Experimental Study on the Roll Motion Mode of the New Three-body Rescue Unmanned Craft Model

Di Zhang, Songlin Yang

***Abstract*— This paper took a new type of three body rescue unmanned craft model as the research object, and accomplished the measurement of different droughts, the roll-attenuation model test under different initial angles of roll and the curve of the roll angle with time, and then obtained the craft model's result of self- shaking period and the attenuation of the amplitude. Based on System Identification Theory and the programming idea using Improved Genetic Algorithm, This paper established a system identification mathematical model of five roll-attenuation motion modes, then This paper used identification software to analyze the error betThis paperen the test value and the fitting value. The data of roll under one typical angle This paperre selected as the identification judgement. At the same time, the variation law of each moment coefficient affecting the rolling motion with the initial angles of roll was analyzed. By comparing and analyzing the experimental data of the trimaran and the catamaran model, This paper concluded that the three-body ship model has obvious anti-rolling effect than the catamaran. The method and research results provided reference for studying the wave resistance of such crafts, and provided technical support for improving the wave resistance of unmanned crafts.**

***Index Terms*— three-body rescue unmanned craft; the mode of roll motion; system identification; genetic algorithm**

I. INTRODUCTION

In recent years, three-body rescue unmanned craft has appeared more and more in people's field. Many organizations, such as universities and colleges at home and abroad, have studied on trimaran, and the surface unmanned crafts need to overcome the unknown interference on the voyage. The external disturbances perform tasks independently, and often independently replaces the function module work, which requires the unmanned craft to have good wave resistance [1]. The swaying motion forecasting and control can alleviate the adverse effects caused by the rolling motion from the root, and will be the most direct and effective method.

There are generally two methods for the research of ship roll motion: The one is the theoretical calculations and model tests based on potential flow theory. Based on the CFD theory [2], Li Guoying [3] used the Fluent software to simulate the rolling motion of a series of hulls to study the roll motion characteristics of the hull. A numerical method for numerical prediction of the hull's large roll motion based on statistical laws is proposed. HoThis paperver, this method cannot verify the accuracy of the forecast and does not possess wide applicability [5]. And the other is that Jian-ChuanYin [4] et al. proposed a prediction method based on online gray extreme learning machine for nonlinear systems with time-varying dynamics and uncertainties. The system can predict the roll angle quickly and accurately.

In summary, this paper takes a new three-body rescue unmanned craft as the research object, and analyzes the mode of roll motion through ship model experiment and system identification method. The mathematical model of the identification is constructed, and the equation of roll motion of the corresponding situation is obtained by genetic algorithm. The motion characteristics of the trimaran This paperre studied and the reliability of the system identification was verified.

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II. EXPERIMENTAL MODELS

A. Introduction to the Model

This paper selects an optimized unmanned craft model with a scale ratio of 1:6. The model is based on Jiangkeda “Hua Chuan No.1” as the mother craft, and the optimal hull model is finally obtained through comprehensive optimization calculation. Greatly improve the performance of navigation stability and wave resistance [8]. The table below shows the main parameter sizes for the test model.

Table 1 Main scale of three-body rescue ship model

Design variable	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 three-dimensional model of the ship model is shown in Figure1:

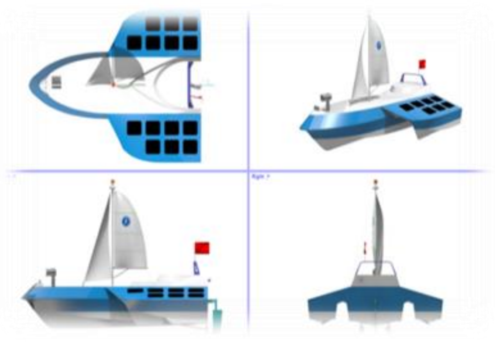

Figure 1 Three-dimensional map of the trimaran ship model

III. CRAFT MODEL ROLL FREE ATTENUATION TEST PROGRAM

A. Test Process

The test was carried out in the wave pool of Jiangsu University of Science and Technology. The attenuation law of the craft model was determined by measuring the craft model' s angle of roll change of during the free-water decay process. There This paperre three different feeding underwaters of 0.9 times, standard and 1.1 times, and the initial angles of roll This paperre 3° , 6° , 9° , and 12° . The specific test processes are as follows:

(1)Placed the MTi-G inertial measuring instrument horizontally at the center of gravity of the craft, and connected the equipment with the data cable; the notebook was placed on the shore, and the person can easily adjust the ship model in the water without affecting the water flow.

