Research on the frame of formation of multi-USV

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***Abstract*—The research of formation is a multi-objective constrained problem. Path planning and collision avoidance is an important task in the formation and application of unmanned surface vessel (USV). It is necessary to generate the path from the specified starting point to the end point, meet the constraint of space collision avoidance on the multi-objective crossing path, and pursue the shortest formation time of the whole formation as far as possible. In this paper, a framework of multi-agent target path planning algorithm is proposed. Firstly, the A-star algorithm is selected to generate waypoints, and then then introduces the safe distance to constrain the movement time and state of different agents. From the level of overall target path planning, the strategy of delayed start is adopted to set the action state of different agents. Simulation results show that the algorithm is effective. The experimental results show that the algorithm avoids the path conflict between unmanned vehicles and effectively ensures the path safety.**

Keywords-component; Formation; Collision avoidance; Path planning; Multi-USV

I. INTRODUCTION

In recent years, path planning and optimization has attracted much attention [1]. The main goal of path planning is to find an effective path to a destination for a mobile agent based on a static or dynamic environment. In addition to finding their own effective paths, intelligent group path planning also needs to fully consider the constraints of resource conditions, space capacity, reaction speed and other behavioral requirements. It has broad application prospects in robot, USV, military, security and other important fields. Path planning of single agent has been studied by many scholars [2-4]. The elements of path planning have been described in detail in the literature [5]. With the development of USV application technology, a single USV can no longer adapt to complex task scenarios, and multi-USV are needed to form formation groups to perform a task together [6]. In the actual formation, the research found that the USVs could not ensure a safe distance with other USVs during path planning due to sensor faults and complex surface environment, and there was a risk of collision between individuals [7]. In order to improve the safety and reliability of USV formation, one can start from two aspects [8-10]. On the first hand, it can improve the accuracy of sensing devices, such as improving the reliability of radar, laser ranging camera, and the stability of supporting algorithms. On the other hand, from the aspect of path planning, the safe path and driving scheme should be planned in advance, so as to ensure the safe distance of path sequence between unmanned boats and avoid collisions between them [11]. The two aspects can also be combined to further improve the reliability of the formation. Starting from the second aspect, this study aims to plan a safe and reasonable USV path and driving scheme, and form an effective USV formation framework.

II. PREPARATION

A. Target assignment

As shown in Figure 1, it is assumed that three USVs named A, B, and C at any position need to go to designated locations 1, 2, and 3 to form a fixed formation.

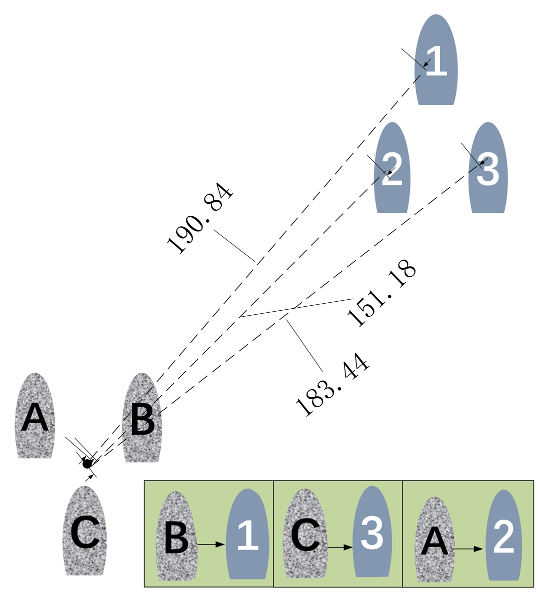

Figure 1. *Formation requirement scenario*

In Figure 1, A, B, C represent the current position of the USVs, and 1,2,3 represent the starting position of the formation. Point O represents the center position of the three USVs before path planning. The distance marked in the figure can be simply calculated according to the positions of the three USVs. It refers to the distance between the center point and the target point. In order to facilitate collision avoidance and shorten the time difference to the specified point, the priority of the target point is specified here. The target point farthest from the center point has the highest priority. The priority of the target point is ranked successively as target 1, target 3 and target 2. In turn, the target with high priority level is assigned according to the position of the current boat. According to the short-circuit allocation principle [12-14], B is the closest to target 1, so B matches target 1, and so on, C matches target 3, and A matches target 2.

