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Study on a Two-layer Path Planning Method of Spherical Multi-robot

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***Abstract* - A path planning method based on a two-layer coordination system is proposed for the compatibility requirement of path planning global optimum and local coordination in a spherical multi-robot system. In the first layer of the algorithm, the global path quality is improved by proposing a nonlinear sine factor and a sparrow search algorithm with improved levy flight strategy to plan the global collision-free optimal path for each robot. In the second layer, a rolling window method is used to determine the possible collision positions of each robot in the system, and a priority-based conflict resolution strategy is proposed to complete the local coordination of the path near the corresponding position.The experimental results show that the path planning method enables the robots to drive along the global optimal path, but still can carry out flexible and orderly local path coordination, which effectively improves the path planning performance of the system.**

Index Terms - Spherical multi-robot; Two-level coordinated path planning; Improved sparrow search algorithm; Rolling window method

I. INTRODUCTION

The research in the field of multi-mobile robots has received more and more attention because multi-mobile robot systems are capable of complex tasks that cannot be performed by a single robot. Among them, the multi-robot path planning problem has been the basis and focus of research on multi-mobile robots. An effective multi-robot path planning method can effectively improve the efficiency of robots. There are many methods used for single mobile robot path planning, such as ant colony algorithm, genetic algorithm,etc[1]. Unlike single robots, in addition to issues such as length, smoothness and obstacle avoidance capability, multi-robot path planning also considers the coordination of collision avoidance among robots.

In recent years, the research on multi-robot path planning has been intensified, in which Shudong Sun used genetic algorithm to plan a multi-robot global path that can achieve coordinated collision avoidance, but it is difficult to adapt to the complex dynamic environment[2]; Wu Jin improved the artificial coordination field to cope with motion jitter and "deadlock" in coordination planning[3]; Chandrasekhar et al. used an improved krill swarm algorithm for coordinated path planning, but failed to verify the feasibility of the algorithm in dynamic obstacle environments[4].It can be seen that in the current multi-mobile robot path planning methods, it is difficult to cope with the real-time coordination of local paths using global planning algorithms, and it is difficult to form high quality global paths by methods that tend to local planning[11]. To address this problem, in the first layer a multi-mobile robot path planning system based on global and local two-layer planning is proposed, a spherical amphibious robot is realized along the global optimal path,the second layer uses the rolling window method to determine whether a collision will occur and applies different collision avoidance strategies for conflict resolution according to different collision types.

The second part focuses on the laboratory spherical multi-robot platform and its topology. The third part describes the problem of multi-robot path planning and establishes the environment model as well as the mathematical model. The fourth part proposes the conflict prediction of robots by rolling window method as well as the priority-based conflict elimination strategy. In the fifth part, the path planning steps and flowcharts of the multi-spherical amphibious robot are presented and simulated and analyzed. The simulation results show that the multi-robot path planning problem can be solved in such a way that the robots can travel along the global optimal path while still performing flexible and orderly local path coordination, avoiding the conflict problem between robots and effectively improving the path planning performance of the system.

II. THE PLATFORM OF SPHERE MULTI-ROBOT

The spherical multi-robot collaborative control system is shown in Figure 1. The communication between robots is based on Zigbee's Xbee wireless module for communication between robots, mainly using distributed structure. One single robot consists of several main parts, the upper part is wrapped with waterproof sphere shell, acrylic plate, and the basic hardware inside to control the movement are: Arduino Mega

2560 control board, servo driver board, motor driver board, LIDAR, ultrasonic sensor, GPS , OpenCV module and power module inside the sphere, and the lower part consists of liquid level switch, water spray motor and four groups of drivers. The ultrasonic sensor can be used to achieve close range obstacle avoidance and distance measurement of the robot, and the ultrasonic distance measurement module HC-SR04 is selected, with a detection range of 2cm to 450cm and an accuracy of about 3mm. The OpenCV module is mainly used for dynamic obstacle and robot identification in path planning and to prepare for the conflict coordination control among multiple robots.The control system is rich in motion modes. When the robot enters the water, it relies on the water jet motor to travel and its motor is less noisy and more stealthy in the military environment and it can realize the action of surfacing, diving and hovering in the water. When the robot is on land, it uses multi-degree-of-freedom motors to travel. The robot is divided into actuator, drive system, sensing system, and control system which ensures that the spherical amphibious robot can achieve free switching and easy action in different environments.

