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The Response Model of Modeling and Identification of Podded Propulsion Unmanned Surface Vehicle

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Abstract. According to Dalian Maritime University podded propulsor unmanned surface vehicle, the idea of MMG separation model is employed to establish its mathematical model of plane motion with three degrees of freedom. Then by analysing and hypothesizing the force of acting on the hull and propulsor, mathematical model of plane motion is simplified as a response model. Based on that, real ship data are collected, which the data are used to identify the response model by recursive least squares. In order to verify the correctness of the identification result, the identified model is used to simulate and compare with the actual experiment. Comparison results show that the error of simulation results with the actual experiments are in the range of confidence, which it proves the correctness of modeling and the feasibility of identification scheme.

Keywords: identification, modeling, POD, response model, unmanned surface vehicle

1 Introduction

Unmanned Surface Vehicle (USV) can be used to monitor water quality, track surface ship, join the battle of the sea and perform dangerous mission. It has a broad market prospect and has become a hot topic at home and abroad in the field of intelligent marine equipment [1]. In the complex and changeable marine environment, USV requires having fast speed and good maneuverability, which puts forward a higher requirement for the performance of its propulsor. POD propulsor is a new type of ship propulsion device developed in recent years, which can save the hull space, increase the payload, improve the efficiency and flexibility of the ship. Based on the above advantages, POD propulsion technology is one of the most promising new technologies in the field of ship propulsion [2]. POD propulsor can surround the axis for 360 degree rotation and generate vector thrust in any direction. This is to say, does not require rudder and lateral thruster [3] ship can achieve rotation, reverse, horizontal movement and other driving operations. So for USV, POD propulsor is not only to meet its basic operation requirements, but also to improve the integrated navigation performance.

In comparison, POD is a new type of propeller, although some literatures about POD have been published at home and abroad. However, most of them are studying on the performance of POD, and only a few literatures study on the overall control performance of podded propulsion ship. Haraguchi [4] evaluates the maneuverability of the podded propulsion ship by changing and maintaining the course. Woodward [5] predicts the performance of the podded propulsion ship. Ma [6] takes the POD propulsor as a research object, and then two methods of numerical calculation and model tests are used to analyze its hydrodynamic performance. In the paper [7], the performance of podded propulsion semi submersible ship is predicted by three degrees of freedom, but the accuracy of the model is not verified. Using the idea of MMG separation modeling, Zhang, Yi and Sun [8] establish a semi submersible vessel with four degrees of freedom motion mathematical model, and it is applied to the navigation simulator. Based on the analysis of a electrical podded propulsor ship, Piao and Guo [9] establish MMG three degree of

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freedom model, and to a certain extent explains the maneuvering characteristics of the ship. On this basis, linear auto disturbance rejection controller is employed to design course controller, and good control effect is obtained in the simulation.

For the study of the control technology of podded propulsion ship, accurate maneuvering model needs to be established firstly. There are two main methods to establish mathematical models, namely, the mechanism modeling method and the identification modeling method. In the field of ship motion modeling, mechanism modeling method is dominant, and so far, many for research purposes white-box mathematical model of ship motion are established. The essence of identification model is a modeling method of black box testing, and it uses the input and output information to reflect the external characteristics of the process. In frequency domain, it is shown as a transfer function, meanwhile, in the time domain, it is shown as differential or difference equations [10]. Between the black box and white box is grey box, and the essence of grey box modeling is that mechanism modeling is used to determine model structure and model parameters. In the paper [11], the support vector machine (SVM) method is applied to the modeling of ship maneuvering motion for the first time which provides a new method for the system identification technology in the mathematical modeling of ship maneuvering motion. In the paper [12], the partial model parameters of MMG are identified by least square method, and then the residual parameters are identified by inverse adaptive. The results are accurate and effective, but this method can only be used in the model ship. Wirtensohn, Wenzl, Tietz and Reuter [13] use different operation methods to identify model parameters, and the identification results are evaluated by using Fisher matrix. For a high speed three body model ship, under the premise of known partial ship model parameters, Herrero and Gonzalez [14] use stepwise regression method to identify the rest unknown coefficients, and then uses the nonlinear prediction error unscented Kalman filter to identify before the optimization. Based on the approximation ability of radial basis function neural network, in the unknown ocean environment, Dai, Wang and Luo [15] proposes a set of methods to precise identify and learn control a surface ship. A series of ship model identification methods and corresponding identification theory are presented in the paper [16].

In summary, Some scholars [4-9] are to study the characteristics of POD propulsion, but they did not study the response model identification of the podded propulsion ship. Some [11-16] are to study ship model identification, but the ship is drove by propeller and rudder. So, the contribution of this paper is that on the basis of force analysis, the three degree of freedom model of podded propulsion USV is reduced to a response model and it response model is shown to be consistent with the classical Nomoto model structure. On this basis, a simple scheme is proposed to identify the model parameters. Maybe the accuracy is a little lower than that of the literatures [10-15], but the method proposed in this paper is more simple and is beneficial to the realization of the project.

