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Analysis of the Pitching Motion Mode of Three-body Rescue Unmanned Craft Based on System Identification

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Abstract— **In view of the excessively large pitch of the unmanned craft, the navigation performance may be degraded. Taking the vertical motion mode of the new three-body unmanned craft model as the research object, the pitch attenuation test was carried out in stable water. Now we established four mathematical models for tilting system identification, it based on the system identification method and the improved programming idea of genetic algorithm, adapting the system of tilting motion mode system identification. It is concluded that with the more draught, the more peak value of pitching speed, and with the increasing the time of the craft model to reach steady. Secondly, the equation of the model of pitch motion of the craft with the best effect is obtained, and the feasibility and adaptation of the model and the reliability of the software; finally, the three-body craft model has the anti-rolling effect, but in a small angle, the variation interval of linear damping moment M of catamaran model is relatively stable from 0.12 to 0.085. The system identification method and software provide a feasible way for such three-body unmanned craft pitching and other swaying modes.**

Index Terms— **three-body rescue unmanned craft, pitch motion mode, system identification, genetic algorithm.**

I. INTRODUCTION

In recent years, the development of unmanned crafts is developing in the direction of modularization, intelligence, systemication and standardization. When the ship is sailing on the sea, it is subject to random interference of waves, which may cause shaking phenomena such as roll, pitch and heave. If the pitch is too large, the navigation performance of the craft model will be reduced and the safety will not be guaranteed. Therefore, the prediction of the pitching motion of the craft model is carried out, and the hydrodynamic coefficient of the craft model pitching process is obtained, thereby improving the accuracy of the craft model pitching prediction.

In order to estimate the pitching performance of the ship [1], the general method is to carry out the longitudinal roll attenuation test of the model, but the analysis of the test results often use the least squares method to calculate the pitch natural period and additional mass inertia of the ship. Moment and dimensionless attenuation coefficient, the calculation process is more complicated by this method [2], and it is generally difficult to test the reliability of the correlation coefficient. Based on this, some scholars from domestic and abroad introduced the system identification method into the craft model pitch test analysis, and used the system identification method to identify and analyze the pitch motion of the craft model [3]. However, after careful researching by the authors and experts, the following problems exist in the actual calculation:(1) The selection of the mathematical model for the three-body craft model pitching motion system has an impact on the results; (2) a set of three-body craft model longitudinal motion system identification calculation software has an impact on the research; (3) the hydrodynamic coefficient pair .The results of the research on the longitudinal motion of unmanned craft models of different craft types have an effect; (4) When the three-body craft model is pitched, the draft is different, and the initial pitch angle has different effects on the research results.

In order to explore the vertical motion mode of the new three-body rescue unmanned craft, this paper selected the parameter model system identification method, identified and analyzed the experiment data through the system identification theory, selected the best working condition, and verified the identification by analyzing the identification results and test data. Based on the feasibility of establishing the model, the three-body craft model and the catamaran model are compared and analyzed, and the trend of the hydraulic moment coefficient and the initial pitch angle is obtained.

II. EXPERIMENTAL MODELS AND EXPERIMENTAL PROTOCOLS

A. Introduction to the Model

This paper chose a rescue three-body unmanned craft model, which is based on Jiangkeda “Hua chuan No.1” as a parent ship. The unique features: (1) Using the CFD method, a series of simulation calculations on the unmanned craft resistance performance, and establishing a database; based on modern optimization strategies and fuzzy decision-making ideas, the design takes into account the four major performances.(3) The three-body craft type with excellent overall layout characteristics. (2) A rotatable sail is installed in the middle of the main body of the hull, which can effectively use wind energy to improve sailing speed and save energy. It can greatly improve the performance of navigation stability and wave resistance[5]. After optimization, the scale ratio is 1:6. The table below shows the main parameter sizes of the test model.

