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A Path Planning Method for the Spherical Amphibious Robot Based on Improved A-star Algorithm

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***Abstract* - In order to improve the autonomous navigation ability and mobility of spherical amphibious robot. A multiple target points path planning algorithm based on global static planning was proposed. Firstly, the A* algorithm is optimized for bidirectional smoothness, and the distance of each path is calculated. Secondly, according to this distance, the ant colony algorithm is used to sort multiple targets, and the global optimal path is planned. Finally, a series of simulations and experiments verify the proposed path planning method.The experimental results show that the robot successfully avoids obstacles from the starting point to the end point. On the one hand, the path distance of the robot is greatly shortened, on the other hand, the robot completes the path planning of multiple target points.**

Index Terms - Path planning. A* algorithm. Ant colony algorithm.

I. INTRODUCTION

So far, autonomous navigation is an important ability for robot to interact with the outside world [1]. an important embodiment of interaction is to achieve global planning, local planning and obstacle avoidance [2]. therefore, all countries are committed to the development of path planning technology, multi-functional robot is born, and has achieved fruitful results.

In order to optimize the generated route in terms of smoothness, Yang et al [3]. proposed a limited angle A* algorithm, in which the number of adjacent nodes increased to 16. Although such an option can avoid sharp turns, it sacrifices computational memory space in each iteration. Wang et al [4]. developed a global path planning algorithm based on the improved A* algorithm, in which hexagonal grid (6 neighbors) was used instead of rectangular grid to increase security and speed. The generated path is smoothed by deleting the second of the three consecutive nodes without conflict. However, it is superfluous to evaluate the conflict of each node. Kim et al [5]. improved the traditional A* algorithm, which considers the dynamic constraints of USV in non-uniform map, but this variable scale will make it difficult to integrate with data acquisition subsystem. Therefore, in order to better retain the advantages of the traditional A* algorithm and seamlessly integrate it into the spherical amphibious robot, an improved bidirectional smoothness optimization A* algorithm is developed.

In addition, the multiple target points path planning of mobile robot refers to the collision free feasible path from the starting point to two or more destinations [6]. For multiple target points path planning, using the existing single destination planning method, it needs to plan the path from the starting point to each destination for many times[7]. There are many problems, such as multiple path round-trip, even invalid path and so on, which affect the path search efficiency of the robot[8]. Therefore, the realization of one-time complete path planning in multiple target points environment is of great significance to save running time and improve planning efficiency. multiple target points path planning problem mainly involves how to quickly search the path between the two locations, quickly sort the destinations and local dynamic planning. Reference [9] proposed a method to solve the multiple target points transportation route planning problem for highway transportation. According to the weight of freight and time of different road sections, the Hamiltonian path was constructed by using the construction conditions of Hamiltonian graph to select the appropriate path in the transportation process and traverse all destinations without repetition, to achieve the optimal effect. In reference [10], a new method of multiple task path planning based on hierarchical particle swarm optimization, genetic algorithm and A* algorithm is proposed. This paper solves the problem that the calculation cost of particle swarm optimization genetic algorithm is too high, and a single algorithm cannot solve the obstacle avoidance problem of mobile robot traversing multiple task target points on the map with obstacles. The above research work studies the global static path planning of multiple target points, the verifies that multiple target points path planning is more efficient than multiple single destination path planning. Therefore, combined with A* algorithm and ant colony algorithm, this paper realizes the global static path planning of multiple target points points, and on this basis, integrates the dynamic window algorithm to realize the multiple target points point path planning algorithm combining the global static planning and local dynamic planning.

This paper is organized as follows: Section II introduces the structure and navigation system of the spherical amphibious robot, Section III discusses the structure and implementation of the hybrid algorithm, and Section IV conducts experiments in virtual environment, complex environment and motion environment. Section V the algorithm is verified by experiments.Section VI summarizes the contribution and future work.

II. Structure of the Spherical Amphibious Robot

As shown in fig.1, In our previous research, we developed a spherical amphibious robot to perform complex operations [11]. In order to obtain better performance in various complex environments, the spherical robot has a four-legged walking mode with a deformable composite propulsion mechanism, and its actuation mode is changed between the four-legged walking modes. In order to improve the speed performance of the spherical robot, a spherical amphibious robot with roller skating walking mode is proposed in reference [12], in which a passive wheel is installed on each leg to realize the roller-skating motion. The multiple joint leg can select discrete foot points when quadruped walks on the land, which can bring high efficiency and stability to the robot even in rugged terrain[13]. On flat terrain and slopes, wheeled motion is more effective than legged motion due to the low friction along the direction of motion[14]. In view of this idea, as shown in Figure 1, we improve the spherical amphibious robot with roller skating walking mode. Install wheels on the bottom of the robot. On the one hand, If the robot is walking on a rough road (such as grass), the leg model can be used. At this time, the wheels are suspended to ensure that the wheels will not move like the legs. On the other hand, if the road is relatively flat, such as marble road, in order to speed up the walking speed, at this time, the legs are lifted and the wheel model is adopted.