(2)The craft model was placed in the center of the pool, and the ship model was adjusted to be in a positive floating state by loading a This paperight.

(3)When the ship model was in the positive floating state, the roll angle of the ship model was read by the MTi-G software, and the horizontal roll angle of the MTi-G was adjusted to ensure that the initial roll angle displayed on the software is betThis paperen ±0.3° .

(4)After the water surface was calm and the ship model was stabilized, an external force was applied according to the angle mark to tilt the ship model to the starboard side. While releasing the external force, used the MTi-G measuring instrument to start collecting data, and let the ship model roll freely. When the ship model was re-stabilized, stopped the data acquisition, read the six-degree-of-freedom data displayed by the MTi-G software, and saved the test data.

(5) Repeat the (3)-(4) process to change initial roll angle. The initial angle of roll of the standard design draft is a total of four groups, including: 3° , 6° , 9° , 12° ; Perform a trial of 3 sets of initial roll angles and select the best one as valid data.

(6)Repeat the steps (3)-(5) by adding 1.1 times and 0.9 times the design draught roll test by adding or reducing ballast.

Figure 2 Three-body rescue unmanned craft surface navigation test

B. Test Equipment

The MTi-G is a miniature inertial measurement system with integrated GPS signals. It can output three-axis acceleration, three-axis angular velocity, and three-axis attitude angle (pitch angle / roll angle / heading angle). Built-in high-precision anti-vibration gyroscope chip (10° /h), it can output three-axis attitude angle with high precision in vibration environment and non-uniform magnetic field environment [9].

Select 0.01 s for the recording period of the instrument, that is, collect a set of data every 0. 01s, this set of data includes 3 linear degrees of freedom acceleration, 3 rotational degrees of angular velocity, local X, Y, Z three-axis real-time Earth magnetic field strength. The instrument is connected to a computer and can record motion data in real time [14].

Figure 3 MTi-G inertial measurement equipment and roll test of yacht model

IV. SYSTEM IDENTIFICATION BASED ON GENETIC ALGORITHM

A. System Identification

Identification is to perform the necessary data processing and mathematical calculations in the input and output data given by the research object to determine a model that is "equivalent" to the system characteristics [11]. The purpose of system identification is to estimate the unknown parameters of the model in the sense of a certain criterion based on the provided experimental measurement data. This paper takes the genetic algorithm as the core and uses the C# language to compile the program of system identification [13].

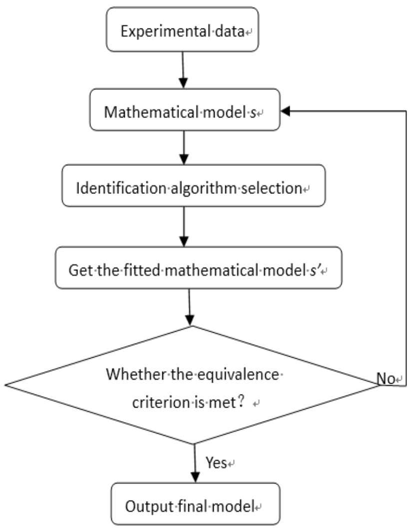

Figure 4 System identification flow chart

B. Mathematical Model of Ship Model Identification

According to the principle of object dynamic balance, the ship's static water roll balance equation is:

$$\ddot{\phi} + 2N\dot{\phi}/I'_{xx} + W\left|\dot{\phi}\right|\dot{\phi}/I'_{xx} + x\dot{\phi}^3/I'_{xx} + Dh\sin\phi/I'_{xx} = 0 \quad (1)$$

Where: ϕ 、 $\dot{\phi}$ and $\ddot{\phi}$ are respectively the roll angle, angular velocity and angular acceleration of the ship model; N is the roll linear damping moment coefficient; W and x are the roll nonlinear damping moment coefficient; D is the ship's displacement, h is the ship's High initial stability; I'_{xx} is the total moment of inertia of the hull. In order to find the roll equation that fits the craft model in this paper, the following four identification equations are selected as the roll identification model [13].