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Table 1 Main scale of three-body rescue ship model

Items	Symbol	Value	Unit
Length	L	1.0	m
Demihull width	B	0.35	m
Depth	D	0.149	m
Main design draught	T	0.108	m
Block coefficient	C_b	0.499	/
Side body captain	L	0.459	m
Side craft width	B	0.159	m
Lateral body type	D	0.073	m
Side body design draught	T	0.05	m
Overall width	B	0.73	m
Total design displacement	Δ	15.0	kg

The cross section of the craft model is shown in Figure 1:

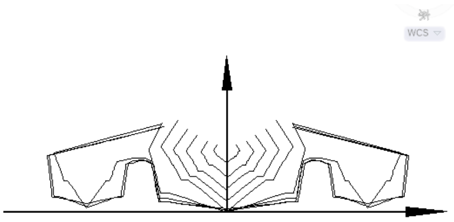


Fig.1 Cross-sectional view of the three-body craft model

III. CRAFT MODEL ROLL FREE ATTENUATION TEST PROGRAM

A. *Test process*

Test site: The wave pool of Jiangsu University of Science and Technology, and in order to reduce the wave effect of the pool wall, the longitudinal section of the craft model parallel with the pool wall, and the distance from the near end of the pool wall is guaranteed to be greater than 2m. In this paper, the attenuation law of the craft model is determined by measuring the variation of the pitch angle of the craft model during the static water free decay process. Into the different feeding habits of 0.9 times, 1.0 times, and 1.1 times, respectively, one test was performed in different initial pitch angles, and a total of 36 groups of pitch tests were performed [6]. The specific test process:

(1) Test preparation: test craft model, MTi-G inertial measurement instrument, data transmission line, computer;

(2) The MTi-G inertial measuring instrument horizontally placed at the center of gravity of the craft, and connect with the devices through the data line;

(3) placing the craft model in the center of the pool, and adjusting the craft mold by loading the weight to make it in a positive floating state;

(4) When the craft model is in the positive floating condition, the pitch angle of the craft model is read by the MTi-G software, and the horizontal pitch position of the MTi-G is adjusted to ensure that the initial pitch angle displayed on the software is between ±0.1° ;

(5) After determining that the craft model is stable and the water surface is calm, the craft mold is tilted to one side by applying an external force. After the initial angle of the pitch is determined, the external force is released, and the MTi-G measuring instrument synchronously performs data acquisition. After the craft model is stabilized, the data acquisition stops, and the data in the MTi-G software is extracted and saved;

Fig.2 craft model in the hydrostatic test

(6) Repeat the (4)-(5) process to change the required initial pitch angle. The initial pitch angle of the standard design draft is a total of four groups, including: 2° , 4° , 6° , 8° ; Perform a trial of 3 sets of initial pitch angles and select the best one as valid data;

(7) Repeat the steps (4)-(6) by adding or decreasing the ballast with 1.1 times and 0.9 times design draught test. After each change of ballast, adjust the floating state of the unmanned craft. After the experiment is finished, waiting for the water to calm down and proceed to the next group.

By experimenting, the initial pitch angle was given by each group is very close to the setting angle, and the error within ± 0.01°, so the data can be used to calculate the analysis. Finally, the craft model obtained 36 sets of data in three hydrops and four initial pitch angle hydrostatic pitch attenuation tests, including pitch angular velocity and pitch angle.

IV. SYSTEM IDENTIFICATION METHOD BASED ON GENETIC ALGORITHM

1) *A craft Model Pitch Motion Equation and Identification Mathematical Model*

According to the hydrostatic moment balance formula, the restorative moments in the pitch equation are transformed in the form of quadratic, quadratic, cubic and sine, respectively, to find the pitch equation that fits the craft model in this paper [7].

