Design and Realization of Autonomous Course Reversal Control System in Long Tunnel of Underwater Detection Robot

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ABSTRACT

Aim at the problem that the cable-controlled underwater robot was out of control as the umbilical cord was wound into a long water tunnel, an autonomous returning control system of underwater robot based on high precision underwater acoustic positioning and six-direction ranging sonar environment perception is designed to realize the Autonomous returning along the water tunnel after signal interruption. Finally, in the actual tunnel environment of hydropower plant, the autonomous return control test was carried out, and the underwater robot successfully returned to its original position after the communication signal was interrupted.  

KEY WORDS

Underwater Robots; Artificial Potential Field Method; Path Planning; Water Conveyance Tunnel; Autonomous Return Control.

INTRODUCTION

In recent years, the cable-controlled underwater robot (ROV) has developed rapidly in the fields of underwater engineering, fishing operations, seabed survey and marine resources development, thanks to its advantages of good economy, high flexibility, good environmental adaptability and high efficiency. It is an effective

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and feasible scheme to use cable-controlled robot for underwater inspection, especially for long distance water conveyance tunnel inspection[1-3]. But the work environment of long distance water conveyance tunnel t is more complex, such as slope, shaft, such as curve tunnel, so that the robot often umbilical cord cable to be wound, interrupt control signal. Then the operator can’t control the robot remotely. Therefore, it is particularly important for robots to be able to autonomously return control after signal interruption. This paper is dedicated to the research of autonomous return control of underwater robots in long tunnels based on artificial potential field method and underwater acoustic positioning technology.

**WORK PRINCIPLE**

When communication signal is interrupted in the course of the assignment, and the control system automatically starts the return control mode. Under the mode, the robot obtains the distance and azimuth information of the current robot relative to the initial point through the guided sonar, and the distance between the robot and the surrounding cave wall through the ranging sonar installed on the robot in the upper, lower, right, left, front and rear six directions. After obtaining the above information, the robot path planning controller carries out the path planning of autonomous return based on the APF method according to the field environment. Then the motion control system controls the robot to track the path movement according to the planned path, so as to realize the autonomous return to initial point along the long-distance transmission tunnel.

**Acoustic Positioning System Composition**

The navigation and positioning system based on acoustic principle mainly includes two parts: guided sonar and 6-direction ranging sonar. As the name implies, ranging sonar measures the distance from the front, back, left, right, top and bottom of the robot to the cave wall. The system composition of the guidance sonar is mainly composed of the guidance machine and the transponder. The guidance machine is placed on the shore and the transponder is installed on the underwater robot. The working principle is shown in figure 1.
The guidance machine consists of 4 parts: the main cabinet, signal transmission cable, forward amplifier electronic cabin and guided transducer.

**The Principle of Distance Measurement**

The guiding machine through direct transducer, to launch guide pulse acoustic signals, transponder sankiyuan direction matrix measurement after the direct sound pulse signal, and then launch a response pulse acoustic signal, then guiding machine receives the response after the sound pulse signal, and can according to the reply pulses between sound signal and direct sound pulse signal delay value, and measure the guidance machine and the distance between the transponder, distance calculation formula is as follows:

\[
d = \frac{(\tau - \tau_0) \times c}{2}
\]

Where, \(d\) is the distance between the seeker and the transponder, \(\tau\) is the delay value of the response pulse acoustic signal lagging the guidance pulse acoustic signal, \(\tau_0\) is the time required for the transponder signal processing (general 538.2ms), and \(c\) is the sound velocity (1465m/s).

**The Principle of Direction Measurement**

A four-beam directional transducer is installed on the underwater robot, which has four beams on the horizontal plane. The directivity diagram of the four beams is shown in figure 2.

The four beams are aimed at the front, back, left and right directions respectively. When the guided pulsed sound signal is incident from different directions to the directional transducer of the four beams, the signal intensity received by the four beams is different. According to the intensity ratio of the signals received by the four beams, the incident direction of the guided pulsed sound signal can be calculated.

In order to get a different incident direction corresponding to the four received signal strength ratio of the beam, the test using the following two steps:
first, in the noise elimination pool according to the resolution of 1 °, the level of 360 ° direction within the scope of each incident direction for the calibration, after calibration for each incident direction of 4 received signal strength ratio of the beam, and according to the resolution of 1 ° to the incident direction of acoustic signal and four beam receiving signal strength ratio make it a lookup table.

Then, measurement is carried out in the actual navigation of the underwater robot. When the directional transducer of the four beams receives the guidance pulse sound signal, it only needs to calculate the intensity ratio of the signals received by the four beams, and then the incidence direction of the guidance pulse sound signal can be searched through the lookup table, so as to obtain the heading angle information of the underwater machine.

