System Identification on the Course Control Response of a Small Rov

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Abstract: in This Paper, through the Analysis of the Rov Model of a Pitch Mechanism, the System Identification Method Based on the Generalized Least Square Method of Arx Model is Adopted, and the Data Results Are Obtained. the Control Model Obtained by This Method is the Basis of the Design of Autonomous Control System of Rov.

1. Introduction

Small Special Underwater Vehicle (Rov) is One of the Current Research Directions of Robot. Rov Robot Has Great Application Prospects in the Development and Utilization of Water Resources, the Detection and Repair of Various Large and Medium-Sized Hydropower Stations and Dams, as Well as the Detection of Narrow and Small Pipelines. However, the Whole Process of Rov Control Needs to Be Controlled by Personnel. Therefore, in Order to Reduce the Workload of Rov Manual Operation and Improve the Automation and Intelligence Level of Rov, It is Necessary to Upgrade the Rov's Pilot to Realize Some Functions of Auv. Therefore, It is Necessary to Design the Attitude Controller, Especially the Heading Controller to Realize the Autonomous Navigation Function.

2. Rov Structure and Control Model

2.1 Response Model of Rov to Course Control:

The ROV in this paper is generally of frame structure (see Fig. 1). In order to increase the payload and improve the maneuverability, high-precision pitch adjustment mechanism and four groups of propelling propellers are added as the main body, two groups of large propellers are added to realize the forward and backward, in addition, a group of high-precision pitch adjustment mechanism and direction control propelling motor are added to realize the course Euler angle and depth keeping control System. The response of the small ROV to the longitudinal control is reflected in the change of the robot's heading angle. The principle of course control is: by adjusting the speed of the main longitudinal motor and the pitch of the propeller blade, under the condition of stable depth, the pitch of the propeller blade of the lateral motor is controlled and the direction is corrected.

Fig.1 The Rov with Frame Structure

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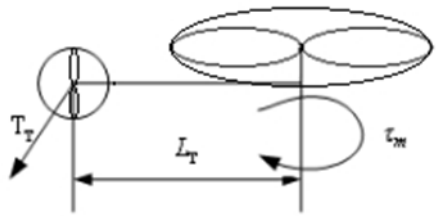

Fig.2 The Model of the Force State of Rov

The principle of course control is: by adjusting the speed of the main longitudinal motor and the pitch of the propeller blade, under the condition of stable depth, the pitch of the propeller blade of the lateral motor is controlled and the direction is corrected. According to the force state of ROV heading in Fig.2, the basic linear dynamic equation of small ROV is as follows: $A\dot{X} = BX + CU$,where $X = \left[\Delta V_x \quad \Delta V_y \quad \Delta V_z \quad \Delta\omega_x \quad \Delta\omega_y \quad \Delta\omega_z \quad \Delta\gamma \quad \Delta\psi \quad \Delta\vartheta\right]^T$ is the state variable, $U = \left[\Delta\varphi_7 \quad \Delta A_1 \quad \Delta B_1 \quad \Delta\varphi_T\right]^T$ is the increment of control input, $\Delta\varphi_7 \quad \Delta A_1 \quad \Delta B_1 \quad \Delta\varphi_T$ is corresponding to the longitudinal motor speed, forward motor 1 speed, forward motor 2 speed, side motor speed respectively, and a, B, C are coefficient matrix,then,the linear model of course operation response can be expressed as follows:

$$\begin{bmatrix} m & 0 & 0 & 0 & 0 \\ 0 & I_x & 0 & 0 & 0 \\ 0 & 0 & I_y & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{V}_z \\ \dot{\omega}_x \\ \dot{\omega}_y \\ \dot{\gamma} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} F_z^{V_g} & F_z^{\omega_x} & F_z^{\omega_g} & F_z^{\gamma} & F_z^{\psi} \\ T_x^{V_g} & T_x^{\omega_x} & T_x^{\omega_y} & 0 & 0 \\ T_y^{V_g} & T_y^{\omega_x} & T_y^{\omega_y} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_z \\ \omega_x \\ \omega_y \\ \gamma \\ \psi \end{bmatrix} + \begin{bmatrix} F_z^{\varphi_T} \\ T_x^{\varphi_T} \\ T_y^{\varphi_T} \\ 0 \\ 0 \end{bmatrix} \cdot \varphi_T \qquad (1\text{-}1)$$

