Dynamic Path Planning of Intelligent Warehouse Robot Based on Improved A* Algorithm

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Abstract. An improved A* path planning algorithm based on an appointment table and obstacle map is proposed in this paper in order to reduce the possible route conflicts. Besides, the coordination and cooperation of multi-robot systems are improved while performing warehousing and logistics tasks, realizing the optimal distribution path planning according to the location of multiple robots. Firstly, the robot platform is built through the NI myRIO main control system, and the storage environment model is set up based on the LabVIEW graphical development tool. Secondly, the improved A* algorithm based on the reservation table and obstacle map is used to obtain the multi-robot position and obstacle map in real-time so that the obstacle map could be utilized to realize the optimal path planning. Dynamic obstacle avoidance is implemented in combination with the robot load priority. Finally, the feasibility of the proposed method is verified in the LabVIEW development environment. The results show that the proposed method completes the collaborative cooperation of multiple robots, avoiding the route conflict and realizing the optimal path planning.

Keywords: Keywords-path planning; NI myRIO system; LabVIEW graphical tool; multi-robot.
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1 INTRODUCTION

With the expansion of e-commerce, the intelligent logistics and warehousing system composed of multiple intelligent robots (Automated Guided Vehicles) has become an indispensable part of the modern logistics industry, which improves work efficiency and accuracy greatly. Besides, the errors and risks caused by human operations have been reduced effectively [1,2]. However, there are high uncertainties in the time-consuming links, such as straight travel, turning, and conflict avoidance of multi-AGVs. That's why ensuring that multi-AGVs work efficiently and accurately in automated warehousing and logistics has become an urgent problem [3]. At present, the research on intelligent warehousing robots mainly focuses on path planning and collaborative control of multiple robots, and a reasonable and optimized path planning algorithm is the key to realizing the efficient collaborative work of multiple AGVs [4].

The path-planning problem of multiple robots has been studied for a long time, and the main purpose of the problem is to plan the optimal path between the start and end points based on accurate positioning information. Other than that, the collision avoidance strategy between multiple robots should be ensured, so that the system could operate normally [5]. As a heuristic search algorithm, the A* algorithm is the most popular robot path planning algorithm because of the simple and efficient method. However, the traditional A* algorithm is a static path planning algorithm, which is obviously contrary to the dynamic characteristics of the storage environment and should be improved to apply to the dynamic intelligent storage system, with the optimal solution of dynamic path planning [6].

An improved A* path planning algorithm has been proposed by Ref. [7] which considers the safety distance, ensuring the mobile robot searches for the shortest path in a conflict-free environment. The method effectively improves conflict avoidance between multiple AGVs and reduces the stagnation caused by collision and deadlock; however, the set safety distance will reduce the utilization efficiency of the path network. Ref. [8] proposes an improved A* algorithm, which effectively enhances the smoothness of the planned path and reduces the length of the planned path, and effectively enhances the smoothness of the planned path, with the length of the planned path reduced, whereas an increase in the number of AGVs may be caused on a specific road section, resulting in congestion. Based on the traditional A* algorithm, the pre-processing and post-processing steps are carried out before the path planning, and the algorithm pre-processing link plans a collision-free path to ensure the safety of AGV movement, and the post-processing step optimizes the path nodes to ensure the optimal distance, to ensure the optimal global path of multiple AGVs. Ref. [9] realized the three-dimensional path planning on the spatiotemporal operation map under the constraints of a special road, which rules by modifying the A* algorithm and comprehensively considered the Manhattan path cost and waiting time cost to complete the optimal scheduling. In order to solve the problem of multi-robot traffic congestion in an intelligent warehousing system, a multi-robot dynamic path planning algorithm based on a reservation grid was proposed. The method of reservation grid and directed graph is mainly used to prevent the collision between robots [10], and the dynamic path planning of multiple robots is realized by improving the A* algorithm, which solves the traffic congestion problem between robots and improves the system efficiency.