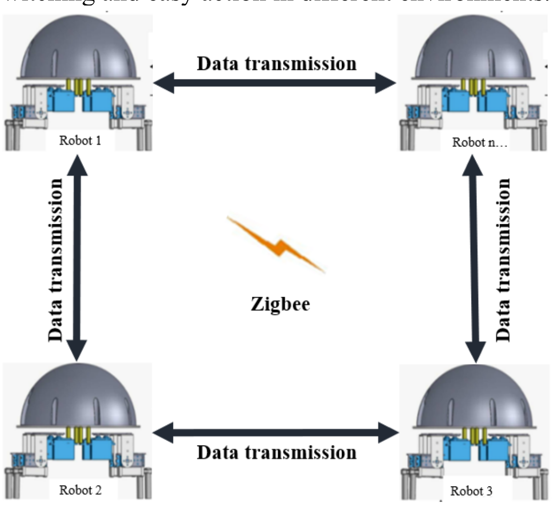


Fig. 1 The structure of spherical multi-robot cooperative control

III. PATH PLANNING OF SPHERE MULTI-ROBOT

A. Analysis of Sphere Multi-robot path planning

The working environment of a spherical multi-robot is a two-dimensional plane with several static obstacles in the environment. Let S={S1 , S2 , S3,......, Sn} denote the set of n static obstacles in the plane.The robot R={R1, R2,..., Rn},the starting point Start={Start1, Start2,..., Startn},the goal point Goal={Goal1 , Goal2 , ... , Goaln }and the information about the obstacles present in the plane is known to the robot.

The path planning of the multi-sphere robot is n robots in the plane solve a collision-free optimal path from the start point Start to the goal point Goal respectively[10].The start points are Start1, Start2, ... Startn goal points are Goal1, Goal2, Goaln. N mobile robots walk from the start point to the goal point along their respective planned paths and no collision can occur between the n robots.

Using the raster method to model the environment, a 20-row and 20-column map environment is used for the robot to walk with many static obstacles distributed in the map as shown in Figure 2. The robot travels in an octree structure.

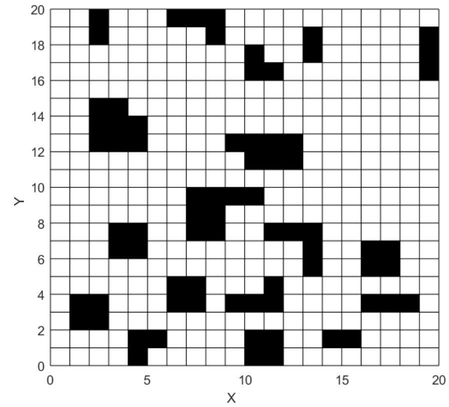


Fig. 2 The 20*20 working environment of spherical *Multi-robot*

B. Mathematical modelling of Multi-robot path planning

Multi-mobile robots operate in a static environment, using the raster method to create a model of the mobile robot's operating environment, according to the improved sparrow search algorithm to plan out the global path planning of each robot, mainly considering the path length, pause time two optimization indicators, the multi-robot cost function is：

$$f(x) = \min[f_1(x), f_2(x)] \tag{1}$$

Type (1): $f_1(x)$ is the the path length, $f_2(x)$ is Pause waiting time.

$$f_1(x) = \max(l_1, l_2, \cdots, l_n) \tag{2}$$

Type (2): l_n is the path length for robot R_n planning;

$$f_2(x) = \sum_{i=1}^{N} T_i \tag{3}$$

Type (3): T_i is the pause waiting time. for robot R_n planning;

Multiple spherical robots plan paths with the shortest possible paths and the shortest possible pause times for multiple robots[5]. In order to simplify the problem model to better explore the path planning problem of multiple mobile robots, the following assumptions and premises are given in this paper:

(1) Each spherical robot in the workspace has the same specification size and can operate normally without faults.

