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Cooperative Hunting of Spherical Multi-robots based on Improved Artificial Potential Field Method

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Abstract **–With the development of robot technology, the research of multi-robot cooperative target search in the military field mainly focuses on avoiding obstacles while surrounding the target, but most of the object-oriented research is a single robot and a single obstacle. In view of the object - oriented simplicity, this paper uses robot cluster to avoid multiple obstacles. Artificial potential field algorithm is widely used in the field of robot obstacle avoidance because of its simple structure, small amount of computation and good real-time performance. But in actual use in the artificial potential field algorithm has certain defects, mainly includes the target unreachable problem and local minimum value problems, by improving the traditional artificial potential field algorithm, this study so as to improve the artificial potential field algorithm when use the deficiencies, in order to improve the artificial potential field algorithm when the mobile robot to round up the target of obstacle avoidance. Finally, the simulation results show that the improved artificial potential field method can solve the problems of local minimum and unreachable target, and has good dynamic obstacle avoidance ability. This method ensures the reliability of spherical robot group and improves the efficiency of multi-robot group.**

Index Terms –Artificial potential field, Objective to round up, Multi-aircraft cooperative, Anneal Arithmetic.

I. INTRODUCTION

Spherical multi-robot system is mainly used to accomplish multi-task in specific environment. Multi-robot cooperation can improve task efficiency, but it also brings challenges to cluster cooperation technology. Multi-robot cluster cooperation is built on the basis of good communication, and real-time location, division results and task information need to be shared in real time. When the number of machines is large, it is necessary to avoid collisions between machines, resulting in resource loss. The battlefield situation is changing rapidly. Replan your route when encountering obstacles. Therefore, multi-robot cluster cooperation technology has become a hot topic in recent years. Target rounding is one of the most common tasks in robot cluster cooperative warfare. In battlefield missions, the key to victory is to discover the enemy's core targets and to monitor or attack them. This requires that the robot crowd can arrive at the battle center in formation from the edge of the battlefield and track the target. In other words, the UAV group should be equipped with efficient formation and cooperative rounding ability. And can carry out effective tracking and rounding up after finding the target, clearing obstacles for the subsequent battle victory [1].

At present, robot rounding up technology has also been widely used in the military. In the field of confrontation, in the face of targets or threats that are difficult to deal with by a single robot. It is necessary to use multiple robots to round up and then carry out follow-up tracking or attack. Therefore, it is of great significance to study the technology of multi-robot cooperative target rounding up [2]. Ant colony algorithm is a path planning algorithm to find the shortest path, which can obtain the optimal solution by accumulating pheromone positive feedback mechanism. But the calculation of the algorithm is too large. A* algorithm is A heuristic algorithm, which uses the evaluation function to select the extension node with the lowest cost as the expected track point at the next moment. So as to plan the track. However, when the space environment is large, the complexity of the algorithm is high. Genetic algorithm transforms the solution of complex problems into the process of chromosome duplication and crossover, and selects the optimal offspring to obtain the optimal solution. All the intelligent optimization algorithms mentioned above have great advantages for route optimization in complex environment. But the algorithm has a large amount of calculation, so it cannot converge to the optimal solution quickly [3]. Which puts forward high requirements on the performance of the robot, and has limitations in the application of multi-robot system.

The artificial potential field method realizes obstacle avoidance by using force field to demarcate gravitational field and repulsive field. The algorithm has a simple structure and a small amount of calculation, and can effectively achieve the optimal collision-free path acquired by the robot in dynamic environment. But there are some problems such as local minimum value and unreachable target. In this paper, annealing algorithm is used to improve the artificial potential field method [4]. The advantages of the improved algorithm are demonstrated by comparing the route changes of multi-aircraft target rounding before and after improvement. Finally, the collision between robots and obstacles can be avoided to realize multi-machine cooperative target rounding up [5].