A* algorithm is a common global optimal path planning algorithm, which has been widely used in the path planning of warehousing robots, however, as a static path planning algorithm, the traditional A* algorithm is difficult to directly apply to the dynamic storage environment, which needs to be improved to be applied to the intelligent warehousing system, so as the optimal solution of dynamic path planning could be solved. Therefore, this paper proposes an improved A* path planning algorithm, which firstly treats the path planning of the warehousing robot as a continuous search problem, and obtains the location and obstacle maps of multiple robots in real time by creating an appointment table, to control the conflict problem of multiple robots when running the same node, and determines the travel order by setting the robot running priority. Secondly, the robot platform is built through the NI myRIO master control system, the storage environment model is set up based on the LabVIEW graphical development tool, and finally, the reliability of the proposed method is verified by setting the changing obstacle environment, in order to realize the coordination and cooperation dynamic path planning of the multi-robot system in the storage environment.

2 THE DESIGN OF THE IMPROVED A* ALGORITHM

The intelligent warehousing system can be regarded as a point-to-point system from the loading point to the unloading point. Besides, what we are concerned with is how to reach the target unloading point from the receiving point, it is necessary to complete the dynamic obstacle avoidance and autonomous path planning functions for the intelligent warehousing robot[11]. The traditional A* algorithm is a commonly used heuristic search strategy, which is only suitable for point-to-point tracking in a static map, and the path of the robot will not change when it reaches the target point after global planning. However, the warehousing environment is a complex environment, with not only stationary obstacles but also running robots, each robot is an obstacle to the others [12]. During the operation of the robot, it is necessary to reach the target point under the premise of ensuring safety. This means that the handling robot should avoid all threats during operation[13]. Simply applying the traditional A* algorithm directly to the warehousing system will most likely lead to problems, such as traffic jams or collisions between robots, and even cause deadlocks in the system, resulting in the collapse of the system.

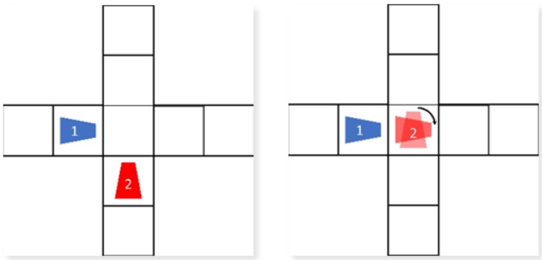
In this paper, the path planning of intelligent warehousing robots in complex environments is regarded as a continuous search problem, and an improved A* algorithm based on appointment tables and obstacle maps [14] is used to plan the path of dynamic environments. Different from ordinary path planning, the algorithm generates a real-time obstacle map through the real-time acquisition of the positions of all handling robots, and each robot carries out path planning based on the map, which effectively prevents the occurrence of the above-mentioned accidents.

2.1 The Raster Modeling Method Constructed

The raster modeling method [15] is used to construct an environmental obstacle map Assuming that each node is a passable unit, and the black lines between the nodes are ignored. RFID electronic tags are implanted in each node for the positioning of the trolley, and each unloading point is defined as a key node, as shown in Figure 1. In order to ensure the stability of the system during operation, the entire warehousing scenario is simplified as follows:

1) The robot only drives in one direction on any road;
2) The cost of the path of the robot going straight through a node is 1;
3) Each grid is only allowed to pass or accommodate one trolley at a time;
4) The robot movement speed is the same.

The above requirements eliminate the collision between robots and the pursuit collision. However, the collision situation will still occur when multiple machines are running at the same time, as shown in Figure 1. The occurrence of cross collision has a certain particularity: the next node that the two robots are about to reach is the same, which can be divided into two situations: one is that the two robots will reach the same node at the same time, as shown in Figure 1 (a); The other is that when a robot turns at a node, another robot is about to reach the node, as shown in Figure 1(b).



(a) (b)

Figure 1: Illustration of cross-collisions.