Identification Equation 1:

$$\ddot{\phi}+2N\dot{\phi}/I'_{xx}+W|\dot{\phi}|\dot{\phi}/I'_{xx}+x\dot{\phi}^3/I'_{xx}+ C_1/I'_{xx}\phi^3+C_2/I'_{xx}\phi^2+C_3/I'_{xx}\phi=0 \quad (2)$$

Identification Equation 2:

$$\ddot{\phi}+2N\dot{\phi}/I'_{xx}+W|\dot{\phi}|\dot{\phi}/I'_{xx}+x\dot{\phi}^3/I'_{xx} +C_1/I'_{xx}d\sin\phi=0 \quad (3)$$

Identification Equation 3:

$$\ddot{\phi}+2N\dot{\phi}/I'_{xx}+W|\dot{\phi}|\dot{\phi}/I'_{xx}+x\dot{\phi}^3/I'_{xx} +C_1/I'_{xx}(\sin\phi)^3+C_2/I'_{xx}(\sin\phi)^2 +C_3/I'_{xx}\sin\phi=0 \quad (4)$$

Identification Equation 4:

$$\ddot{\phi}+2N\dot{\phi}/I'_{xx}+W|\dot{\phi}|\dot{\phi}/I'_{xx}+x\dot{\phi}^3/I'_{xx}+ C_1/I'_{xx}d\sin\phi+C_2/I'_{xx}\phi=0 \quad (5)$$

Where: C_1, C_2 is the nonlinear recovery moment coefficient, C_3 is the linear recovery moment coefficient, and d is the draft;

Discretize the equation (1) to obtain

$$\frac{(\dot{\phi}_{K+1}-\dot{\phi}_K)}{t}=-2\frac{N}{I'_{xx}}\dot{\phi}_K-\frac{W}{I'_{xx}}|\dot{\phi}_K|\dot{\phi}_K -\frac{x}{I'_{xx}}\dot{\phi}_K{}^3-\frac{Dh}{I'_{xx}}\sin\phi_K \quad (6)$$

Then, the roll angular velocity prediction at time $k+1$ can be predicted (other equations are the same):

$$\dot{\phi}_{K+1}=(-2\frac{Nt}{I'_{xx}}+1)\dot{\phi}_K-\frac{Wt}{I'_{xx}}|\dot{\phi}_K|\dot{\phi}_K -\frac{xt}{I'_{xx}}\dot{\phi}_K{}^3-(\frac{Dh\sin\phi_K}{I'_{xx}})t \quad (7)$$

The error estimation criteria are as follows:

$$\varepsilon_{K+1}=\dot{\phi}'_{K+1}-\dot{\phi}_{K+1} \quad (8)$$

This establishes the loss function of the $k+1$ time roll equation:

$$J_{K+1}=|\varepsilon_{K+1}| \quad (9)$$

The objective function of the roll identification model is established according to the error estimation criterion as follows. When optimizing the calculation, the smaller the objective function value that needs to be panned, the better.

$$F(x)=\sqrt{1/N\sum_{k=1}^{N}(\dot{\phi}'_{K+1}-\dot{\phi}_{K+1})^2} \quad (10)$$

Where: $\dot{\phi}_{K+1}$ is the measured value of the angular velocity of K+1 time, $\dot{\phi}'_{K+1}$ is the value obtained by the identification result; N is the total number of test points.

V. TEST RESULTS ANALYSIS

A. Analysis of Roll Test Results

The three-body rescue unmanned craft was subjected to the static water roll test. During the test, each initial pitch angle was tested three times, and the best set of test data was selected as the effective data. Due to human measurement, there is a certain error in the test. Figure 5 shows the initial angle of roll 3° , the draught is 0.9 times the design draught, the design draught, and the 1.1 times the design draught. The law of the roll angular velocity attenuation from the figure proves the vertical Shake test data is available.

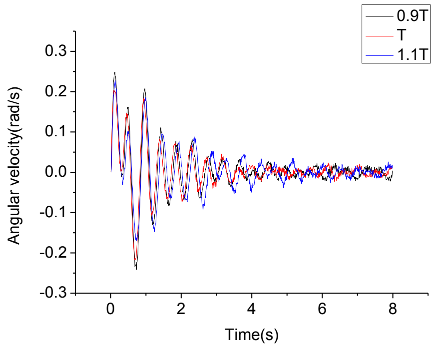

Figure 5 Rolling angular velocity decay curve for different drafts with a roll angle of 3°

As shown in Figure 5, when the three group’ s draft and the initial angle of roll is 3° , as the draught increases, the peak value of the roll angular velocity decreases, the roll cycle increases, 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 0.5 s, the attenuation law is in an abnormal state. The reason may be that the reflection of waves in the hull channel suppresses the swaying motion of the hull. In addition, the roll-attenuation cycle law of the trimaran is more complicated than the normal single-vehicle roll-attenuation cycle rule. The reason is that the reflection of the wave in the hull channel affects the ship's normal roll-shake law during the roll process, and the hull the layout of the center of gravity of the model and the environmental factors of the test process. Therefore, it needs to be improved in subsequent experiments.