Identification formula 1: When the craft tilts to a small angle ψ , the damping torque is nonlinear, and when the restoring moment is linear, the model equation is:

$$\ddot{\psi} + 2\frac{M}{I_y}\dot{\psi} + \frac{V}{I_y}\left|\dot{\psi}\right|\dot{\psi} + \frac{y}{I_y}\dot{\psi}^3 + \frac{DH}{I_y}\sin\psi = 0 \tag{4.1}$$

Identification formula 2: The damping torque is nonlinear, and when the restoring moment is a linear plus square term, the model equation is:

$$\ddot{\psi} + 2\frac{M}{I_y}\dot{\psi} + \frac{V}{I_y}\left|\dot{\psi}\right|\dot{\psi} + \frac{y}{I_y}\dot{\psi}^3 + \frac{C_2}{I_y}\psi^2 + \frac{C_3}{I_y}\psi = 0 \tag{4.2}$$

Identification formula 3: The damping torque is nonlinear, and when the restoring moment is a linear plus square term plus three terms, the model equation is:

$$\ddot{\psi}+2\frac{M}{I_y}\dot{\psi}+\frac{V}{I_y}\left|\dot{\psi}\right|\dot{\psi}+\frac{y}{I_y}\dot{\psi}^3 \qquad (4.3)$$

$$+\frac{C_1}{I_y}\psi^3+\frac{C_2}{I_y}\psi^2+\frac{C_3}{I_y}\psi=0$$

Identification formula 4: The damping torque is nonlinear, and the restoring moment is the linear plus square of the sine value plus the cubic term. The model equation is:

$$\ddot{\psi}+2\frac{M}{I_y}\dot{\psi}+\frac{V}{I_y}\left|\dot{\psi}\right|\dot{\psi}+\frac{y}{I_y}\dot{\psi}^3+\frac{C_1}{I_y}(\sin\psi)^3 \qquad (4.4)$$

$$+\frac{C_2}{I_y}(\sin\psi)^2+\frac{C_3}{I_y}\sin\psi=0$$

Among the above four identification formulas: I_y—the total moment of inertia of the hull body; ψ —pitch angle; $\dot{\psi}$ —pitch angular velocity; $\ddot{\psi}$ —pitch angular acceleration; M—pitch line type damping moment coefficient; V and y—pitch non Linear damping moment coefficient;C_1— linear recovery moment coefficient; C_2— square term recovery moment coefficient;C_3— cubic square recovery moment coefficient;

Among the four identification models, the error estimation criterion at the K+1th moment is obtained by measuring the angle of the experiment K:

$$\varepsilon_{k+1}=\dot{\psi}'_{k+1}-\dot{\psi}_{k+1} \qquad (4.5)$$

In this formula: $\dot{\psi}'_{K+1}$ is the measured value of the angular velocity at time k+1 is the value obtained by the identification result.

The objective function of the pitch identification model is established according to the error estimation criterion as follows. In the optimization calculation, the smaller the objective function value that needs to be recognized by the pitch, the better, and the smaller F(x), the better the equation fitting effect.

$$F(x)=\sqrt{1/M\sum_{k=1}^{M}(\dot{\psi}'_{K+1}-\dot{\psi}_{K+1})^2} \qquad (4.6)$$

Selecting the design variable:I_y，M，V，y，C_1，C_2，C_3，the design variables range from Table 3.

B .Basic idea of system identification

System identification can be generally divided into: non-parametric model identification method and parameter model identification method [9]. In this paper, method 2 is selected. By setting up the pitch motion model and using the error criterion function, the identification model parameters are obtained [10]. The identification software is divided into four parts: reading the data module, selecting the identification model module, selecting the optimization algorithm module and the output file module [11].

V. ANALYSIS OF TEST RESULTS

A. .Analysis of the Results of the Pitch Test

The three-body rescue unmanned craft static water shaking test selects the best test data as effective data. Figure 3 shows the initial pitch angle of 8 °, the draught is 0.9 times the design draught, the design draught, and the 1.1 times the design draught. The composite law of the pitch angular velocity attenuation from the figure proves that the pitch test data is available.