In the event of a cross-collision, one of the robots can be stopped to avoid it, so there is a requirement for priority between the robots. According to the workflow of the robot and the requirements of the model establishment, the priority of the robot in the turning state is the highest, and the priority when the robot is fully loaded is higher than the priority when the robot is unloaded, as shown in Table 1.

Athletic status	Load status	Priority
turn	—	high
Go straight	unladen	middle
Go straight	unladen	low

Table 1: Different statuses and priorities of robots.

2.2 Improved A* Algorithm for Autonomous Path Planning

The traditional A* algorithm obtains the optimal route from the current location to the target location; the original static system to a dynamic system is proposed in this section; that is, the position of obstacles in the map is variable, so it can be combined with the reservation table to obtain the improved A* algorithm. According to the method we proposed, the obstacle that may be encountered is the node occupied by the rest of the robots in the process of robot operation, in addition to the key nodes such as the loading point and unloading point. The next action of the robot can be analyzed to judge the coordinates of the next node, and then the point is added to the map as an obstacle.

Each robot only considers the next action and the node to be reached, uploading the information to the control center, and then the control center sorts out this information to obtain a real-time obstacle change map. The new path according to this map uploads the next action and the node to be reached is determined by each robot. According to this method, the path planning of multi-machine collaboration can be realized.

3 SYSTEM SIMULATION VERIFICATION ANALYSIS

The system simulation environment in this paper is mainly based on the LabVIEW development environment, and the library functions of LabVIEW fully meet the various functions required by the high-performance FPGA development of NI myRIO, and the excellent graphical interface also provides great convenience for the display of robot status and map information in the later simulation and actual operation process.

3.1 Rasterization of Environmental Maps

The A* algorithm is realized by calculating the cost that the robot needs to pay when passing through a certain location, when the storage environment map is rasterized, the cost of the impassable node is specified to be 100, and the cost of the passable node is only 1, to rasterize the whole map and construct a map matrix. LabVIEW has a good graphical display interface, in which the intensity chart could clearly display the intensity value of each coordinate. In the map modeling, 1 represents the passable coordinates, 100 represents the impassable coordinates, to meet the requirements of the intensity table, as shown in Figure 2, where black is the impassable coordinate and setting 100, and white represents 1, means the passable coordinate.

3.2 Simulation Process Design of Improved A* Algorithm

During the whole operation process, the intelligent warehousing robot needs to complete tasks according to the new obstacle map with the current coordinates, including the update of the obstacle map, the adjustment of the conflict coordinates, and the re-planning of the path of each vehicle.

100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
100	1	1	1	1	100	100	100	100	100	100	100	100	100	100	100	100
100	1	1	1	1	1	1	1	1	100	1	1	1	1	1	1	100
100	1	100	1	100	100	1	1	100	100	1	100	100	100	1	1	100
100	1	100	1	100	100	1	1	1	1	1	100	1	1	1	1	100
100	1	100	1	100	100	1	1	100	1	1	100	100	100	100	1	100
100	1	1	1	100	100	1	1	100	1	1	1	1	1	1	1	100
100	1	1	1	100	100	100	100	100	100	100	100	1	1	1	1	100
100	1	1	100	100	1	1	1	1	1	1	1	1	1	1	1	100
100	1	1	100	100	100	100	1	100	100	1	1	1	1	1	1	100
100	100	1	100	100	100	100	1	100	100	1	1	1	1	1	100	100
100	100	1	100	100	1	1	1	1	1	1	1	1	1	100	100	100
100	100	1	100	100	1	100	100	1	1	1	1	1	1	100	100	100
100	100	1	100	100	1	100	100	1	100	100	100	100	100	100	100	100
100	100	1	100	100	1	1	1	1	100	100	100	100	100	100	1	100
100	100	1	100	100	100	100	100	100	100	100	100	100	100	1	1	100
100	100	1	100	100	100	100	100	100	100	100	100	1	1	1	100	100
100	100	1	1	1	1	1	1	1	1	1	1	1	1	1	100	100
100	100	1	1	1	100	100	100	1	100	1	1	1	1	1	100	100

