Research on Bionic Perception Technology Based on Flow Field

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Abstract. Aiming at the research of underwater detection technology based on the information of relative motion flow field between underwater objects, firstly, theoretical analysis is carried out, through the modeling of underwater moving objects, the abstract modeling of obstacles is carried out, and the characteristics of flow field around underwater moving objects are studied by hydrodynamics, and the distribution characteristics of geometric and physical parameters of flow field are systematically analyzed. The driving law of characteristic parameters on the flow field and the interference effect of obstacles on the flow field around the moving body are obtained. The correlation between the characteristic parameters of obstacles and the characteristics of the flow field around the moving body is obtained, and the judgment criteria for detecting obstacles are formed.

1. Introduction
The development of underwater exploration technology is an important support for the development of marine environmental monitoring and resource development. Due to the complex environment inherent in the development of ocean activities and the rapid development of various noise reduction technologies, the role of underwater detection technology based on acoustic principles, mainly sonar detection technology, has been limited. In order to meet the needs of modern underwater detection, many countries have invested in the field of underwater non-acoustic detection in recent years. At present, the main information sources of non-acoustic detection technology are magnetic field, laser, electric field, temperature field and so on. The target information source signal is identified to achieve the purpose of detection. However, there are always some shortcomings such as instability and shieldability to weaken and eliminate the propagation of the signal source, which poses a huge challenge for detection.

As a signal source not affected by the current underwater stealth technology, the flow field has been paid more and more attention by researchers, and is committed to underwater detection research. It is essentially different from the traditional detection principles such as underwater acoustic, because the disturbance information of underwater moving target has strong correlation with its surface parameters and motion characteristics, and has obvious advantages over other detection technologies. It has been found that the fish lateral line is a key component of the fish sensory system. It affects many aspects of fish behavior through the pressure signal of the flow field, including maneuvering in complex fluid environment and navigation in poor visibility environment.

In 2011, Vicente I. Fernandez and other researchers carried out some research on the detection principle of side lines. Through experiments and bionic simulation, pressure sensor arrays were used to...
simulate the detection, location, recognition and wake tracking of moving targets [1]. The feasibility of this principle was preliminarily demonstrated.

This paper mainly studies the intrinsic characteristic field of the obstacle itself and its coupling effect with the flow field, analyses the interference effect of the obstacle on the flow field, realizes the correlation between the characteristic parameters of the obstacle and the flow field information, and provides the basis for the judgment criterion research of the obstacle avoidance of underwater moving body. With numerical simulation as the main means, the real physical process of the moving body is simulated, and the interference effect of obstacles and moving body characteristic parameters on the change of head pressure of the moving body is analyzed. The judgment criteria of acquiring global information and full-time and omni-directional autonomous perception and analysis of obstacle information in front of the underwater body are formed.

2. Analysis of Flow Field Characteristics of Underwater Moving Body

At present, most underwater vehicles and organisms are streamlined, and their shapes are similar to cylinders or flat cylinders, and have a certain aspect ratio. We mainly analyze the pressure distribution on the head of the moving body, so we can ignore the infinite length of the half body and replace it with the finite length [2].

Combining the relationship between flow field velocity and flow function, Bernoulli equation of planar irrotational flow and coordinate transformation between Cartesian coordinate system and polar coordinate system.

The center of obstacle material is set at \( z_0 = x_0 + i y_0 \). The flow field of obstacle radiation is a dipole flow field with \( z_0 \) position and \( M_0 \) intensity. The uniform incoming velocity encountered is approximated by the velocity \( u_0 \) of the dipole flow field of moving body radiation at \( z_0 \). Let the velocity of the moving body be \( U \), the radiation dipole flow field of the moving body be \( M \), and the radius of the head of the moving body be \( R \). In the process of detecting obstacles, some purposes can be achieved by detecting the size of obstacles without ascertaining their shape. Therefore, the specific shape of obstacles is ignored in the analysis and regarded as an approximate circle with radius \( R_0 \). As shown in Fig. 1, Cartesian coordinate system is selected. The coordinate system is fixed on the moving body and follows the movement of the moving body. The origin is at the center of the head of the moving body.

