Research on Mobile Robot Positioning and Navigation System Based on Multi-sensor Fusion

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Abstract. The mobile robot integrates walking and operation functions, which can greatly expand the application range of traditional industrial robots. Aiming at the shortcomings of single sensor positioning under unknown indoor environment, such as large accumulated error and environmental limitations, a multi-sensor fusion positioning navigation system is designed to improve the positioning accuracy of autonomous navigation of mobile robots. The mobile robot uses the laser sensor as the core sensor to obtain two-dimensional information of the environment and realize real-time display of algorithms and interfaces such as map construction, positioning and navigation. The data results of the indoor navigation experiment show that the system has good robustness. At the same time, the feasibility and reliability of the system are verified.

1. Introduction
The mobile operating robot is composed of a mobile robot platform and a mechanical arm. It has both moving and operating functions. It can effectively expand the application range of traditional industrial robots. It has been widely used in logistics and storage systems, automated production, special environmental operations, smart home services, education and scientific research [1].

There are two key issues in the research of mobile operating robots: one is positioning and navigation, which is divided into three aspects: map construction, robot positioning, and path planning; the other is joint planning and control of the mobile operating arm, which combines the mobile robot platform and the robotic arm. as a whole redundant degree of freedom system for motion planning, mobile grasping strategy research. In order to meet the above key issues, the robot control system needs to be stable, scalable, high-performance, and low-cost. In this paper, lidar, IMU and wheel odometer are selected as sensors, A set of multi-sensor nonlinear fusion positioning system is designed by nonlinear fusion of lidar measurement information, IMU and wheel odometer measurement information through Gaussian Newton equation, The state estimation for a longer period of time and
longer distance can provide high-precision and high robustness positioning for autonomous localization and navigation of mobile robots.

2. Introduction of algorithm

2.1. ROS platform
The design of mobile robot system is based on the control system of ROS. ROS is a robot software platform, which can simplify the development of complex and stable robot software on different robot platforms by providing a variety of functions [2]. It provides functions such as underlying device control, driver management, common function execution, interprocess message passing and package management, which is similar to operating system. ROS is also a distributed software framework, which can realize communication between nodes (processes) through network protocols, and easily integrate codes of different languages and different functions.

2.2. Introduction of multi sensor principle

2.2.1. Lidar

Figure 1. Principle Diagram of Triangular Ranging

This article uses a lidar based on the principle of triangulation ranging, which can accurately measure the distance of indoor obstacles. As shown in Figure 1, the basic principle is to use a laser beam emitted from A to illuminate an object in front at a constant angle $\alpha$, and to converge the laser beam reflected from the object at an angle at B. The distance between angle and AB can be calculated by algorithm. According to the geometric relationship, the measured distance $D$ is:

$$D = AB \frac{\sin \alpha \sin \beta}{\sin(\alpha + \beta)}$$

The coordinates $(x, y)$ of the laser scanning point can be calculated by $D$, but the coordinates obtained are only the coordinates under the lidar coordinate system, and need to be converted into the coordinates under the world coordinate system.

2.2.2. Inertial measurement unit IMU. IMU is a measuring device mainly composed of gyroscope and accelerometer. The gyroscope uses the internal capacitance change to reflect the magnitude of the Coriolis force to obtain the angular velocity, and the angle of rotation is obtained by integrating the angular velocity. The accelerometer measures the position of the internal mass to calculate the acceleration. Generally, complementary filtering algorithms can be used to make the angle of the IMU accurate enough.

2.2.3. Wheel odometer. The wheel odometer is mainly composed of the encoder on the robot's traveling wheel motor, and the update rate is high. The displacement and angle of the robot can be directly measured, with high local accuracy. In this article, the wheel odometer measures the robot displacement.
3. Positioning and navigation system design

The mobile operation robot positioning and navigation system is developed based on ROS. A network connecting all process nodes has been created and operated in the ROS framework. On the basis of making full use of the open source community resources, new function packages and nodes are established to make each function node combine them in real time to become a reliable and efficient robot control system. The overall framework of the system is shown in Figure 2 [3].

![Diagram of Positioning and navigation ROS system framework](image)

**Figure 2. Positioning and navigation ROS system framework**

The PC system also includes rviz, which is a very powerful graphical simulation environment provided by ROS. By sharing the ROS server with NUC, the status of each node in the system can be monitored in real time, such as map information and odometer information, so as to realize the function of remote monitoring the state of robot in the environment. The functions of each part in the system are as follows:

- **Sensor information.** Collect and process sensor data, including the collection and processing of laser sensor data, the collection and processing of IMU data, and package and release the processed data to the system.
- **Map building.** Acquire environmental two-dimensional data and odometer information through laser sensors, build a map, and publish the map information to the system.
- **Global path planning.** According to map data, robot odometer information, target location information, etc., calculate the global optimal path, and publish the path to local path planning.
- **Local path planning.** According to the global optimal path, combining the speed information of the robot, the obstacle information detected by the laser sensor and the information of the target position, the local optimal path is calculated, and the speed command is issued by the local path to control the mobile operation robot platform.
- **Platform control.** The speed command output by the local path planning node is sent to the underlying PLC through the serial port to control the motion of the mobile robot platform. The node can also communicate with the servo drive to get feedback of the encoder speed, which will be released into the robot body speed information after processing.