The specific implementation steps are as follows.

Step 1: Obtain the current positions of USVA, USVB and USVC, denoted as PA, PB and PC, and the center position PO was calculated.

Step 2: Calculate the lengths of dO1,dO2, and dO3 according to the positions of the target points 1, 2, and 3, and then sorted to determine the priority of the target.

Step 3: Starting from the target point with the highest priority, the USV closest to the target point is assigned to it.

According to the above example, the target allocation of multiple USVs can also be realized.

B. *Formation strategy*

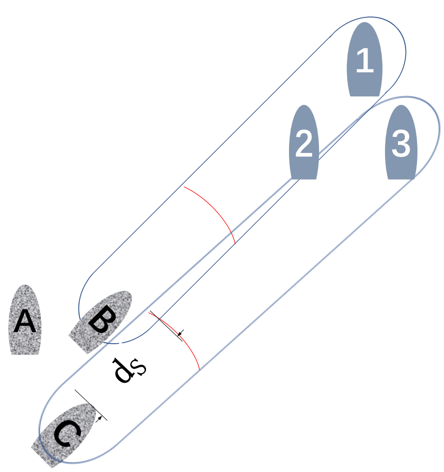

Figure 2. *Demonstration of the process close to the target*

In Figure 2, the USVB is heading towards target 1, while the USVC is heading towards target 3. Where dS indicates the set safe distance. To determine how USV can keep a safe distance to the target location, upon the completion of the target distribution, began to exercise track cross, ignore the low priority priority waterway channel disorder, low priority within the channel such as a priority channel is detected, indicating that the safe distance cannot be maintained. For the situation that the USV cannot pass safely, the USV with low priority among the two unmanned craft that have crossing risks should be delayed starting strategy until it passes safely.

The specific implementation steps are as follows.

Step 1: Assuming that the speed of the three USVs is the same, the sailing starts from the same time, and the sailing trajectory and time situation of the three UVs are deduced.

Step 2: To calculate the distance between USVs and other USVs at the same time in the deduced situation of their planned channel.

Step 3: If the distance between USVs at all times is greater than the safe distance dS, then the path planning is completed; otherwise, step 4 will be entered.

Step 4: To find the nearest crossing distance, calculate the required lag time according to the safe distance, start the USV with low priority delay, and then return to the first step.

Through the above target assignment and target approach, the framework of formation of USV formation can be realized. Next, specific algorithm ideas are given to achieve the above objectives, and experiments are carried out in the simulation environment.

III. FORMATION PATH PLANNING

A. *Establishment of water environment model*

In order to verify the waters, the feasibility of USV formation framework in a complex environment, this paper established the waters range specified in the simulation environment, set to 20 x20 grid environment, between the target area and the starting area three barriers are set up. In order to guarantee the safety of navigation of USV, this study on edge expansion process of obstacles, as shown in Figure 3, taking the first obstacle as an example, (5,16) is the actual obstacle position, and the expanded obstacle is a blue grid of size 3×3. Therefore, in the subsequent simulation results, even if the USV is sailing close to the edge of the expanded obstacle, it can ensure that the USV will not encounter the obstacle.

