Design of an Interactive LiDAR-Vision Integrated Navigation System

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Abstract. In order to further improve the accuracy of indoor navigation for mobile robots, this paper introduces the hardware design of a mobile robot combining Light Laser Detection and Ranging (LiDAR) with visual localization system. In this system, the LiDAR-based localization system and visual localization system run in parallel. The LiDAR-based localization system runs on the ROS system for measuring the LiDAR-based position, which helps to solve the deficiencies of low visual navigation frequency.

Visual location makes up for the weakness in short detection range and little data of LiDAR. The pose data obtained by the two methods are filtered by Kalman [1] filter and reweighted fusion to obtain a more accurate position and motion trajectory of the mobile robot. The results from indoor robot movement test show that the mobile robot system integrating visual and LiDAR positioning has an obvious improvement in regard to accuracy compared to other methods.

Keywords: LiDAR · Visual localization system · Mobile robot localization

1 Introduction

Nowadays, with the rapid development of modern society and the maturity of technologies and the needs of better productions and living condition, the application of mobile robots becomes more and more extensive. Compared with human, unmanned mobile robots are more efficient, more convenient and can adapt to various environments such as in many civil engineering fields like medical equipment, warehouse handling, (unmanned) assisted driving, and cleaning, as well as in military fields like remote unmanned combat equipment, replace people in special environments (toxic, nuclear radiation, earthquake-stricken areas [2], outer space, etc.). When mobile robots work becomes more and more complex, the requirements of the results are more and more accurate. In many situations, higher requirements are set for navigation accuracy and anti-interference ability of mobile robots.

Currently, the navigation and positioning of mobile robots in production are mainly using GPS positioning [3]. Developed by a U.S. military project, GPS

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has so far built a network of 24 GPS satellites covering 99% of countries and regions on earth. For more than 60 years, the cost of using GPS has been reduced and integrated navigation accuracy has reached millimetre level. These are all advantages of GPS in open/outdoor areas but not in indoor areas especially underground areas. It is due to the influence of buildings and various obstacles which makes it very difficult to receive GPS signals and seriously affects the accuracy of GPS positioning [4].

To solve the problem of indoor GPS positioning, the Lincoln Laboratory at the Massachusetts Institute of the Technology was the first to use LiDAR [5] navigation for indoor mobile robots. By receiving the reflected laser signal, LiDAR can directly scan the position of the surrounding obstacles and terrain to locate itself. One of the most representative usages is laser SLAM [6] technology which has achieved high accuracy in indoor proximity. At present, the development of LiDAR navigation technology has been relatively mature. This method has the advantages of simple structure, long life and high accuracy within short distances. However, limited by a scan line or several scan lines, the laser radar data can not fully restore the surrounding scene information and the details of the scene texture can not be reflected very clearly.

Compared with LiDAR navigation, visual location can acquire more types of information about the surrounding scene. Visual location and navigation obtain image information through monocular, binocular or depth camera, then process the collected image information by computer to obtain the actual position coordinates of the robot. It has the advantages of low cost, wide application range, etc., but the requirements for external environment (ground, light, etc.) are relatively high. At present, a relatively mature solution for visual mileage is the visual SLAM method for image mapping by extracting image features [7]. Usually, visual positioning relies on a single camera to collect data and some feature points cannot be accurately positioned, which affects the accuracy of visual positioning to some extent. When vision SLAM locates complex terrain and broad scene, there will be more image information which requires a high-performance computer to compute. Meanwhile, the computing delay will also greatly affect the timeliness of the entire positioning system.

In the design of a mobile robot positioning system, the single positioning method is often difficult to meet the increasing demand. To adapt to the more complex surrounding environment and enable mobile robots to provide better services [8], LiDAR and binocular cameras are combined to conduct position analysis and to obtain more detailed information about the surrounding environment. In this paper, a hardware design method combining LiDAR and visual positioning is proposed.

The rest of the paper is structured as follows: Sect. 2 proposes the hardware design of each part of the navigation system, Sect. 3 gives the conclusion.