(2) Each spherical robot is considered as a mass point in the planning process, and their starting and target points are given in advance and are different from each other.

(3) Each spherical robot starts its task at the same time.

(4) The spherical robots run at the same speed and can only travel at a constant speed or pause directly without considering the transition time between two states.

IV. CONFLICT AND DISSIPATION STRATEGIES ON SPHERE MULTIPLE ROBOTS

In a multi-robot system, priority is set for each robot separately and when two robots are in conflict during travel, the priority rule plays a crucial role in coordinating the path planning of the two robots and the robot with high priority simply continues to travel along the original planned optimal global path, while the robot with low priority needs to avoid the high-level robot[12].

Considering the complexity of the robot in a dynamic environment,a dynamic priority assignment scheme is proposed to improve the optimal efficiency of the whole system when performing tasks[6].The dynamic priority assignment scheme is as follows:

Let the remaining path lengths of robots R1 and R2 on the static initial paths be L1 and L2 at a certain point in time. If the sensors detect conflicting parts of the motion paths of the two robots during the operation of the robots at this time, the calculation compares L1 and L2 and when the remaining untraveled path length is longer, this robot has a higher priority and vice versa, the shorter the remaining untraveled path length, the lower the priority. If L1>L2, the priority of this robot is higher. If L1>L2, the priority is PRI={R1<R2}, if L1<L2, the priority is PRI={A1>A2}.

A. Conflict of Sphere Multi-robot

There are three main types of motion conflicts between multiple spherical robots in static environments as shown in Figure 3,4,5.

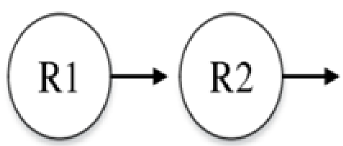


Fig.3 Isotropic motion conflict

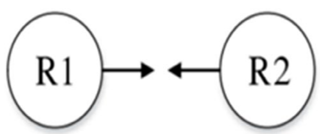


Fig.4 Reciprocal motion conflict

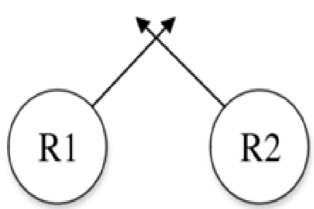


Fig.5 Intersecting motion conflicts

(1)When no robot is detected in the robot's rolling window or the robot's trajectory is parallel, there is no possibility of robot collision[8]. In this paper, the speed of robots is specified to be the same, so there is no possibility of robot collision.

(2)When there is a moving robot in the robot's scrolling window, the robot's trajectory coincides with the current robot's trajectory and moves in opposite directions, there must be a collision between the robots[13].

(3)When a moving robot is detected in the robot's scrolling window and the robot's trajectory intersects with the current robot's trajectory, there is a possibility of collision between the robots.If $\left|\frac{L_{R1}}{V_{R1}}-\frac{L_{R2}}{V_{R2}}\right| < \Delta t$ the time difference between the two robots is very small and not within the safety range, the robots will collide with each other. Conversely, if $\left|\frac{L_{R1}}{V_{R1}}-\frac{L_{R2}}{V_{R2}}\right| > \Delta t$ means that the robots will not collide with each other.

B. Coordination strategy for multi-robot path planning

For the different collision situations of spherical robots, two path coordination strategies are proposed in this paper: pause and wait strategy and local path replanning strategy. For the case of intersecting motion that is not in the same line, the robot can adopt the two strategies of pause and wait and local path replanning for local collision avoidance, while in the case of phase motion, two robots move in the same line and their paths overlap, the collision problem cannot be solved by using the pause and wait strategy, and only the local path replanning strategy can be used to make one of the robots change its path so as to achieve collision avoidance[7]. The two coordination strategies are described in detail below.

