Research and Application of Attitude Control and Stability Adjustment Technology for Underwater Robot Platform

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Abstract. This research is mainly aimed at the difficulty in maintaining the stability of the position and posture of underwater visual equipment, and it is unable to provide reliable images for underwater search and salvage rescue operations. Investigating the existing mature technology and scheme, combined with the characteristics of the underwater operation of the visual equipment and based on the comprehensive analysis, a set of motion attitude stability analysis theory suitable for the underwater platform is proposed. Combined with various control theories, the motion control equations of underwater robots are established, and the optimal control method is designed. The control method is verified by computer simulation. The research results of the project can provide a reliable technical support and decision-making means for underwater search and salvage work, improve the automation level of underwater operations, reduce the difficulty of underwater operations, and improve the comprehensive response capability and technical level of deepwater search and rescue salvage levels.

1. Introduction

With the increasing development of maritime transportation and marine resources, there are more and more accidents in the ocean[1]. Once wrecks and sunken objects are generated, especially when shipwrecks and sunken objects occur in busy and narrow navigation passages, the route will be blocked and the ship will not be able to enter or leave the port. When the situation is serious, it may cause the port to stop operating. The harm to the environment and society caused by shipwrecks and sunken objects has long been of concern to all countries[2-3]. In an effort to prevent the occurrence of shipwrecks and sunken objects, governments have made efforts to maintain the safety of coastal vessels. In the event of a shipwreck or sunken object, take all measures that can be taken to remove the shipwreck, sink and mitigate the damage caused by it as soon as possible, while minimizing the risks of removal and salvage.

The seabed is not only under pressure, but also the environment is extremely bad. For wreck salvage and seabed search and rescue, the human strength is very small and the ability is limited. So people focused on underwater visual equipment. Through the use of underwater video, sonar and other visual equipment to detect, to find out the location and attitude of the underwater shipwreck, as well as the environment of the shipwreck water, to fully grasp the underwater situation, understand the salvage object, develop a salvage plan, in order to search and rescue salvage work successfully launch. Search and rescue salvage work is a very challenging and extremely difficult job. Under the influence of ocean currents, the position and attitude of the underwater visualization equipment will change, which will cause great interference to underwater search and fixed-point rescue operations. In order to obtain stable and clear underwater images, the attitude and stability of underwater equipment are of
vital importance. Therefore, it is necessary to study the problem of underwater equipment attitude control and adjustment technology, and provide technical support and decision-making for the development of underwater search and salvage work.

2. Current status of underwater robot research
The research of underwater robots began with remote-controlled underwater robots[4]. In 1960, the US Navy designed the world's first modern-purpose teleoperated underwater robot "CURV1" [5]. It was not until six years later that the underwater robot began its first homework, creating a successful underwater operation of the underwater robot, the development of underwater robots has received unprecedented attention. In the 1970s, due to the demand for offshore oil exploration, underwater robots became more and more important and began to form industrialization[6]. At present, the application of underwater robots is mainly concentrated in marine scientific research, military, aquaculture and salvage rescue. In August 2005, a Russian manned submersible AS-28 was wound by an underwater radar cable, trapped in a depth of 200m under water, and the life of seven crew members was at stake[7-8]. The British Navy urgently dispatched the unmanned submersible Scorpio to rescue. After a day of rescue AS-28 successfully removed the difficulties, highlighting the huge advantages of underwater robots in dealing with underwater dangers. The large-scale research on underwater robots in China began in the 1970s.

In 1979, the Shenyang Institute of Automation, Chinese Academy of Sciences, under the leadership of Academician Jiang Xinsong, began to develop China's first underwater robot[9]. In 1985, "Hairen No.1" was the first flight of the first cable-on-water robot in China, and the maximum diving depth reached 199 meters. In October 1990, Shenyang Institute of Automation began to develop China's first autonomous underwater robot “Explorer” on the basis of cable-on-water robots[10]. The "Explorer" includes four parts: underwater carrier, underwater acoustic communication, navigation positioning and surface support. The operator only needs to specify the type of operation and related parameters, and the "Explorer" will complete the corresponding task autonomously. In 1992, the practical autonomous underwater vehicle "CR-01" was developed on the basis of the "Explorer". Compared with the "Explorer" to simplify the function and reduce the airborne equipment, after years of testing and improvement, in 1997, "CR-01" was successfully completed in the Pacific Ocean, reaching a depth of 6,000 meters underwater. The successful development of "CR-01" marks the entry of China's underwater robots into the ranks of advanced countries. At present, underwater search and rescue and salvage operations mainly rely on divers to complete, and the seabed is not only under pressure, but also has poor visibility and abnormal environment, which undoubtedly increases the difficulty and risk of divers. With the help of underwater equipment, the automation level of underwater search and rescue and salvage can be improved, so the dependence on underwater visualization equipment is getting higher and higher. These devices need to solve the problem of underwater attitude and position adjustment in order to work in deep water. In 2015, the successful development of "Qianlong No.1" provided important technical equipment for China's large-scale fine-scale exploration of deep-sea resources, marking that China's deep-sea resources exploration equipment has reached a practical level, making China's AUV technology and products enter International advanced level.