The main structure of this paper is as follows: in the second chapter, Dalian Maritime University USV and its POD propulsion system are introduced. In the next chapter, the force and moment on the propulsor and USV are analyzed, and according to the mechanical characteristics, the MMG model is simplified as a responding ship motion mathematical model. Later, on the basis of collecting experimental data, the responding model of USV is identified by recursive least squares. In order to verify the correctness of the model, the identification results are verified by contrast tests. Finally, full paper is summarized and the next research is introduced.

2 USV and Its Propulsion System

The so-called mathematical model of ship motion is using mathematical language to describe the dynamic characteristics of the ship motion. By the actual experience shows that too complex model does not mean a better description of the physical characteristics, because such models often mean that the parameters of difficult to estimate are taken into account leading to increasing difficulty of analysis problems. However, overly simplified mathematical model often ignores some important system characteristics which it will reduce the reliability and availability of the model. Model is the basis of ship motion control performance, so it is very necessary that establishes a mathematical model with suitable complexity and precision [17]. At present, there are two ways to study the hydrodynamic model of ship maneuvering motion: one is the integral model of ship motion mathematical model, namely Abkowitz model; the other is a separate type of mathematical model, also known as the MMG model. These two mathematical models have their respective advantages and disadvantages. In this paper, the idea of MMG separation type modeling is used to study the model of unmanned surface vehicle.

2.1 USV

Dalian Maritime University "lanxin" USV is an intelligent small fast unmanned surface vehicle which has the abilities of water sample collection, marine monitoring, marine rescue and other functions. The USV is shown in Fig. 1.

Fig. 1. Lanxin USV

To achieve the precise control of the unmanned surface vehicle, first of all, the motion state and the surrounding environment of real-time information are obtained through a variety of sensors. The multi sensor system of unmanned vehicle mainly consists of the following three parts: attitude detection sensor, DGPS navigation sensor and boat carrier network. The attitude detection sensor mainly provides the attitude information of the unmanned vehicle, for example, the roll angle, pitching angle and course angle. DGPS navigation sensor mainly provides latitude and longitude information, and the boat carrier network system through the CAN bus provides the state information and the surrounding environment information, such as speed, engine speed, water depth, etc. The multi sensor structure of unmanned vehicle is shown in Fig. 2.

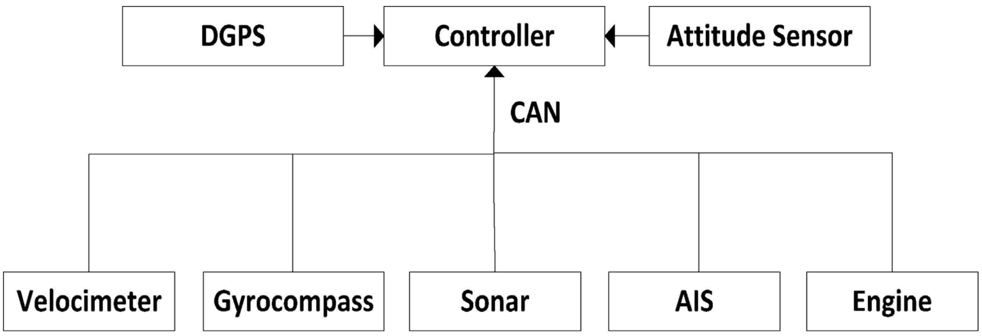

Fig. 2. The multi sensor structure of unmanned vehicle

2.2 POD Propulsion System

Most of the ship's propulsion device uses propeller and rudder, and rudder is placed behind the propeller. The speed of the ship can be changed by adjusting the speed of the propeller, meanwhile, the rudder angle can be adjusted to change the thrust distribution of the propeller in the longitudinal direction and the transverse direction, thus provides the steering force of the ship. The propulsor of USV adopts mercury company's BRAVO series stern machine. As shown in Fig. 3.

Fig. 3. The structure of propulsor

It can be seen from the picture that the stern machine has the functions of propulsion and steering, which they are set in one device. From the principle of the structure, the propulsion mechanism belongs to a single-fin POD propulsor [18]. The stern machine can be divided into fin and propeller in structure, and the fin is in front of the propeller. When the advancing angle is changed, the vector thrust produced by the propulsor can be decomposed into two directions in the attached body coordinate system: maintains the longitudinal thrust of keeping ship forward and produces the transverse thrust of the steering effect.