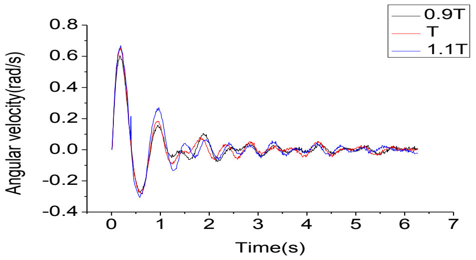


Fig. 3 Vertical angular velocity decay curve with different drafts and pitch angle of 8°

As shown in Fig. 3, when the three groups draught and the initial pitch angle is 8°, with the draught increasing, the peak value of the pitch angular velocity increasing, the pitch period increasing, and the displacement is 1.1 times when the draft is designed. The mode takes the longest to reach a steady state. When the curve is 1.5s, the attenuation law is in an abnormal state. The reason may be that the hull pitch induces a heave motion to generate waves. In addition, the pitch decay period of the three-hull craft is more complicated than the normal single-craft pitch decay period. The reason is that the induced hull produces a heave motion during the pitching process. The reflection of the waves affects the normal longitudinal of the craft. The law of shaking is changed, and the center of gravity of the hull model is related to the environmental factors of the test process. Therefore, it needs to be improved in subsequent experiments.

B. System identification analysis

The improved genetic algorithm [8] was selected, and the basic parameters were set as: optimized algebra 2000; population size 200; crossover probability 0.8, mutation probability 0.15; genetic factor 0.05, evolution weight 0.9. The identification systems of four different pitches and different initial pitch angles are analyzed by four different pitch mathematical models. The identification results are shown in Table 2:

Table 2 identifies the objective function value of the mathematical model

Objective function value		Equation 1	Equation 2	Equation 3	Equation 4
Initial pitch angle 2°	0.9T	0.008350143	0.008365491	0.008419511	0.00840963
	T	0.008437855	0.008452053	0.008514436	0.008475041
	1.1T	0.008133565	0.008142889	0.008514436	0.008172014
Initial pitch angle 4°	0.9T	0.009668406	0.009676159	0.009954213	0.00970216
	T	0.009196406	0.009211396	0.00952961	0.009225105
	1.1T	0.009877627	0.009890814	0.00952961	0.009930053
Initial pitch angle 6°	0.9T	0.010856595	0.010872922	0.011880628	0.010889171
	T	0.011264826	0.011280642	0.011966379	0.011298658
	1.1T	0.010944226	0.010958664	0.011966379	0.011004978
Initial pitch angle 8°	0.9T	0.02052821	0.020552123	0.02613461	0.020531651
	T	0.013282046	0.01329177	0.015565819	0.013310807
	1.1T	0.01242812	0.012441779	0.015565819	0.012453325

By analyzing the objective function values of the four identification formulas, it is found that the objective function values of the three initial pitch angles and the three different underwater recognition formulas 1 are the smallest, indicating that the fitting effect of the identification formula 1 is the best, and the design draft is 1.1 times. For example, the pitch angle is 2°, and the target function value after identification is 0.00883535. The values of each design variable are shown in Table 3:

Table 3 Identification formula 1 optimization value of each design variable

Design variable	Lower limit	Upper limit	Optimization value
Total moment of inertia I_y	0	0.1	0.090243325
Pitch linear damping moment coefficient *M*	0	0.5	0.098322896
Pitch nonlinear damping moment coefficient *V*	0	0.5	0.000479988
Pitch nonlinear damping moment coefficient *y*	0	0.2	0.001392731
Linear recovery moment coefficient H	0	0.5	1.30E-05

Its pitching motion model:

$$\ddot{\psi}+2.1791\dot{\psi}+0.00532\left|\dot{\psi}\right|\dot{\psi}+0.015433\dot{\psi}^{3}+0.000145\sin\psi=0 \qquad (5.1)$$

In order to analyze the error between the experimental value and the fitted value, the angular velocity test value of the 1.1 times design draught and the initial pitch angle of 2° and the fitted value identified by the formula 1 are placed in the same coordinate system, as shown in the figure. 4 shows:

