Research on Path Planning Algorithms of Multiple Mobile Robots in Intelligent Warehousing

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Abstract

In recent years, with the rapid development of e-commerce industry, people's demand for intelligent automatic storage system has become more and more urgent. Therefore, the research on intelligent storage system based on multi mobile robots has turned into a hot spot and development direction of intelligent manufacturing industry. Among them, the collaborative path planning between multi mobile robots has become a key problem to be solved. In order to solve this problem, this paper will propose an improved A^*algorithm based on reservation table. Firstly, the reservation table is generated through centralized control; Then, the collision problem between robots is prevented by reservation table and directed graph; Finally, through the distributed control method, the multi robot cooperative path planning is realized by using the improved A^* algorithm. The effectiveness of the algorithm is verified by simulation.

Keywords: multi-robot system; path planning; intelligent warehouse; A^* algorithm

1. Introduction

With the rapid development of e-commerce industry and industrial automation, the demand for efficient intelligent automatic warehouse system is becoming more and more urgent. Intelligent warehouse system has become one of the hot spots in the field of intelligent system research. Therefore, the automatic warehouse system based on multi-mobile intelligent robot has become the research hotspot of intelligent warehouse system.

Collaborative path planning among multi-robots is the key to realize intelligent warehouse based on multi-mobile robots. This paper will solve the above problems through the reservation table and the improved A^* algorithm under the directed graph, so as to build a safe and stable intelligent warehouse system.

At present, the main control methods of multi-robot system include centralized control method and distributed control method.[1] The centralized control method is coordinated by the central processing system to find the global optimal path of the robots. However, with the increase of the number of robots in the warehouse, the computational complexity of the centralized control method will be greatly increased. Distributed control method is a kind of path planning method which can adapt to the rapidly increasing number of robots and the rapidly changing warehouse environment. However, due to the limited information obtained, the distributed control method can only find the local optimal path for the robot, and may cause conflicts among machines. In this paper, the advantages of centralized control method and distributed control method are combined. On the one hand, the centralized control method is used to obtain the global information of the warehouse (such as the status and location of the robot, etc.), and the global information is used to construct the reservation table to provide real-time traffic information for the robot in the intelligent warehouse. On the other hand, the robot system adopts distributed control mode, and each robot carries out path planning according to the information provided by the central control system, which not only reduces the burden of the central control system, but also provides global information for multi-robot path planning.

2. Intelligent Warehouse Model and Task Analysist

Because the warehouse environment is a structured environment, this paper uses grid map to represent the warehouse environment. As shown in Figure 1. The grid map mainly includes three parts: 1. The picking table $S = \{s_1, \dots, s_m\}$ (m is the number of picking tables) on the left side of the grid map. The staff pack at the picking table, which is located at the edge of the warehouse to facilitate the distribution of goods; 2. The path continuously composed of adjacent grids in the grid map; 3. The shelf $L = \{l_1, \dots l_e\}$ (e is the number of shelves). A group of robots $R = \{r_1, \dots, r_n\}$ (n is the number of robots) walk and carry goods in the warehouse at a uniform speed v. [2]

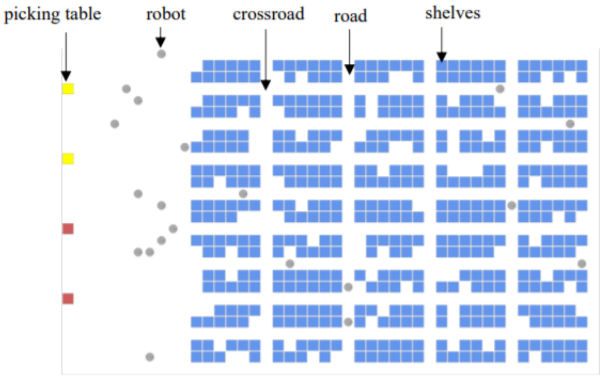


Fig. 1. Intelligent warehouse model.

The process of muti-robot transporting goods in intelligent warehouse is shown in Figure 2. The central control system arranges the order information and sends it to the idle robot. The order information mainly includes the shelf position information and the position information of the picking table. The robot first goes to the shelf position to carry the shelf for picking (the robot that does not carry the goods can move under the shelf during the movement), transports the shelf to the corresponding picking table, does not carry out the picking work, and then sends the shelf to the original position after picking, then the order task ends. The state of the robot changes from working to idle and continues to execute the next order task.