(1) Pause and wait strategy:

When two spherical robots do not move in the same straight line, the robot's rolling window predicts that an intersecting collision will occur between the robots,the robot with low priority needs to make a concession to the robot with high priority. In this case, the collision strategy is based on a pause and wait strategy, the robot with low priority needs to wait for a step in place while the robot with high priority continues along the planned path, thus successfully coordinating the collision conflict between the two robots.

(2) Local Path Replanning:

When two spherical robots travel in the same straight line and move in opposite directions, a collision conflict must occur between the robots at this time. Again, the selection of obstacle avoidance is based on the priority of the robots and for the robot with low priority, the spherical robot with high priority is then seen as a static obstacle and the local path of the robot with low priority is modified to solve the collision conflict[9]. The basic principle of the local path replanning strategy is that when the rolling window of the robot with low priority detects the appearance of the high priority robot at when a step distance from the collision point, the low priority robot replans a local path with the adjacent point of the collision point as the target point and then the low priority robot travels along this local path, while the high priority robot travels along the planned optimal global[14].The low-priority robot then follows this local path while the high-priority robot continues to drive along the planned optimal global path, thus successfully coordinating the collision conflict between the two spherical robots.

V. Path Planning Steps and Simulation Analysis of Sphere Multi-robot

In this paper, a two-layer coordinated planning approach is used for multi-robot path planning. The first layer uses an improved sparrow search algorithm to plan the shortest global path for each robot from the starting point to the end point and the second layer uses a rolling window method to perform conflict prediction and assign the conflict types between robots and finally use a conflict resolution strategy to perform conflict resolution. In this paper, a two-layer coordinated planning approach is used for multi-robot path planning. The flow chart of multi-robot inter-planning planning in static environment is shown in Figure 6.

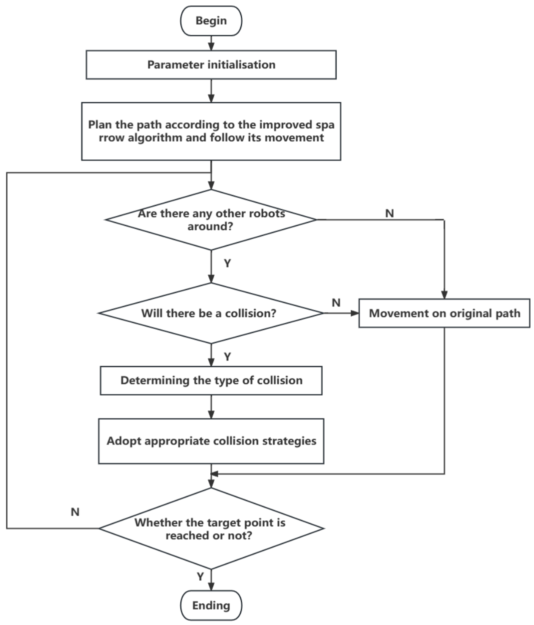


Fig. 6 The flow chart of multi-robot path planning

In this paper, we simulate a multi-robot path planning algorithm in a 20*20 static environment on a MATLAB platform.There are two identical spherical robots in the environment, denoted as R1 and R2 and the coordinates of the starting point and target point of R1 are (1.5, 1.5) and (14.5, 15.5), the coordinates of the starting point and target point of R2 are (1.5, 17.5) and (14.5, 8.5), the robots travel at the same speed, the radius of their rolling windows are both 2 times the step length, the environmental information are the same as described in Section 3.The global initial path planning of R1,R2 for each of the two robots using the improved sparrow search algorithm ignoring the other robots as showm in Figure 7. The red dashed line shows the initial path of R1 and the blue dashed line shows the initial path of R2 where the two paths have intersection points.

