Path Planning Method for Underground Survey Robot in Dangerous Scenarios

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Abstract. Over the past 20 years, there has been a growing demand for autonomous exploration of underground environments such as tunnels, urban underground corridors, and complex cave environments. With the development of robotics, dangerous tasks that used to be done by humans have been replaced by underground survey robots. To avoid obstacles in the process of robot work, path planning technology has become one of the important components of underground survey robot. The underground survey robot not only needs to move in the plane, but also needs to climb along the pipe. However, the existing research is mostly two-dimensional plane, which cannot be directly applied to the underground exploration robot. Firstly, this paper compares the existing research and chooses Dijkstra algorithm for three-dimensional implementation. After that, the environment map is established, and the position of obstacles faced by the robot was set for simulation verification. Simulation results show the effectiveness of the proposed algorithm.

Keywords: Dijkstra algorithm, Scheduling algorithm, Robot.

1. Introduction

1.1. Background

The emergence of mobile robots, instead of manual execution of all kinds of dangerous operations, improve people's lives, reduce all kinds of accidents in the process of work. However, path planning and path tracking control technology are essential to make the robot run correctly.

Path planning and path tracking control technology of mobile robots are the most important research topics in robot navigation. Due to rapid development of related hardware and software technology of mobile robots, the continuous deepening of related theoretical research makes the path planning and trajectory tracking control of mobile robots become a hot topic in current research.

In recent years, the improvement of computer processing power brought rapid progress on computer vision technology, and the ability of mobile robots to recognize and detect objects in the driving environment has also been improved. As a result, perception and avoidance technology is widely used in a variety of robots, including factory delivery robots, delivery robots, medical service robots and underground exploration robots.

In the development of perception and avoidance technology, optimal path search technology is the basic and premise of robot path tracking. The mobile robot must rely on various sensors to complete the detection of the environmental information, and make path planning based on certain algorithms based on the environmental information obtained by the sensors, so that the robot can find the optimal path without obstacle collision. Therefore, the study of robot path planning algorithm is of great significance to the development of robot field.

1.2. Research Status

Andrews and Khatib et al. proposed artificial potential field method that realize robot path planning in 1994 [1]. In this algorithm, Khatib et al. creatively introduced the idea of imaginary force field. In this algorithm, the motion of the robot on the real two-dimensional plane is regarded as the force motion in the virtual field. The target point attracts the robot, the obstacle point repels the robot. After the force analysis of the robot, the robot will move forward along the direction of the resultant force. The most significant advantage of artificial potential field method is that it is very simple and convenient to control the bottom layer, which improves the ability of the mobile robot. But it still has the disadvantage of oscillating in a narrow area and having a local minimum point. Based on the artificial potential field method, Ge et al. proposed a potential field suitable for dynamic environment by considering environmental changes [2, 3], and finally applied the algorithm with stronger environmental adaptability to the path search of robots, the simulation results were in good agreement with the final experimental results.

Dennis et al. proposed a method of "visibility potential field" [4], and Sato proposed a method of Laplace potential field method [5]. These two improved methods can solve the problem that the previous potential field algorithms fall into the local optimal solution in path planning to a certain extent, but they are not perfect solutions. In addition, due to the increase of obstacles in the environment, the calculation amount increases in the path planning process and the planned path may not be the shortest path, which are also two problems that need to be solved at present. The A* algorithm proposed by P. Hart, N. Nilsson, et al in 1968 is a heuristic search algorithm [6], also known as the best first search algorithm. Whether it can find the optimal collection-free path depends on the choice of the estimated function $f(n)$. The disadvantage of using A* algorithm in robot path planning is that A* algorithm is not suitable for unknown environment and dynamic change of obstacles in the environment. Frantisek Duchon, Martin Kajan et al. proposed an improved A* algorithm based on raster map environment [7], which extended the search for the optimal path with 8 adjacent directions of a grid and introduced Angle information into the search process. The proposed improved algorithm shortens the path planned by the robot compared with the previous algorithm. However, the existing problem is that when map information increases, the calculation amount increases correspondingly. J Holland et al. proposed a genetic algorithm [8]. Based on the theory of genetic mechanism, the algorithm is suitable for global search. The basic idea of genetic algorithm is to convert the changes of waypoints into binary string code. First, the path population is initialized, and then a series of genetic operations such as crossover, selection, mutation and replication are carried out. After several generations of genetic evolution and evolution, evolution terminates and finally reaches the optimal path. Genetic algorithm solves the problem of local minimum value, but it also has some problems such as not fast computing speed, large computing time and storage space.