II. The Platform of Spherical Multi-robot System

Our spherical multi-robot platform is shown in fig.1. Since this study is aimed at amphibious, which requires spherical robot walking on land and water, land walking and water jet propulsion system are mainly introduced. The four steering gear under the sphere is mainly used in the land walking mode [6]. According to the PWM speed control to control the motor how many steps forward and the specific step length, so as to control its speed. When traveling under water, water spray is used to assist. Water jet propulsion device is a new type of power device. Different from common propeller propulsion, the thrust of water jet propulsion is obtained by the reaction force of water flowing out of water pump. In the direction, the rotation angle of the steering gear and the water flowing out of the pump make the robot move in a certain direction [7]. For multi-robot, cooperative cooperation is the best working mode of swarm robot. And the realization of multi-robot cooperative target rounding is an important embodiment of this mode [8].

Single robot combat mode can no longer meet the complex task, now multi-robot unified cooperative combat has become a hot topic. Mobile robot path planning refers to finding an optimal or suboptimal collision-free path from the starting point to the target point. And safely bypassing the known or unknown obstacles in the environment by referring to certain indexes. To realize multirobot cooperation, a unified and effective control method should be used to plan the task path while avoiding obstacles [9].

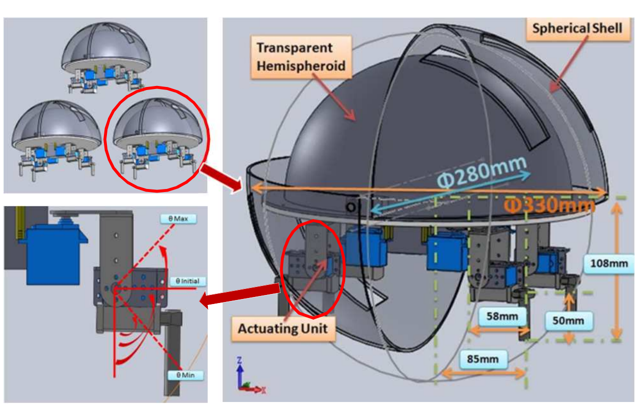


Fig. 1 Structure of spherical robot.

In the third part, the construction of artificial potential field and the improvement of the algorithm are described. In the fourth part, annealing algorithm is used to solve the target unreachable and local minimum problems in artificial potential field method. In the fifth part, the improved algorithm is simulated to realize multi-robot rounding up. Indicating that the improved artificial potential field algorithm can improve the reliability of multi-machine cooperative rounding up [10].

III. Artificial Potential Field

A. Artificial potential field model and analysis

The basic idea of artificial potential field path planning method is to design the movement of the robot in the surrounding environment as an abstract artificial gravitational field movement. The target point produces "gravity" to the mobile robot, and the obstacle produces "repulsion" to the mobile robot. Finally, the movement of the mobile robot is controlled by finding the reltant force [11].

At present, the most comonly used gravitational potential field function is:

$$U_{att}(X) = \frac{1}{2}\lambda_1 d^2(X) \tag{1}$$

Type (1): λ_1 is the gravitational constant, $\lambda_1 > 0$; $d(X) = \|X - X_t\|$Is the distance between the current position of the robot and the target point[8].

The commonly used repulsive potential field function is:

$$U_R^i(X) = \begin{cases} \frac{1}{2}\lambda_2\left(\frac{1}{d_i(X)} - \frac{1}{d_i^0}\right)^2, & d(X) \le d_i^0, \\ 0 & ,d(X) > d_i^0; \end{cases} \tag{2}$$

$$d_i(X) = \min_{X' \in X_i^0} \|X - X'\| \tag{3}$$

Type (2): λ_2 is the repulsion constant, $\lambda_2 > 0$; d_i^0 is the influence distance of the ith obstacle. Type (3) $d_i(x)$ is the shortest distance between the current robot position and the ith obstacle; X_i^0 is the position coordinate of the ith obstacle.