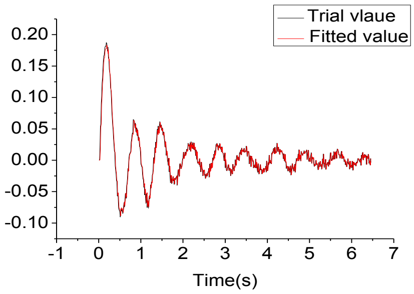
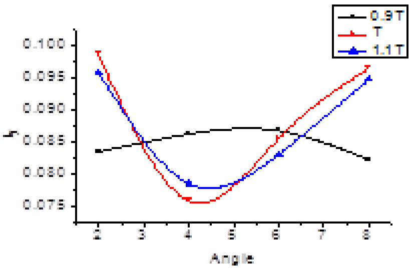
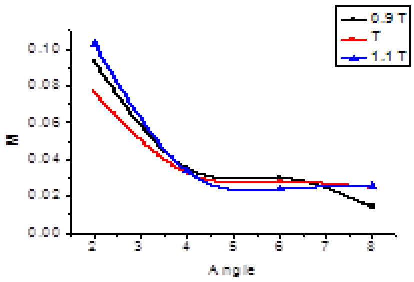


Figure 4 Test angular velocity and identification angular velocity fitting curve

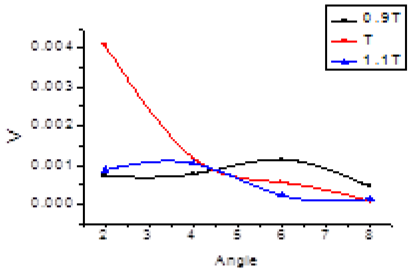
It can be seen from Fig. 4 that the test angular velocity and the identification angular velocity has a good fitting effect, which can prove the reliability of the identification software compiled in this paper. Therefore, the identification software can predict the pitch angular velocity at the next moment. Through the identification calculation of 12 sets of pitch test data, the total moment of inertia Iy, the linear damping torque coefficient M, the square damping torque coefficient V, the cubic damping torque coefficient y and the craft model are obtained in each case. Each moment of recovery torque. Among them, the variation curve of each design variable with the initial pitch angle under three kinds of eating water is shown in Figure 6:



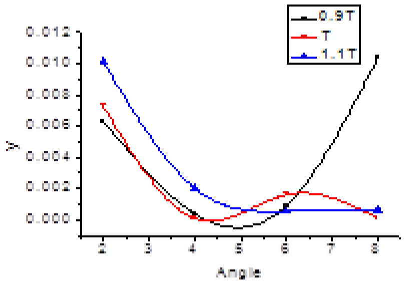
(a)The pitching total moment of inertia I_y varies with the pitch angle



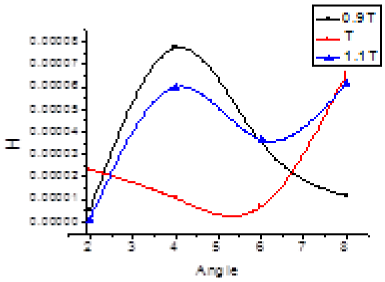
(b) The pitching linear damping torque M varies with the pitch angle