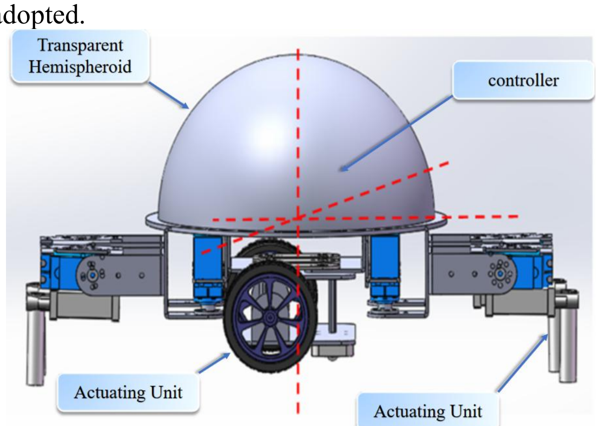


Fig. 1 Structure of the Spherical Amphibious Robot

As shown in fig.2, the control system is composed of sensor system, control system, drive system and actuator. The sensor system uses lidar and IMU to collect the loop information to construct the map, the transmits the environmental information to raspberry pie. After the upper control processing, it plans the path, and sends the speed command to arduino, so as to drive the actuator and complete the navigation.

Fig. 2 Control System of the Robot

III. Path Searching Method Based on Ant Colony Optimization

A. *Path Smoothness Optimization*

The purpose of this paper is to provide a global path planning method for spherical amphibious robot, which not only solves the problem that the path is not smooth due to many turning points in the existing technology, but also solves the problem that the path can only be planned for a single target point. It is a simple and easy to implement path planning method.

A* algorithm is the most effective direct search method to solve the shortest path in the static road network. The map model is built based on grid method. The path planned by A* algorithm is composed of grid center nodes. There are many problems in the path, such as redundant path nodes, multiple inflection points, and the path nodes can only be located in the center of the grid. If the path nodes planned by A* algorithm are directly substituted into the dynamic programming algorithm, the path is not the shortest and the smoothness is poor. Therefore, the path nodes planned by A* algorithm are optimized to delete redundant nodes. In collision isolation processing, the safe distance is set to D. The improved algorithm is as follows:

Step 1: judge whether the node position is the middle position of a path, and then delete the middle node in the same direction, leaving only the starting node, the node at the corner and the target point.

Step 2: Starting from the starting grid node s, take points every k steps between the reserved path nodes, and take each point to judge whether there is an obstacle between the node and the path node at the front end, and calculate the distance d from the obstacle beside the path to the path by the formula, as shown in formula

$$d = \frac{\left|(y_b - y_a)x_e + (x_a - x_b)y_e(x_b x_a - x_a y_b)\right|}{\sqrt{(y_b - y_a)^2 + (x_a - x_b)^2}} \quad (1)$$

Judge the size of the distance d and the safe distance D, if it is beyond the safe distance, the node meets the path requirements, and select the current node as the path node, otherwise it is not selected; the safe distance D in the step is the diameter of the spherical amphibious robot.

Step 3: The path after planning is bi-directional optimized, that is, the point is taken from the target point in the reverse direction, the distance is judged according to step 2, the path is saved, and the distance matrix e is generated, which is the path after smoothness optimization.

B. Multiple target points Path Planning

The ant colony algorithm is used to determine the traversal order of all the target points, and the shortest distance that can traverse all the target points and return to the starting point is found as the mobile path of the amphibious robot. Ant colony algorithm can be described as knowing the distance of all target points

$$P = (C_1, C_2, C_3, \ldots C_n) \quad (2)$$

it can solve the shortest path traversing n target points on the premise that each target point only passes once:

$$f(p) = \sum_{i=1}^{n} d(c_i, c_{i+1}) + d(c_1, c_n) \quad (3)$$

Where p is the traversal order of the target point, C is the target point number, i = 1, 2, …, n, d represents the distance between adjacent numbered target points. f(p)traverses the path of N target points. The specific steps for determining the traversal order of the target points are as follows:

Step 1: The number of ants is m, n is the number of target points, and each ant randomly selects one of the N targeting points as the starting point.