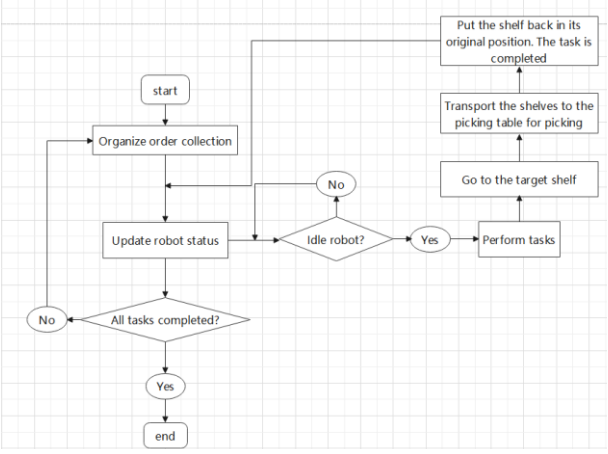


Fig. 2. Task flow.

3. Improved A^* Algorithm

The A^* algorithm is called the best first heuristic algorithm, which is simpler and faster than the unknown exploration algorithm.[3] The algorithm steps are as follows: starting from the starting grid, each time the robot selects the grid to be expanded in the next step, it will estimate the grid path cost adjacent to its own grid. Path cost refers to the shortest estimated value of the robot from the starting grid to the target grid after passing through the grid to be expanded. After obtaining the estimated cost of the surrounding grid, put it into a candidate table with expansion nodes, and then select a grid with the lowest estimated cost in the table for expansion. The robot repeats the above steps until it extends to the target grid. The estimated cost per grid is:

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

Where: $g(n)$is the real cost of the robot moving from the starting grid to the current grid n:

$$g(n) = \frac{d}{v} \tag{2}$$

v is the speed at which the robot travels at a constant speed, and d is the real distance from the starting grid to the current grid n.

$h^*(n)$ is a heuristic equation to calculate the estimated cost of the robot moving from the current grid n to the target grid:

$$h^*(n) = \frac{d_n}{v} \quad (3)$$

d_n is the shortest estimated distance from the current grid n to the target grid, i.e. Manhattan distance:

$$d_n = abs(n.x - goal.x) + abs(n.y - goal.y) \quad (4)$$

$n.x$ and $n.y$ are the horizontal and vertical columns of the current nodes in the raster map, $goal.x$ and $goal.y$ are the horizontal and vertical columns of the target nodes in the raster map.

Distance, and time can be used to estimate $f^*(n)$. The traditional A^* algorithm mainly uses Manhattan distance, Euler distance, etc., as the cost of the estimation function in the formula, while this paper uses time as the cost of estimation.

When the A^* algorithm is used in the warehouse there are still some problems, as shown in figure 3, starting from the same starting grids, the robot can choose a few different paths to reach the same target grid, called path a and b.

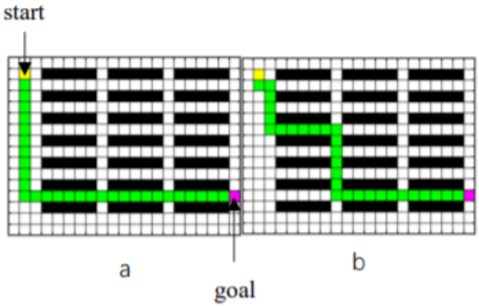


Fig. 3. The paths.

Respectively, in a structured intelligence warehouse, the same length of the path, the traditional A^* algorithm will randomly select a path to extend. However, in a real warehouse environment, the robot would spend more time turning around corners, so it would take different time for the robot to walk along different paths of the same path length. As shown in the figure, there is one turn when the robot walks along path 1, and there are five turns when the robot walks along the path and walks. Therefore, the turning cost time t_{turn} is proposed in this paper. When the robot decides to turn at the intersection, t_{turn} is added into the estimation function, and "Eq. (1)" is modified as

$$f^*(n) = g(n) + h^*(n) + t_{turn} \quad (5)$$

Using the improved method, a path with shorter distance and less time consumption can be selected, thus improving the efficiency of path planning for a single robot.

4. Reservation `Table` and Directed `Graph`

Collisions and even deadlocks may occur in robots running continuously in A dynamic environment, which cannot be solved by the improved A* path planning algorithm alone. Figure 4 shows four typical collision scenarios.

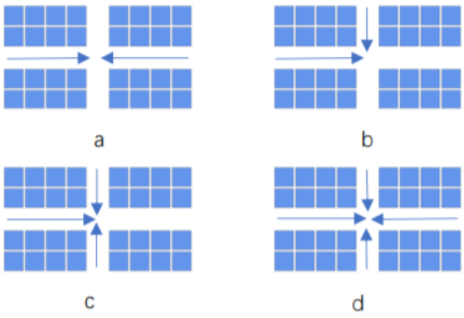


Fig. 4. Several collision types.