(c) The square damping coefficient V varies with the pitch angle



(d) Cubic damping coefficient y as a function of pitch angle



(e) Resting torque coefficient H as a function of pitch angle

Fig.5 Curve of hydrodynamic coefficient of pitch motion with pitch angle

It can be analyzed from Fig. 5 that the values of the torque coefficients of the hull will change with the change of the draft and the initial pitch angle. The total inertia moment Iy of different drafts are first decreased and then increased, while in 0.9 times of design draught, the total moment of inertia fluctuation is smaller with the pitch angle, which may be related to the error of the collected data; the relative linear damping moment coefficient M With the increase of the initial pitch angle, the change trend is relatively stable after 5° tilt; the square damping moment coefficient V decreases with the increase of the initial pitch angle, 1.1 times the design draught and 0.9 times the design. The change of draught is relatively stable, the change of design draught is relatively large, and the overall trend is decreasing, and finally tends to 0; the cubic damping torque y decreases with the increase of the initial pitch angle, and when the pitch angle is 5°, y There is an increase, but it tends to be stable soon. The variation of 0.9 times design draught is relatively large; the change trend of nonlinear restitution torque coefficient, with the increase of draught, the nonlinear resilience torque coefficient increases first and then decreases, design draught The magnitude of the change is relatively large. As the initial pitch angle increases, it decreases first and then gradually increases, while the 1.1 times design draught increases continuously when it is pitched 6°.

VI. COMPARATIVE ANALYSIS OF THREE-BODY CRAFT MODEL AND CATAMARAN MODEL

This paper selects the three-body model and the two-body craft model with the same draft, the same pitch angle, and compares the experimental angular velocity to analyze the curve of the pitch angular velocity with time, as shown in Figure 6.

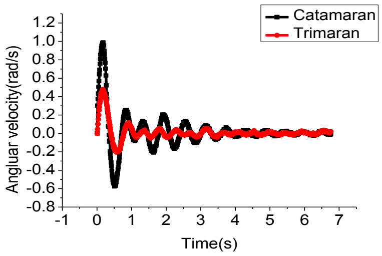
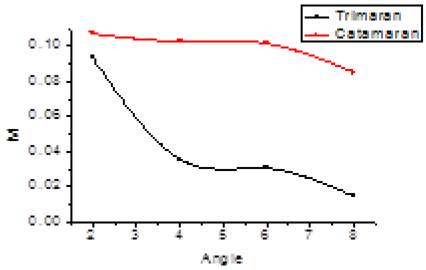


Fig.6 Vertical angular velocity decay curve of a three-body craft and a catamaran model at the same draft and a pitch angle of 6°

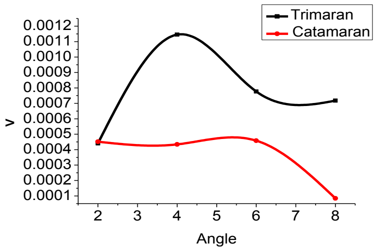
By selecting the same draft and the initial pitch angle is 6°, the free attenuation test data at the same pitch angle can be obtained when the three-body craft model and the catamaran model are in the same draught condition. The catamaran model is the first. The cycle speed attenuation changes greatly, and the fourth cycle tends to be stable. The three-body craft mode changes with the pitch angle. After the first cycle, the speed decays faster. From the second cycle, it is obvious that the three-body craft is obviously stable, and the three-body craft model has a certain anti-rolling effect compared with the two-body craft model.

A. Comparative analysis of hydrodynamic coefficients

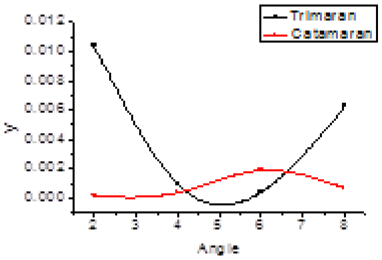
Select the three-body craft model and the catamaran model with the same draft, and systematically identify the data, and compare the pitch-type damping moment coefficient M, the square damping moment coefficient V, and the cubic damping moment coefficient y corresponding to the pitch angle change. Analyze the variation of each design variable with the initial pitch angle in three eating waters.



(a) The pitching linear damping torque M varies with the pitch angle M



（b）The square damping coefficient V varies with the pitch angle



（c）The cubic damping coefficient y varies with the pitch angle

Fig.7 Comparative analysis of hydrodynamic coefficients of three-body craft model and catamaran model

Comparing and analyzing Figure 7, it can be seen that when the three-body craft and the catamaran model are in the same draft, the initial pitch angle increases, and the linear damping torque M of the catamaran model is decreasing, with a range of 0.12-0.085. The three-body craft's pitching linear damping torque is also decreasing, the variation interval is 0.1-0.02; the square damping torque coefficient V, with the increase of the initial pitch angle, the square damping torque coefficient of the three-body craft first increases and then decreases. The pitch angle of the catamaran is not changed much in the range of 2°-6°, the coefficient is 0.00045, and then decreases first, and the third-order damping torque coefficient y, the variation of the catamaran is not large, and remains at 0 line. Nearby, but the cubic damping torque of the three-hull craft, with the increase of the pitch angle, tends to decrease first and then increase, and the minimum value is obtained at 5°.

