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Construction Method of Unmanned Surface Vehicles Power Control Platform Based on Environmental Force Feedback

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Abstract: With the rapid development of intelligent technology, the technology in the field of unmanned surface vehicles (USV) control is gradually improving, and the manual mode plays a vital role in the navigation safety of USV. In this paper, the fault tolerance of data transmission is improved by adopting three-linear interpolation technology in attitude data feedback, and the speed of unmanned ships is controlled based on PID control technology, and finally the construction method is verified through real ship experiments, which can provide theoretical support for future unmanned ship control systems.

Keywords: USV; Force feedback; PID control; Trilinear Interpolation; Control system;

1.Introduction

In recent decades, with the continuous progress of sensor technology and intelligent control technology, USV system technology has become a hot topic[1]. Due to the increased desire of human beings for ocean exploration, and in order to reduce casualties and costs in the process of ocean exploration, people are eager to obtain new technologies to replace human beings working in dangerous environments, and also hope that human beings can have the feeling of being in the environment and grasp the state of work timely in the process of replacing human operations. Thus improving the accuracy and stability of operation[2].

The control technology with force feedback is a collection of modern sensor technology, artificial intelligence technology, network technology and modern control technology in one of the technology, the rapid development of this technology, mainly benefit from the development of multi-information fusion technology and countries vying to explore the unknown world needs. The remote control system with force feedback enriches the human perception and behavior ability of traditional operation, and assists humans to complete some tasks with high accuracy requirements in dangerous and extreme environments[3]. The system mainly uses the sensors carried by the controlled object to collect the force generated by the interaction between the ship and the environment and other motion-related data information through the data acquisition card, and then the control system analyzes and processes the data, and then feeds back to the operator. According to the feedback data information, the operator can effectively perceive the change of the remote environment and the movement state of the controlled object. Making the corresponding action adjustment in time can make the operator control the controlled object more accurately, enhance the safety of the operating system and improve the efficiency of the operator. Therefore, it is of great significance to carry out power control for ships working in dangerous environments.

Ships often appear in dangerous places such as maritime rescue, ocean exploration and battlefield reconnaissance, because they work in uncertain locations. With the increasing intelligence of ocean engineering, the price of unmanned ships is also increasing. In addition, each ship needs staff to work on the site in person. In case of unexpected situations on the site, it is likely to lead to the empty of both people and ships[4].

C.R. Wagner et al. focused on the application of force feedback techniques to intraoperative intermittent dissection. He believed that compared with the weak feedback technology, the system performance of the tele-operated robot can be improved by 70% with the force feedback technology. When the tissue around the trauma has serious lesions, the instrument with force feedback technology can overcome the limitations of microsurgery defined by the surgeon, so as to be operated accurately and flexibly[5]. Zou et al. studied finite-time output feedback attitude control of rigid spacecraft, which ensures that rigid spacecraft can track the attitude of time-varying reference attitude in finite time, thus improving the application efficiency of spacecraft[6]. In the field of motion assistant control of unmanned ships, He G et al. used YOLO algorithm in ship object detection, which played a crucial role in ship navigation safety[7]. Lv C et al. proposed a hybrid coordinated control strategy based on signal energy method for the speed and heading control problem of underactuated USV, and the results show that the algorithm has certain effectiveness and stability[8]. Aiming at the loss of communication data in busy waters, Zhao J et al. proposed a ship speed extraction framework based on UAV airborne video. The results show that the average speed measurement accuracy of the framework in complex waters is above 93%, which has excellent performance[9]. Acanfora M et al. proposed a numerical model of synchronous and parametric roll resonance intelligent detection of ships for the severe roll motion of ships. In the face of maritime threats, different evading actions will be simulated and compared according to the change of course and speed, and finally the course will be changed[10]. Song L et al. proposed an emergency collision avoidance algorithm for USV based on motion ability database for the dynamic obstacle avoidance of USV during the task, and the effectiveness of the algorithm was demonstrated by simulating the emergency avoidance experiment[11].

Based on the shortcomings of the above methods in the field of USV safety assistance, a USV control platform based on environmental force feedback is proposed. The operator can make decisions on the current situation more intuitively through the ship motion attitude feedback of the 6-DOF motion platform, which can reduce the damage probability of the unmanned ship, thereby reducing property losses.