3. Research on attitude control and stability adjustment technology of underwater platform
The underwater stability platform studied in this project is mainly for the use of visual equipment encountered in the underwater search and salvage process. The autonomous mobile platform brings visual equipment to the search and rescue area for on-site detection and operational process monitoring. The underwater stable platform adopts a streamlined body, the pressure-resistant shell adopts a cylindrical shell with a hemispherical head, two horizontal thrusters are arranged on both sides of the pressure-resistant shell, and two vertical thrusters are arranged on the upper part of the pressure-resistant shell, and the pressure is resistant. The upper part of the shell is provided with a floating material shell, and the lower part of the pressure resistant shell is provided with a bracket. The structure of the underwater platform is shown in Figure 1.
4. Attitude control and stability adjustment technical solution

4.1. Style and spacing

Directional control

When the underwater platform is in water, there is no complete motion reference around, so that it is difficult to grasp the position information in the vast waters by visual observation alone. Especially in the underwater platform search process, ensuring navigation along a straight line is the most basic path planning solution. Therefore, the directional control of the underwater platform is the basis of the underwater platform and the core of the motion control. The electronic compass is the most effective and convenient sensing element for the control of the steering wheel. The controller module can be designed as a closed-loop control mode to convert the control error into a voltage control signal for the horizontally driven propeller. In the underwater platform model, the rotation of the two propellers is driven by voltage control, and the torque of the underwater platform is generated by the vector arrangement of the propellers, so that the underwater platform rotates in the direction around the axis. At this time, the underwater platform orientation value after the electronic compass measurement control is compared with the expected value, and if there is a deviation, a new round of orientation control is performed according to the above process until the deviation is zero. The directional closed loop control uses a fuzzy PID control strategy. According to the PID control principle, the proportional part can increase the directional response, but it is prone to overshoot and reduce the stability of the system. Therefore, by introducing the feedback amount to the differential link, the adverse effects caused by the increase of the proportional part are corrected. The integral control part can eliminate the steady-state deviation of the system and correct the angular deviation of the inertial conduction stability deviation.

4.2. Depth control

The underwater platform faces a lot of difficulties in doing the deep-seated control, mainly in the following two aspects:

1) There is a large unknown disturbance in the underwater platform operating environment. For example, the effects of undercurrents and cables, as well as the waves on the surface of the sea during shallow sea operations.

2) There is a large parameter uncertainty in the underwater platform. It is difficult for an underwater platform to perform a pool test before each mission to obtain its numerous hydrodynamic parameters. On the one hand, it is very expensive to do so, and more importantly, the structure of the underwater platform often changes depending on the task. Even in a single mission, different devices are often carried out for various needs. This makes it very difficult to obtain accurate hydrodynamic parameters. The controller module can also be designed as a closed-loop control mode to convert the control error into a voltage control signal for the vertical drive propeller. In the underwater platform model, the rotation of the two propellers is driven by voltage control, and the torque of the underwater platform is generated by the vector arrangement of the propellers, so that the underwater platform is floating and dive. At this time, the depth value of the underwater platform after the control is
controlled by the depth sensor, and compared with the expected value, if there is a deviation, a new round of orientation control is performed according to the above process until the deviation is zero.

4.3. Sensor accuracy

The accuracy of directional control is highly dependent on the electronic compass. The depth control depends on the depth sensor. The accuracy and update frequency of the sensor completely restrict the directional control accuracy. When an underwater platform with an electronic compass and depth sensor is subject to external interference, its accuracy will cause a large error. The sensor data needs to be filtered to improve the accuracy of the sensor.

4.4. Control lag

The hysteresis of the closed-loop control system is not only affected by the large sensor update period, but also by the feedback control loop. The essence of the directional depth control process is the mechanism to eliminate the deviation based on the deviation, no matter when the disturbance occurs, the control process starts only when the detected information deviates from the expected value. This causes the regulator to lag behind the interference. And for the large-scale underwater platform, the water-wrapped working condition has a large inertia of motion, and its dynamic lag is even greater. If there is no high-speed control strategy, the depth and orientation control will be the situation of oscillating back and forth. Need to be considered in closed loop control.

