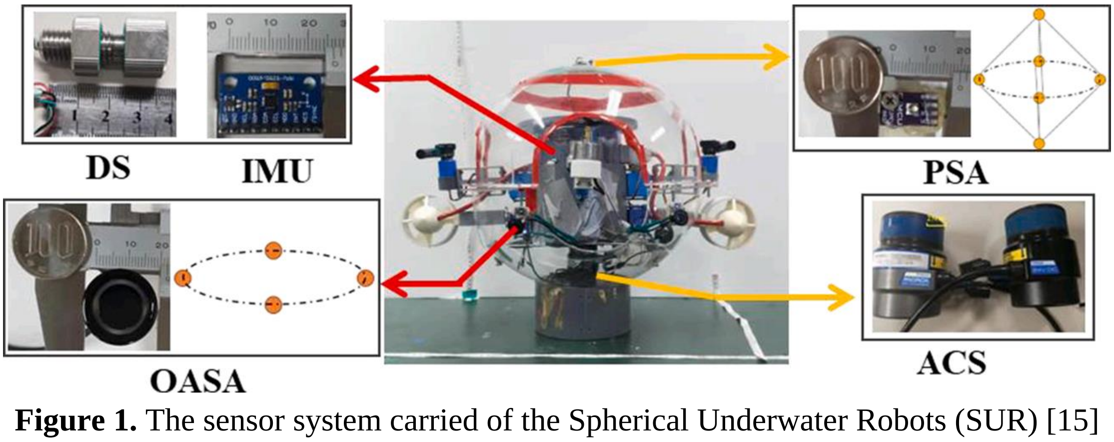

Figure 1. The sensor system carried of the Spherical Underwater Robots (SUR) [15]

A novel system proposed by BALL et al. based on GNSS, inertial navigation systems, and visual sensors enables robots to perform tasks for three hours at night while avoiding obstacles. It also enables robots to operate normally for 5 minutes without GNSS signals [16]. JianWei Zhao et al. developed a new detection module based on a single ultrasonic sensor obstacle avoidance robot, incorporating visual information and infrared ranging sensors [17]. As shown in Fig. 2, the layout of robot sensors is shown. Nine ultrasonic sensors are installed on the periphery of the robot to detect information about environmental obstacles; The infrared ranging sensor is installed between the front wheels to detect the condition of ground pits; The road sign information is detected based on the camera.

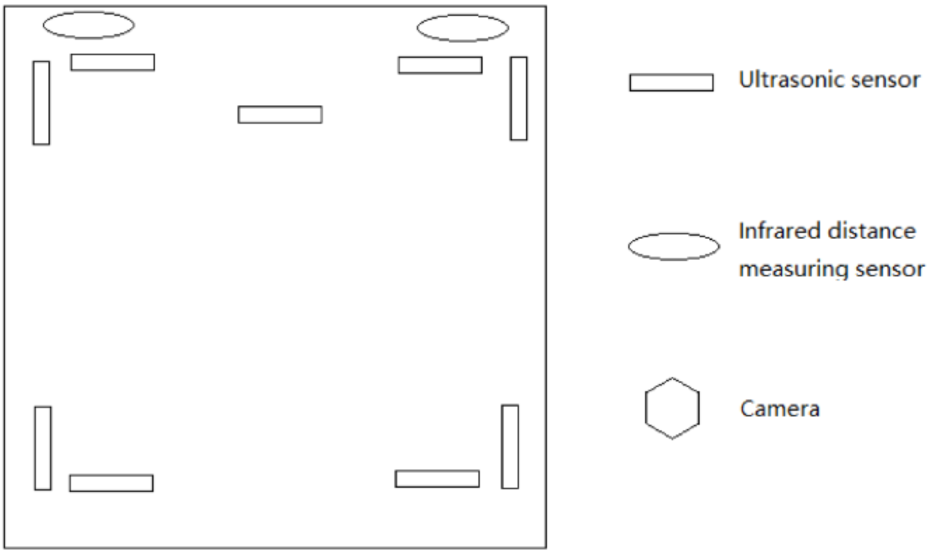

Figure 2. Sensor Layout [17]