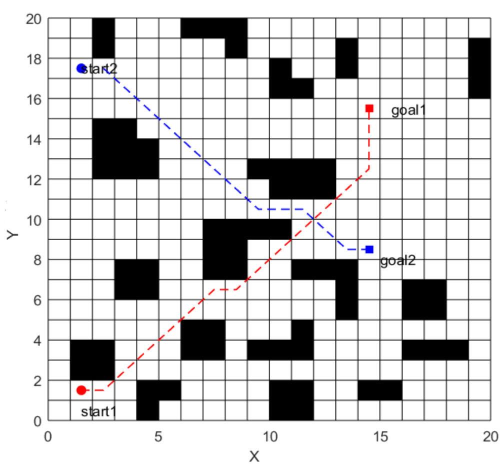


Fig. 7 The global initial path planning of R1,R2

At a certain point, both robots discover each other's existence through the scrolling window and at this time, if both robots move according to the original path, they will have intersecting collision conflicts that are not in the same line, as shown in Figure 8.

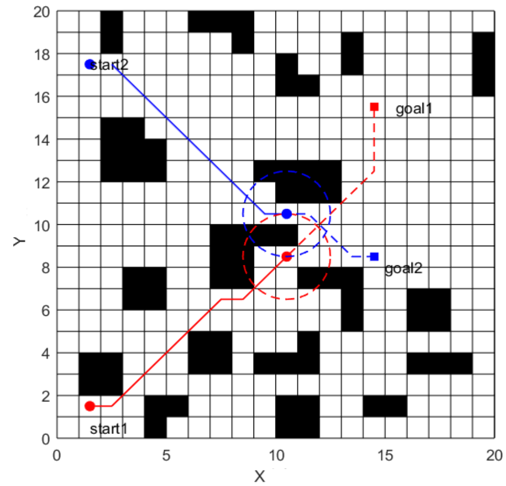


Fig. 8 The Path conflict between R1,R2

At this time, the robots exchange information among themselves and assign the priority of the two robots according to the remaining length on their respective initial paths. By judging this, we can see that the remaining path length of the robot is longer than the remaining path length of robot 2, so we can tell that the priority of robot 1 is higher than that of robot 2. The robot with a low priority will avoid the robot with a high priority, R2 will pause and wait, and R1 will travel on the original path. This means that the R1 robot does not change its motion and has priority to pass the collision point, while R2 waits before the collision point, as shown in Figure 9.

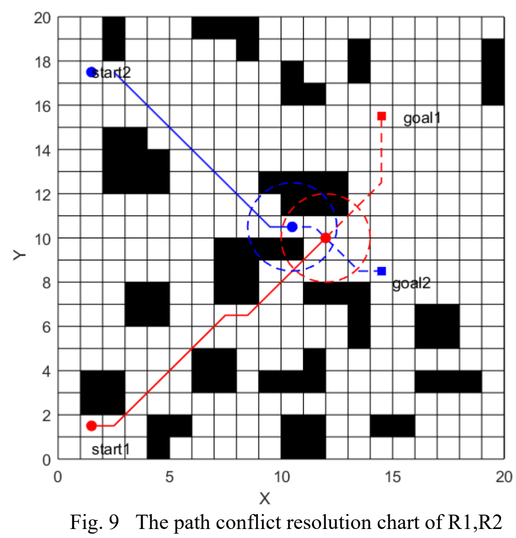


Fig. 9 The path conflict resolution chart of R1,R2

When the intersecting conflict between robot 1 and robot 2 is dissolved after the conflict is dissolved by the conflict dissolution strategy, R1 and R2 continue to travel further on the original path, and R1 and R2 have reached the target point, as shown in Figure 10.

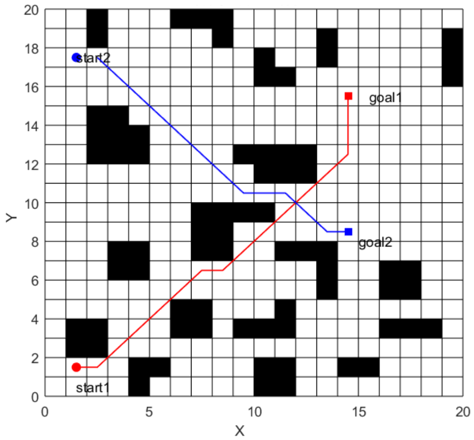


Fig. 10 The final path planning of R1,R2

When three identical spherical robots exist in a 20*20 static environment, denoted as R1, R2, R3, the coordinates of the starting point and target point of R1 are (15.5, 5.5), (2.5, 17.5), the coordinates of the starting point and target point of R2 are (3.5, 4.5), (15.5, 13.5) and the coordinates of the starting point and target point of R3 are (8.5,4.5), (16.5,9.5). The initial paths of R1,R2,R3 are shown in Figure 11.The red line shows the global path of robot R1, the blue line shows the global path of robot R2,the green line shows the global path of robot R3.