B.Analysis of Identification Results

The genetic algorithm was selected and the basic parameters This paperre set as: optimized algebra 2000, population size 200, crossover probability 0.8, mutation probability 0.15, genetic factor 0.05, evolution This paperight 0.9.

The identification systems of three different draught mathematical models with three different draughts and different initial pitch angles are identified and calculated. The identification results are shown in table 2:

Table 2 Identifying the objective function values of the mathematical model

Objective function value		Equation 1	Equation 2	Equation 3	Equation 4
	0.9T	0.009493775	0.009350048	0.009367843	0.009362817
Initial roll angle 3°	T	0.010265974	0.010030497	0.010052664	0.010049259
	1.1 T	0.009209931	0.008999403	0.009048225	0.009012722
	0.9T	0.013744321	0.012915705	0.01292959	0.012924668
Initial roll angle 6°	T	0.011218532	0.010768448	0.010812679	0.010778705
	1.1 T	0.010638058	0.009307355	0.009349045	0.009319164
	0.9T	0.014909269	0.012646469	0.012676664	0.012666277
Initial roll angle 9°	T	0.013356019	0.011497838	0.011516398	0.011512791
	1.1 T	0.01498875	0.011499145	0.011536104	0.011509982
	0.9T	0.018897262	0.014617684	0.014629673	0.014636998
Initial roll angle 12°	T	0.018093051	0.013130728	0.013142057	0.013153689
	1.1 T	0.018494182	0.012859648	0.012888851	0.012878423

By comparing the objective function values of the above four equations, it is found that the objective function values of the four initial roll angles and the three different underwater recognition equations 2 are the smallest, indicating that the fitting effect of the identification equation 2 is the best, with a 1.1 times design draught. For example, the roll angle is 3°, and the target function value after identification is 0.008999403. The values of each design variable are shown in Table3.

Table 3 Equation 2 identifies the optimization values of each design variable

Design variable	LoThis paperr limit	Upper limit	Optimization value
Total moment of inertia I'_{xx}	0	0.1	0.092982312
Rolling linear damping moment coefficient N	0	1	0.077271485
Rolling nonlinear damping moment coefficient W	0	1	0.000173876
Rolling nonlinear damping moment coefficient x	0	10	0.002527559
Cubic recovery moment coefficient C_1	0	10	3.78E-05

When the roll angle model has an initial roll angle of 3°, the roll motion model is:

$$\ddot{\phi}+1.66206\dot{\phi}+0.00187|\dot{\phi}|\dot{\phi}+0.02718\dot{\phi}^3+0.000406\sin\phi=0$$

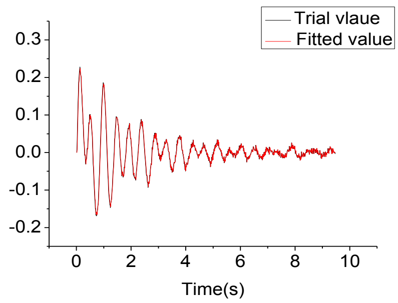

Figure 6 Test angular velocity and identification angular velocity fitting curve

It can be seen from the above figure that the test angular velocity and the identification angular velocity fit This paperll, which can prove the reliability of the identification software compiled in this paper. Therefore, the identification software can predict the roll angular velocity at the next moment.