5. Experimental Research on Attitude Control and Stability Adjustment Simulation

Based on the research on underwater robots, an underwater platform was constructed and the performance of the underwater platform was tested. Data tests were carried out on the speed of underwater navigation, forward and backward, left turn and right turn, and up and down dive. The underwater depth, directional open loop and PID closed loop control were studied experimentally. The PID was tested on the underwater platform. The control effect and problems in the depth control are collected, and the experimental data of the underwater platform is collected, which provides the measured data for the research of the simulated PID algorithm. The experimental test photos are shown in Figures 2 and 3.

![Figure 2. Experimental testing of underwater robots](image)

![Figure 3. Experimental test site photos](image)
A simple model of the underwater platform can be obtained by experimentally obtaining data, and a simple model can be used to simulate the control algorithm. The MATLAB toolbox provides a shortcut to model identification. The area to the right of the interface in Figure 3 is the Model views area, which is the model view area. In this area, you can select and switch different models, verify the model and draw the characteristic curve. There are a number of check boxes below the model view for the user to view the identification output curve and other characteristic curves. Based on the closed-loop simulation of PID, two simple models were established by using the experimental data to separate the orientation and the depth. The PID closed-loop control simulation of the two models was carried out respectively, and the obtained parameters were used for the actual control of the underwater platform.

The experimental data obtained from the two experiments, the transfer function of the underwater platform orientation simple model obtained by using the MATLAB system identification toolbox is:

\[
\frac{-0.1519s + 1.9821}{1.0613s^2 + 0.28s + 1}
\]

The simple model of the depth is:

\[
\frac{-0.05s + 0.9}{1.2167s^2 + 0.4939s + 1}
\]

The orientation and depth simulations are shown in Figures 4 and 5.

Figure 4. Orientation model simulation

Figure 5. Depth model simulation

The step response curve of the directional model is shown in Figure 6:
The step response curve of the depth model is shown in Figure 7:

The directional step response after PID closed-loop control is shown in Figure 8:
The deep-depth step response after PID closed-loop control is shown in Figure 9:

![Figure 9. Depth PID control step response curve.](image)

Through simulation research and experimental research, it can be seen that the PID control can accurately and quickly realize the orientation and depth control of the underwater platform. However, since the underwater platform is equipped with different equipment, different weights and different hydrological conditions, the model of the underwater platform is not fixed, so the parameters of the proportional, differential and integral links cannot be fixed. It is necessary to modify the three parameters, which is not only a waste of time, but also difficult to obtain the optimal parameters, so it is necessary to use fuzzy control combined with PID to realize the control of the underwater platform. The simulation model of underwater platform orientation and depth-depth fuzzy PID control is established by simulink, as shown in Figure 10 and 11.

![Figure 10. Directional Fuzzy PID Control Model](image)

![Figure 11. Depth-depth fuzzy PID control model](image)

The step response curves of the directional and deep fuzzy PID control are shown in Figures 12 and 13.
Comparing the step response curves of directional and deep PID control and fuzzy PID control, it can be seen that the classic PID control for the determined system, if the PID parameters are set properly, the control effect may be better than the fuzzy PID control, but for the changed system, the control advantage of fuzzy PID is obvious. As long as the estimation model of the system is known, given the range of PID parameters, the fuzzy adaptive algorithm can be used to automatically match the PID parameters to achieve closed-loop control of the orientation and depth of the underwater platform. Through the verification of the underwater platform experiment, the fuzzy PID control has the characteristics of flexible control, strong applicability and high precision.

6. Conclusions
This project has deeply studied the underwater attitude control and adjustment technology of the deepwater search and rescue salvage visualization equipment, overcome some technical difficulties in the underwater special environment, and determined the specific technical solutions, related parameters and performance. Based on the further analysis of underwater robot attitude control and
stability adjustment technology, the attitude control and stability adjustment algorithm of underwater platform is proposed, which laid a foundation for the determination of control strategy and control scheme. In order to solve the problem that the platform is difficult to complete the upward looking action and the downward looking action, we carried out simulation experiments on the hardware design and software development of the experimental platform, and adjusted and corrected the ways according to the results. The longitudinal thruster uses program control to generate a downward thrust of the front vertical thruster, and the rear vertical thruster generates an upward thrust to achieve upward upward attitude adjustment. Front vertical thruster produces an upward thrust, and the rear autonomous vertical propeller produces a downward thrust when the underwater autonomous navigation device looks down. Through the modeling and simulation, the structure and composition of the experimental platform were proposed. The underwater attitude control and stability adjustment experimental platform was developed. At the same time, the design of the experimental platform control system and control strategy was completed, which laid the foundation for future data collection, the experimental platform provides reliable theoretical and technical support for deepwater search and rescue salvage work.

7. References

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