3 USV Model

3.1 Planar Motion Model

To study the movement of the USV in the ocean, according to the practice of convention the attached body coordinate system and the inertial coordinate system are adopted. As shown in Fig. 4, $O-X_0Y_0Z_0$ is the inertial coordinate system and $o-xyz$ is the attached body coordinate system. The actual movement of the unmanned vehicle is very complex during the course of the voyage, and it having six freedom degrees includes the surge velocity u 、sway velocity v 、heave velocity w, yaw rate r 、rolling rate p and pitching angle q . ψ is course angle and δ is rudder angle.

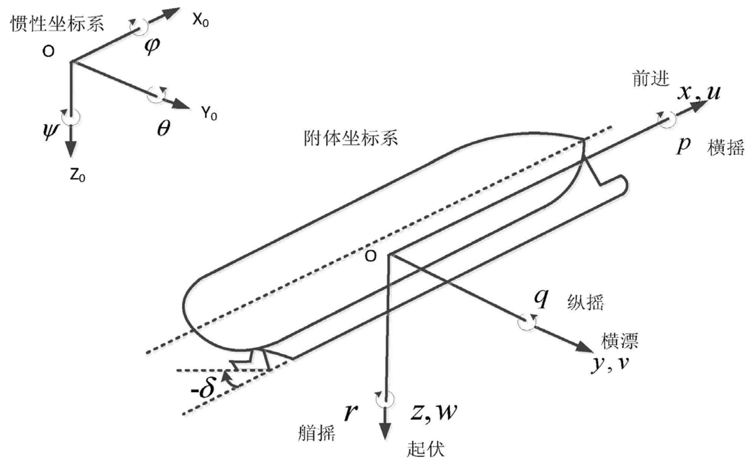

Fig. 4. The inertial coordinate system and the coordinate system

Although there are 6 degrees of freedom of USV, but does not mean that we should take all 6 degrees of freedom to consider. According to the existing experience, we can ignore the heave velocity, rolling rate and pitching angle, which focus on u, v, r . Assuming that the ship is symmetrical and the center of gravity is located the origin of the attached coordinate system, the MMG model can be simplified as a planar motion model with three degrees of freedom.

$$\begin{cases}(m+m_x)\dot{u}-(m+m_y)vr=X\\(m+m_y)\dot{v}+(m+m_x)ur=Y\\(I_{zz}+J_{zz})\dot{r}=N\end{cases}. \quad \textbf{(1)}$$

Where m is the weight of ship, m_x is the additional mass in the x axis direction, m_y is the additional mass in the y axis direction, I_{zz} is the moment of inertia of the o_x axis, J_{zz} is the additional moment of inertia in the direction of the z axis, X, Y and N are the hydrodynamic forces and moments acting on the hull.

$$\begin{cases}X=X_H+X_p\\Y=Y_H+Y_p\\N=N_H+M_p\end{cases}. \quad \textbf{(2)}$$

Where H is the hydrodynamic force acting on the bare hull, P is the propeller force (It does not refer to the thrust of the propeller, but rather a force). Because this article uses the method of system identification to determine the parameters, so it does not introduce each regression formula and its methods of approximate estimation.

3.2 Model Derivation and Simplification

The plane motion variables of USV are shown in Fig. 5. Where V is the speed of USV.

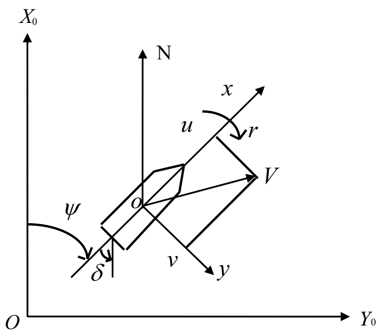

Fig. 5. Variable description of the plane motion

According to the analysis of existing literature, the hydrodynamic forces acting on the bare hull are:

$$\begin{cases}X_H=X(u)+X_{Hvv}v^2+X_{Hvr}vr+H_{Hrr}r^2\\Y_H=Y_{Hv}v+Y_{Hr}r+Y_{NL}\\N_H=N_{Hv}v+N_{Hr}r+N_{NL}\end{cases}. \quad \textbf{(3)}$$

Where Y_{NL} and N_{NL} are nonlinear fluid dynamics, and compared with the linear hydrodynamic force, they can be considered as a high order small quantity, which can be ignored. According to the paper [19], the propulsor thrust is

$$T=cV\delta_n+d\left|\delta_n\right|\delta_n. \quad \textbf{(4)}$$

Where V is the speed of ship, δ_n is the speed of propeller, c and d are the coefficients of greater than zero.

When the advancing angle is δ, the vector thrust in different directions are

$$\begin{cases} X_P = (cV\delta_n + d|\delta_n|\delta_n)\cos\delta \\ Y_P = (cV\delta_n + d|\delta_n|\delta_n)\sin\delta \\ N_P = x_{\delta s}(cV\delta_n + d|\delta_n|\delta_n)\sin\delta \end{cases} . \tag{5}$$

Where $x_{\delta s}$ is the length of vertical arm from the center of rotation to the fulcrum of the propulsor.