If the collision is in case b, the robot can be resolved by waiting for other robots with higher weights to pass first. When the other three collision situations occur, it will take a lot of time to avoid collision and avoidance among robots, and with the increase of the number of machines, collision and avoidance will cause deadlocks. The above three situations can be avoided by building a directed graph. It is stipulated that each road between shelves in the warehouse is a one-way street, and the direction of the two adjacent roads is opposite.[4] When the robot walks in the warehouse, it can only move forward in the direction of the road, thus avoiding collision and deadlock to a large extent. The robots move in order according to the traffic rules in the intelligent warehouse. As shown in Figure 5, the horizontal arrow indicates that the robot can only move from left to right in accordance with traffic rules; the longitudinal arrow indicates two one-way streets in opposite directions; the position of the shelf is a two-way arrow, and the two-way arrow indicates that the robot can move in both directions. That is, the direction of the directed graph should be followed when the improved A* algorithm is used for global path planning.

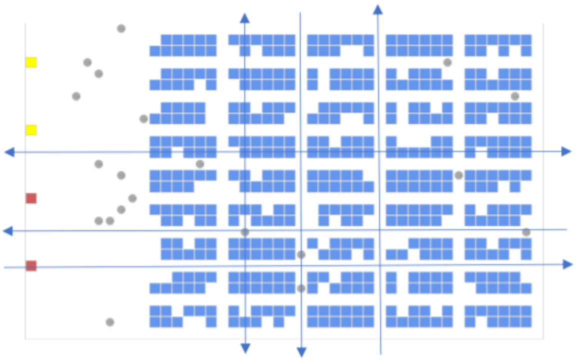
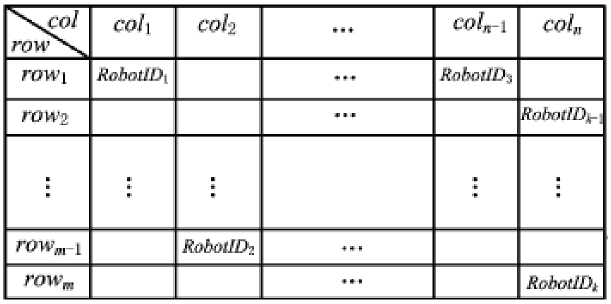


Fig. 5. Directed graph.

Even with traffic rules, there will still be a type b collision in the robot world as shown in Figure 4. Therefore, each grid in a raster map can only be occupied by one robot at a time.[5] If the grid that the robot intends to enter is occupied, it must wait until the grid becomes idle. In this paper, the reservation table is used to record the state of each grid in the grid map. Figure 6 shows the reservation table from the current time t.



col / row	col_1	col_2	…	col_{n-1}	col_n
row_1	$RobotID_1$		…	$RobotID_3$	
row_2			…		$RobotID_{k-1}$
⋮	⋮	⋮		⋮	⋮
row_{m-1}		$RobotID_2$	…		
row_m			…		$RobotID_k$

Fig. 6. Reservation table.

After each robot path planning, the central control system will update the reservation table once. The reservation table is a two-dimensional table the size of a raster map, and the Spaces in the table record the usage of each grid in the corresponding raster map. If the grid is occupied, the ID of the robot occupying the grid and the time of the robot occupying the grid will be recorded in the corresponding position in the table. Other robots can decide whether to move forward or wait for another robot to pass by querying the reservation table at the current time. If multiple robots occupy a grid at the same time, the order of occupancy will be determined according to the weight. Robots that start early have higher weights.

5. The Simulation Results

In this chapter, the warehouse model proposed above is used to simulate and verify the effectiveness of the path planning algorithm. Set the number of robots to 20 and the number of orders to 100.

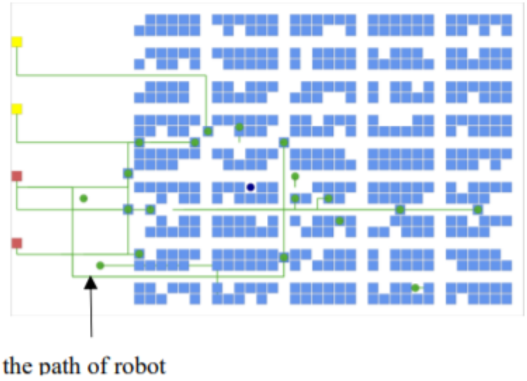


Fig. 7. Improve A^* algorithm simulation process.

As shown in Figure 7 of the simulation process, the total time spent by the robots to complete the task was 13 minutes and 47 seconds, and the total distance traveled was 4221 meters. No collision or deadlock occurred between the robots. The proposed algorithm is effective.

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