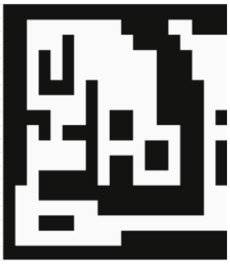
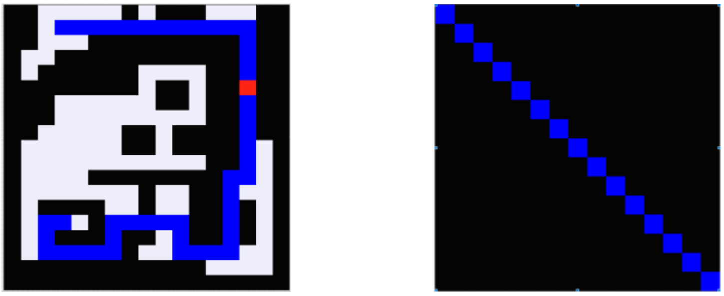


Figure 2: Rasterized modeling of the environment map.

In order to reduce the complexity of the simulation design, each robot predicts the node coordinates of the next step, and the host coordinates the potentially conflicting robots and updates the obstacle map according to the node coordinates of the next step of all robots. The traditional A* algorithm is used to calculate the best path to reach the target coordinates, so some impassable paths will be planned, as shown in Figure 3.



(a) Diagram of an impassable path (b) Diagram of a diagonal motion path

Figure 3: Schematic diagram of the motion path.

The red denotes the impassable node. In practice, it is obvious that this is not possible, so we add a verification procedure for the validity of the path so that we can verify whether there are impassable coordinates in the path.

In order to achieve this function, it is necessary to process the impassable coordinate data in the obstacle map to facilitate the verification of the validity. At the same time, it can be judged whether the next coordinate of the robot is the obstacle coordinate, and then the next action can be judged. In the A* algorithm, there are eight directions of movement from a node to the periphery, as shown in Figure 3(b), but in the warehouse, diagonal motion is not possible. The solution of the A* algorithm is the solution with the lowest total cost, so this situation can be excluded by changing the cost of diagonal motion, which is impassable like impassable nodes, so its cost is set to 100. Figure 4 shows the dynamic path planning flow diagram of the warehousing robot in this paper.

3.3 Obstacle Avoidance Simulation of Warehouse Robots

Figure 5 shows a real-time processing simulation of two robots when they collide, with robot 1 having a higher priority than robot 2, blue representing robot 1 and red representing robot 2.

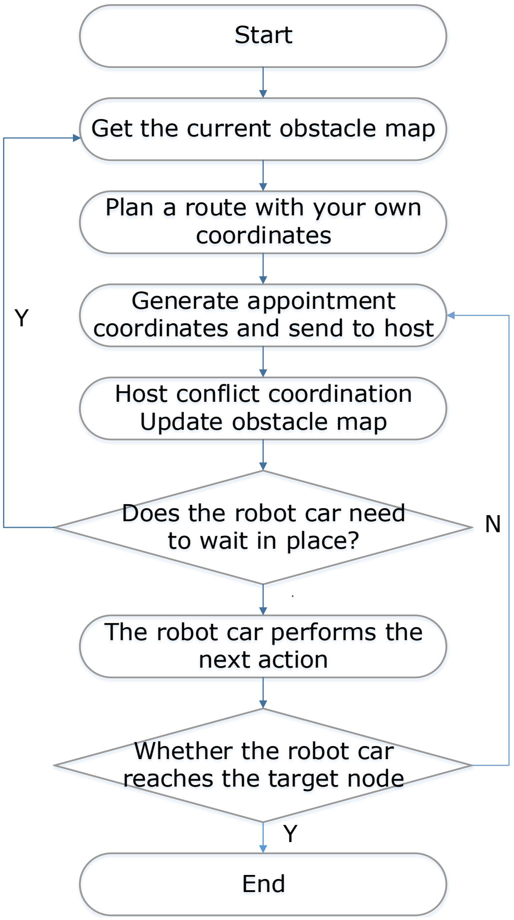


Figure 4: Flowchart of dynamic path planning of the warehouse robot.