2 Hardware System Design

The hardware part of the whole system consists of six parts: LiDAR navigation module, binocular camera positioning module, mobile robot motor control module, power module, communication module and a host computer. (The relationship among parts is shown in Fig. 1 and the real hardware is shown in Fig. 2)

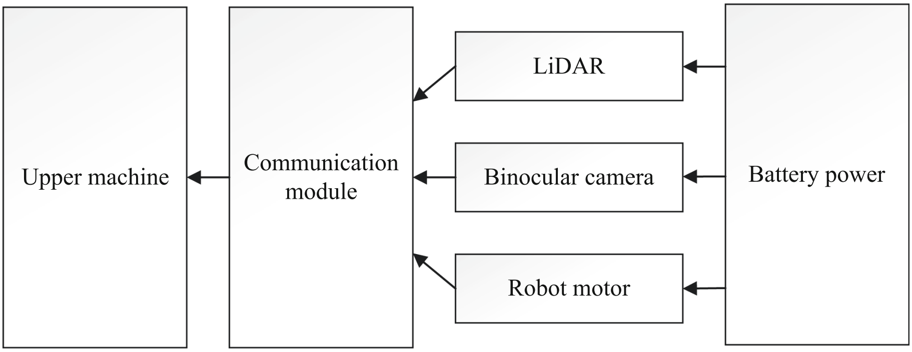

Fig. 1. Design of hardware parts of the mobile robot.

Fig. 2. Mobile robot

2.1 LiDAR System

The LiDAR module is Silan RPLiDARA1 (as shown in Fig. 3). It is a 360-degree laser radar developed by SLAMTEC Company and is able to achieve 360-degree laser scanning within a radius of 12 m. This has met the needs of mobile robot positioning under most indoor conditions. The radar has a normal scanning frequency of 5.5 Hz and can scan up 10 Hz. It can perform up to 8000 ranging operations per second. A1 laser radar uses laser triangulation ranging system. First, light-emitting infrared laser is sent and received after the object reflected laser. Later, its built-in DSP processor calculates the corresponding point of the measured distance and the angle of the object according to each moment received signal. After testing, the positioning accuracy requirement of mobile robot can be satisfied in many different indoor scenes or outdoor scenes with weak light. After the radar is started, the ranging core located at the top of the centre will rotate clockwise under the drive of the motor to scan the surrounding environmental and obtain indoor environmental data of 360°. Then the serial port/USB output the obtained distance information to the host computer for processing.

Fig. 3. RPLiDARA1 LiDAR

2.2 Binocular Camera

The system binocular camera is the Millet camera depth high precision version of d1300-IR-90-color. The camera has a 60FPS frame rate, a 2560*720 resolution for regular images, and a 1280*720 resolution for depth images. The diagonal, horizontal and vertical angles of the images are 103, 90 and 48° respectively. The d1300-IR supports a range of 0.3–4 m from the normal shooting depth. It also supports an infrared mode, which can take infrared images with a detection range of 2.5 m. Compared with the structural light or ToF scheme commonly used in visual cameras, Mi camera innovatively adopts the inertial navigation scheme of Mi binocular structured light (also known as active binocular). The single passive binocular scheme has poor imaging accuracy in the dark and no obvious texture environment, while the small binocular structure photo inertial navigation camera scheme has a good performance. On the other hand, the new scheme can effectively avoid the problem of different cameras interfering with each other and resulting in the deterioration of the collected data. In addition, in order to facilitate visual information acquisition and simplify information processing steps. This camera is built with a chip that can calculate individual depth information, so that depth data can be directly sent to the host computer without an external GPU/CPU, which greatly facilitates the research and design. (MYNT Binocular camera, as shown in Fig. 4)

Fig. 4. MYNT Binocular camera

2.3 Mobile Robot Platform

The experimental platform with LiDAR and binocular cameras is the official ROS Turtlebot2. It is a platform designed to provide an experimental environment for research on different robot projects. Its maximum translational velocity on the horizontal ground is 70 cm/s, and its maximum angular velocity of rotation is 180°/s (when the angular velocity greater than 110°/s, the performance of the gyroscope in the system will be significantly reduced). Mechanical balance on the system is kept by bumpers, cliff sensors, and wheel drop sensors. The flat ground payload is 5 kg. It can travel through the depression with a drop of less than 5 cm, climb the bump, has a battery of 4400 mAh, can operate for more than 2.5 h. The host computer can communicate with the platform through the USB interface or the RX/TX pin of the parallel port. In this experiment, Turtlebot2 can realize horizontal movement and 360° omnidirectional rotation of the mobile robot under indoor conditions and form complex motion trajectory to verify the accuracy and stability of positioning and navigation methods combining LiDAR and vision systems.

3 Conclusion and Future Work

To solve the indoor mobile robot positioning navigation accuracy problem, this paper presents an integrated navigation hardware design that combines LiDAR and visual positioning. The position and pose information of two groups of mobile robots are obtained through two navigation modes, then the host computer fuse the information to calculate accurate positions in real-time. The experimental results show that the design combining LiDAR and visual positioning can greatly improve the accuracy of indoor navigation.

There are some points can be further improved. For example, as more modern machine learning based information fusion methods are emerging and shows great results [6]. Besides, as the information from different systems is not totally trusted, so belief theory can be used to mine deeper information and make decisions [7,8]. We are planning to investigate them in our later work.

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