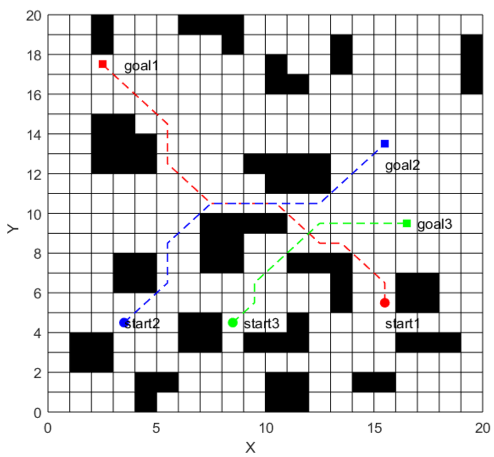


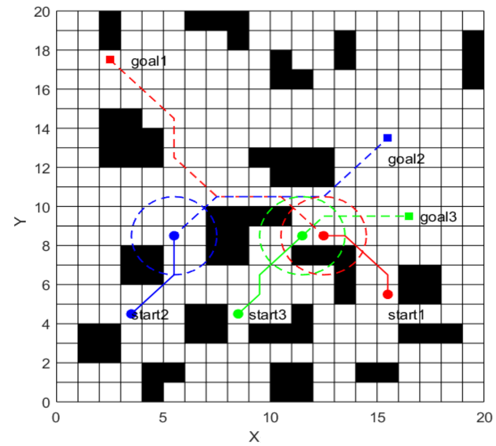
Fig. 11 The global initial path planning of R1,R2,R3

The conflict between the three spherical robots and the dissipation are shown in Fig.12. At a certain point, the rolling windows of R1 and R3 predict that they are about to collide as shown in Fig.12-(a).

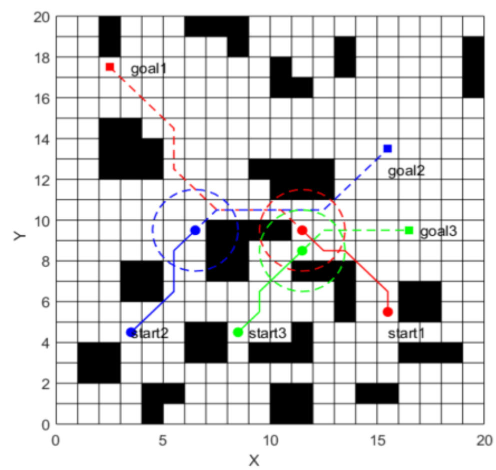
At this time the distance from R1 to the target point E1 is greater than the distance from R3 to the target point E3, according to the priority rule, R1's priority is greater than R2's. R1's driving route is not in a straight line with R3, and the collision type is intersecting collision, and according to the multi-robot coordination strategy, R3 chooses the pause and wait strategy at this time. R3 waits in the same place,R1 and R2 continue to move forward on the original path as shown in Fig.12-(b).

The rolling window of R1 and R2 predicts that the robots are about to collide, as shown in Fig.12-(c). Since the distance from R1 to the target point E1 is greater than the distance from R2 to the target point E2 at this time, the priority of R1 is greater than R2. and R1 and R2 are traveling in opposite directions, the local path replanning strategy is selected as in Fig.12-(d).

