Research on optimization of ship's automatic berthing and unberthing control model

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Abstract. The automatic berthing and unberthing of ships is one of the very important links in the process of ship navigation. Due to the relative increase of interference from external factors such as wind, waves, currents, and the relative increase in system information, the automatic berthing and unberthing operations are more complicated. Traditional control methods have been difficult to meet the technical requirements of automatic berthing and unberthing. This research created a control model for automatic berthing and unberthing, optimized the parameters of the created control model, performed parameter identification on the ship model, and tested the established mathematical model. The test results met the requirements for automatic berthing and unberthing. It provides a good reference value for the future development of automatic berthing and berthing.

1. Introduction

The automatic berthing problem of ships involves the low-speed movement of ships in shallow waters. Due to the relatively increased interference from external factors such as wind, waves, currents, and the relatively increased amount of system information, it is extremely difficult to control ships[1]. Automatic berthing and unberthing is a problem. It is a difficult but important link in the course of ship navigation[2-3].

The mutual interference of the hull, rudder, propeller and other parts and its reversing characteristics are fully considered[4-5]. On this basis, the impact of shallow water, low speed, wind, current and other port environment are considered, we should establish a mathematical model of ship motion to ensure the continuity of the operation in the port improves the accuracy of the model[6].

2. Research on Mathematical Model of Automatic Berthing and Unberthing

With the large-scale and rapid development of ships, the more and more complicated ship berthing and unberthing operations have brought certain difficulties to ship maneuvering and navigation safety. Ship berthing and unberthing operations are critical operations with high risk. Therefore, in order to improve the accuracy and safety of berthing and unberthing control, it is necessary to establish a set of high-precision mathematical models for berthing and unberthing maneuvers.

The state of a ship in the process of berthing and unberthing is very different from the ship motion in the constant speed domain. In the process of establishing the berthing and unberthing model, not only the calculation of the fluid force, propeller and rudder force acting on the hull, but also the basis In addition, the impact of shallow water, low speed, wind, current, quay wall and other berth
environment should be fully considered for model modification. The mathematical model of the study is introduced as follows:

\[
\begin{align*}
(m + m_x)\ddot{u} - (m + m_y)\ddot{v}r &= X_H + X_P + X_R + X_w + X_L + X_T + X_S \\
(m + m_y)\ddot{v} + (m + m_x)\ddot{u}r &= Y_H + Y_P + Y_R + Y_w + Y_L + +Y_T + Y_S \\
(I_{xx} + I_{zz})\ddot{r} &= N_H + N_P + N_R + N_w + N_L + +N_T + N_S
\end{align*}
\]

(1)

Among them: \(m\) is the quality of the ship, \(u\) is the longitudinal speed of the ship, \(v\) is the lateral speed of the ship, \(r\) is the bow angular velocity of the ship, \(\ddot{u}\) is the longitudinal acceleration of the ship, \(\ddot{v}\) is the lateral acceleration of the ship, \(\ddot{r}\) is the angular acceleration of the ship's bow, \(m_x\) is the additional inertial mass along the length of the ship, \(m_y\) is the additional inertial mass along the width of the ship, \(I_{xx}\) is the additional moment of inertia of the ship's bow, \(I_{zz}\) is the moment of inertia of the ship's bow. \(H\) is the bare hull viscous force, \(P\) is the propeller, \(R\) is the rudder, \(w\) is the wind, \(L\) is the flow, and \(T\) is the side Pusher, \(S\) is the quay wall.

3. Research on Optimization of Related Parameters of Mathematical Model

For the ship mathematical model, the mutual interference of the hull, rudder, propeller and other parts is fully considered, model optimization and parameter correction are carried out, and the mathematical model of ship motion is established. On this basis, the influence of the harbor environment is fully considered for model correction.

3.1. Low-speed domain optimization

When the ship moves in the low-speed domain, there is a large drift angle. In this case, the model will no longer be suitable for the calculation of viscous forces. Instead, the Fangcun model is more suitable. The cubic spline interpolation calculation method is used for interpolation in the calculation.