Robots can obtain information about obstacles and distance from road signs in the external environment through ultrasonic sensors. They can also refer to road signs to indicate direction through visual modules, and use infrared sensors to detect road conditions and obtain information about road environments with depressions and potholes to achieve obstacle avoidance functions. Qu Dongyue et al. designed a multi-sensor system to achieve autonomous obstacle avoidance and navigation of robots in unknown environments [18]. The ultrasonic sensor in the sensor system adopts a distributed structure, and the infrared sensor adopts a LiDAR like design. The obstacle and external environment are modeled using the polar coordinate vector method, and the obstacle avoidance function is achieved using the "rolling window" obstacle avoidance algorithm. Zhang et al. proposed a multi-sensor fusion factor graph (MSF-FG) localization method based on the study of indoor mobile robots, which integrates three sensors: IMU, Odometer, and LiDAR. By utilizing the different characteristics of each sensor and utilizing factor graph theory, an MSF-FG localization model was established to improve localization accuracy and reduce computational complexity. The positioning scene and positioning system structure are shown in Fig 3. When constructing the map, the robot first collects information through three types of sensors. When the robot navigates and locates, the IMU will obtain information on the robot's acceleration and angle, while the Odometer sensor will obtain information on the robot's speed and direction; LiDAR receives robot location information from temporary and spatial correlation perspectives. Then, the optimal pose of the robot under navigation conditions is obtained through a multi-sensor fusion factor map positioning model. Simulation results show that compared with traditional inertial navigation systems (INS) and extended Kalman filter (EKF) algorithms, the MSF-FG positioning method reduces the average positioning error by about 40%. It enhances the stability of the system while reducing computational complexity [19].

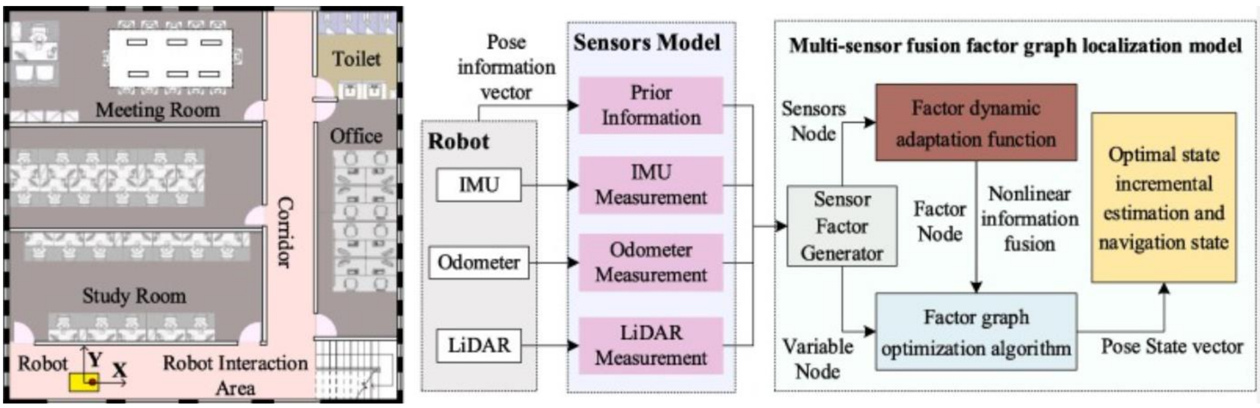

Figure 3. The structure of positioning scenario and positioning system [19]

As more and more robot technologies are applied in agriculture, REINA et al. have developed a multi-sensor platform to automatically detect obstacles and distinguish between accessible areas and different traffic areas in order to deal with various situations that may be encountered in agricultural scenes. They combine different sensors to deal with the unknown and complex scenes in practical applications. REINA et al. proposed a method based on the fusion of LiDAR and visual sensors, which compensates for the limitations of LiDAR in dense terrain with visual sensors. When data targets are scarce and acquisition frequency is low, LiDAR is used to compensate for the limitations of visual sensors; A system for 3D obstacle avoidance detection based on integrated radar and stereo vision was also proposed. The radar serves as a supervised algorithm to detect potential obstacle targets, and then enhances the information of obstacles, such as shape and color data, through visual sensors; There is also a method that combines thermal imaging and HDR stereo vision to detect organisms and other types of obstacles through 3D stereo vision measurement and temperature [20].

4. Conclusion

The obstacle avoidance and application scenarios of intelligent robots based on a single sensor are limited. With the development of society, this paper needs robots with adaptability and diverse scenarios. Therefore, there is a need to develop intelligent robot technology that leverages multi-sensor fusion. Integrating information obtained from ultrasonic, visual, infrared, radar, and even tactile sensors for decision-making can improve the obstacle avoidance accuracy and reliability of robots. As a result, these robots exhibit excellent obstacle avoidance performance and adaptability in complex environments.

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