Assume that the outside interference is small, that is, it is always moving in the vicinity of the initial equilibrium state. At this point the linear hydrodynamic force acting on USV occupies a dominant position, and the higher order terms can be ignored. In the field of ship model research, the uniform linear motion of the ship is generally regarded as the initial equilibrium state. Assume $u = u_0$, $v = v_0 = 0$, $r = r_0 = 0$ and $\delta = \delta_0 = 0$. Where u_0 is the longitudinal initial velocity of USV. When the USV is disturbed by interference, the changes of motion state are Δu, $\Delta v = v$, $\Delta r = r$ and $\Delta\delta = \delta$. Then $u = u_0 + \Delta u$, $v = v_0 + \Delta v$, $r = r_0 + \Delta r$ and $\delta = \delta_0 + \Delta\delta$. The formula1 is simplified as

$$\begin{cases} (m + m_x)\Delta\dot{u} = X \\ (m + m_y)\dot{v} + (m + m_x)u_0 r = Y \\ (I_{zz} + J_{zz})\dot{r} = N \end{cases} . \tag{6}$$

The hydrodynamic forces on an unmanned vehicle are discussed in the presence of perturbations. Keep first order small quantities Δu , v , r , δ and ignore high order small quantities of two and above.

$$\begin{cases} X_H = X(u_0 + \Delta u) \\ Y_H = Y_{Hv} v + Y_{Hr} r \\ N_H = N_{Hv} + N_{Hr} r \end{cases} . \tag{7}$$

Where $X(u_0 + \Delta u)$ is the direct resistance of USV which can be expressed as

$$X(u_0 + \Delta u) = -\frac{1}{2}\rho S C_t (u_0 + \Delta u)^2 . \tag{8}$$

Where S is the area of wet, ρ is water density, C_t is the total drag coefficient, and its essence is a function of speed. The formula 8 can be expanded as

$$X(u_0 + \Delta u) = -\frac{1}{2}\rho S[C_{t0} + (\frac{\partial C_t}{\partial \Delta u})_{u0}\Delta u](u_0 + \Delta u)^2 . \tag{9}$$

When the speed is u_0, its total resistance coefficient is C_{t0}. The Δu of formula 9 is linearized as

$$X_H = -\frac{1}{2}\rho S C_{t0} u_0^2 - \frac{1}{2}\rho S[2C_{t0}u_0 + (\frac{\partial C_t}{\partial \Delta u})_{u0} u_0^2]\Delta u . \tag{10}$$

Make $X_0 = -\frac{1}{2}\rho S C_{t0} u_0^2$ and $X_{Hu} = -\frac{1}{2}\rho S[2C_{t0}u_0 + (\frac{\partial C_t}{\partial \Delta u})_{u0} u_0^2]$.

Where X_0 is the straight line resistance of the unmanned vehicle in the initial state. Then $X_H = X_0 + X_{Hu}\Delta u$. That is, the formula 7 can be converted to

$$\begin{cases} X_H = X_0 + X_{Hu}\Delta u \\ Y_H = Y_{Hv} v + Y_{Hr} r \\ N_H = N_{Hv} + N_{Hr} r \end{cases} . \tag{11}$$

Taking into account the δ is small, so $\sin\delta \approx \delta$, $\cos\delta \approx 1$. Then the thrust of the propeller can be simplified as

$$\begin{cases} X_P = cV\delta_n + d\left|\delta_n\right|\delta_n \\ Y_P = (cV\delta_n + d\left|\delta_n\right|\delta_n)\delta \\ N_P = x_{\delta s}(cV\delta_n + d\left|\delta_n\right|\delta_n)\delta \end{cases} . \quad \textbf{(12)}$$

So the formula 2 can be expressed as

$$\begin{cases} X = X_0 + X_{\mathrm{pu}}\Delta u + X_p \\ Y = Y_H + Y_p = Y_{Hv}v + Y_{\mathrm{Hr}}r + X_p\delta \\ N = N_H + M_p = N_{Hv}\mathrm{v} + N_{Hr}r + x_{\delta s}X_p\delta \end{cases} . \quad \textbf{(13)}$$

Because in the initial state, the resistance of the unmanned vehicle is equal to the thrust of the propulsor. Then $X_0 + X_P = 0$.

$$\begin{cases} X = X_u\Delta u \\ Y = Y_{Hv}v + Y_{\mathrm{Hr}}r + X_p\delta \\ N = N_{Hv}\mathrm{v} + N_{Hr}r + x_{\delta s}X_p\delta \end{cases} . \quad \textbf{(14)}$$