AUTONOMOUS RETURN BASED ON APF

Principle of Artificial Potential Field Method

The artificial potential field method is to construct an artificial potential field in the motion region of the robot: the target point establishes an attractive potential field, which has an attractive effect on the robot; Obstacles establish a repulsive force potential field and exert a repulsive force on the robot. In this potential field, the robot moves along the gradient of the potential field from the starting point of high potential energy to the target point of low potential energy. In this way, the robot can approach the target point and avoid colliding with the tunnel wall.

Autonomous Return Design Based on APF

Construct an artificial potential energy field in the water transport tunnel: establish an attractive potential field at the initial point (the entry point of the robot) and exert an attractive effect on the robot; A repulsive force potential field is established on the tunnel wall of the water conveyance tunnel, and a repulsive force is applied to the robot. In this potential field, the robot moves from the high potential energy point to the low potential energy point along the gradient direction of the potential field, so that the robot can return to the water point along the tunnel.

According to the above definition, it is assumed that the distance between the robot and the target is:

$$\rho(q, q_{goal}) = \|q_{goal} - q\|$$

(2)

Where, $q$ is the current position of the underwater robot, and $q_{goal}$ is the position of the target point.

Then, the attraction of the underwater robot in the artificial potential field $F_{att}$:
$$F_{\text{att}}(q) = -\nabla U_{\text{att}}(q) = \frac{m}{2} z \rho^{m-1}(q, q_{\text{goal}})$$ \hspace{2cm} (3)$$

Where, $z$ is a positive scaling factor, and $m$ is the distance and attraction action parameter generally $m=1$.

The repulsive force of the robot in the potential field is:

$$F_{r} = \begin{cases} \eta^* \frac{1}{\rho(q, q_{\text{obs}})} - \frac{1}{\rho_0^*} \frac{1}{\rho^*(q, q_{\text{obs}})} \ast \nabla \rho(q, q_{\text{obs}}); & \rho(q, q_{\text{obs}}) \leq \rho_0 \\ 0 & \text{otherwise} \end{cases}$$ \hspace{2cm} (4)$$

Where, $\eta$ is the exclusion coefficient, and $\eta = 0.1$, $\rho(q, q_{\text{obs}}) = |q - q_{\text{obs}}|$ is the distance between the underwater robot and the obstacle. The resultant attraction and repulsive force of the robot in the tunnel are:

$$F = F_{\text{att}} + F_{r}$$ \hspace{2cm} (5)$$

![Figure 3. Testing environment.](image1)

![Figure 4. The entry point.](image2)

The robot always moves in the direction of the resultant force in the process of autonomous return. In the actual application process, the closest distance between the robot and the obstacle is first calculated, and whether the robot reaches the repulsive force range or not is considered as open water if it is not in the repulsive area.

**THE AUTONOMOUS RETURN CONTROL TEST**

**Test Environment**

In order to test the effectiveness of the autonomous returning, an autonomous returning experiment is implemented in the water conveyance tunnel within 300 m of Hainan Qiong Zhong pumped storage power station of the China Southern Power...
Grid, field test environment as shown in figure 3. The entry point of robot and guidance sonar is plant under the gate slot, as shown in figure 4. The robot process and motion path back into the hole as shown in figure 5.

**Autonomous Return Control Test**

![Figure 5. Motion path of the robot.](image1)

![Figure 6. Data graph of test.](image2)

In return test, the robot was about 300m away from the outlet hole of the lower reservoir within the tunnel. At this point, the control signal of the underwater machine is cut off manually, the robot starts the return mode independently, and independently returns to the starting point following the sound source without manual intervention. The data curve of the robot's self-return is shown in figure 6.

As figure 6, at the beginning of autonomous return, obviously, the underwater robots will course changed from 120° to 300°, then basic stay the course and the azimuth, along the direction of the water conveyance tunnel to the initial point near. The distance curve of the guided sonar intuitively reflects that the distance between the robot and the sound source is constantly shrinking in the process of autonomous return of the underwater robot, that is, the robot keeps moving towards the sound source. It can be seen from the comparison between the distance measured at the sonar end and the distance measured at the robot end that the two have good consistency.

To sum up, after the autonomous return function is started, the robot automatically adjusts its course and continues to drive towards the sound source. Finally, the robot realizes at the surface of the water (20m) at the distance set by the sonar sound source.

**CONCLUDES**

Based on the high-precision hydro acoustic positioning system and the artificial potential field method (APF) path planning method, this paper designs the autonomous return control system of underwater robots in hydropower plants, and realizes the autonomous return function of underwater robots along the water.
transmission tunnel after signal interruption. The 300m autonomous homing test of the underwater robot was carried out successfully in the real environment of the tunnel in the hydropower plant, which effectively verified the practicability and effectiveness of the autonomous return control system mentioned above.

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