Step 2: Each ant calculates the next target point to be visited according to the state transition probability shown in equation (4), that is, it moves from the i target point to the next vertex J, until all ants complete a tour, that is, all target points are traversed by all ants:

$$P_{\mathrm{ij}}^{k} = \begin{cases} 0, & others \\ \dfrac{\tau_{ij}^{\alpha}(t) \times \eta_{ij}^{\beta}(t)}{\sum_{s \in allowed_k} \tau_{ij}^{\alpha}(t) \times \eta_{ij}^{\beta}(t)} & \end{cases} \quad \mathrm{k} = 1,2,3 \ldots \mathrm{m} \quad (4)$$

Step 3: After all ants complete a cycle, record the total length L of each ant's path and the shortest path of the current iteration, and update the pheromone concentration between the target points according to the pheromone update formula of formula (5) - (7).

$$\overline{\rho} = (1 - \rho_0) \times \left(\frac{N_C}{N_{C\max}}\right) \quad (5)$$

$$\tau_{ij}(t+1) = (1 - \overline{\rho})\tau_{ij}(t) + \Delta\tau_{i,j} \quad (6)$$

$$\Delta\tau_{i,j} = \begin{cases} \dfrac{Q}{L}, & ant \text{ k through(i, j)} \\ 0, & \text{else} \end{cases} \quad (7)$$

Step 4: If the number of iterations reaches the maximum, the optimal traversal order is output, which is regarded as the order of the target points traversed by the spherical amphibious robot in the path planning process, so as to complete the multiple target points path planning of the robot; otherwise, the number of iterations is increased by 1, and the ant path record table is cleared, and return to step (2) to continue.

C. Multiple target points Path Planning Algorithm Flow

Step 1: Initialize the raster map model and confirm n destination coordinates.

Step 2: Generate (n X n + n) planning groups.

Step 3: Based on A* algorithm, path planning is performed for all groups, and bidirectional smoothness of path nodes is optimized.

Step 4: Based on ant colony algorithm, all the paths are sorted to get the complete optimal path.

Step 5: get the start move command.

Step 6: judge whether the current destination is the starting point. If the conditions are met, the movement ends; otherwise, prepare to move to the next destination.

IV. Simulation Analysis

In order to verify the feasibility and effectiveness of the improved algorithm, a path planning simulation experiment is designed. For the convenience of comparative study, it is assumed that the grid side length of mobile robot working environment is 1m, the map model is 30 × 30, and the parameters in the improved A* are k = 0.1 and d = 0.8m.

A. Path Smoothing Simulation Experiment

In order to verify that the path optimized by smoothness can shorten the original path distance, so as to improve the motion efficiency of the robot, multiple groups of experiments are set up. Under the same environment background, different target points are selected, and one of them is selected for simulation, as shown in fig.3.

The improved path is shown in fig.4. It can be seen from the figure that under the same background, the improved path has fewer turning points than before, thus increasing the smoothness of the path and achieving the effect of path shortening. In addition, for seven different target points, the length and distance of seven groups of paths are collected for comparison. Each group of data is in the same background, and the same target point is selected. As shown in fig.5, the path distance of seven groups of data is shorter than the original. The simulation results show that the improved path is shorter than the original path.