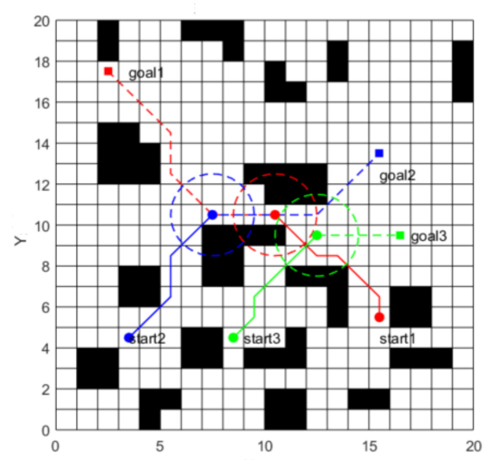
R2 plans a local path that avoids R1 at this time and then travels along this path,while R1 as a high priority robot continues to travel along the global optimal path. This is shown in Fig.12-(e).



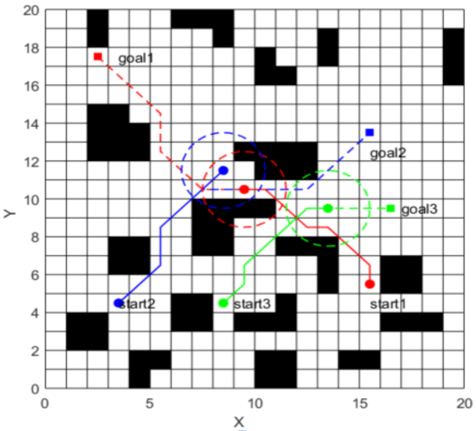
(a)The conflict detection of R1 and R3



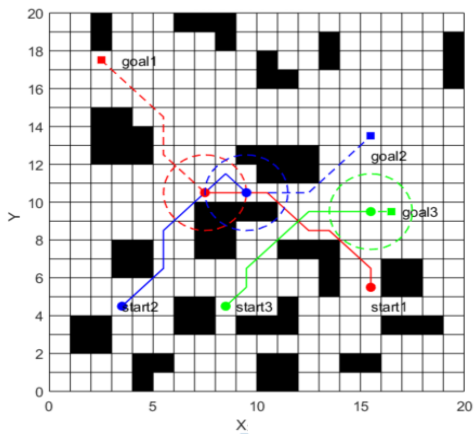
(b)The conflict resolution of R1 and R3



(c)The conflict detection of R1 and R2



(d)R1 the original path and R2 path replanning



(e)The conflict resolution of R1 and R2

Fig. 12 Conflict and dissolution of R1,R2,R3

The final path trajectories of the three robots in a given 20*20 environment are shown in Fig.13. Where the red line is the path of robot R1, the blue line is the path of robot R2 and the green line is the path of robot R3.

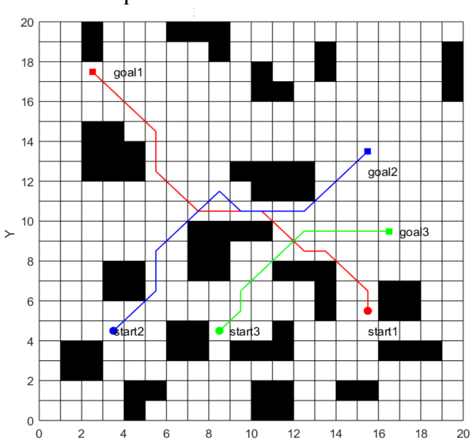


Fig. 13 The final path planning of R1,R2,R3

The simulation analysis of different number of robots in the same environment shows that the proposed robot based on priority motion can make the robot's path conflict problem well solved by the double-layer coordinated path planning algorithm and coordinated collision avoidance strategy.

VI. Conclusions and Future Work

This paper proposed a two-layer path planning algorithm, the first layer completes the global path planning layer, the second layer used the rolling window method to determine whether a collision will occur according to different collision types to apply different collision avoidance strategies for conflict resolution, so that the spherical amphibious robot can travel along the global optimal path while solving the conflict problem between spherical robots. Finally, the spherical multi-robot independently developed by the group was tested and the results fully verified the feasibility of the method in practical engineering and further improved the cooperative operation capability of the multi-mobile robot system.

Future research will continue to expand the study of practical application scenarios. The environment in this paper is two-dimensional space, while future research in three-dimensional space environment will also face more challenges.

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