Robot 1 moves from A to B, and robot 2 moves from C to D, and the next step of the two robots is node E as shown in Figure 5(a), and a cross collision occurs. After the host coordinates according to the priority, robot 2 waits in place, and the robot 1 continues to move, as shown in Figure 5(b); After robot 1 passes node E, robot 2 continues to move forward, as shown in Figure 5(c); Finally, the two robots successfully passed through node E, as shown in Figure 5(d).

3.4 Cost Analysis of Path Planning of Warehousing Robots

If there is an impassable node on the actual route, the passable node will be passed first in the path planning in the A* algorithm, and then the impassable node will be passed. Therefore, the reciprocating behavior shown in Figure 6 will occur when applied to a complex warehousing environment. In Figure 6(a), robot 1 moves from E to B and passes through E→A→C→B in turn; When robot 1 arrives at node A, assuming that C is occupied by robot 2, after the next obstacle map update, C is an impassable node, A will re-plan the route as shown in Figure 7 (b), the next action of robot 1 will return to node E, when robot 2 leaves node C, robot 1 will return to node A, and there is a reciprocating behavior.

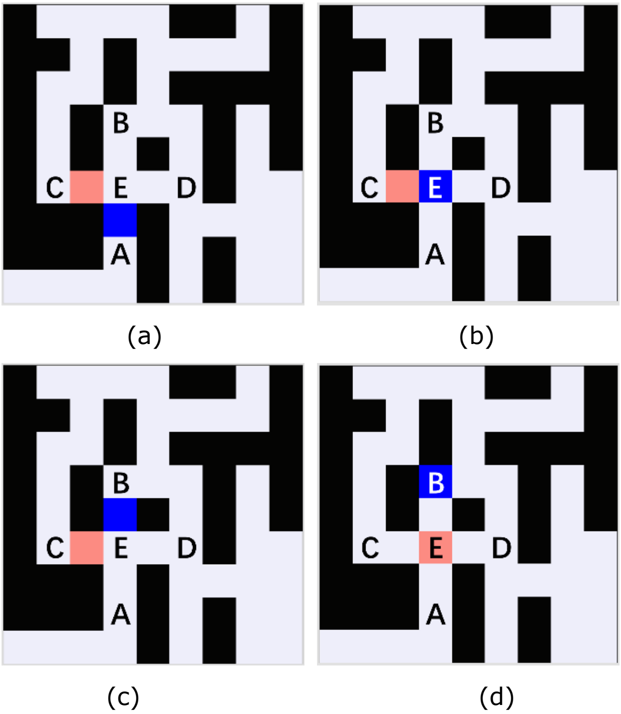


Figure 5: Simulation of real-time processing when two robots collide.

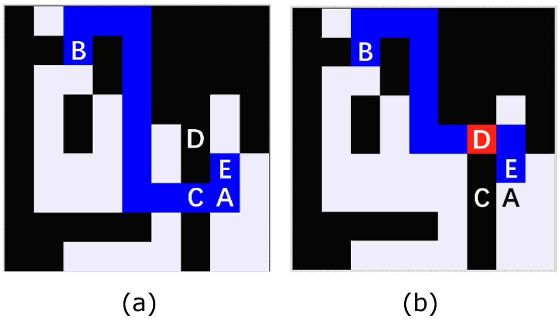


Figure 6: Illustration of the reciprocating behavior of a complex storage environment.

After analyzing the A* algorithm, it can be found that when there are two paths with the same total cost, the A* algorithm will give preference to the path with the lower cost of the first point. In order to ensure that the robot does not have similar reciprocating motion, the cost of the two paths is reduced as much as possible, so that the cost of the node occupied by the robot cannot be the same as the cost of obstacles such as walls, and it should be appropriately reduced according to the actual storage environment.

