Robot Trajectory Planning based Attack and Defense Strategy for Water Polo Confrontation

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Abstract. Taking account of the attack of the enemy fish and disturbance of water waves generated in the water polo match, the fish head wiping the ball due to displacement of the target ball often occurs. In this paper, a tail sweeping based double fish alternate attack strategy is proposed. In this strategy, ball attack can be achieved by any part of the fish body, and it assures that the hitting of the ball no longer dependents on the fish head only, thus improves the robustness of the attacking scheme. Furthermore, as the short distance requirement for posture adjustment provides valuable time for the strategy of double fish alternation, we add the opponent fish attacking movement in the return phase. The experimental results show that the goal attack time of the tail sweeping strategy is shortened by 38.5% (single fish) and 66.9% (double fish alternation) respectively, which proves the performance efficiency of this strategy.

1. Introduction

The water polo 2V2 in the International Aquatics Robot Competition (from 1997 to now) is a highly competitive project[1], in which the bionic robot fish is often employed. Similar to robot soccer, the teams can obtain the real-time coordinates of both sides fishes and water polo ball through the global CCD camera, and the team with more goals into the opponent's net will be the winner.

For the ball-pushing design of robot fishes, Literature [3] proposes a region division based strategy that divides the field into 8 types of regions, and designs the fish posture adjustment in according regions. Literature [4] proposes the Algorithm of Cut Round Push Ball, which delimits the cut in circle for the fish, drives the fish to move to the boundary of the driving circle, and then moves along the cut in circle to the ball jacking point. It is an accurate ball jacking method. In literature [5], it is found that the robot fish is often affected by the disturbance of water wave when performing the tracing action, which leads to the deviation of the position between the fish and the target ball. A long-distance
posture adjustment scheme is proposed which enhances the robustness of the scheme. However, it takes longer time to adjust the posture and is not conducive to quick attack\cite{6}.

We find that the problem of the fish head passing the ball is due to the small contact area of the fish head in which the deviation of the water polo ball may cause the fish head to miss. Therefore, this paper proposes a tail sweeping based ball jacking method, which makes use of the larger contact area of the fish body and greatly weakens the requirements of the fish head for posture adjustment, and thus improves the robustness of attacking the ball. Furthermore, in the return phase of the end of the attack, a defensive strategy of attacking the opponent fish is designed, which not only takes advantage of the short-term posture advantage brought by the tail-sweeping, but also introduces the confrontation with the opponent fish into the strategy of 2v2 project for the first time.

2. Bionic robot fish

Bionic robot fish mainly consists of fish head, fish body and fish tail. The fish head is composed of control circuit board, battery, communication module, power switch and pectoral fin while the fish body consists of three joints. A global vision sensor is integrated in the field to identify the position coordinates of the robot fish and water polo ball for both sides. The bionic robot fish has 15 speed gears and 15 direction gears. The higher the speed range, the faster the speed. Its direction gear is divided into two parts, 0-6 for left turn, 7 for direct travel, 8-14 for right turn. During the competition, the fish body is moved forward by constantly wagging its tail.

3. The tail-sweeping strategy

In the actual competition, we find that the precise way of ball jacking takes a lot of time to adjust the posture. This period is crucial, because when we adjust our posture, the enemy may have gained the first opportunity to reach the vicinity of the water polo ball and launch an attack, and we may fall into the unfavorable situation of passive pursuit. In addition, the water waves generated in this process are large, which may cause the ball to drift. In view of the above problems, this paper proposes an optimized ball jacking method, the tail-sweeping method, and the strategy of double fish alternate tail sweeping. Since the tail-sweeping method does not require precise posture adjustment, it can be used to reduce the time for the fish to adjust the posture. The double fish alternate tail sweeping method enables the two fish to take the ball jacking in turn and attack the enemy fish, which can alternate the ball jacking more efficiently.

3.1. Method of tail-sweeping ball jacking

We propose a method of tail-sweeping ball jacking that does not require precise posture adjustment, that is, when the fish is close to the ball, it uses the side of the fish to hit the ball to make the ball move towards the enemy’s goal. The sketch map of the tail sweeping is shown in Figure 1. The specific settings are as follows: set P as the center of the circle, the distance r1 between P and the center of the ball B as the length of a fish (It is observed from the match that such a distance setting is the best distance for the fish to sweep the ball, so that the fish has a certain buffer before reaching the ball, avoiding the situation that the fish can't reach the ball or just circle the ball when turning), and the circle region Ω 1 with r2 as the
radius as the "tail-sweeping control area"; set the radius of the ball as R, and the coordinate of the fish head as headP_fish, where r2=1/2*r1. The tail-sweeping process is described as follows,

1. The fish swims towards the point P when it is not in the Ω1 area, and the direction of the fish head is shown as dir1 in Figure 1.

2. When the fish head coordinate headP_fish enters the Ω1 area, the target point of the fish is immediately converted to the ball center B, and the fish swims towards the ball center B. The direction of the fish head is as shown in dir2 in Figure 1.

3. When the fish head coordinate headP_fish leaves the Ω1 area, the target point of the fish will be changed to P point again. At this time, the fish will have a big turning action, which will cause the side of the robot fish to hit the ball. The trajectory of the fish is shown as Route1 in Figure 1. Such a route setting ensures the efficiency of our head ball and avoids a lot of time spent in adjusting the posture.