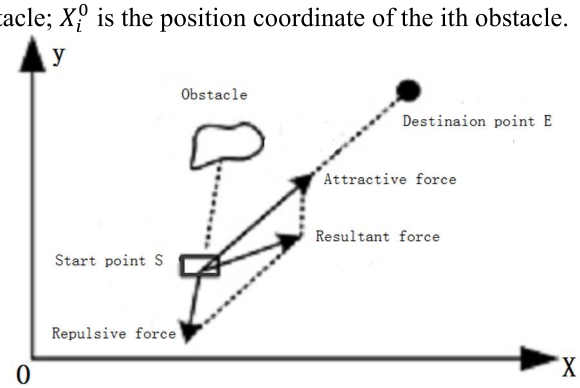


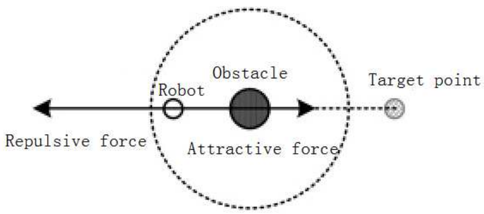
Fig. 2 Robot force diagram.

The established artificial potential field model is shown in fig.2. Assume that the starting point of the robot is S and the end point is E. And the robot moves from the starting point S to the end point E in the joint direction of the obstacle and the target point. The resultant force on the robot will change with the relative positions of the three [12].

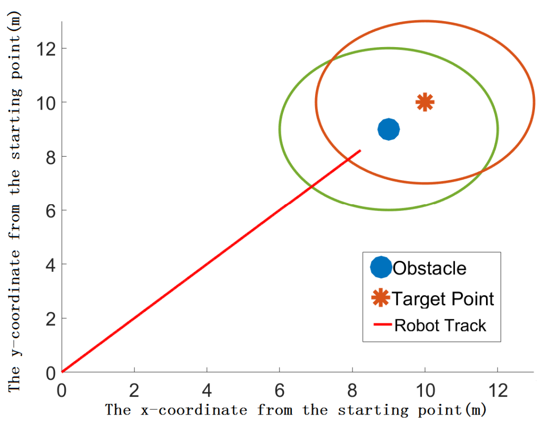
The path planned by potential field method is generally smooth and safe, but it has problems of local minimum value and unreachable target.

B. Local minimum analysis

Local minima can occur in two ways. The first is that when the robot, the obstacle and the target point are in a three-point alignment. When the robot reaches a certain position under the action of the resultant force, the repulsive force and the gravitational force are the same. And the resultant force is 0. (a) is the schematic diagram of the local minimum point. (b) is the simulation diagram, where the blue is the obstacle and the red is the target [13].



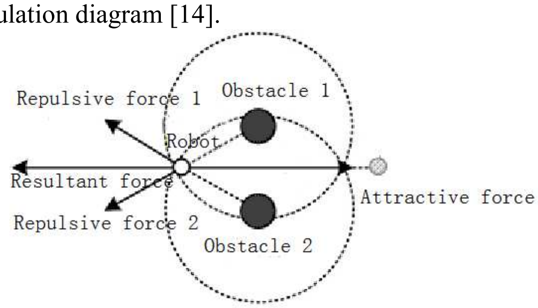
(a) Three-point diagram.



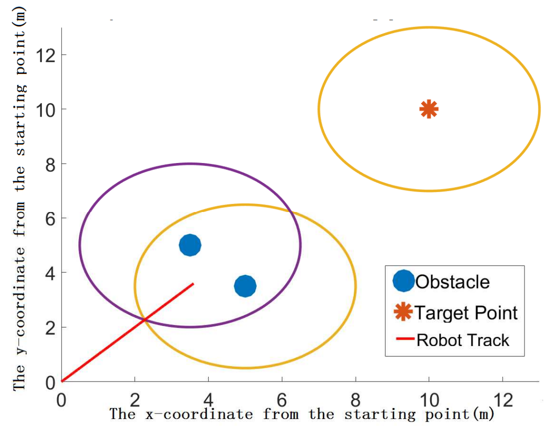
(b) Three-point first-line simulation diagram.