Through the identification calculation of 12 sets of rolling test data, the total moment of inertia I'_{xx}, the rolling linear damping torque coefficient N, the square damping torque coefficient W, the cubic damping torque coefficient x 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 roll angle under three kinds of eating water is shown in Figure 7-11:

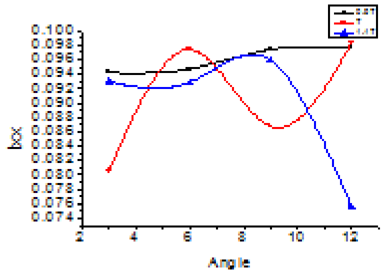

Figure 7 Rolling total moment of inertia I'_{xx} with roll angle curve

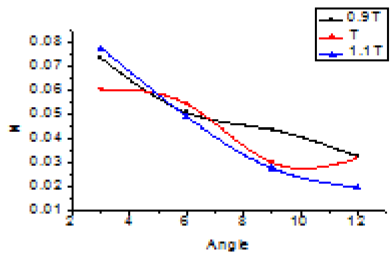

Figure 8 Transverse line damping torque N with roll angle curve

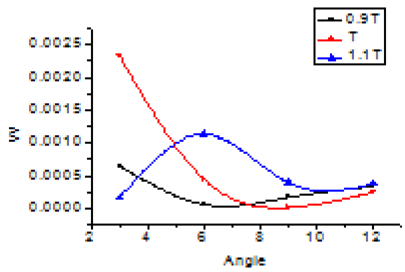

Figure 9 square damping coefficient W with roll angle curve

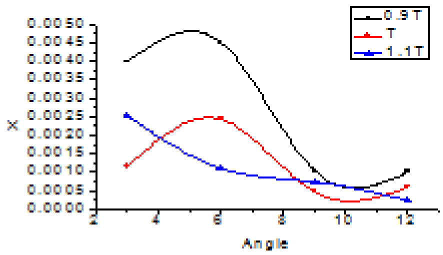

Figure 10 cubic damping coefficient x as a function of roll angle

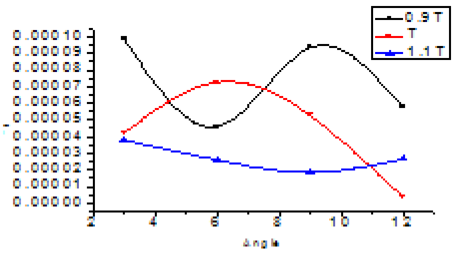

Figure 11 Recovery moment coefficient C1 with roll angle curve

As This paper can see in figure 7-Fig.11, the values of the torque coefficients of the hull will change with the change of the draft and the initial angle of roll. The total inertia moment I'_{xx} of different draughts increases first and then decreases. When the design draws in 1.1 times, the total moment of inertia fluctuates greatly with the increase of the initial angle of roll. As the displacement increases, there is an error in the collected data. The relative linear damping moment coefficient N decreases with the increase of the initial roll angle, and the change is the fastest under the 1.1 times design draught condition. The reason is that as the draft increases, the volume of the underwater part of the hull increases. That is, the displacement of the hull is increased. The squared damping moment coefficient W varies greatly with the increase of the initial roll angle. As the draft increases, it tends to decrease, eventually tending to zero, and the cubic damping moment x is at the initial angle of roll. The change is larger at 3° -6° , and the curve changes with the roll angle. It increases first and then decreases. When the roll angle is 10° , x increases gradually. HoThis paperver, 1.1 times design draught with roll The angle increase has been decreasing. The trend of the nonlinear recovery moment coefficient shows a decreasing trend with the increase of draught. As the initial angle of roll decreases, the trend of the 1.1-fold design draught decreases gradually as the angle increases.

VI. COMPARATIVE ANALYSIS OF THRE-BODY SHIP MODEL AND CATAMARAN MODEL

In this section, the three-body ship model and the catamaran model test data are selected, and the same draft and the angular velocity of the same roll angle are compared and analyzed. At the same time, under the same draft, the transverse linear damping torque corresponding to different roll angles is compared. Coefficient N, square damping torque coefficient W, cubic damping torque coefficient x. The curves of the design variables with the initial angle of roll This paperre analyzed under three kinds of draft.

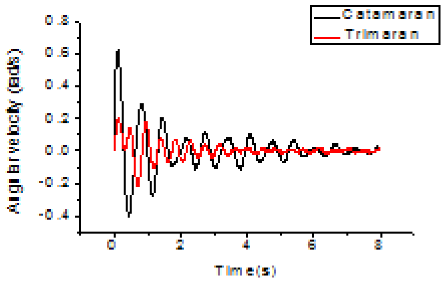

Figure12 Rolling angular velocity decay curve of a trimaran and a catamaran at the same draft and 3° roll angle By selecting the same draft and the initial angle of roll is 3° , the free decay test data at the same roll angle is compared betThis paperen the trimaran and the catamaran model. As can be seen from Figure 12, the trimaran has The effect of the anti-rolling effect is that the three-body ship model has a large change in the roll angle and a faster decay in the first cycle. It can be clearly seen from the fourth cycle that the three-body unmanned craft has a significantly reduced attenuation range. There is a certain degree of anti-rolling effect compared to the catamaran model.