The transfer function of the response of the small underwater ROV to the course control signal can be obtained by the pull transformation of 1-1:

$$\frac{\psi(s)}{\varphi_t(s)} = \frac{\Delta_\psi(s)}{\Delta(s)} \qquad (1\text{-}2)$$

Among them:

$$\Delta(s) = \begin{vmatrix} ms - F_z^{V_g} & -F_z^{\omega_x} & -F_z^{\omega_g} & -F_z^{\gamma} & -F_z^{\psi} \\ -T_x^{V_g} & I_x s - T_x^{\omega_x} & -T_x^{\omega_y} & 0 & 0 \\ -T_y^{V_g} & -T_y^{\omega_y} & I_y s - T_y^{\omega_y} & 0 & 0 \\ 0 & -1 & 0 & s & 0 \\ 0 & 0 & -1 & 0 & s \end{vmatrix} \qquad (1\text{-}3)$$

$$\Delta_\Psi(s) = \begin{vmatrix} ms - F_z^{V_g} & -F_z^{\omega_x} & -F_z^{\omega_y} & F_z^{\gamma} & F_z^{\varphi_T} \\ -T_x^{V_g} & I_x s - T_x^{\omega_x} & -T_x^{\omega_y} & 0 & T_x^{\varphi_T} \\ -T_y^{V_g} & -T_y^{\omega_x} & -I_y s - T_y^{\omega_y} & 0 & T_y^{\varphi_T} \\ 0 & -1 & 0 & s & 0 \\ 0 & 0 & -1 & 0 & s \end{vmatrix} \qquad (1\text{-}4)$$

Expand formula 1-3 and 1-4 to obtain:

$$\frac{\psi(s)}{\varphi_T(s)} = \frac{\Delta_\psi(s)}{\Delta(s)} = \frac{b_3 s^3 + b_2 s^2 + b_1 s + b_0}{a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0} \qquad (1\text{-}5)$$

In formula 1-5,

$a_5 = m I_x I_y$

$$a_4 = m(I_y T_x^{\omega_x} + I_x T_y^{\omega_y}) - I_x I_y F_z^{V_g}$$
$$a_3 = I_x (F_z^{V_g} T_y^{\omega_y} - F_z^{\omega_y} T_y^{V_g}) - I_y (F_z^{\omega_x} T_x^{V_g} - F_z^{V_g} T_x^{\omega_x}) + m(T_y^{\omega_y} T_x^{\omega_x} - T_x^{\omega_y} T_y^{\omega_x})$$
$$a_2 = F_z^{\omega_y} (T_y^{V_g} T_x^{\omega_x} - T_x^{V_g} T_y^{\omega_x}) + T_x^{\omega_y} (F_z^{V_g} T_y^{\omega_x} - F_z^{\omega_x} T_y^{V_g}) + T_y^{\omega_y} (F_z^{\omega_x} F_y^{V_g} - F_z^{V_g} T_x^{\omega_x}) - I_y F_z^{\gamma} T_x^{V_g}$$
$$a_1 = F_z^{\gamma} (T_x^{V_g} T_y^{\omega_y} - T_y^{V_g} T_x^{\omega_y})$$
$$a_0 = 0$$
$$b_3 = m I_y T_y^{\varphi_T}$$
$$b_2 = I_x (T_y^{V_g} F_z^{\varphi_T} - F_z^{V_g} T_y^{\varphi_T}) + m(T_y^{\omega_y} T_x^{\varphi_T} - T_x^{\omega_y} T_y^{\varphi_T})$$
$$b_1 = -F_z^{\varphi_T} (T_y^{V_g} T_x^{\omega_x} - T_x^{V_g} T_y^{\omega_x}) + T_x^{\varphi_T} (F_z^{V_g} T_y^{\omega_x} - F_z^{\omega_x} T_y^{V_g}) - T_y^{\varphi_T} (F_z^{\omega_x} F_y^{V_g} - F_z^{V_g} T_x^{\omega_x})$$
$$b_0 = -F_z^{\gamma} (T_x^{V_g} T_y^{\varphi_T} - T_y^{V_g} T_x^{\varphi_T})$$

At the same time, the transfer function from the control signal to the response of the side push motor:

$$\frac{\varphi_T(s)\partial}{\delta_p(s)} = \frac{K_t}{s^2 + 2\xi\omega_n + \omega_n^2} \qquad (1\text{-}6)$$