Formula 14 is brought into the 6. Then

$$\begin{cases} (m + m_x)\Delta\dot{u} = X_u\Delta u \\ (m + m_y)\dot{v} + (m + m_x)u_0 r = Y_{Hv}v + Y_{\mathrm{Hr}}r + X_p\delta \\ (I_{zz} + J_{zz})\dot{r} = N_{Hv}\mathrm{v} + N_{Hr}r + x_{\delta s}X_p\delta \end{cases} . \quad \textbf{(15)}$$

Assuming that the ship is subjected to a small disturbance, the longitudinal velocity is constant, so X, Y and N can be decoupled separately considered. The formula 15 can be divided into

$$(m + m_x)\Delta\dot{u} = X_u\Delta u . \quad \textbf{(16)}$$

$$\begin{cases} (m + m_y)\dot{v} + (m + m_x)u_0 r = Y_{Hv}v + Y_{\mathrm{Hr}}r + X_p\delta \\ (I_{zz} + J_{zz})\dot{r} = N_{Hv}\mathrm{v} + N_{Hr}r + x_{\delta s}X_p\delta \end{cases} . \quad \textbf{(17)}$$

Make $Y_{\mathrm{Hv}} = Y_v$, $Y_{Hr} = Y_r$, $X_{\mathrm{p}} = Y_\delta$, $N_{Hv} = N_v$, $N_{Hr} = N_r$, $x_{\delta s}X_p = N_\delta$. The formula17 can be simplified as

$$\begin{cases} (m + m_y)\dot{v} = Y_v v + (Y_r - (m + m_x)u_0 r) + Y_\delta\delta \\ (I_{zz} + J_{zz})\dot{r} = N_v v + N_r r + N_\delta\delta \end{cases} . \quad \textbf{(18)}$$

In order to simplify the problem, assuming that the initial state is uniform motion, all the motion variables have zero initial value, then $\Delta u(0) = 0$, $v(0) = 0$, $r(0) = 0$, $\dot{v}(0) = 0$, $\dot{r}(0) = 0$, $\delta(0) = 0$, $\dot{\delta}(0) = 0$. After Laplace transformation, the formula 18 is converted to 19.

$$\begin{cases} (m + m_y)sv(s) = Y_v v(s) + (Y_r - (m + m_x)u_0)r(s) + Y_\delta\delta(s) \\ (I_{zz} + J_{zz})sr(s) = N_v v(s) + N_r r(s) + N_\delta\delta(s) \end{cases} . \quad \textbf{(19)}$$

Then the transfer function of propulsion angle δ and yawing angular velocity r can be got.

$$H(s) = \frac{r(s)}{\delta(s)} = \frac{K(1 + T_3 s)}{(1 + T_1 s)(1 + T_2 s)} . \quad \textbf{(20)}$$

Where T_1, T_2, T_3 and K are model parameters and the relationship between the parameters of formula 20 are

$$T_1T_2 = \frac{(m+m_y)(I_{zz}+J_{zz})}{Y_vN_r - N_v\{Y_r-(m+m_x)u_0\}}, \quad \textbf{(21)}$$

$$T_1+T_2 = \frac{-(m+m_y)N_r-(I_{zz}+J_{zz})Y_v}{Y_vN_r - N_v\{Y_r-(m+m_x)u_0\}}, \quad \textbf{(22)}$$

$$K = \frac{N_vY_\delta - N_\delta Y_v}{Y_vN_r - N_v\{Y_r-(m+m_x)u_0\}}, \quad \textbf{(23)}$$

$$T_3 = \frac{(m+m_y)N_\delta}{N_vY_\delta - N_\delta Y_v}. \quad \textbf{(24)}$$

In particular cases, the values of T_1, T_2, T_3, and K are fixed values [16]. So we can get the corresponding value according to the formulas 21-24. There is a certain inertia in the motion of the unmanned vehicle, and the energy of the propulsion mechanism's is limited, so the movement of the unmanned surface vehicle has the characteristics of low frequency. So formula 20 can be reduced to a one order model at low frequency.

$$H(s) = \frac{r(s)}{\delta(s)} \approx \frac{K}{Ts+1}. \quad \textbf{(25)}$$

Where $T = T_1 + T_2 - T_3$. The transfer function of the course angle and the advancing angle is

$$\frac{\psi(s)}{\delta(s)} = \frac{K}{Ts^2+s}. \quad \textbf{(26)}$$

Two order yawing response equation can also approximate to a first-order yawing response equation.

$$T\dot{r} + r = K\delta. \quad \textbf{(27)}$$

This is the famous Nomoto model. Thus it can be seen, for the podded propulsion USV, although the propulsion system is different from the general propeller rudder propulsion system, however, its essence is still consistent with the Nomoto model.