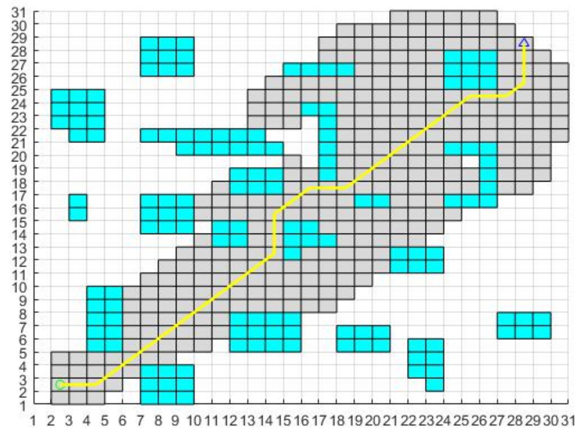


Fig. 3 Simulation without Optimal Algorithm

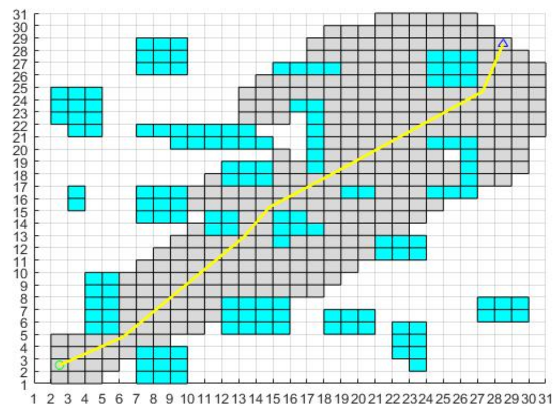


Fig. 4 Simulation with Optimal Algorithm

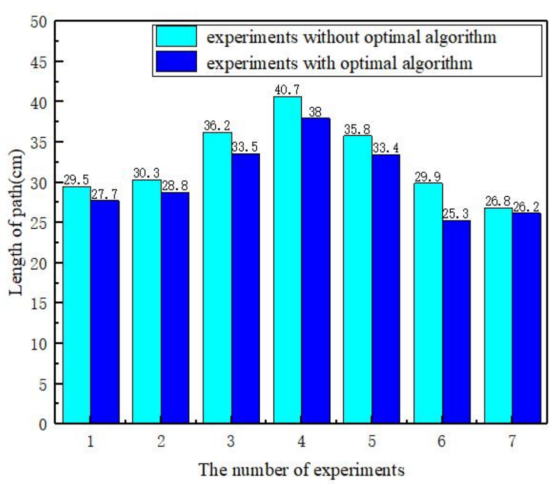


Fig. 5 Path Length Comparison of Single Target Point

B. *Multiple Target Points Simulation Experiment*

In order to verify that the multiple target points path planning algorithm can improve the transportation efficiency of the loading and unloading robot, seven groups of simulation experiments are established, and the number of destinations in each group increases gradually. The length of the mobile path obtained from the experiment is shown in fig.6. The cyan color represents the path distance of a single target point, and the green color represents the comparison of the planned paths of seven destinations after the fusion of ant colony algorithm, as shown in fig.7 and fig.8. In the figure, the s point represents the transportation position of the robot, the t point (I = 1,2,3,4,5,6,7) represents the transportation destination, the cyan grid area represents the obstacles, and the solid line represents the planned path.

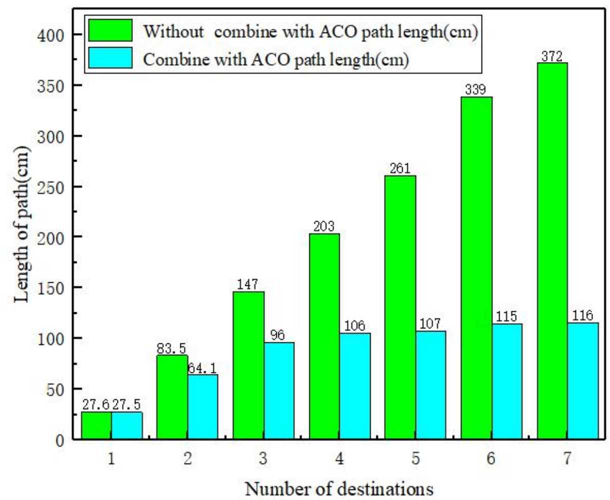


Fig. 6 Path Length Comparison of Multiple Target Point.

It can be seen from fig.7 that the solid lines with different colors represent the paths of the robot to different target points, and the single destination path planning leads to the mobile robot need to return to the starting point many times, which reduces the transportation efficiency of the robot; in fig.8, the multiple target points path planning in this paper can reach all the destinations at one time, and finally return to the starting point to complete the task, thus shortening the operation path The distance between them. It can be seen from the path length comparison chart in fig.6 that with the increase of the number of destinations, the path length planned by the single destination path planning algorithm increases rapidly, increasing the energy consumption of the robot, while the path length planned by the multiple target points path planning algorithm designed in this paper increases gently, especially when the number of target points is more, the length increases more gently, which is compared with the single destination path planning algorithm By comparison, the path distance is significantly shortened, which verifies the efficiency of the algorithm.