So far, there are many literatures on the optimal path search algorithm of mobile robots, such as A* algorithm, genetic algorithm and so on. Each algorithm shows its unique advantages in path planning. However, most of the existing research are limited to two-dimensional scenes, and there are few researches on three-dimensional scenes. This paper mainly studies the path planning algorithm of underground survey robot in dangerous scene. In this paper, 3D environment map is established first, and then Dijkstra algorithm is improved on the basis of Dijkstra optimal path search algorithm to adapt to 3D scene.The main research contents of this paper are as follows:

Chapter 1: introduction. The research background and significance are introduced in detail, and the research status of robot path planning algorithm is elaborated in detail. Finally, the research content of this paper is introduced.

Chapter 2: path planning principle of underground survey robot. The purpose of path planning for underground surveying robot is introduced in detail, and several common path planning algorithms are introduced. Finally, the characteristics of each algorithm are compared and the Dijkstra algorithm used in this paper is selected.

Chapter 3: Path planning of underground exploration robot based on Dijkstra. Firstly, the 3D environment map of the robot was established. Dijkstra algorithm is used to calculate. This method is proved to be effective.

Finally, the achievements and problems of this research are summarized.

2. Path Planning Principle of Underground Survey Robot

Path planning refers to planning a complete path with a known map. Path planning can be divided into three steps. Start by modeling the work environment. Second step is path search. As the core problem of path planning, path search refers to the application of path planning algorithm to map the map environment model and find the optimal path that meets the performance requirements. The third step is to smooth the path. As a post-processing stage of path planning, path smoothing can eliminate and reduce the factors that are not consistent with the actual requirements and have no reliability in optimal path solving to a certain extent. This chapter describes common path planning algorithms.

2.1. A* Algorithm

Peter Hart, Nils Nilsson and others from Stanford University first proposed the A* algorithm in the paper. A* algorithm is a heuristic state space search algorithm. In the A* algorithm, two sets are defined, OPEN set and CLOSED set. By constructing a function $f(n)$, the algorithm represents the "desired search degree" of a certain raster node. This function is called the evaluation function. Its function is to estimate the importance level of the nodes to be searched and determine the search order of the nodes to be searched in the OPEN set according to it. Estimating the importance of a node is usually done in two ways: the cost that has been spent and the cost that will be spent.

The estimated cost function:

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

Specific steps of A * algorithm:

1). Start from the initial node grid S and store it as the node grid to be processed in the OPEN set, which is a node grid list to be checked;

2). Look for reachable adjacent node grids around the starting node grid S, store them in the OPEN set, and set their "parent node grid" as S node;

3). Delete the start node grid S from the OPEN set and add the start node S to the CLOSED set;

4). Calculate the value of the evaluation function of the node grid in the OPEN set, select the node C with the smallest value of the evaluation function, delete it from the OPEN set, and put it in the COLSED set;

5). Check all adjacent and reachable node grids of node grid C, if these grids are not in the OPEN set, store them in the OPEN set, calculate the estimated cost function f(n) value of these node grids, and set the "parent node grid" of these nodes to C;

6). If the adjacent reachable grids of node grid C are already in the OPEN set, check whether the g value will be lower if the new path is used to reach it. If the new g value is lower, change the "parent node grid" of the node grid to node grid C, and then conduct a secondary calculation and update of the evaluation function f value of the node grid. If the g value is higher after the second update, it means that going through C to the grid is not a wise choice, because it requires a longer way, then we don't have to do anything;

7). Repeat steps 4, 5, and 6 until the destination node grid appears in the OPEN set, indicating that the final path has been found. In addition to the start node grid, each node grid in the OPEN set has a "parent node grid" through which it can be indexed to the original "start node grid", which is the final path.