![Figure 1. Location relationship between moving body and obstacle](image)

In Figure 1, \( r_0 \) is the distance from the obstacle to the center of the head of the moving body, and \( \theta_0 \) is the angle between the obstacle and the center of the head of the moving body and the x-axis. In the detection process, the detection range is two or three quadrants of the graphical coordinate system, so \( \theta_0 \) range is \( \left( \frac{\pi}{2}, \frac{3\pi}{2} \right) \) and \( r_0 \) range is \( (R, +\infty) \). The radiation dipole flow field of the moving body is taken as the detection flow field, and the radiation dipole flow field of the obstacle is taken as
the detection object. There are the following equations of pressure distribution on the surface of the moving body.

The above formula is the pressure distribution equation of the flow field near the moving body caused by the interference of the radiation dipole flow field of the obstacle to the radiation dipole flow field of the moving body. Taking $p_{\infty}$ is hydrostatic pressure at 5 m depth. $p_{\infty} = 150300$ (P). Water at room temperature. $\rho = 1000$ kg/m$^3$. When $r = R$ is substituted for the formula above, the distribution of head surface pressure with $\theta$ is obtained by taking $\pi/2 < \theta < 3\pi/2$, $p = p(\theta)$.

3. Numerical simulation of flow field around underwater moving body

3.1. 3-D Simulation Model Establishment and Algorithms Research

3-D fluid simulation calculation has one dimension more than 2-D, so it is more complicated in computational model, meshing, especially in calculating pressure distribution and setting related parameters. In the model design, the 2-D plane model is extended to 3-D space model, which is constructed by external CFD software. According to different working conditions, different solving regions, moving bodies and obstacles are established[3]. As shown in Figure 2, the rectangular solution domain, the moving body and the spherical obstacle can be reduced as much as possible to improve the computational efficiency under the condition that the navigation distance of the moving body is satisfied.

![Figure 2. Schematic diagram of computational domain of underwater moving body](image)

Considering the actual conditions, more than 50 kinds of three-dimensional simulation calculations are carried out by changing the parameters of moving bodies and obstacles through controlling variables, which provides a certain amount of data support for subsequent experimental processing, result analysis and rule-making. Specific working conditions are as follows:

1. Speed of moving body: 5m/s, 10m/s, 20m/s;
(2) Shape of the moving body: Spherical head cylinder
(3) Diameter of moving body: 300mm, 320mm,
(4) Obstacle shape: Sphere, cylinder, spherical head cylinder
(5) Windside shape of obstacles: rectangular, circular, etc.

3.2. Typical results of three-dimensional simulation
The research involves a lot of work, and only one of them is selected for specific analysis. Figure 3. Shows the pressure nephogram of the navigating body at different positions of the windward area of the head of the body with double obstacles.

![Figure 3. Pressure nephogram of a sphere with an obstacle of 1 times windward area at a velocity of 5 m/s](image)

Observing Figure 3 and combining with the actual data of observation points, it can be found that the pressure distribution of the moving body and obstacle at different relative distances is generally the same at all points on the head surface of the moving body. When the moving body approaches the obstacle, the disturbance of the pressure characteristics of the flow field around the moving body increases with the approach of the obstacle. The pressure value increases with the decrease of distance, and the closer to the obstacle, the more obvious the change trend is.

3.3. Fluid Simulation Analysis
By observing the clouds, the effect of pressure interference caused by obstacle migration is not obvious. According to the seven different sensing points of the head, the position of the sensing points is in the horizontal direction and the vertical direction of the symmetrical line of the head of the moving body, 0 degree, 15 degree, 30 degree and 60 degree respectively. Under the condition of the moving body speed 10m/s and the obstacle is a sphere with double head windward area, the data curve is observed.