VII. IN CONCLUSION

(1) By comparing the same angle and different pitching motions, it is concluded that the three-body rescue unmanned craft increases with the draught, the peak value of the pitching angular velocity increases, the pitching period increases, and the craft model reaches a steady state;
(2) According to the identification result of identification equation 1, the error between the experimental value and the fitted value is obtained. The results show that the predicted value and the experimental result are in good agreement. The

feasibility of the system model of the pitching motion mode and the reliability of the software are verified ;

(3) Using the parameter model system identification method to identify the longitudinal damping torque coefficient, the recovery moment coefficient and the total moment of inertia of the craft model, the pitching motion of the craft model can be predicted, which is the longitudinal of the same type of hull. Shake motion analysis provides a reference;

(4) Through the analysis of the test data of the three-body craft model and the double-body craft model, it is concluded that the three-body craft model has obvious anti-rolling effect compared with the catamaran, but the linear damping torque is used when the catamaran model is tilted at a small angle. M changes are more stable, with a range of 0.12-0.085.

The research shows that the system identification software provides a feasible way for the unmanned craft pitching motion mode, which provides a reliable theoretical support for the real-time effective reduction of longitudinal and stability of such unmanned crafts.

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REFERENCE

[1] Su Shaojuan, Lan Wei, Wang Tianlin, Zhao Yong. Research on ship wave resistance index in marine information environment [J]. Ship Science and Technology, 2018, 40 (05): 55-60.

[2] Tang Yuanguang, Wang Zhiguang. Design and implementation of ship motion attitude measurement system[J]. Ship Science and Technology, 2017, 39(13): 108-111+144.

[3] Zhang Wei, Ma Jianhong. Analysis of the model of pitch motion pattern recognition based on genetic algorithm[J]. Ship Science and Technology, 2015, 37(11): 35-38.

[4] Li Jun. Research on a motion pattern recognition system for surface unmanned crafts [D]. Jiangsu University of Science and Technology, 2016.

[5] Falzarano J, Somayajula A, Seah R. An overview of the prediction methods for roll damping of ships[J]. 2015, 5(2):55-76.

[6] Yan Juan.Study on Data Intelligent Storage Optimization Method in Ship Monitoring System[J].Ship Science and Technology,2018,40(20): 181-183.

[7] Shengping Jing, Songlin Yang, Man Liu, Zifan Wei. The Analysis on Comprehensive Optimization of Performance of a Certain UUV and Research on Optimization Algorithm[J]. International Journal of Scientific Engineering and Applied Science (IJSEAS), 2016(6): 225-236.

[8]Abhilash Somayajula, Jeffrey Falzarano, Application of advanced system identification technique to extract roll damping from model tests in order to accurately predict roll motions[J]. Applied Ocean Research, Volume 67, September 2017, Pages 125-135, ISSN 0141-1187.

[9] ZHANG Heng,LI Ji-de,ZHAO Xiao-dong.Solving Nonlinear Motion Response of crafts Based on System Identification Method[J].Journal of Dalian Maritime University,2008,34(4):67-71.

[10] Li Yongtao. Research on parameter identification method for surface unmanned crafts [D]. Harbin Engineering University, 2015.

[11] YANG Chun-lei,ZHU Ren-chuan,MIAO Guo-ping,FAN Ju.Numerical simulation of rolling for 3-D ship with forward speed and nonlinear damping analysis[J].Journal of Hydrodynamics,2013,25(01): 14 8-155.