3.3 Servo System Model

Normally, the response model of the advancing angle change process is usually regarded as a first order inertial link.

$$\dot{\delta} = -\frac{1}{T_r}\delta + \frac{1}{T_r}\delta_r. \quad \textbf{(28)}$$

Among them: the time constant T_r is about 1.2s. The target advancing angle is δ_r and its constraint condition is $|\delta| \le 35^\circ$.

4 Model Identification and Validation

4.1 Experimental Data Acquisition

In order to ensure the accuracy of the experimental data, turning test with 5 degrees and z type test with 15 degrees/15 degrees are carried out in a relatively stable condition. Furthermore, in order to better observe the experimental results, the experimental trajectories are displayed on the control platform which it is developed by C++, and the trajectories are shown in Fig. 6 and Fig. 7. Due to record too many data, only part of the data are listed in this paper, as shown in Table 1 and Table 2.

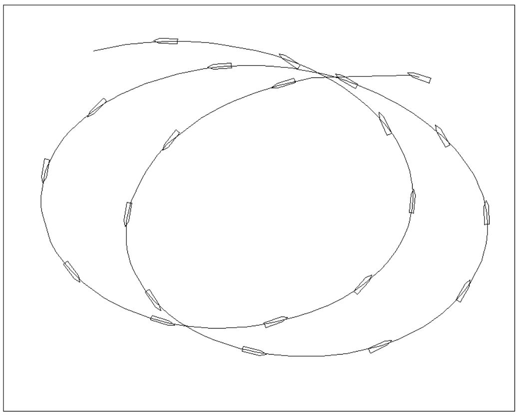

Fig. 6. Turning trajectory

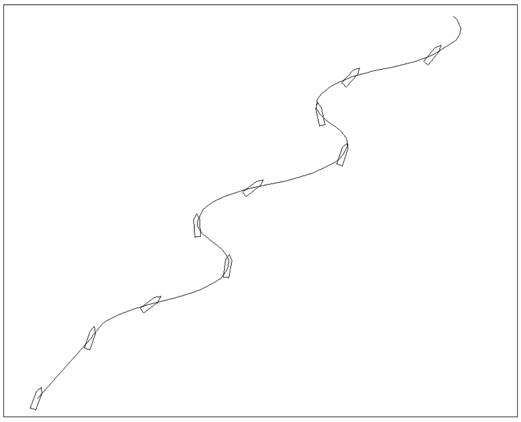

Fig. 7. Z type trajectory

Table 1. Turning test data

NO.	Time	Angle	Speed	Course
1	0.0	4.9	9.65	0.36
2	0.5	4.9	9.65	0.36
3	1.0	4.9	9.46	0.36
4	1.5	5.0	9.46	6.40
5	2.0	5.0	9.46	6.40
6	2.5	5.1	9.46	6.40
7	3.0	4.9	9.36	7.45
8	3.5	5.0	9.40	8.78
9	4.0	5.0	9.40	14.38
10	4.5	5.0	9.40	14.38
...	…	…	…	…
211	105.0	4.9	9.90	346.25
212	105.5	5.2	9.90	347.61
213	106.0	5.1	9.90	353.50
214	106.5	5.1	9.90	353.50
215	107.0	5.1	9.90	353.50
216	107.5	5.0	9.90	357.35
217	108.0	5.0	9.90	357.35
218	108.5	5.1	9.90	359.49

Table 2. Z test data

NO.	Time	Angle	Speed	Course
1	0.0	-12.4	9.01	235.04
2	0.5	-16.9	9.01	224.64
3	1.0	-17.4	9.05	220.78
4	1.5	-12.6	9.11	218.36
5	2.0	-12.9	9.11	207.83
6	2.5	-16.0	8.81	204.07
7	3.0	-17.3	8.81	204.07
8	3.5	-13.0	8.81	193.36
9	4.0	-13.2	8.69	188.37
10	4.5	-13.4	8.69	182.45
...	…	…	…	…
25	12.0	14.0	9.11	213.52
26	12.5	13.9	8.81	218.00
27	13.0	14.0	8.81	218.00
28	13.5	13.9	8.81	227.55
29	14.0	13.3	8.69	232.33
30	14.5	13.3	8.69	237.52

4.2 Identification Method

In this paper, recursive least square is used to estimate the parameters of the model, and its basic idea is: current estimated value $\hat{\theta}(K)$ equals last estimated value $\hat{\theta}(K-1)$ plus corrected value. Its formula is

$$\begin{cases} \hat{\theta}(n) = \hat{\theta}(n-1) + K(n)[y(n) - \phi^T(n)\hat{\theta}(n-1)] \\ K(n) = \dfrac{P(n-1)\phi(n)}{1+\phi^T(n)P(n-1)\phi(n)} \\ P(n) = [I - K(n)\phi^T(n)]P(n-1) \end{cases} . \quad \textbf{(29)}$$

Where $\hat{\theta}$ is the parameter estimation of ship, $\phi(k)$ is the data of vector [20]. The system identification process is shown in Fig. 8.