4. When the fish head coordinate headP_fish re-enters the Ω1 area, repeat the above action to complete the circular tail-sweeping action until the ball is swept into the goal.

3.2. Double fish alternate tail-sweeping strategy

Since the global visual water polo 2v2 competition is the two teams to control the two fish in the team to fight and hit the ball respectively, the cooperation between the two fish is also the necessary condition to win the game. We put forward the method of "double fish alternately sweeping the tails and jackening the ball". One fish attacks the ball and the other drives the enemy fish that is coming to attack in the process of swimming back. The two fish in the team circulates alternately until the ball is pushed into the opponent’s goal. The two fish alternate the action of "sweeping the tail" and "attacking the enemy", which can achieve periodic defense and attack. The strategy is shown in Figure 2.

We set it as a period that each fish heads the ball once. An alternate attack and defense cycle is divided into the following steps:
1. At time T1, select fish 1 to go to point P, and fish 2 to target the center coordinates of the opponent's fish and move to attack the enemy fish.

2. At time T2, when the fish head coordinate of the fish 1 reaches the $\Omega_1$ area, the target point of the fish 1 is changed to the ball center B. The fish 2 completes the attack on the enemy fish, and is ready to advance to point P.

3. At time T3, when the fish head coordinate of fish 1 has left the $\Omega_1$ area, and the tail sweeping action is started, the fish head coordinate of the fish 2 head$_{fish2}$ reaches the vicinity of the $\Omega_1$ area.

4. At time T4, when fish 1 completes the tail sweeping action, its target point is turned to the center point of the nearest enemy fish. The target point of fish 2 is changed to the ball center B, and the tail sweeping action is started. Subsequently, fish 2 completes the tail sweeping action and prepares to attack the enemy fish. Fish 1 returns to point P and is ready for tail-sweeping.

According to the above steps, the alternating head ball of the next cycle was carried out. This way of alternating head ball effectively reduces the time spent on adjusting the posture of the two fish. In the time interval when one fish finishes the tail sweeping action and swims back to the P point, the other fish catches up after attacking the enemy fish and keeps attacking the ball to complete the periodic continuous attack. The strategy process is shown in Figure 3:

**Figure 2.** Sketch of double fish alternate tail-sweeping strategy.

**Figure 3.** Strategy flow chart of double fish alternate tail-sweeping.
4. Experiment

Two groups of tests were carried out on the water polo 2v2 global visual competition platform: single fish tail sweeping strategy and double fish alternate tail sweeping strategy. Because the long-distance posture adjustment strategy [5] and the strategy we put forward represent two kinds of batting ideas, both of which include single fish hitting and double fish alternating, we compared the two strategies in each test group to check out the time spent in scoring and the number of goals scored in five minutes.

First, we configure the single fish tail sweeping testment as follows: the ball is initially located at the focal point of the pool diagonal; the fishes start from random position, and the speed is set to 15 (maximum speed). The number of goals scored in five minutes are recorded. The experimental results are shown in Table 1. The average goal time of the long-distance posture adjustment strategy is 78.4 seconds, and is 56.6 seconds for our scheme, with a compression ratio of 38.5%. The number of goals scores in five minutes is 3 and 5, respectively. It can be seen that the single fish tail sweeping strategy has a higher offensive efficiency.

| Table 1. Performance of tail sweeping and posture adjustment strategy (single fish) |
|---------------------------------------------------------------|
| Single fish strategy | Goal time | Goals scored in five minutes |
|----------------------|-----------|-------------------------------|
| Long-distance posture adjustment | 78.4 | 3 |
| Tail sweeping strategy | 56.6 | 5 |

The initial configuration of the double fish alternate tail-sweeping strategy is the same as that of the single fish test. As shown in Table 2, the average goal time of the long-distance posture adjustment strategy is 72.6 seconds, and our scheme compressed it to 43.5 seconds with a compression ratio of 66.9%. The number of goals scored in five minutes was 3 and 6. It can be seen that there is no change in the number of goals after the introduction of double fish alternation in the long-distance posture adjustment strategy, while the strategy based on the tail sweep has scored one more goal in five minutes, and the number of goals has increased by 20%, which is desirable for the match. It is further seen that the double fish tail-sweeping strategy is more efficient in attacking, due to the fact that the tail-sweep strategy saved much time compared with the long-distance posture adjustment strategy. In the actual competition, the long-distance posture adjustment strategy needs to increase the distance between the pre-attack point and the ball in order to meet the needs of accurate posture adjustment. Once the opponent gains the ball right in the attack, the return distance of one’s own side will increase with the ball, which will lead to the passive deterioration.

| Table 2. Performance of tail sweeping and posture adjustment strategy (double fish). |
|---------------------------------------------------------------|
| Double fish alternative strategy | Goal time | Goals scored in five minutes |
|---------------------|-----------|-------------------------------|
| Long-distance posture adjustment | 72.6 | 3 |
| Tail sweeping strategy | 43.5 | 6 |
5. Conclusion

Single fish tail-sweeping can enable the fish approach the ball quickly in different positions and reduce the time of posture adjustment, while the double fish alternate tail-sweeping can make the two fish cooperate closely, so that the attack of the two fish has continuity and can score faster in different situations. Experiments have proved the effectiveness of the strategy. Using the method of double fish alternate tail-sweeping attack proposed in this paper, Beijing Information Science and Technology University won the second prize in the 2V2 project of the robot fish water polo in the 2019 URC International Water Robot Competition, and the scheme was verified.

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