2.2. Ant Colony Algorithm

Ant colony algorithm [9] (ACO) is found that in the process of searching for food, ant colonies communicate foraging information by releasing a biological hormone of pheromone and choose the direction according to the pheromone situation in the path. As time goes by, the choice of shortest path changes with the concentration of path pheromone. Gradually select the shortest path, in this process found that the ant group has a strong organization, learning ability. The ants can eventually choose the best path tm regardless of whether the scene changes. In general, the ant colony algorithm is good at dealing with the shortest path problem, and really in the traveling salesman problem on has achieved fairly good results. At present, it has been gradually applied to other fields, such as vehicle scheduling problem, resource allocation, communication network and data cluster analysis. Ant colony algorithm also has some problems in the real application. The idea of ant colony algorithm is heuristic selection, but it is easy to fall into prematurity, so it is difficult to find the best path. Some literature mentioned the idea of combining heuristic selection with random selection. Thus, an improved ant colony algorithm is generated, which does a good job in path planning and path information, adds the initial objective function and priority to plan the path selection, and adjusts the overall path information according to the priority and state transition probability. This idea expands the search scope at the initial stage and solves the premature problem well. In the later stage, the optimal path was selected by the initial objective function, and the path of the underground exploration robot perfectly avoided the set obstacles and finally reached the target position. The method proposed in this paper achieves good results.

Compared with other algorithms, ACO is more robust and capable of searching for better solutions. It is easy to combine with various heuristic algorithms to improve algorithm performance. In the process of solving the planned shortest path by using this algorithm, several iterations will be used in the search process, at the same time, more resources will be invested in the search, and the results will be processed and counted for many times, greatly reducing the performance of the algorithm. When the pheromone concentration is too high, the algorithm falls into the optimal solution of a certain part, and it is difficult to find the real optimal solution. The global search range of the algorithm is significantly reduced.

2.3. Dijkstra's Algorithm

Dijkstra search algorithm found the optimal path of the robot [10]. Dijkstra algorithm adopts the greedy algorithm model to solve the typical method of shortest path. Its main feature is that the initial node is the center of the expansion layer by layer, until the expansion search to the target node grid. Dijkstra algorithm is a breadth-first search method. Dijkstra algorithm as shown in Fig. 1.

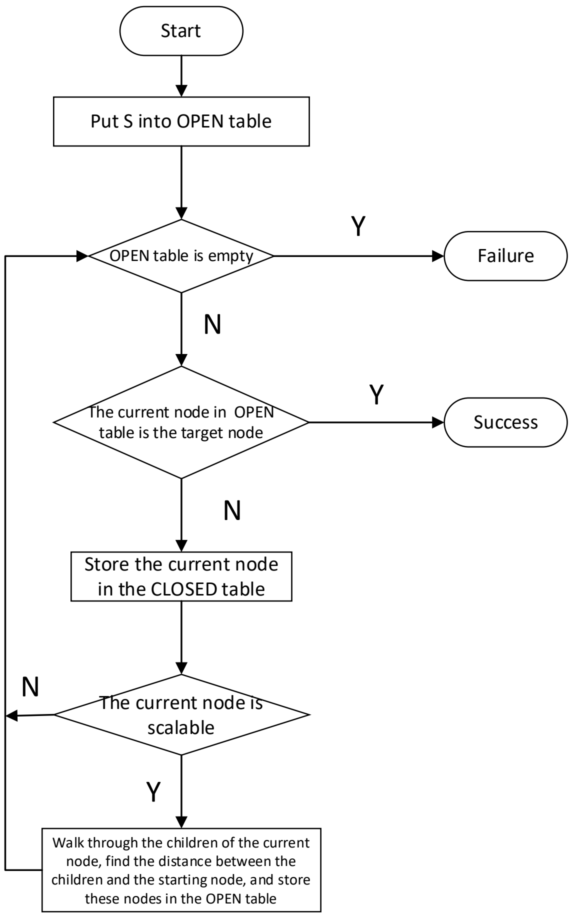

Figure 1. Dijkstra algorithm path planning flowchart

Dijkstra algorithm is used to carry out path planning for mobile robots in the following steps:

1). First, two sets, OPEN set and CLOSED set, are generated. OPEN set stores all the generated node grids that have not been searched and checked, and CLOSED set stores the node sets that do not need to be checked again.

2). Save the grid S of the starting node in the OPEN set to be searched and checked.

3). Check whether the grid S of the start node is the grid of the target node. If the grid S of the start node is the target node, the search check will be stopped and the search will end.

