Research on Collision Avoidance Method for Underwater Robot Based on Role

Yi-yang HUANG, Shu-qin LI*, Jie FANG, Bo-wen SHI and Hui MIAO
School of computer science, Beijing Information Science and Technology University
*Corresponding author

Keywords: Underwater robot fish, Role, Collision avoidance algorithm.

Abstract. Based on URWPGSim2D simulation robot fish platform, the collision problem of fish collaboration often occurs in the process of completing the simulation project. In this paper, a collision avoidance method for underwater robot based on role is studied. The robot fish that is about to collide is divided into two parts, the right fish and the duty fish, and the right fish continues to move in the original direction while the duty fish avoids the right fish by deflecting a certain angle, and then goes to the original direction after deflection. In this paper, the collision of robot fish is divided into two cases and the collision avoidance algorithm is designed and implemented respectively. The experimental results indicate that the collision avoidance algorithm based on role for underwater robot achieves the effect of fast collision avoidance. This algorithm can not only be applied to the robot fish, but also can be applied to ship water collision avoidance and other anti-collision applications, which has high expansibility.

Introduction

International Underwater Robot Contest is the first world robot match sponsored by the Chinese and it has been continuously held for 10 sessions from 2008 to 2017. It has high technology content, wide subjects, far-reaching research significance and strong display and other characteristics, which has attracted many well-known universities at home and abroad. Among them, the competition for the underwater robot simulation team does not need to invest massive hardware facilities and is easy to realize. Many schools take the robot simulation competition as the breakthrough point and join in the big family of robot competition gradually.

According to the document [1], the underwater robot simulation team adopts underwater robot water polo simulator 2D version software (Underwater Robot Water Polo Game Simulator 2D Edition, URWPGSim2D) as the competition platform. At present, the simulation contest of the simulation team includes 4 projects: survival challenge, water transportation, snatch ball game and synchronized swimming and each project requires at least 2 fish to work in coordination to complete the action. It has been observed that it is very easy for multiple fish to collide when they complete the action so that they cannot reach the predetermined motion as shown in Figure 1. and Figure 2. Therefore, it is worth studying how to make robots avoid collision and avoid collision quickly as far as possible in the process of completing the task.

Figure 1. Fish predecessor collision.

Figure 2. Fishtail collision.
In the document [2], underwater robot adopts the path planning method based on the target area to overcome the problem that the simulation robot fish cannot reach the target point accurately due to the disturbance of water fluctuation. The document [3] designs a graphic action of nine fish to make fish reach different destinations to avoid collisions by preventing the destination for a synchronized swimming project. The two documents are both related to the cooperation between fish and fish, but they cannot solve the problem of collisions between fish and fish perfectly. Therefore, based on the developer manual provided by the document [4] platform and ship collision avoidance and path optimization in open water area based on the ship obstacle avoidance research provided by the document [5]. A path planning collision avoidance method for underwater robot based on role is designed, which can help the team to solve the collision problem when the fish cooperate with each other.

**Thought of Collision Avoidance Algorithm for Underwater Robot Based on Role**

Firstly, the swimming situation of robot fish in the simulation platform is observed. When the distance between the two-robot fish Fish1 and Fish2 is small to a certain range, it is considered that the possibility of collision between two fish is greatly increased. The role of fish is defined according to the two-fish swimming direction, which is called right fish and Voluntary fish. The right fish continues to move in the original direction while the voluntary fish avoids the right fish by deflecting a certain angle, and then goes to the original direction after deflection. The specific algorithm flow is shown in figure 3.

![Flow chart of path planning collision avoidance algorithm for underwater robot.](image)

**Design and Implementation of Collision Avoidance for Underwater Robot Based on Role**

**The Definition of Robot Fish Role**

2D model definition of a simulated robot fish in URWPGSim2D competition platform [1], the structure and size are basically consistent with the proportion of a hypostatic robot fish. As shown in Figure 4. It consists of a curved head, a rectangular body, three isosceles trapezoid based length decreasing fishs tail with end to end connection, a slender rectangular tail fin and two right triangles pectoral fin. And the head radius of the fish head is 22mm; the length of the fish body is 160mm, and the width of it is 45mm; the color of the fish body is red by default, the same team simulated the same
color of a robotic fish; the color of the fish body number is black by default; the platform tells the rigid fish body X coordinates, Z coordinates, and the direction.

![Figure 4. 2D simulation fish.](image)

**Definition: Duty_fish and Rights_fish**

Fish1 and Fish2 were calculated in two body motion direction and the angle between two rigid connection center line segments, denoted as angle_a and angle_b. The fish with small angle is called Duty_fish, and the fish with large angle is called Right_fish. The concrete steps are as follows:

1. **Step 1:** Fish1 rigid body coordinate A (xa,za) and direction angle_a, Fish2 rigid body coordinate B (xb,zb) and direction angle_b are obtained respectively.
2. **Step 2:** The linear equation of the current path of Fish1 and Fish2 in the platform coordinate system is obtained.
   
   \[
   y = \frac{ka \times x + za - ka \times xa}{ha \times x + zb - ha \times xb} 
   \]

   Step 3: The direction vectors of Fish1 and Fish2 are obtained by the linear equation.