2.Method

2.1 Ship Force Feedback Input

Force feedback technology is a new technology closely related to information interaction technology proposed with the demand of remote control. As an extension of visual, auditory and other perception technologies, it can break the limitations of visual, auditory and other perception technologies, and has great flexibility and ultra-high work efficiency[12].

Force feedback technology is to use modern sensing technology to transform the movement of objects in the environment into the mechanical movement of physical equipment around the operator. Through specific sensing equipment and mechanical transmission devices, combined with computer technology, the force generated by the movement of unmanned ships is obtained, and the force is fed back to the operator through a specific actuator, so that the operator can feel the existence of environmental forces. It increases the operator's immersion in the process of controlling the ship, and improves the operation efficiency and accuracy [7]. The basic composition of the force feedback system and the control structure of the unmanned vessel is shown in Figure 1.

The whole system is divided into two parts: the first part is the force feedback input loop. When the human body receives the feedback information from the sensor device, the environmental information is transmitted to the brain through the relevant sensory nerves, and the brain makes decisions and sends out motor commands to activate the corresponding muscles, causing the operator's arm and finger to move [8]. The other part is the ship control output loop, when the operator operates the controller, the controller will pass the control signal to the actuator, so as to realize the remote control of the unmanned ship.

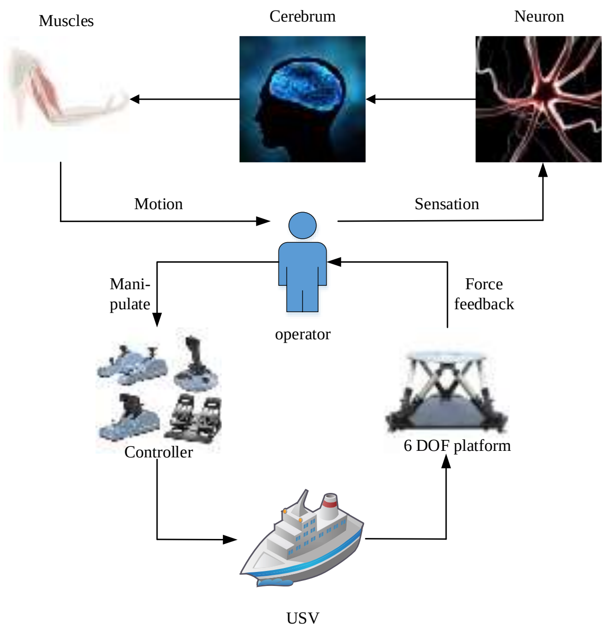

Figure 1. The basic components of the manipulation structure

In this paper, the following rectangular coordinate system is used to study the motion of the unmanned vessel. Figure 2,Where, the following coordinate system-OXYz is used to describe the motion state and force conditions of the unmanned vessel. For the convenience of analysis, point o is set at the center of gravity G of the unmanned vessel, and the X-axis points to the bow, the Y-axis points to the starboard, and the Z-axis points to the bottom of the vessel.

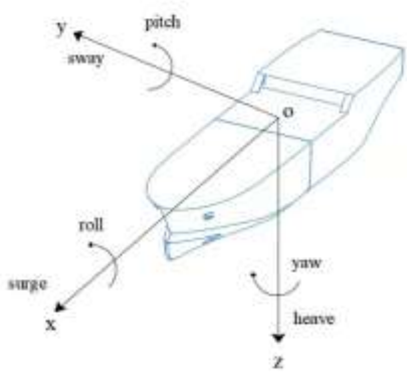

Figure 2. The following rectangular coordinate system

The motion of unmanned vessel in three-dimensional space can be divided into two parts. One part is the translation with oxyz plane, which is swaying, swaying and heaping respectively. The second part is the rotation around the oxyz axis, which are roll, pitch, and yaw. The mathematics of 6-DOF motion of the unmanned vessel is represented by the above two parts of motion physical quantities.