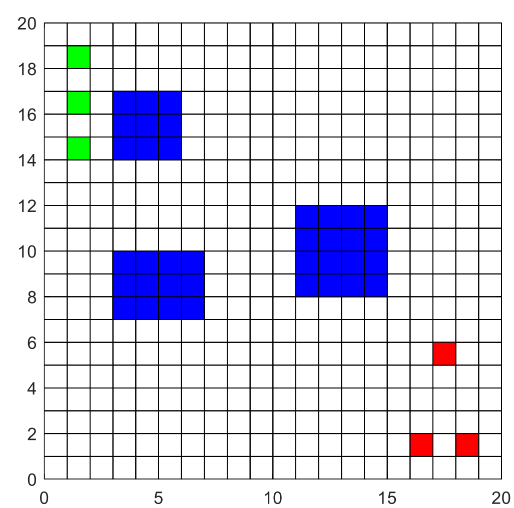

Figure 3. *Surface environment model*

B. *Path planning*

About obstacle avoidance path planning method, there are many mature algorithms such as particle swarm optimization (PSO) algorithm, A-star algorithm, artificial potential field method can be used, such as various kinds of heuristic algorithm in the presence of A static obstacles path planning is very effective, because this article research fleet formation framework is the focus of the study, so no longer compare and discuss the advantages of different algorithms, In this paper, A-star algorithm is selected as the basic algorithm for path planning [15]. Of course, other algorithms are also applicable here [16]. For the implementation of A-star algorithm, one can refer to the literature [17-19]. This article will not go into the detailed steps of A-star algorithm. Based on the simulation environment, this paper uses A-star algorithm for simulation. The path plan shown below is obtained.

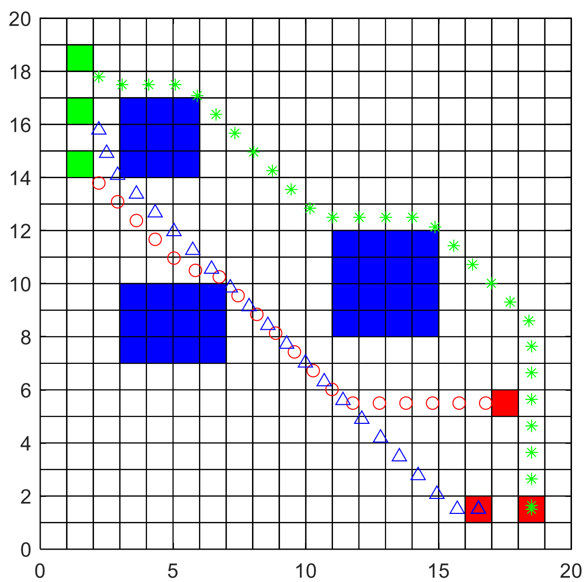

Figure 4. *Path planning results*

In Figure 4, the green point is the starting point of the three USVs, and the red point is the target point of the USVs, which is also the initial point of formation. The positions of USVs and target points in the figure are expressed in the form of coordinates. Without loss of generality, the distribution method is assumed to be (2,19) → (19,2), (2,17) → (12,2), (2,15) → (18,6). In the figure, the green asterisk represents the planned trajectory of the first USV, the blue triangle represents the planned trajectory of the second USV, and the red circle represents the planned trajectory of the third USV. The trajectory is generated according to a fixed step length, and it is assumed that the distance moved by the USV per unit time is the distance of a cell. Under the above conditions, three path sequences can be easily generated by comparing the planned trajectory. Finally, through the cyclic calculation method for each USVs, the path sequence is used to judge when the distance between USVs is less than the safe distance.

IV. SIMULATION

The specific execution process is shown in Figure 5.