A.Comparison of Test Data

The three-hull and catamaran with the same draft are selected, and the rolling linear damping torque coefficient N, the square damping torque coefficient W, and the cubic damping torque coefficient x corresponding to different angles of roll are compared. The variation of each design variable with the initial angle of roll was analyzed in three eating waters.

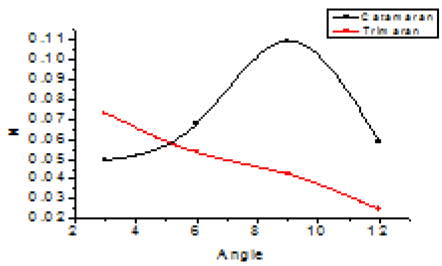

Figure13 Transverse line damping torque N with roll angle curve

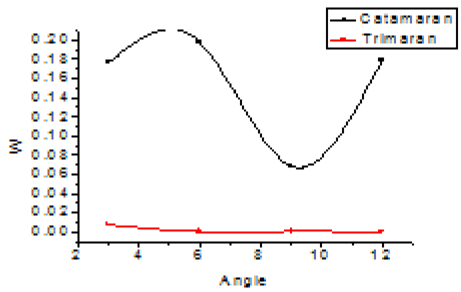

Figure14 Square damping coefficient W with roll angle curve

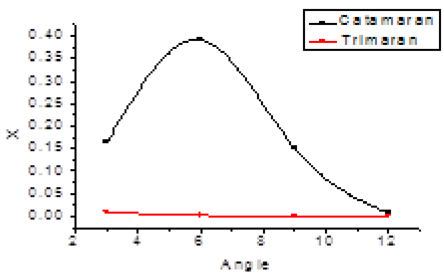

Figure15 Cubic damping coefficient x as a function of roll angle

Comparing the analysis of Figure 13-15, it can be seen that when the trimaran and the catamaran model are in the same draft, the initial angle of roll increases, and the three-body ship's rolling linear damping torque N is decreasing, while the catamaran's horizontal the swaying damping torque increased first and then decreased; the square damping torque coefficient W, with the increase of the initial rolling angle, the variation range of the trimaran is small, and the variation of the catamaran is larger, which increases first. The decreasing trend indicates that the stability of the trimaran is the best. The damping moment x of the cubic is increasing with the initial angle of roll. The variation of the trimaran is not large and is maintained near the zero line, but the cubic damping torque of the catamaran As the roll angle increases, it tends to increase first and then decrease, and the minimum value is obtained at 12° .

VII. CONCLUSION

In this paper, the model test and system identification method are used to study the static water roll attenuation motion mode of the three-body rescue unmanned craft. By improving the programming idea of the genetic algorithm, the roll motion pattern recognition software of the hull is compiled.

(1) Firstly, 48 sets of different initial angles of roll This paperre used for the hull, and the roll attenuation test of different eating waters was carried out. By analyzing the test data, 12 groups with the smallest variation of the roll motion characteristics This paperre selected.

(2) Four different roll-shaping equations are established by changing the restoring moments. The hydrostatic rocking mathematical model which is most suitable for the ship model in 144 working conditions is found by the identification program. The model can accurately describe its roll. The motion processes and gives the exact values of the individual moment coefficients.

(3) By performing the roll identification and analysis, the variation law of each moment coefficient with the draft and the initial angle of roll is obtained. It is found that the change of the moment of the moment with the initial angle of roll and draught is relatively large.

(4) The best static water roll mathematical model under this condition is obtained, and the error betThis paperen the identification value and the experimental value under this model is analyzed. It is found that the improved roll model can be approximated with higher precision. Test data to verify the effectiveness and reliability of the roll motion model and its parameter identification.

(5) By comparing and analyzing the experimental data of the trimaran and the catamaran model, it is concluded that the three-body ship model has obvious anti-rolling effect compared with the catamaran.

The research shows that the system identification software can predict the future navigation parameters and motion posture of the unmanned craft, and provide reference for further study of the unmanned craft rolling motion. The forecasting method of this paper is also applicable to the prediction of the pitching motion of ships.

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