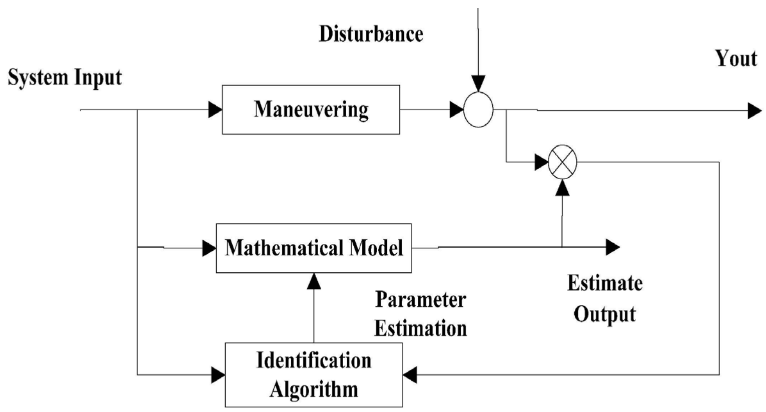

Fig. 8. System identification process

4.3 Parameter Identification

Firstly, the Nomoto model is identified by the z type experimental data. The identification curves are shown in Fig. 9.

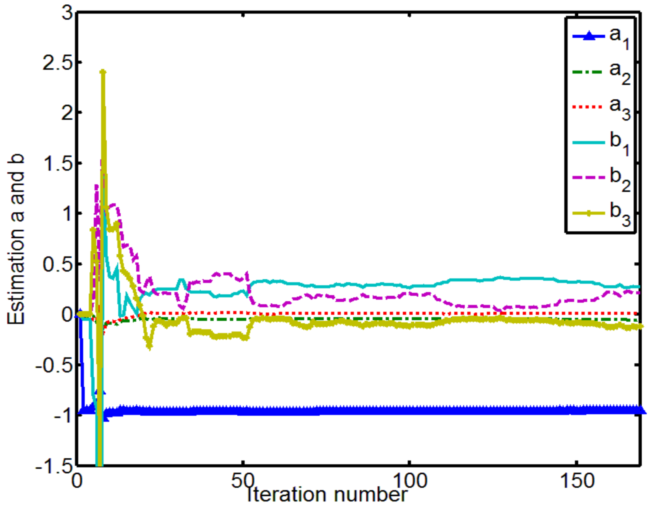

Fig. 9. Nomoto identification convergence curve

$a_1 \sim a_3$ and $b_1 \sim b_3$ are the coefficients of discrete transfer function. The transfer function is shown in 30.

$$\frac{0.2743z^2 + 0.2122z - 0.118}{z^3 - 0.9537z^2 - 0.5476z + 0.007182}. \tag{30}$$

Discrete transfer function is transformed into continuous transfer function and it is shown in 31.

$$\frac{1.65s^3 - 10.63s^2 + 88.19s + 225.9}{s^4 + 14.26s^3 + 106.8s^2 + 322s - 0.7904}. \tag{31}$$

From 31 can be seen that the higher order terms and the low order term coefficients have a greater difference in the level. So can omit the higher order items.

$$\frac{225.9}{106.8s^2 + 332s}. \tag{32}$$

Compared with formula 26, $K = 0.707$ and $T = 0.332$.

4.4 Model Validation

Turning experiment verification. Under the same state as the actual experiment (speed and advancing angle), the identified model is used to carry out turning simulation experiment. The simulation result is shown in Fig. 10.

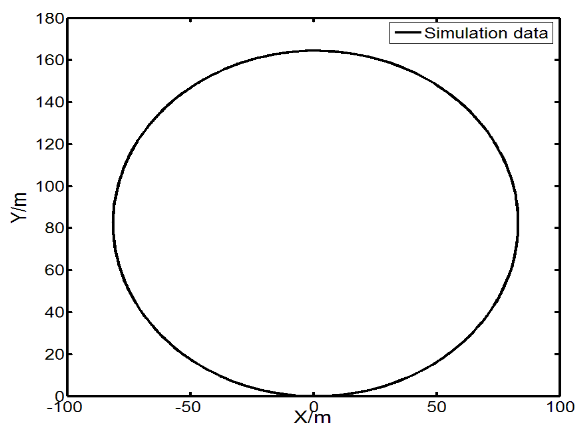

Fig. 10. Simulation result of turning experiment

The actual trajectory is shown in Fig. 11.