4. Robot path planning

4.1. Environment modeling

As shown in Figure 3, the premise of global path planning is electronic map. Common map construction methods include topological map method, viewable method and grid map method. Among them, the grid map is efficient and concise, easy to maintain, and widely used [4]. This article uses grid map to build a two-dimensional map to store the basic situation of the robot working environment.
4.2. Global path planning

Robot global path planning can be understood as an optimization problem with constraints. Common path planning algorithms include A* algorithm, genetic algorithm, Dijkstra algorithm and so on. The A* algorithm is an effective method for solving the shortest path in a static raster map. The execution efficiency of the A* algorithm depends on the evaluation function to a very large extent, which is defined as the arrival from the initial node through the current node the estimated cost of the minimum cost path of the target node is as follows:

\[ F(n) = G(n) + H(n) \]  

\( F(n) \) is the evaluation function, \( G(n) \) is the known cost from the initial node to the current node, and \( H(n) \) is the estimated function from the current node to the target node, which is actually the so-called heuristic function. Suppose the starting point is \( S(x_s, y_s) \), the ending point is \( G(x_e, y_e) \), and the intermediate point is \( N(x_i, y_i) \). The evaluation function can be expressed as:

\[ F(x) = G(x) + |x_i - x_e| + |y_i - y_e| \]  

The core of the A* algorithm is to design an evaluation function. The measurement standards are Euclidean distance and Manhattan distance. Taking into account the calculation efficiency, the Manhattan distance evaluation function has a small amount of calculation and is not strictly a priority, but it can guarantee the direction of approaching the target point. This method is a compromise solution to improve the calculation efficiency.

4.3. Local path planning

Compared with global path planning, local path planning needs to consider real-time requirements and make correct decisions based on environmental information during robot movement. The dynamic window method DWA is mainly based on the cross-combined sampling space of the robot's linear velocity and angular velocity, sampling multiple sets of velocities, and simulating the moving trajectory of the mobile robot at these velocities, and selecting the angular velocity and linear velocity corresponding to the best trajectory to drive the robot to move [5]. Some trajectories in the sampling group are feasible, and some trajectories are not feasible, so the following function is used to evaluate the rows:

\[ G(v, w) = \alpha \cdot \text{Head}(v, w) + \beta \cdot \text{dist}(v, w) + \gamma \cdot \text{velo}(v, w) \]  

\( \text{Head}(v, w) \) evaluate the angle difference between the simulated trajectory and the target trajectory at the current sampling speed, \( \text{dist}(v, w) \) evaluate the distance to the obstacle in the current trajectory, and set the trajectory line without obstacles Is a constant, if there are obstacles, it is set to zero. \( \text{velo}(v, w) \) evaluates the current speed, which is the influence of the equilibrium sub-evaluation function on the overall evaluation result. It is necessary to normalize \( \alpha, \beta, \) and \( \gamma \). The calculation method is as follows:
The DWA algorithm uses heuristic search methods to optimize the path at any stage of the scrolling. The entire calculation process is continuously updated with feedback to achieve real-time obstacle avoidance of mobile robots. The reaction speed is fast and the calculation complexity is not high. In the actual environment, the robot is limited by the sampling frequency, speed amplitude, and motor torque [6].

5. Experimental result

In order to prove the feasibility and accuracy of the multi-sensor fusion positioning and navigation system, relying on the ROS robot operating system to remotely control the mobile robot on the PC side through the local area network to conduct navigation experiments in an indoor environment with no obstacles. The basic principle of the integrated navigation system is to use the complementary characteristics of multiple or multiple sensor information to improve the accuracy and stability of the navigation system [7]. At present, the information fusion technology adopted by the integrated navigation system mainly includes the track deduction method, Kalman filter method, Bayesian estimation method, neural network, support vector machine and other methods. Later, researchers improved on the classic Kalman filter algorithm and derived a series of better information fusion filtering techniques, such as extended Kalman filter, unscented Kalman filter and other algorithms. The experiment carried out 10 consecutive navigation experiments on single-source lidar navigation, fusion lidar and micro-inertial measurement data integrated navigation, and recorded the distance error and navigation time. The distance error records of ten experiments are shown in Figure 4. The navigation time record of ten experiments is shown in Figure 5.

![Figure 4. Distance error](image1)

![Figure 5. Navigation time](image2)

Experimental data shows that in a barrier-free environment, the overall range error of single-source navigation and integrated navigation is small and not much different, and the error accumulation is not obvious. However, the single-source navigation has a large fluctuation in the single navigation time, with a floating range of seven seconds, and the combined navigation time is relatively stable, only floating for two seconds. When random obstacles appear in the environment, the navigation system...
can update and modify the global optimal path and the local optimal path, so as to avoid the obstacle smoothly and reach the target point. The result of the experiment proves that the positioning and navigation control system has good reliability.

6. Conclusion
In order to meet the common requirements of robots for basic functions of autonomous navigation, this paper designs a multi-sensor information fusion autonomous navigation control system based on ROS, and in this paper, the overall design ideas of the system and the detailed design of each module are introduced. Firstly, the system collects the status information and environment information of the robot body through sensors; secondly, through the manual control based on the ROS system, the map is drawn in the indoor environment; finally, based on the map information, the positioning and navigation experiment is carried out, and the reliability of the system is verified by the experiment. And the experimental results show that the multi-sensor integrated navigation has more advantages in map construction accuracy and navigation stability. The work done in this paper has certain practical significance and application value.

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