Fig. 3 Three points and one line in the local minimum.

The second is when multiple obstacles are between the robot and the target point, as shown in (a). Repulsive forces of two obstacles and equal and opposite directions to gravity cause the occurrence of local minimum values (b) is the simulation diagram [14].



(a) The obstacle is in the middle diagram.



(b) Obstacles in the middle simulation

Fig. 4 Graph of equal attraction and repulsion in local minima.

C. The analysis target is unreachable

When the obstacle is on the other side of the robot and the target point (mostly behind the target point), it is easy to cause the problem of unreachable target [15].

The first case is also a special three-point alignment, but the obstacle is behind the target.Its simulation diagram is shown in fig.5.

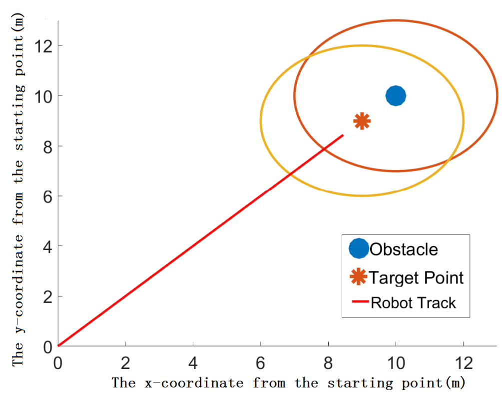


Fig. 5 Schematic diagram of unreachable goals at three points and one line

The second case is that in general the obstacle is around the target point. The simulation diagram of one of these cases is shown in fig.6.The rest is the same .

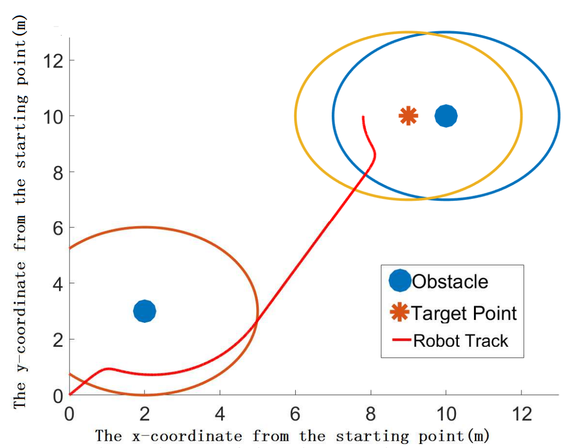


Fig. 6 Diagram of obstacles around target point

The clock target unreachable condition will make the robot stay around the target point all the time and never reach the target point. So we need to use annealing algorithm to improve [16].

IV. Analysis of Improved Artificial Potential Field Algorithm

In order to solve these two problems, simulated annealing algorithm is used in this study. The basic idea is: when the robot falls into the local minimum or does not move, a random point is selected near its current position. And the potential field of the local minimum point and the nearby random point is calculated by using the formula [17]. If the potential energy of the nearby random point is small, the random point is taken as a traveling point of the robot [18]. On the contrary, with a certain probability P accepts the nearby point as the next moving point, and T attenuates in a certain way, in the specific form:

$$\begin{cases} P = exp(-\Delta/T); \\ \Delta = d(S_1) - d(s); \\ T(t) = \alpha T(t-1). \end{cases} \tag{4}$$

Type (4): S is the local lowest point; S_1 is the nearby random point.

The improved algorithm flow is shown in fig.7.