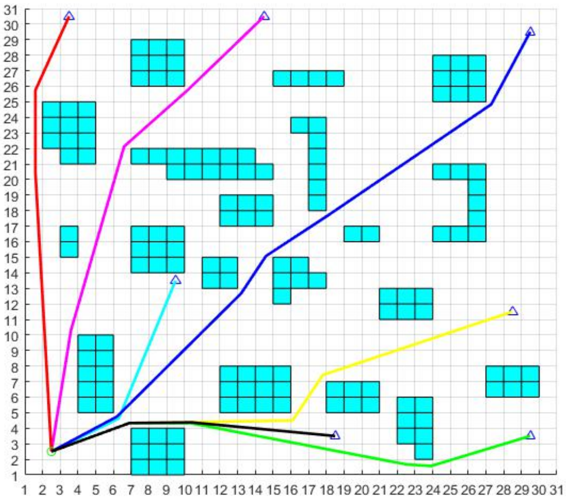


Fig. 7 Seven Times Single Objective Point Path Planning

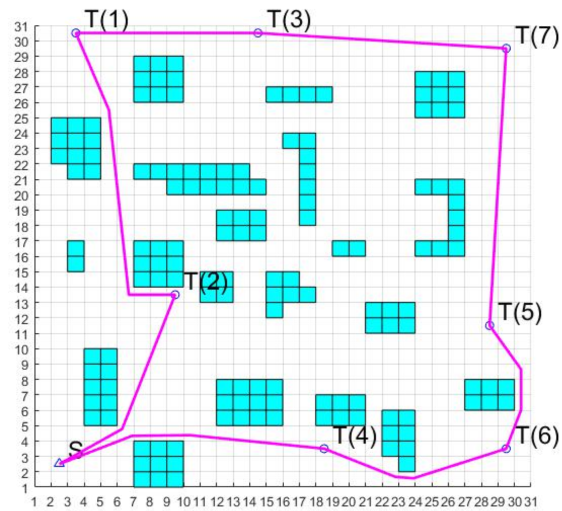


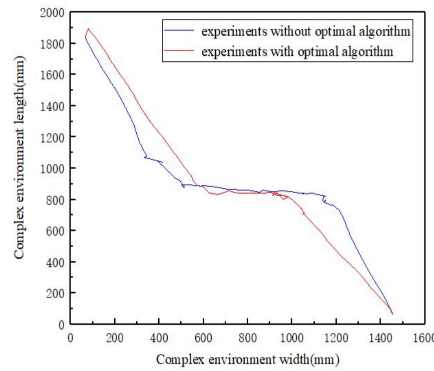
Fig. 8 Seven Times Multiple Target Points Path Planning

V. Experimental Results

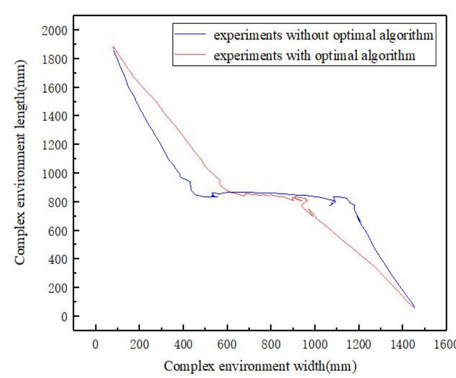
In order to verify the feasibility and effectiveness of the improved algorithm, a path planning experiment of spherical robot is designed. In order to facilitate the comparative study. Before the experiment, the robot collects the environment information around the environment, and after collecting the coordinates of each target point, the robot places the starting point, inputs each target point into the robot, starts the robot, and the robot starts the path planning. In order to accurately describe the spherical underwater robot path, we need the robot's location information collection and feedback, so this article adopted (NDI) optical positioning system to position the spherical robot. The spherical robot is mounted with a passive rigid body fitted with an optical positioning system.

A. Path Smoothing Experiment

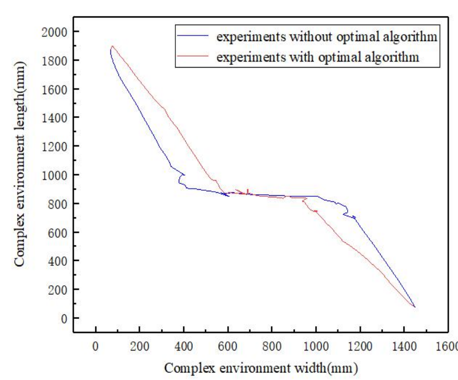
In order to verify the effectiveness and practicability of the algorithm, the algorithm is transplanted to the spherical robot for many experiments, and three groups of experiments are collected for comparison. As shown in fig.9, we first arrange a 2m * 1.6m environment with obstacles. the blue solid line is the actual trajectory before the improvement, and the red solid line is the actual trajectory after the improvement. The data show that the improved A* algorithm shortens the original path and improves the efficiency of the robot.