![Figure 4. Evolution law curve of distance streamline pressure of obstacle relative to moving body](image)

Because both the moving body and the obstacle are centrally symmetrical, the data of observation points with the same angle on the transverse and longitudinal axis are highly similar. The data trend of No. 1 observation point on the head of a moving body is enlarged separately[4]. When the velocity of
the moving body is 10 m/s, the distance of the obstacle and the pressure curve of the observation point are shown in Figure 5.

![Figure 5](image)

**Figure 5.** Evolution of Streamline Pressure in Sensing Channel No. 1 Relative Distance between Obstacles and Moving Body

After enlarging the data curve of observation points, it can be clearly found that the head pressure of the moving body decreases obviously with the increase of the distance between the moving body and the obstacle, and when the distance is 0-2 meters, the pressure decreases most obviously, and the back section shows a linear downward trend. According to a large number of working condition data and calculation, it is found that when the distance between the moving body and the obstacle exceeds the relative distance of the head of the 16-fold moving body, the pressure of the head decreases rapidly, and the change of the pressure disturbed is not obvious. Therefore, the relative distance between the moving body and the obstacle has an important influence on the detection of the moving body.

### 3.4. Judgment Criteria for Motion Body Avoiding Obstacles

Through the study of the flow field around the moving body and the analysis of the interference effect of obstacle characteristic parameters on the flow field around the moving body, the judgment criteria of the effective obstacle avoidance of the moving body are explored. From the analysis, it can be seen that the characteristic parameters of obstacles have a great influence on the pressure value (P) and the change rate of pressure value (∆p) of the head surface of the moving body, and there is a strong correlation between them. The distance between the obstacle and the moving body can be judged based on the corresponding relationship between the peak pressure distribution on the surface of the moving body and the change rate of the peak pressure. Figure 6 shows the relationship between the relative distance between the obstacle and the moving body and the pressure peak value and pressure change rate on the surface of the moving body [4].
The Regular Change Curve with Relative Distance R

The analysis shows that the expressions of peak pressure and peak pressure change rate \( \frac{\Delta P}{P} \) and relative distance \( R \) of the pressure distribution on the moving body surface are as follows:

\[
\frac{\Delta P}{P} = 0.3 \ln(-R + 10e^{f(x)}) - 0.05 \tag{1}
\]

\[
R = 10e^{f(x)} - e^{(10\Delta p)/3p+1/6} \tag{2}
\]

Formula (2) can calculate the relative distance between the obstacle and the moving body according to the peak pressure distribution on the surface of the moving body and its change rate, which provides a preliminary preparation for the complete detection of the obstacle. In formula (1), \( f(x) \) represents the relationship between the velocity of obstacle and the ratio of velocity of moving body \( [5] \). According to the ratio of head pressure change rate of moving body to the velocity of obstacle and moving body, the expression of \( F(x) \) is obtained, as shown in formula (3).

\[
f(x) = \left(1 + \frac{2(\Delta p)}{R} + 1\right)/4 \tag{3}
\]

According to the rule of the influence of obstacles on the critical streamline distortion rate around them, the derivation process of the geometric parameters of the stationary point in the head of the moving body is deduced according to the existing conclusions \( [6] \), and the relative distance between the obstacle and the moving body and the position of the obstacle are judged.

4. Conclusion

In this paper, based on the technical method of detecting obstacles in water through the flow field information of underwater moving body, the basic physical model of the flow field around underwater moving body is established, the interference effects of different characteristic parameters of obstacles on the flow field around moving body are studied, the research methods of the flow field are analyzed, and the numerical simulation models under different working conditions are established. The effect of the relative distance of obstacles on the flow field of moving body is described in detail. The following conclusions are drawn:

(1) An underwater obstacle detection method based on relative motion flow field information is proposed. The pressure distribution equation of the flow field and the surface pressure distribution equation of the moving body in the area before the head are obtained.
(2) The spatial dynamic grid technology is used to study the disturbance effect of moving obstacles on the flow field of moving body, and the correlation between the parameters of moving obstacles and the flow field changes of moving body head is analyzed, and the general judgment criteria for detecting obstacles of moving body are obtained.

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