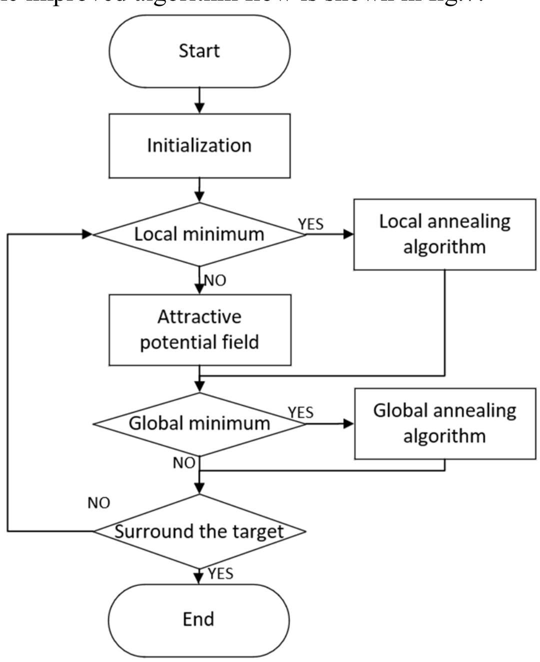


Fig. 7 Improved algorithm flow chart.

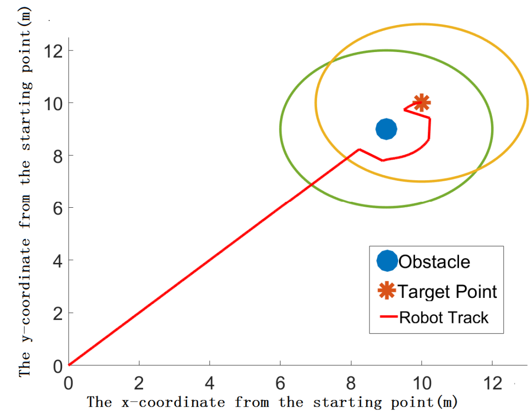
V. The Improved Algorithm Is Simulated

Annealing algorithm is introduced to improve the artificial potential field, which solves the problems of local minimum and unreachable target [19]. In order to verify the effectiveness of the improved artificial potential field algorithm, MATLAB simulation is carried out [20].

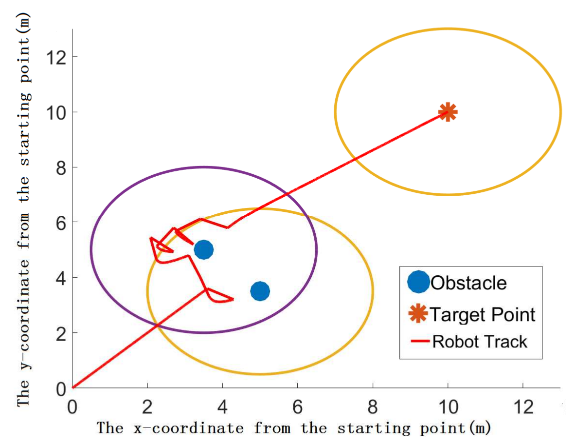
A. Single robot chasing target simulation

The simulation parameters are set as follows: the single step length of the captured target is 0.01, the single step length of the robot is 0.02. And the repulsion coefficient is 2.The initial position of the robot is (0,0), the destination position of the target point is (10,10), the distance affected by the obstacle is 3, and the unit length is m.

Fig.8 and 9 below are the simulation diagrams for solving the local minimum value and the target unreachable problem in four cases proposed above.