(a) The First Experiment



(b) The Second Experiment



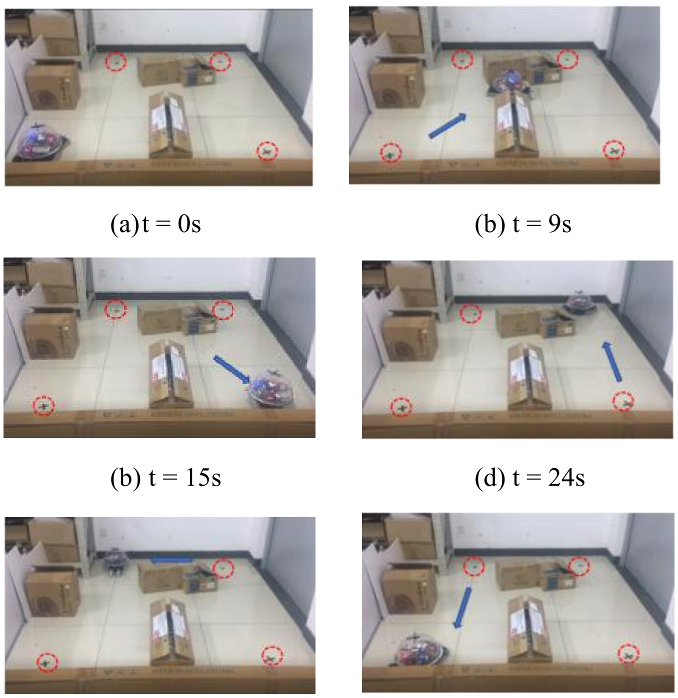
(c) The Third Experiment

Fig. 9 Path Comparison of Single Target Point

B. Multiple Target Points Experiment

This part mainly verifies the path planning of multiple target points after the fusion of ant colony algorithm.

Similarly, several groups of experiments were carried out, and the states of the robot at different times were recorded, as shown in fig.10, This part mainly verifies the path planning of multiple target points after the fusion of ant colony algorithm. Similarly, several groups of experiments were carried out, and the state of the robot at different times was recorded.



(a)t = 0s (b) t = 9s

(b) t = 15s (d) t = 24s

(e) t = 31s (f) t = 43s

Fig. 10 Spherical Robot Path Planning Experimental

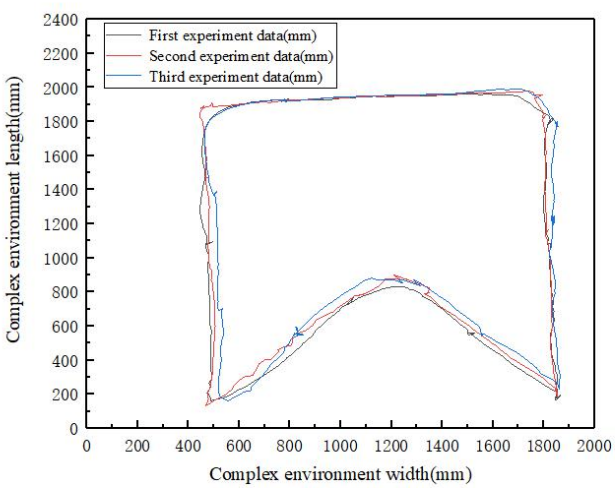


Fig. 11 Experimental trajectory of spherical amphibious robot

As shown in fig.11, the NDI optical positioning system is used to collect the trajectory of the robot, and the results show that the robot achieves the multiple target points path planning well.

VI. CONCLUSIONS AND FUTURE WORK

This paper designs a multiple target points path planning algorithm based on improved a * and ant colony algorithm. Firstly, a * algorithm is used to plan the path between two points to optimize the bidirectional smoothness of the path nodes. Then, the ant colony algorithm is used to sort the planned paths to get the global optimal path. Finally, the optimized path node and target position are dynamically set as the current path node, so that the mobile robot can move smoothly according to the global path, avoid obstacles in time, and move to the target accurately. The simulation results show that the path length of the multiple target points path planning algorithm is 44.2% smaller than that of the single objective path planning algorithm, which improves the work efficiency of the mobile robot. Compared with the traditional dynamic obstacle avoidance method, local dynamic programming can effectively improve the stability and efficiency of mobile robot motion speed.

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