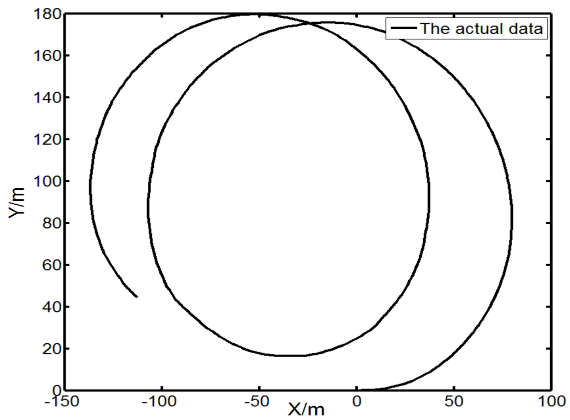

Fig. 11. Real ship turning trajectory

From Figs. 10 and Fig. 11 can obtain that the turning radius of simulation is 85.7621m and the steady turning radius of the real ship is 84.9716 m. The absolute error is 0.7905m in the trusted range. Beside can be seen from the actual experiment that even in a relatively stable state carries out experiment, but there are still some environmental disturbance, so the drift phenomenon has been produced in the turning experiment.

Z type verification. In the case of considering the characteristics of the servo system, the response model is used to carry out 15 degrees/15 degrees z type simulation experiment. The simulation results are shown in Fig. 12 and the real ship experimental results are shown in Fig. 13.

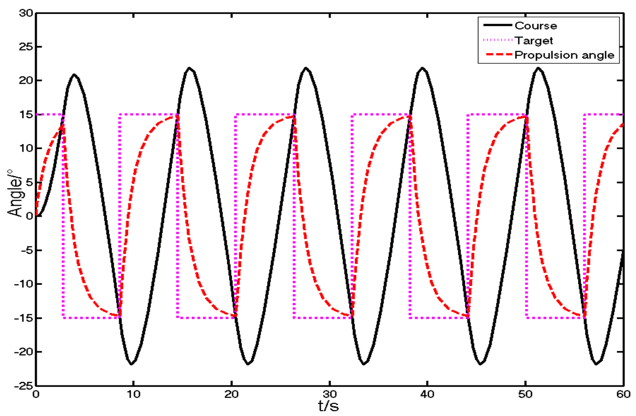

Fig. 12. Simulation results of z type experiment

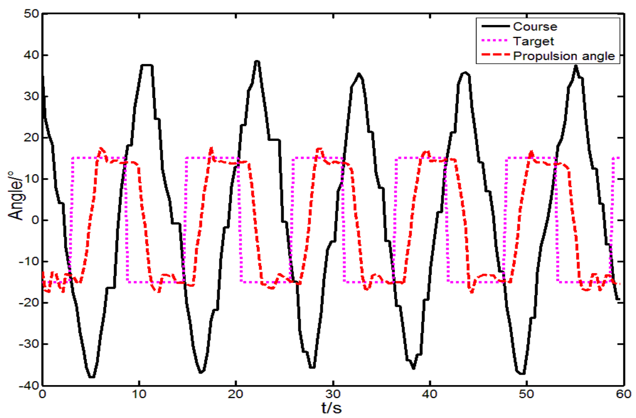

Fig. 13. Results of z type experiment on a real ship

Can be seen from Figs. 12 and Fig. 13, the simulation of the propulsion angle period is 12.3 seconds and actually is 12.9 seconds. The absolute error between the simulation and the actual experiment is 0.6s.

In summary, in turning experiment verification, its relative error is 0.9%, and in Z type verification, its relative error is 4.7%. So by the above two verification experiments can prove that the identified model is in line with the actual situation, and further explain the correctness of the modeling. Although there are some errors in modeling, however, the model is constantly changing in the real navigation, so the results of this paper are in the trusted range. The advantages of this scheme are simple and easy to implement. But beyond that, it is not only suitable for small model ships but also for large ships. For example [11], although SVM is a new method for ship model identification, it is difficult to regulate the coefficient compared with recursive least squares. For example [12], because of the need for towing test, large ships are difficult to carry out. That is to say, its method is only applicable to model ships, and is difficult to be applied in practical engineering. In sum, compared with literatures [10-15], the method of this paper is suitable for all kinds of ships, and the requirements of engineering personnel is not high.

5 Conclusions

Based on Dalian Maritime University "lanxin" podded propulsion USV, this paper carries on the analysis and identification of the model. Firstly, USV and its propulsion system are introduced, and then under reasonable assumptions, the response model is proved that it is consistent with the classical Nomoto model. Meanwhile, recursive least square is used to identify the response model. Finally, in order to prove the correctness of the model derivation and identification results, in the simulation, the turning experiment and z type experiment are carried out, which the simulation results are compared with the actual data. The final results show that the simulation results and the experimental results are in a credible range, which proves the correctness of this paper. In the next research plan, multi modal model under different conditions will be identified.

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