   With rigid center Fish1 and Fish2 as the starting point, the two factors of the two linear equations of the fish and the fish direction in the platform quadrant, find a point in front of the current path of Fish1 (XA1, za1). Similarly, Fish2 finds a point (xb1, zb1) to obtain the direction vector (xa1-xa, za1-za) of the Fish1 and the direction vector (xb1-xb, zb1-zb) of the Fish2.

   **Step 4:** The angle_a and angle_b are obtained by the direction vectors of Fish1 and Fish2.

   \[
   \text{angle}_a = \cos^{-1} \left( \frac{(xa1-xa) \times (xb-xa) + (za1-za) \times (zb-za)}{(xa1-xa)^2 + (za1-za)^2} \times \sqrt{(xa1-xa)^2 + (za1-za)^2} \right) 
   \]

   \[
   \text{angle}_b = \cos^{-1} \left( \frac{(xb1-xb) \times (xa-xb) + (zb1-zb) \times (za-zb)}{(xb1-xb)^2 + (zb1-zb)^2} \times \sqrt{(xb1-xb)^2 + (zb1-zb)^2} \right) 
   \]

3. **Step 5:** Compared the size of angle_a and angle_b, if angle_a is less than angle_b that Fish1 is Duty_fish, and Fish2 is Right_fish; If angle_b is less than angle_a that Fish1 is the Right_fish, and Fish2 is the Duty_fish.

**Collision Situational Classification**

In this paper, the body is divided into two parts by the center of the rigid body. The part before the center of the rigid body is denoted as Fish_forward, and the part behind it is Fish_back. We recorded as case 1 if two Fish_forward have the possibility of a collision. In addition, a fish's Fish_back may collide with another fish's Fish_forward, recorded case 2. In this paper, the cross product is used to distinguish the case 1 and the case 2, and the cross product is perpendicular to the plane formed by two vectors. The direction vector of Fish1 and the direction vector of Fish2 have the same plane S.

The direction vector of Fish1 fish is \((xa1-xa, za1-za)\), and the direction vector of Fish2 fish is \((xb1-xb, zb1-zb)\). The definition of right_fish center as a starting point and duty fish center as an ending point for vector \(\rightarrow\), let the vector \((xa-xb, za-zb)\) respectively with the direction vector of the Fish1 do the cross product to get PA, with direction vector of Fish2 do the cross product to get PB. Formula is as follows:

\[
PA = (xa-xb) \times (za1-za) - (za-zb) \times (xa1-xa) 
\]

\[
PB = (xa-xb) \times (zb1-zb) - (zb-zb) \times (xb1-xb) 
\]

If PA and PB are same symbol, indicating that PA and PB are the same side of S. Because of the cross product in the same vector \(\rightarrow\), the Right-hand grip rule shows that the direction vector of Fish1
and the direction vector of Fish2 is in the same sides of vector $\vec{BA}$, that is Fish_forward and Fish_forward for the collided, which is the case of 1. On the contrary, if PA and PB are different symbols, the direction vector of Fish1 and the direction vector of Fish2 are on the different sides of vector $\vec{BA}$, indicating that Fish_forward collided with Fish_back, which is the case of 2.

**Algorithms of Different Collision Avoidance**

The Right_fish continued to go in its original direction. The Duty_fish avoids the Right_fish by deflecting a certain angle, and then going to the original direction after the deflection is completed. In order to obtain the actual deflection angle $t$ of the Duty_fish, different algorithms are adopted in different situations. The fish body is represented in solid line with a length of $L$. It is assumed that the line between the center of the rigid body Duty_fish and the center of the rigid body Right_fish, and the angle between the direction of the Duty_fish is $\angle a$, and the angle between the direction of the Right_fish is $\angle b$.

**Situation 1: Fish_forward collide Fish_forward**

In order to make the two fish in the direction of movement of the extension line has no intersection (i.e. the collision point), Duty_fish need to rotate angle $t$ that was parallel with Right_fish. As shown in figure 5. The calculation formula of rotation angle $t$ is as follows:

$$t = 3.14 - \angle a - \angle b$$

![Figure 5. Case1 deflection angle model.](image)

**Situation 2: Fish_back collide Fish_back**

Because of Fish_forward collided with Fish_back, it is necessary to let Duty_fish swim behind the tail of Right_fish. Extended line with Duty_fish direction, extended line with opposite direction of Right_fish, intersect at point $o$. The connection line between $o$ and Duty_fish rigid body is $c$. Make circle with radius $r$ by $o$, define the circle as the danger zone for two fishs collision. Duty_fish turns the danger zone out of the tail of the Right_fish by rotating the $t$ angle. End the model. The end judgment condition is that the $y > r$ indicates that the Right_fish tail has been out of the danger zone, they will not have the possibility of collision.

