Analysis of Current Positioning and Path Planning Technologies for Transfer Robots

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Abstract. With the development of robot technology, transfer robots have gradually occupied a major position in various industries headed by the service industry, replacing manpower to complete the corresponding transfer work. Robot positioning and path planning through corresponding technologies are important prerequisites for transfer robots to successfully complete tasks. By understanding the principles and advantages and disadvantages of various technologies related to positioning and path planning, related technologies can be better improved. To this end, this article conducts the following research: For positioning technology, the principles and advantages and disadvantages of various commonly used and mature positioning methods such as GPS positioning technology, grid map positioning technology, and SLAM positioning technology are introduced and analyzed. At the same time, the improvement methods of some positioning technologies that have appeared in recent years are introduced to provide inspiration and methods for improving such technologies. For path planning algorithms, this article divides them into global planning and local planning according to the perception degree of different spatial obstacles of the algorithms, and introduces several very common algorithms in the field of transfer robots, such as fuzzy logic algorithm, A* algorithm and artificial potential field method. The principles and advantages and disadvantages of these algorithms are explained in detail with the help of charts, and the application scenarios of each algorithm are demonstrated through comparison, and the direction of improvement is proposed.

Keywords: Transfer robot, Algorithm, Positioning, Path planning

1 Introduction

With the development of society, robotics and artificial intelligence technologies are now quite mature. As an important part of robots, transfer robots play a significant role in various fields and continuously promote the development of information and intelligent society. In the field of transfer robots, positioning technology and path planning are important core technologies that enable transfer robots to complete their required tasks. Robots obtain and process information through positioning technology to determine their own positions, and use path planning to determine the action path to improve work efficiency.

When a transfer robot is in an unknown environment, the robot obtains and processes environmental information through the installed external sensors, and finally realizes its own positioning. Then the robot needs to plan the path, which requires timely receipt of changes in external information, while ensuring safety, and finally being feasible in actual operation.

This article studies the positioning technology and path planning technology of transfer robots as follows: briefly describe and compare different transfer robot positioning technologies, classify the path planning technology of transfer robots, introduce and analyze the advantages and disadvantages of local path planning technology and global planning technology, and make a review and summary.

2 Positioning Technology

If the robot needs to realize the function of autonomous navigation in an unknown environment, it must first determine the robot's own position and posture. The process of determining its own position is the positioning of the transfer robot. The robot obtains and processes information about the environment through external sensors to achieve its own positioning. The transfer robot generally uses real-time positioning technology and surrounding environment map construction technology to control the robot's position and direction [1]. The following is an introduction to some typical positioning technologies:

2.1 GPS Positioning

GPS positioning technology is a widely used positioning technology, and it is also widely used in the transfer robot field. The GPS positioning of transfer robots relies on the GPS receiver installed on the robot. The GPS receiver of the transfer robot receives signals from multiple GPS satellites and uses the information in these signals to calculate the specific location of the transfer robot.

In an open environment, the transfer robot can use the GPS system for positioning [2], so that the robot's positioning can cover most areas. At the same time, if it is in an open environment, GPS can provide high-precision and real-time positioning information. However, in indoor environments or areas with dense buildings, the GPS signal will be blocked or interfered, or the number of signal reflections will increase, resulting in an increase in positioning error, and the positioning signal is weak, resulting in inaccurate positioning [3].

2.2 SLAM Positioning

When building a map of an unknown environment, the environment in which the mobile robot is located is completely unknown. At this time, the robot needs to build a map while moving and correct its own posture in real time. This is the SLAM. The robot's simultaneous positioning and map building is also called SLAM technology.

SLAM systems usually consist of several core parts: sensor data, front-end processing, back-end optimization, loop detection, and map building. The data provided by sensors (such as lidar, cameras, IMU, etc.) is input to the front-end to infer the position and motion state of the robot in the current environment. The front-end usually processes these raw sensor data to generate local maps or pose estimates, and then passes them to the back-end for further optimization.