When the drift angle value is in the interval of \([20^\circ, 30^\circ]\), the hydrodynamic derivative \((X_H, Y_H, N_H)\) can be represented by \(x_i\), and \(i\) is the number of nodes \((i = 0, 1, 2, \cdots, n)\). Let \(a_{20}, b_{30}\) be the boundary of hydrodynamic force \((X_H, Y_H, N_H)\) when the drift angle is 20° and 30°.

The cubic spline function \(S_1(x)\) uses a piecewise cubic polynomial to approximate the function \(Y\). After two integrations, the expression of the cubic spline difference function can be obtained as:

\[
S_1(x_i) = \frac{h_{i-1}}{6h_{i-1}}(x_i - x)^3 + \frac{h_{i-1}}{6h_{i-1}}(x - x_{i-1})^3 + \left(\frac{y_{i-1}}{h_{i-1}} - \frac{h_{i-1}}{6}h_{i-1} \right)(x_i - x) + \frac{y_{i-1}}{h_{i-1}} - \frac{h_{i-1}}{6}h_{i-1}(x - x_{i-1})
\]

(2)

Among them, \(S_1(x)\) is the cubic spline function, \(y\) represents the function approximated by cubic spline interpolation. Among them, \(y_{i-1}\) represents the approximation of the function value by the cubic spline interpolation of \(x_{i-1}\), \(x_i\) nodes. When using MATLAB simulation, you can take the points first and then use the spline function to perform cubic spline interpolation fitting.

3.2. Shallow water optimization

The water depth of the water area the ship is navigating affects the maneuverability of the ship. It is usually expressed by the water depth to draught ratio and its influence is quantitatively analyzed. When the water depth becomes shallow in the ship port, the ship resistance will increase and the rudder effect response will become worse, which brings certain difficulties to the ship's maneuvering. In order to predict the maneuverability of ships in shallow waters, the model parameters are revised and applied to shallow waters. Mainly include the following amendments:

3.2.1. Additional hull mass and additional moment of inertia correction

Compared with deep waters, the additional mass and additional moment of inertia of the hull are significantly increased. Considering that the modified model is too sensitive to the impact of shallow water, the following modified model is used.
3.2.2. Cross flow resistance coefficient correction

The cross flow resistance coefficient optimization is as follows:

\[
\frac{m_{sh}}{m_{xx}} = \left( \frac{h}{d} - 1 \right)^{1.3} + \frac{3.77 + 1.14 \frac{B}{d} - 0.233 \frac{l}{d} - 3.43C_b}{(\frac{h}{d} - 1)^{1.3}}
\]

\[
\frac{m_{bh}}{m_{y0}} = \left( \frac{h}{d} - 1 \right)^{0.82} + \frac{0.413 + 0.032 \frac{B}{d} + 0.0129 \left( \frac{B}{d} \right)^2}{(\frac{b}{d} - 1)^{0.82}}
\]

\[
\frac{f_{zh}}{f_{zz0}} = \left( \frac{h}{d} - 1 \right)^{0.82} + \frac{0.413 + 0.0192 \frac{d}{h} + 0.00554 \left( \frac{d}{h} \right)^2}{(\frac{h}{d} - 1)^{0.82}}
\]

(3)

3.2.3. Propeller Wake Score Correction

The optimization of the propeller wake fraction is as follows:

\[
\left( 1 - \frac{w_P}{w_{PP}} \right) = \cos \left( 1.4C_b \frac{d}{h} \right)
\]

(5)

3.2.4 Rudder related parameter correction

The optimization of rudder related parameters is as follows:

\[
\frac{\gamma_{Rh}}{\gamma_{Rho}} = 1 + 0.0161 \frac{d}{h} + 4.4222 \left( \frac{d}{h} \right)^2 - 4.9825 \left( \frac{d}{h} \right)^3
\]

(6)

Among them: h represents the water depth.