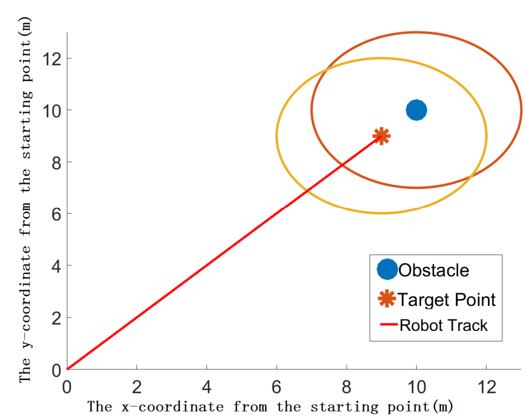


(a) Three-point solution to the problem

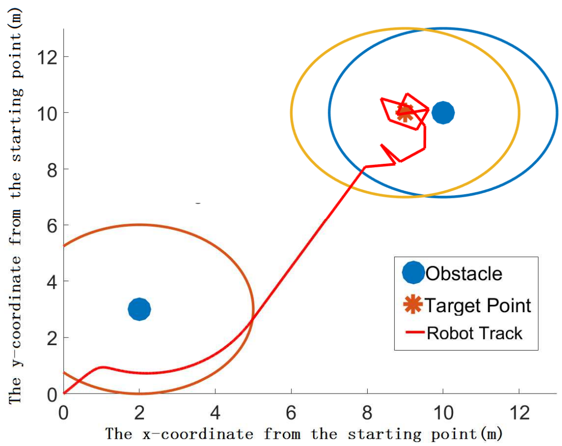


(b) The local minimum of multiple obstacles is reached.

Fig. 8 Two kinds of problem solving in local minima.



(a) Obstacles behind target point resolved.



(b) Obstacles around the target have been resolved.

Fig.9 There are two types of problem solving in unreachable goals.

It can be seen that the path shown in fig.8(b) and 9(b) is not the optimal path. This is because there are two obstacles in FIG. 8a that are very close to each other, and there is a complete equal repulsion and attraction between them and the robot. This is the worst local minimum, so the robot can only go around from the side.

Through the simulation experiments, which can be concluded that, after improved artificial potential field method. Implements the aversion to the success of the obstruction [21]. In the whole operation process, after the fall into local minimum, call the simulated annealing algorithm, near its random points, overcome the trapped in local minimum [22]. And target inaccessible, and marching to the target position successfully.

B. *Simulation of multiple robots rounding up targets*

After solving the problem that the repulsion force and attraction force are not correct for a single robot, several robots are introduced to round up the target using the same algorithm [23]. Fig.10 below is the simulation diagram of multiple robots rounding up targets.

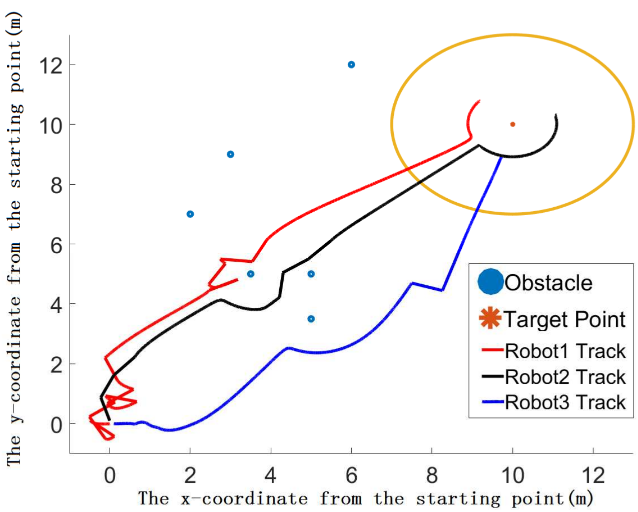


Fig. 10 Multiple robots rounding up targets.

Through the above simulation analysis, it can be seen that the improved artificial potential field method proposed. In this paper overcomes the problems existing in the traditional algorithm [24]. Such as local minimum value and target unreachable, so that the robot cluster can successfully and safely move to the target position and round up [25]. These two problems existing in traditional artificial potential field algorithms will lead to the robot's time to surround the target for infinite distance [26]. But the improved algorithm will obviously complete the rounding up task in a limited time.

VI. Conclusions and Future Work

Through the above simulation analysis, it can be seen that the improved artificial potential field method proposed. In this paper overcomes the problems existing in the traditional algorithm. Such as local minimum value and target unreachable, so that multiple robots can successfully and safely round up the target.

In order to avoid obstacles for amphibious robots, a multi-robot target rounding method based on artificial potential field method was proposed. Firstly, the traditional artificial potential field method is briefly introduced. And then an improvement scheme is proposed for two problems existing in the traditional algorithm. Then, the correctness of the algorithm is verified by MATLAB simulation. Finally, an amphibious robot independently developed by the research group is tested, and the results fully verify the feasibility of the algorithm in practical engineering.

Acknowledgments

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