As shown in figure 6. The calculation formula of rotation angle $t$ is as follows:

1. The value of $y$ by sine formula: \[
\frac{a}{\sin a} = \frac{b}{\sin b}, \text{available solution } y = \frac{(L+y)}{\sin(a+t)} = \frac{\left|BA\right|}{\sin(\angle b-\angle a-t)}
\]

2. In order to calculate the deflection angle $t$, we need the value of $c$, and the value of $c$ is derived from cosine formula: \[
c = \frac{(t+L)^2 + \left|BA\right|^2 - 2 \cdot \left|BA\right| \cdot \cos(\pi - \angle b)}{2 \cdot \cos(\pi - \angle b)}
\]

3. We use cosine formula to find $t$:

$$t = \frac{\cos^{-1}\left(\frac{x^2 + y^2 - (x+L)^2}{2xy}ight)}{2\cos(\pi - \angle b)} - \angle b$$
Experiments and Operation Results

This experiment uses URWPGSim2D simulation robot fish platform, VS2015 development software and c# language to write collision avoidance algorithm for underwater robot based on role. In this experiment, we use the platform synchronized swimming project to do experiments on the swimming process of fish No. 2 and No. 3. We test two cases of fish collision avoidance separately, which are divided into experiment 1 and experiment 2. During the test, the excel table returned by the platform collects the movement data of the fish every 1 second during the driving process, and then the data is imported into the testing program. The rationality and validity of the algorithm are verified by comparing the movement status of fish in the moving process and the results of testing program. In the model, the parameter setting risk distance is $x=500$ (unit distance), the radius of danger zone is $r=300$ (unit distance), and the length of fish is $L=500$ (unit distance).

**Experiment 1 situation 1 experimental results show**

Figure 7. 9:12s fish No. 3, fish No. 2.
Figure 8. 9:10s fish No. 3, fish No. 2.
Figure 9. 9:08s fish No. 3, fish No. 2.

At 9:12s, fish No. 2 and No. 3 go forward in their respective directions. Fish No. 2 is determined as the voluntary fish, and No. 3 fish is determined as the right fish. At 9:10s, fish No. 2 starts to deflect, and fish No. 3 continues to advance in its original direction. At 9:08s, fish No. 2 stops deflecting, and fish 3 goes forward. During this process, 1.0194 radian systems are deflected, and the time 3S is used.

**Experiment 2 situation 2 experimental results show**

Figure 10. 9:19s fish No. 3, fish No. 2.
Figure 11. 9:18s fish No. 3, fish No. 2.
Figure 12. 9:16s fish No. 3, fish No. 2.
At 9:19s, fish No. 2 and No. 3 go forward in their respective directions. Fish No. 2 is determined as the voluntary fish, and No. 3 fish is determined as the right fish. At 9:18s, fish No. 2 starts to deflect, and fish No. 3 continues to advance in its original direction. At 9:16s, fish No. 2 stops deflecting, and fish 3 goes forward. During this process, 0.68 radian systems are deflected, and the time 3S is used.

After repeating experiment 1 and experiment 2 100 times respectively, statistics show that the number of collision avoidance is 98 times. The accuracy is 98 per cent. The average time of collision avoidance is 2 to 3 seconds.

Summary
In the paper, a collision avoidance method for underwater robot based on role is studied based on URWPGSim2D simulation robot fish platform. After analyzing the collision behavior of the robot fish, the robot fish collision is divided into two cases and the collision avoidance algorithm is designed and implemented respectively. The experimental results indicate that the collision avoidance algorithm based on role for underwater robot achieves the effect of fast collision avoidance. At present, the algorithm of the collision avoidance is just researched on two fish, and the collision problem between more fish will be studied next step.

Acknowledgement
This work is supported by 2017 Talent-Development Quality Enhancement Project of BISTU (Project Number 5111723400), and by the special bidding project of teaching & education reform (Project Number 2017JGZB08)

References
[1] International Federation of underwater robots, 2016 international water robot contest 2D simulation group competition and rules (2016).
[2] Zhang Jin, LI Shu-qin, Hou Xia, Research on Strategy of Two Robotic Fishes' Collaboration to Pass Through Hole, J. Computer Simulation, 2011, 30(1).
[3] Yang Yang, Li Shuqin, Studying and Implementing for Synchronized Swimming Actions of 2D Simulation Water Robot, Ordnance Industry Automation, 2016. 35(12).
[4] Intelligent Control Laboratory of Peking University, URWPGSim2D developer manual (2012).
[5] Tian Ye, Computer Simulation Application of Ship Collision Avoidance and Path Optimization in Open Water Area (2009).