4). The grid of the nearest adjacent node of the starting node grid S is saved into the OPEN set and searched, and one of the nodes is selected for expansion.

5). Traversal all the child node grids of this node, calculate the distance, and store these child node grids into the OPEN set.

6). Repeat step 4 and step 5 until the OPEN set is empty or the target node grid appears in the OPEN set and the target node grid is found, indicating that the whole pathfinding process is completed. The path search is completed.

2.4. Summary

When A * algorithm selects the next node to search. In addition, A * algorithm expands all the subsequent nodes of the current node every time. Therefore, the OPEN table needs to store a large amount of node information, leads to another node query problem. Thousands of nodes may have to be counted in the whole node query process. A * algorithm is a heuristic rule that seeks feasible solutions. When finding its unique heuristic rule for each problem, it is generally not universal, and it is difficult to apply to other problems. Ant colony algorithm has strong robustness and the ability to search for better solutions. In the process of solving the planned shortest path by using this algorithm, several iterations will be used in the search process, at the same time, more resources will be invested in the search, and the results will be processed and counted for many times, greatly reducing the performance of the algorithm. The algorithm is easy to fall into the optimal solution of a certain part, and it is difficult to find the real optimal solution. Dijkstra algorithm is simple and practical. The complexity and time of its algorithm are not much different from other algorithms. Therefore, Dijkstra algorithm is the best choice for scheduling path planning.

3. Path Planning of Underground Exploration Robot

To study the path planning of underground survey robot, to express the working environment of underground survey robot, that is, to model the working environment of underground survey robot. After the work environment modeling of underground survey robot is completed, the path planning research of underground survey robot should be started. Because the accurate expression of the working environment information of the underground survey robot has a crucial impact on the path planning of the underground survey robot. Therefore, this chapter firstly models the working environment of underground survey robots. Through literature reading, it is found that the working environment modeling methods of underground survey robots mainly include raster method, topological map method and geometric map method, while the working environment of underground survey robots involved in this paper is a known structured environment. Therefore, grid method is the best method to model the working environment of underground survey robot.

3.1. Environment Map Modeling

The correct expression of environmental information, namely the establishment of environmental map, is the basis and premise for the path planning and path tracking control of underground surveying robots [11]. The modeling method used to model the environment is closely related to the information of the environment itself. Secondly, the accuracy of environmental map construction is inversely proportional to the rapidity of path planning of underground surveying robots. Therefore, the complete expression of environmental information, namely the precision information, and the rapidity of navigation of underground surveying robots should be taken account during map modeling [12].Since the path planning and path tracking control of underground survey robot explored in this paper are carried out in a known structured environment, it is impossible to complete the required scene only by establishing a two-dimensional map. Create a more complex three-dimensional environment model. The model is as shown in Fig. 2. The Table 1 describes the environment parameters.