In the force analysis of the following coordinate system oxyz, X, Y, and Z are used to represent the component forces along the three coordinate axes, and U, V, and W are used to represent the component moments around the three coordinate axes. The following formula (1) can be used to represent the 6-DOF motion of the unmanned vessel in three-dimensional space:

$$\alpha = [x_0, y_0, z_0, \theta, \omega, \varphi]^T$$
$$\beta = [u_0, v_0, w_0, p, q, r]^T$$
$$\gamma = [X, Y, Z, U, V, W]^T$$
(1)

Here, α represents the spatial position and attitude Angle of the USV, β represents the linear and angular velocity of the USV, and γ represents the component force and torque of the USV.

Since the 6-DOF moving platform needs to reflect the current state of the ship, it only needs to consider the state of roll, pitch and yaw when considering the movement of the moving platform, which can help the operator fully perceive the current environment of the ship and its own state.

On the impact of environmental forces on unmanned ship, even if an accurate motion model is designed, the complex model will increase the difficulty of controller design, and the relatively simple motion model will have a large error on the current motion of the ship. Therefore, an idea is proposed, the current state of the unmanned ship every 0.1 seconds is analyzed in real time and sent to the 6-DOF motion platform. Therefore, the current motion state of the unmanned ship can be accurately reflected, but if the data is fed back once every 0.1 seconds, the motion will be incoherent. In this paper, the idea of trilinear interpolation is used to make the average value of the current data and the last data, fill the missing value between the 0.1 seconds, and then the sequence is sent to the 6-DOF motion platform to complete the motion data feedback of the unmanned ship. For example, the data interpolation of a_9 and a_4 is a, and the trilinear interpolation principle is shown in Figure 3 As shown.

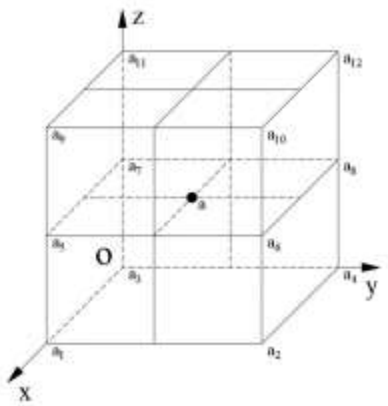

Figure 3. The trilinear interpolation principle

In the process of remote data transmission, due to the large amount of information transmission data, coupled with the interference of the external environment, there is a lot of noise and redundancy in the information transmission, which will reduce the accuracy of data information, so it is necessary to have a certain fault tolerance capability of remote communication, which is also the key mechanism to ensure the availability of remote communication data. It is also the basis for improving the data processing efficiency of unmanned ship control system.

2.2 ship manually control output

Manual control output means that it sails according to the course and speed set by the operator in advance. However, in order to make the unmanned ship achieve the expected course and speed in the operation process, it is necessary to adjust the speed of the motor and the Angle of the servo of the unmanned ship, and return the ship motion information detected by the sensor to the host computer for timely adjustment.

In order to improve the manual control performance of the unmanned vessel, the PID control algorithm which is widely used in the design of the controller is used. Because of its flexible structure change, especially PID control does not require the control object to need accurate mathematical model, which is difficult to get or not accurate mathematical model for most of the control object, no doubt more suitable for PID control.

PID regulator is composed of proportional regulator (P) integral regulator (I) and differential regulator (D). It uses the calculated control quantity to control the controlled object after the proportional, integral and differential operation of the deviation value. shows the block diagram of PID control system in Figure 4.

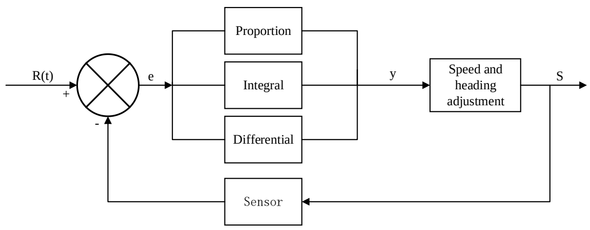

Figure 4. PID control system process

When PID algorithm was used to control the speed and direction of the unmanned vessel, the difference ΔV between the set speed V_a and the actual speed V_b was used as the input of the controller, and the motor speed y_0 was used as the output of the controller. Similarly, in the servo control, the deviation Angle Δ_θ between the set rudder Angle θ_a and the actual rudder Angle θ_b is used as the input of the controller, and the rudder Angle y_1 is used as the output of the controller. The regulation law can be expressed in formula (2).