Therefore, the transfer function from the controller signal to the ROV heading angle is:

$$\frac{\psi(s)}{\delta_p(s)} = \frac{\Delta_\psi(s)}{\Delta(s)} \cdot \frac{\varphi_T(s)}{\delta_p(s)} = \frac{K_t}{s^2 + 2\xi\omega_n + \omega_n^2} \cdot \frac{b_3 s^3 + b_2 s^2 + b_1 s + b_0}{a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0} \qquad (1\text{-}7)$$

2.2 Transform the Transfer Function of Handling Response into Arx Model:

The detailed steps of transformation are as follows:

The transfer function $G(s) = {b_0 + b_1 s + ... + b_m s^m} / {a_0 + a_1 s + ... + a_n s^n}$,is converted into the difference form as follows:

$$y(k) + \sum_{i=1}^{n} a_i y(k-i) = \sum_{i=1}^{n} b_i u(k-i) \qquad (*)$$

Define: $z^{-1} y(k) = y(k-1)$

$$1 + a_1 z^{-1} + ... + a_n z^{-n} = a(z^{-1})$$
$$b_0 + b_1 z^{-1} + ... + b_n z^{-n} = b(z^{-1})$$

Then:formula (*)is equate to :

$$a(z^{-1}) y(k) = b(z^{-1}) u(k)$$

According to the conclusion formula 1-7, under the simple condition of underwater and low-speed suspension, the driving mechanism from the control signal to the pitch of the vertical motor can be approximately equivalent to the first-order linear link. Therefore, the transfer function formula 1-7 from the command signal of operation to the electromechanical mechanism of deep suspension control can be simplified as follows:

$$\frac{\psi(s)}{\delta_p(s)} = \frac{\Delta_\psi(s)}{\Delta(s)} \cdot \frac{\varphi_T(s)}{\delta_p(s)} = \frac{1}{s} \cdot \frac{b_3 s^3 + b_2 s^2 + b_1 s + b_0}{a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0} \qquad (1\text{-}8)$$

It is transformed into an equivalent difference equation, in which,a5 and a4 since both Ix and Iy are very small values, the influence of them can be ignored. 1-8 can be converted into:

$$y(k) + a_1 y(k-1) + a_2 y(k-2) + a_3 y(k-3) + a_4 y(k-4) = b_0 u(k) + b_1 u(k-1) + b_2 u(k-2) + b_3 u(k-3)$$

Thus form:

$$y(k) + \sum_{i=1}^{4} a_i y(k-i) = \sum_{i=1}^{3} b_i u(k-i) \qquad (1\text{-}9)$$

Define as formula* : $z^{-1}y(k) = y(k-1)$ $\quad 1 + a_1 z^{-1} + \ldots + a_n z^{-n} = a(z^{-1})$

$b_0 + b_1 z^{-1} + \ldots + b_n z^{-n} = b(z^{-1})$

then:1-8 can be converted into ARX model:

$$a(z^{-1})y(k) = b(z^{-1})u(k) \qquad (1\text{-}10)$$

3. Course Input, Response and Parameter Identification Results of Rov Collected by Experiments

3.1 Input and Response Curve of Underwater Rov Course Channel Collected by Experiment:

The sensors installed on ROV collect the data generated by Euler angle and pseudo-random function of the body. The data are converted and recorded synchronously according to time series. The system includes multi axis acceleration sensor, multi axis angular velocity sensor, data acquisition processor, zero buoyancy optical cable data transmission system, ground control integrated display and control, etc. See Fig.3, Fig.4 for the data. The corresponding random control input signal and attitude sensor output state are sampled respectively. The mean value processing results are as follows:

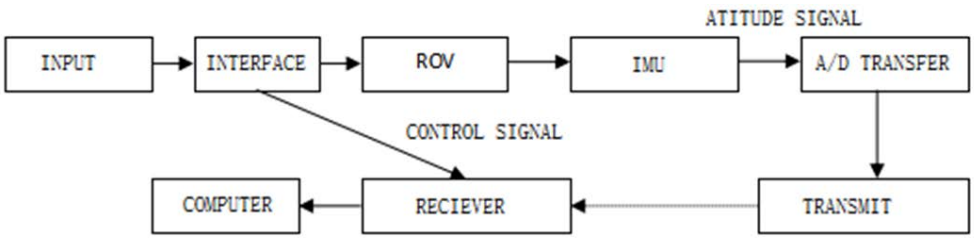

Fig.3 Data Collection and transmission system for ROV robot

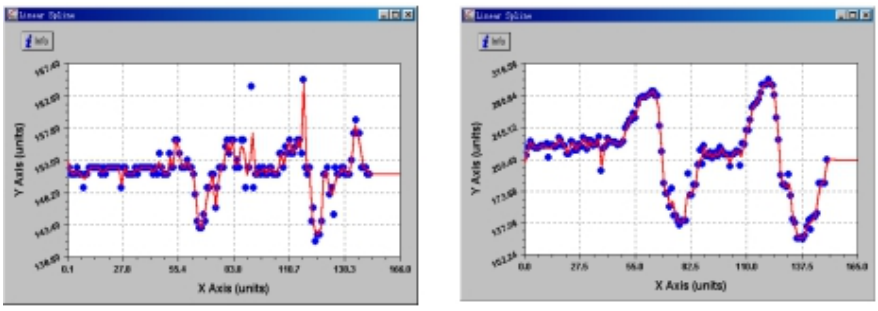

Fig.4 The Control Signal and the Response Signal of the Rov

3.2 Process and Results of Arx Model Parameter Identification

Through the MATLAB system identification tool which contains ARX function toolbox of minimum identification method ls, the fast calculation of system identification part is realized, and the identification result is shown in Fig.5, Fig.6 as below:

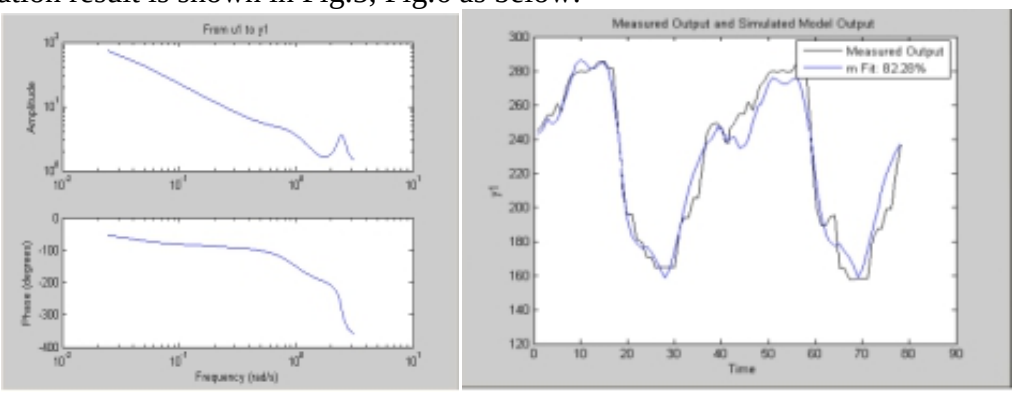

Fig.5 Identification Result Curve

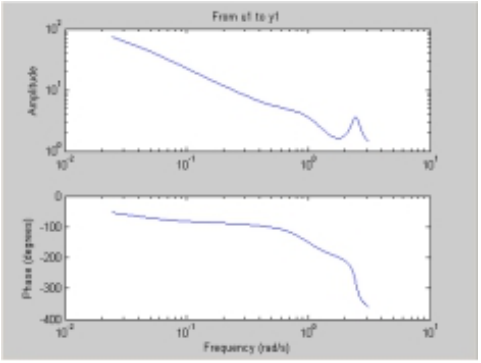

Fig.6 Bode Figure

The transfer function of the ROV robot yaw channel is:

$$\frac{\psi(s)}{\delta_p(s)} = \frac{0.2215s^5 - 3.154s^4 + 81.35s^3 + 5019s^2 + 161500s + 1394110}{s^5 + 12.68s^4 + 915.5s^3 + 5682s^2 + 80840s + 12099}$$

4. Conclusion

The parameter estimation and identification method of course control proposed in this paper is to derive the linear model of the underwater ROV robot, analyze the transfer function of the course control response, process the data collected from the input control signal and response according to the inertial sensor of ROV body, and obtain the identification result with certain accuracy by the generalized least square method based on ARX model. Later research shows that the control rate model obtained by the method of this paper is an important basis for refitting ROV into autonomous AUV underwater robot in the next stage.

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