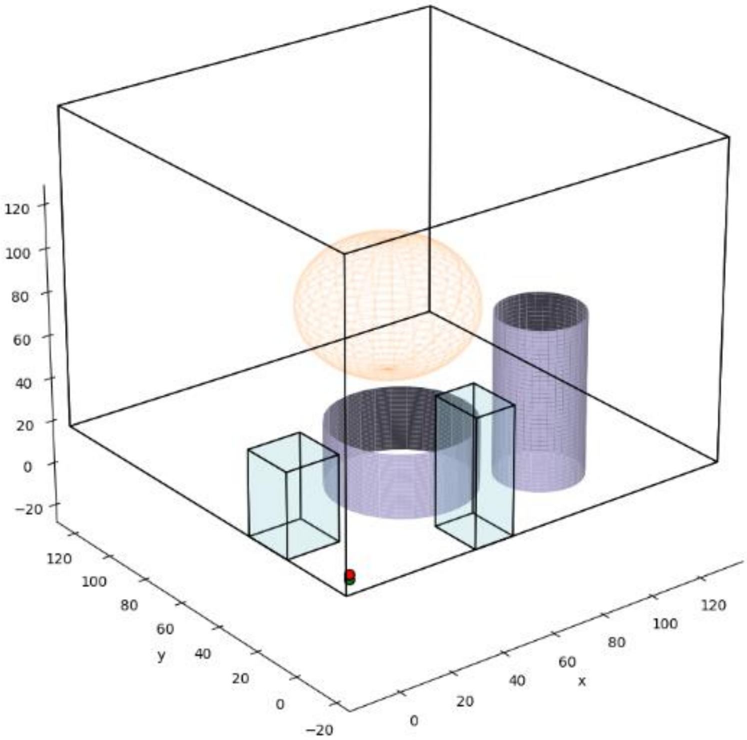

Figure 2. Three-dimensional environment model

Table 1. Description of the Environment Parameters

Parameter	Values
Range of space	[100, 100, 100]
Coordinates of origin	[0, 0, 0]
Display space range	[150, 150, 150]
Rectangular color number	[142, 207, 201]
Cylinder color number	[190, 184, 220]
Sphere color number	[255, 190, 122]
Center coordinates of the underside of the cylinder	[100, 30, 0]; [60, 50, 0]
Radius of cylinder	[25]; [30]
Height of cylinder	[75]; [30]
Spherical center coordinates	[70, 70, 70]
Radius of sphere	[30]

3.2. Experimental Results

In the established 3D environment model, the motion starting point and stopping point of the underground exploration robot are set, and the program is run. The experimental results are shown in Fig. 3. Path planning 2D diagram is shown in Fig. 4. The underground survey robot path perfectly avoided the set obstacles and finally reached the target location. The method proposed in this paper achieves good results.

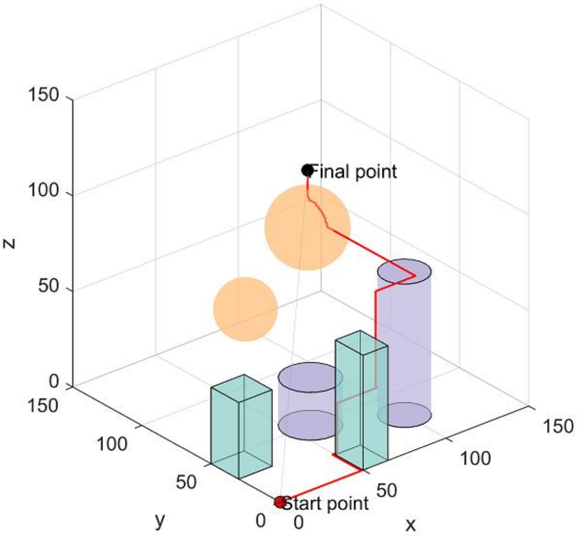

Figure 3. Path planning 3D diagram

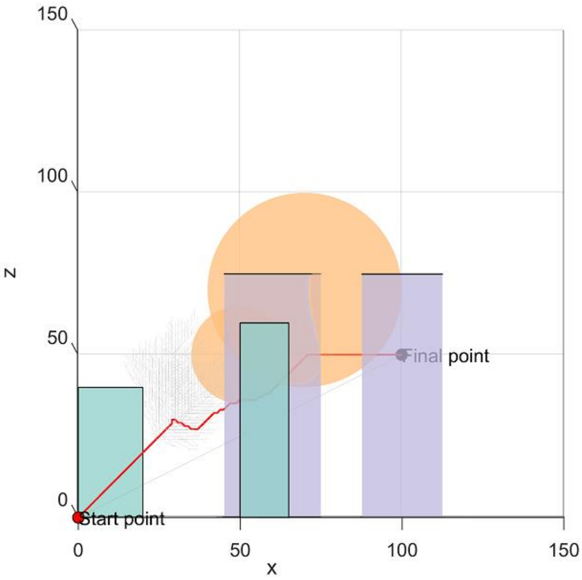

Figure 4. Path planning 2D diagram

4. Conclusion

Aiming at the problem of path planning of underground exploration robot, this paper improved Dijkstra algorithm to carry out 3D path planning of robot. The operation of underground survey robots is complicated and often dangerous. Through the modeling of the working environment of the underground survey robot and the simulation experiment, it can help the underground survey robot to establish the driving trajectory. The study of this paper also has some shortcomings, and there is still a place for further research. The method is only verified by simulation, and the effect after field operation needs to be further explored. Although the method is effective, it has the disadvantage of long computation time, and it is necessary to consider how to shorten the computation time further.

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