In real-life traffic, traffic congestion caused by excessive traffic flow in some areas often occurs, which will affect the capacity of the road. In the same way, something similar will happen in the storage system, when the number of robots in a certain area reaches the tolerance limit of the area, the efficiency of the handling robot through the area will become very low, affecting the overall efficiency of the storage system. Therefore, the robot should be allowed to avoid the path of the area during path planning, the A* algorithm is analyzed and combined with the reason for the previous robot's reciprocating behavior. When the number of robots in a certain area is large, the path cost obtained through the area will be higher in the path planning, and if the cost is greater than the maximum cost between the two target points (the product of the Manhattan distance between the two target points and the cost of the obstacle), the wrong route through the wall may be planned, as shown in Figure 7.

The optimal path of the robot moving from point A to B is shown in Figure 7(a), when there is a robot on this path to stay, assuming that the cost of the occupied node is 100, and the planned path is shown in Figure 7(b), but when there are two robots staying, the total cost of the path through the two robots is greater than the total cost of passing through the wall, and an impassable path is wrongly planned, as shown in Figure 7(c). It can be seen that the setting of the cost of the node occupied by the robot has certain requirements, and the value of the cost should be reasonably set according to the actual storage environment and the number of robots. In the above-mentioned environment, two robots occupy the passage path as an obstacle, and the setting cost is 50, and the path planning algorithm could work normally, as shown in Figure 7(d), and this value can also further reflect the traffic congestion in a certain area.

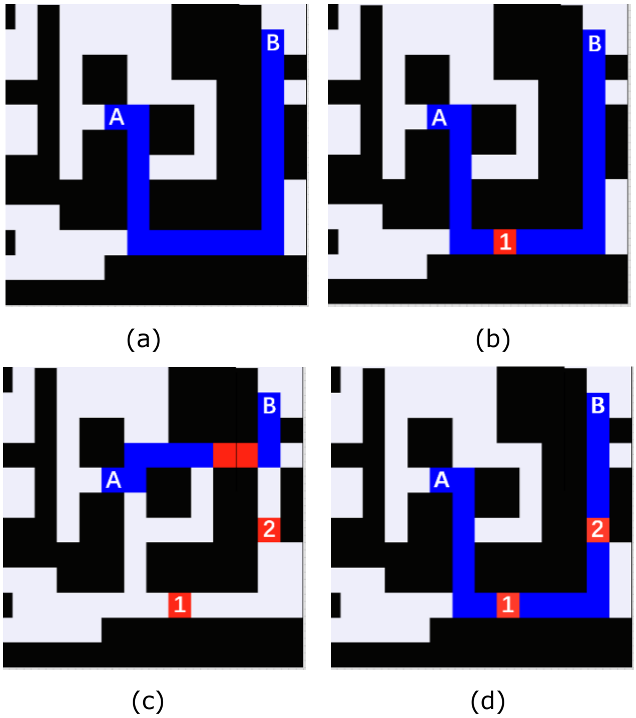


Figure 7: The path map is illustrated by the wrong route map through the wall.

4 CONCLUSIONS

In order to realize the dynamic path planning and collaboration of multiple robots in the storage environment, an improved A* path planning algorithm based on the reservation table and obstacle map is proposed in this paper. The method creates the storage environment model through the LabVIEW graphical development tool and regulates the position information of multiple robots in real-time based on the reservation table to avoid conflicts. The results show that the proposed method in this paper ensures the reliability and efficiency of multi-robot warehousing tasks and achieves better warehousing utilization rate and path planning efficiency. However, there is a limitation that reservations are made solely for the next move of each car so that it can not meet the application of a large-scale storage environment, which will still be the possibility of trolley blockage and then lead to system collapse. In practical application, we should start from the size of the site and the actual number of operations, with a reasonable balance between the robot and the scenario so that the system can be reliable.

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