As shown in Figure 1:

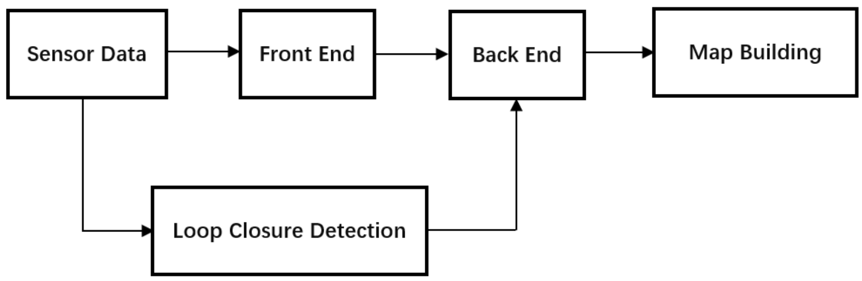

Fig. 1. SLAM system core components

SLAM technology is applicable to scenarios where the robot's environment information is completely unknown. It obtains map points in the environment through the perception of surrounding features by feature sensors, and obtains the position of the feature sensor body by tracking these environmental points frame by frame [4]. If the number of map points in the environment is large and clear, and the feature association algorithm of the feature sensor is also accurate, then the accuracy of this technology will be very high. However, as time goes by, the environmental points in the map maintained by the system gradually increase in size with their own trajectories, and the computational overhead of the system will also gradually increase [5]. In some environments where features are missing, the feature sensors of the SLAM system cannot extract enough feature points, which is very likely to cause positioning failure [6]. Moreover, this method is extremely dependent on the perception of the surrounding environment. In a static environment, the SLAM system can obtain extremely high positioning accuracy, but in a non-static environment, the SLAM system is very likely to fail in positioning [7].

2.3 Other Positioning Technologies

There are many other commonly used positioning technologies in the field of transfer robots: Grid map positioning is a very common positioning method. The map is rasterized, which can save environmental information more completely and is easy for robots to process, but the real-time performance is low when processing large-scale maps; ultra-wideband technology does not rely on environmental characteristics, is relatively inexpensive, and is easy to arrange and install and carry. Compared with mainstream positioning technologies, it has unique advantages.

3 Local Path Planning Algorithm

Local path planning is a dynamic planning algorithm. The transfer robot perceives the external conditions based on the sensors installed on it and generates a route for the robot to travel safely. Avoiding obstacles and planning the optimal path is the significant task of local path planning. The following will introduce some typical local path planning algorithms:

3.1 Artificial Potential Field Method

This method is a very commonly used in many fields. It regards the robot in the environment as a particle, and the surrounding environment as a force field. There are repulsive fields and gravitational fields in the force field. The obstacle and the target point generate two types of forces on the robot respectively. Two fields together constitute a potential field, which is called the artificial potential field. The place where the potential field function decreases is the direction of the robot's movement. The robot finds a collision-free path through the function [8].

The method often uses the way of imitating the electrostatic field of charges to describe the establishment of artificial potential fields [9]. In the electrostatic field, there are many positive and negative charges acting together on the entire electrostatic field. The positive charges in the electrostatic field are equivalent to the obstacles in the artificial potential field, and the negative charges are equivalent to the target points. The target point generates a gravitational potential field U_{att}, and the negative gradient is obtained to get the gravitational force F_{att}. F_{att} attracts robot and the robots moves toward the target point. The obstacle generates a repulsive force on the robot and generates a repulsive field U_{rep}, and the negative gradient is obtained to obtain F_{rep}. Preventing the robot from colliding with the obstacle is the task of the repulsive force. The combination of the repulsive force and the gravitational force is F_{total}.

The artificial potential field method has a certain robustness to control and sensor errors, but when applied to this field, there are two problems: the target is unreachable and the local minimum point.

3.2 Fuzzy Logic Algorithm

Fuzzy logic algorithm can also be used for local path planning. Sensors help it to obtain environmental information, without the need to establish a model. The robot movement is controlled by fuzzy rules and can handle uncertainty and ambiguity. We can use fuzzy logic algorithms to process fuzzy obstacle positions and external information to determine the optimal path for the transfer robot to move.

In the fuzzy logic algorithm, we need to define the input and output variables. Common input variables include the distance between the robot and target, the current angle of robot, and the position of obstacle. The output variables usually include the angular velocity and speed of robot. Then define the fuzzy sets of output and input variables and their membership functions. The membership function describes the degree of membership of the output and input variables in different fuzzy sets. We need to use fuzzy rules to infer the output variable's value based on the degree of membership of the input variable. The advantage of simple calculation is pretty clear, but the disadvantage is also obvious. Its computing power is not strong. When obstacles number increases, the algorithm calculation amount increases, and a better path cannot be planned.