$$y(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right] \quad (2)$$

Or appears as a transfer function(3):

$$G(s) = K_p(1 + \frac{1}{T_i s} + T_d s) \quad (3)$$

Where: K_p is the scaling coefficient, T_i is the integration coefficient, T_d is the differential constant, and t represents the current time. Through the real ship test, the values of K_p, T_i and T_d are constantly adjusted to achieve the best sailing effect of the unmanned ship. After calculating the motor speed y_0 and rudder Angle y_1 through the above formula, they are input into the control system of the unmanned ship to obtain the adjusted speed V_{b0} and heading θ_{b0}. Then the speed V_{b0} and heading θ_{b0} are feed back to the control system to realize the closed-loop control.

3. Experiment

3.1 Pool experiment

Before the actual ship test, the current stability of the unmanned ship was tested through the artificial pool in Figure 5. The size parameters of the small unmanned ship tested this time are shown in Table 1.

Table 1. Unmanned ship size parameters

Parameter names	Parameter information
Dimensions of hull (cm)	150(l)*50(w)*30(h)
Dead weight of hull (kg)	23
Load capacity (kg)	14
Type of ship	Catamaran ship
Mode of propulsion	Double propeller

The accuracy of forward, backward, left turn and right turn of the power control were tested in the test pool. The speed heading mode was used for forward and backward tests at a speed of 1 Kn, as shown in Figure 5, as well as left turn and right turn tests, as shown in Figure 6.

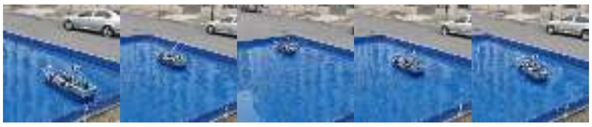

Figure 5. Forward and backward test

Figure 6. Left and right turn trials

3.2 Artificial Lake experiment

After the test in the test pool is correct, it enters the artificial lake of the school for testing. The test scene is shown in Figure 7, where the left picture shows the indoor scene and the right picture shows the outdoor scene.

Figure 7.Test scenario

The test was carried out at the set speed of 1m/s, 2m/s and 3m/s per minute, respectively. In the test, the current speed data of the unmanned ship was obtained in real time, and the data was imported into Origin 2022 in a cycle of 3 seconds, as shown in Figure 8.

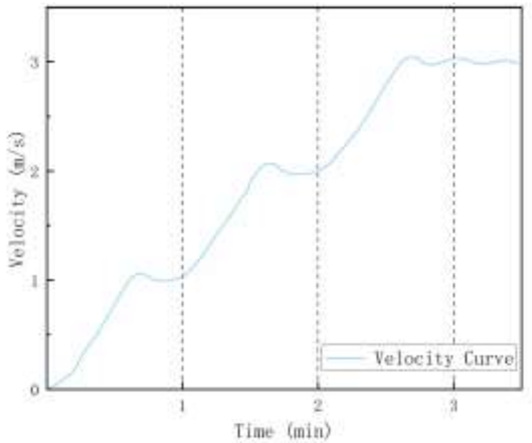

Figure 8.Curve of USV speed change

It can be seen from Figure 8 that when the speed of the unmanned vessel starts from 0, it can reach the set speed with a good speed change rate. Due to certain communication data interference and environmental interference such as wind pressure difference from the water during the test, there is a certain deviation between the actual speed of the unmanned vessel and the set speed. However, in the overall test results, it can achieve the effect of near the set speed and meet the test expectations.

4.Conclusion

This paper discusses the development status of environmental force feedback and unmanned ship control, and designs a construction method of power control platform for unmanned ship based on environmental force feedback. It involves two aspects. PID control technology is used to control the speed of the unmanned vessel. The reliability and stability of the control platform and the feasibility of the construction method in this paper are tested by the actual ship test. Therefore, in the future, we will study the disturbance of the external environment and constantly optimize the construction method of the control platform.

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