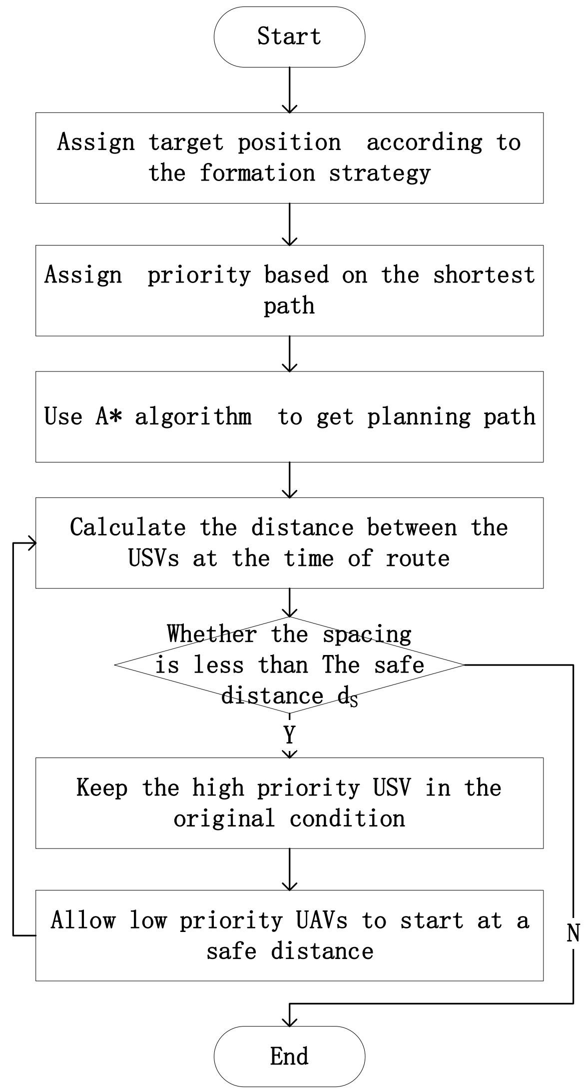

Figure 5. *Simulation flow chart*

The parameters of the USVs in this simulation environment are set in Table 1.

TABLE I. PARAMETERS OF USVS TABLE TYPE STYLES

USV	Initial position	Target position	Speed	Safe distance
USV1	2，19	19，2	v_1=1	
USV2	2，17	12，2	v_2=1	d_S=2
USV3	2，15	18，6	v_3=1	

There is no track crossing between USV1 and other USVs, so there is no need to consider the collision problem for USV1. There is track crossing between USV2 and USV3. After calculation, it can be found that the time of the nearest distance is at t7, and the distance is 1.4, which is less than the safe distance 2. Determine that the USV3 should depart at least 0.6 units of time later.

According to the simulation calculation. The USV1 path length is 28.14, the path length of the USV2 is 21.80, the path length of the USV3 is 19.73.

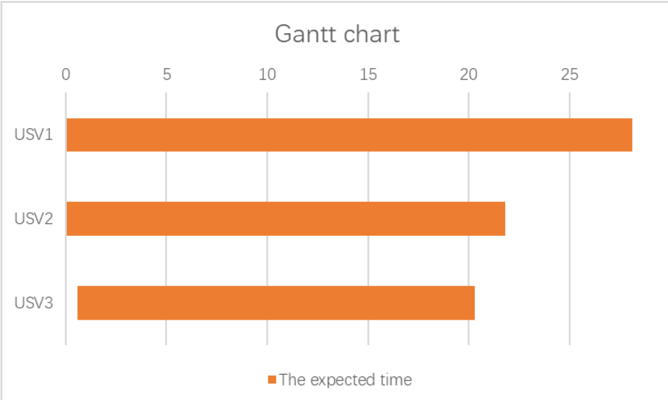

Figure 6. *USVs operation Gantt chart*

After drawing the above Gantt chart, it can be clearly seen that the startup time of each unmanned boat. In Figure 6, the startup time of USV1 and USV2 is 0, and the startup time of USV3 after 0.6 unit time can ensure that all three USVs can reach the destination safely.

Obviously, with the Gantt chart, many functions can be achieved, such as setting the same time to achieve, or changing the economic speed, to achieve the optimal solution of the cost function.

V. Conclusion

Here, the work of this study is all over. In order to solve the problem of formation of USVs, this study combined the path planning algorithm and the method of solving the shortest circuit, as well as the selection of the optimal allocation, made adjustments to the path planning problem of multi-USVs, and took three USVs as an example, and gave a specific formation framework.

The next work, in addition to the mathematical analysis and improvement of this research framework, is more important to keep the USV sailing in accordance with the agreed time and planned route, that is, the problem of precise control. The precise control of navigation trajectory will be analyzed in detail in other studies of our team.

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