3.3 Other Algorithms

In terms of local path planning, there are many other algorithms: In 2020, Yuan et al. [10] proposed an improved virtual obstacle local path planning method based on the minimum criterion, and proved through simulation experiments that the algorithm can solve problems such as local minimum; Dynamic Window Approach (DWA) is also a speed-based local planning algorithm [11], which has the advantages of small computational complexity and easy implementation [12]. However, it also has problems such as evaluation function failure or path redundancy.

4 Global Path Planning Algorithm

The global path planning algorithm is about static planning. It finds an optimal path between the starting point and the target point based on existing environmental information. The following will introduce some typical global path planning algorithms:

4.1 A* Algorithm

A* algorithm is a relatively effective global path planning algorithm. Many algorithms are improved based on A* algorithm. A* algorithm is a pretty effective direct search method. But compared with a lot of preprocessing algorithms, the real-time query efficiency of A* algorithm is much lower than that of preprocessing algorithm [13].

The formula is:

$$f*(n) = g*(n) + h*(n) \tag{1}$$

In formula (1), the minimum estimated distance from the initial state to the target state through state n is $f*(n)$. $f*(n)$ has two parts. The part from the initial state to state n is $g*(n)$, and the part from state n to the target state is $h*(n)$. The selection of the minimum distance estimation function $f*(n)$ is a necessary condition to ensure that a shortest path is found.

The estimated distance from state n to the target state is $h(n)$, and the selection of $h(n)$ is as follows:

When $h(n) > h*(n)$, the efficiency is increased because the number of search points and the range is small, but it is difficult to get the optimal solution.

When $h(n) < h*(n)$ the efficiency is reduced because the number of search points and the range is large, but the optimal solution can be obtained at this time.

When $h(n) = h*(n)$, this time the search efficiency is the highest.

4.2 Ant Colony Algorithm

If the robot can perform path planning in any environment, then the ant colony algorithm can be used for path planning. In order to realize multi-robot collaborative work in the dynamic environment of farmland, Marco Dorigo proposed a probabilistic path planning algorithm called ant colony algorithm in 1992 [14]. The search efficiency can be greatly improved.

The principle of ant colony algorithm is: the path formed by the entire group in search of food constitutes the solution space to be optimized, and the path walked by the ants can represent the feasible solution to be optimized. When ants walk along a shortest path, they will leave more pheromones. As time goes by, more and more pheromones are left, and more and more ants walk along the path. Eventually, the whole colony will find the shortest path under the action of positive feedback. According to the algorithm's characteristics, the positive feedback mechanism continuously optimizes the path and finally obtains the optimal solution. The ant colony algorithm has the characteristics of distributed computing. Multiple units in the algorithm perform parallel computing, which significantly improves computing power and efficiency. Its heuristic probabilistic search method is also easy to plan global paths.

4.3 Other Algorithms

In addition to the above methods, there are many global path planning algorithms: RRT (Rapidly-Exploring Random Tree) algorithm is a sampling-based path planning algorithm. And It can use to solve path planning problems in high-dimensional space and complex constraints [15]; Particle Swarm Optimization is a cluster optimization algorithm proposed by JE Kenndy Eberhart [16], which has a high convergence speed. However, when multiple mobile robots are searching for paths at the same time, it is very easy to fall into the local optimal solution, thereby reducing the accuracy of path search.

5 Summary and Outlook

This article reviews the positioning and path planning technologies of transfer robots, introduces many important positioning and path planning technologies in the current transfer robot field, and analyzes the pros and cons of each technology of positioning, global path planning and local path planning. In the positioning technology part, by introducing various common positioning methods such as GPS positioning technology, grid map positioning technology, SLAM positioning technology, etc., different positioning technologies are compared. For path planning algorithms, this article introduces local path planning algorithms such as artificial fuzzy logic algorithm and potential field method. The advantages and disadvantages of these algorithms are discussed. In this section, the article points out the local minimum problem that may occur in the practical application of the artificial potential field method, and then introduces an improved virtual obstacle local path planning method based on the minimum criterion that can solve the local minimum and other problems. By introducing and summarizing the advantages and disadvantages of each method, it provides new optimization ideas for the mutual combination of future path planning algorithms and the improvement of adaptability in complex dynamic environments. And for global planning algorithms, this article introduces very mature and basic common algorithms such as A* algorithm. By introducing the principles and comparing different algorithms, the advantages and disadvantages of the algorithms and future improvement directions are introduced.

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