4. Ship model system identification

For the mathematical model, the fluid power acting on the ship is mainly divided into two parts: inertial hydrodynamics and viscous hydrodynamics. The magnitude of the inertial hydrodynamics depends on the shape of the hull and the choice of coordinate axes, and has nothing to do with the interference of the ship. The system identification method can analyze the data generated in real time and predict the hydrodynamic derivative at the next moment, and can consider the influence of various external disturbances on the hydrodynamic derivative in real time. It can be used as a smart ship automatic berthing motion forecast Solution.

4.1. Basic principles of system identification

System identification is to determine a model equivalent to the tested system from a set of given model classes on the basis of input and output data. System identification includes three main factors, candidate mathematical model set, identification criteria and identification algorithm.

System parameter identification mainly includes four aspects, namely test design, model structure identification, model parameter identification, and model verification. For a given system, the basic identification steps are: first clarify the purpose of model identification, use the prior knowledge of some existing systems, preliminarily determine the structure of the model, conduct experimental design, collect data and perform appropriate processing, first Perform model structure identification. After the model structure is determined, model parameters are identified. Finally, the determined model is verified through the model verification standard to obtain the final system model.

4.2. Steps for identification of ship model parameters

The application of traditional identification theory can realize the estimation of various hydrodynamic derivatives in the mathematical model of ship motion. The rudder angle \( \delta \), the propeller speed \( n \) and the ship motion state variables \( u, v, r, \psi \) are used as input variables. The identification value of the derivative is used as the output, and the basic framework of parameter identification is as follows:
The whole process is mainly divided into the following steps: It is very important to clarify the purpose of model application before identification, because it will determine the type of model, accuracy requirements, and a series of issues such as what identification method needs to be used. For example, if the model is used for constant value control, the requirements for model accuracy can be relatively low, if the model is used for follow-up system control or prediction and forecasting, then the accuracy requirements for the system are relatively high.

4.2.1. Priori knowledge
For a given system, before identifying it, we need to adopt some methods to process the system to obtain more prior knowledge, such as the degree of non-linearity, time-varying or time-invariant properties of the system, time constant, transition time, proportional and integral characteristics, cut-off frequency, pure delay properties, noise characteristics and operating conditions.

4.2.2. Experimental design
In order to make the collected data contain as much of the internal information of the actual system as possible, the design of the experiment needs to consider the following information: ① input signal amplitude, frequency band, etc., ② system sampling time, ③ identification time length or collection data length, ④ Open-loop identification or closed-loop identification, ⑤ Off-line identification or online identification.

4.2.3. Data collection and processing
Apply some input to the system that needs to be identified, measure and record the corresponding output response information. Generally, the collected input and output data will contain certain DC components, low-frequency components and high-frequency components. At present, there is no identification method that can directly eliminate their influence on the identification accuracy of the system. Therefore, certain input and output data need to be processed before model identification to improve the identification accuracy.

4.2.4. Model structure identification
Model structure identification usually includes preliminary selection of the model structure and determination of the parameters of the model structure. The preliminary selection of the model structure can be based on the specific identified object and identification purpose, using the prior knowledge to analyze the identified system, and then a pre-existing model structure can be preliminarily determined. After the model parameter estimation is completed, the evaluation can be performed. It is verified.
4.2.5. Identification of model parameters
Once the structure of the model is determined, the input and output data need to be used to identify the parameters of the model, that is, to determine the estimated parameters of the identification model. For pure modeling problems, offline identification can usually be used. A large number of field secretaries are stored in the hard disk through a computerized data acquisition system, and then the identification program is used for unified processing to obtain Parameter estimation of the process. Online identification is mainly used in adaptive control systems to estimate process parameters in real time for controller calculations.

4.2.6. Model checking
In the process of system identification, model checking is one of its indispensable steps. If the model is unqualified, the model structure and model parameters need to be re-identified, if the model is qualified after verification, the final model of the system is obtained, and the system identification process ends. the method of discretizing the nonlinear system can be used to construct a linear system with respect to the identification parameters, and then use the least squares The multiplication algorithm identifies the parameters.

5. Model test
In order to verify the validity of the established mathematical model of ship motion and the identification method, the "Zhiteng" was used to complete the corresponding actual ship test, and at the same time, the actual information of the ship and the model forecast information were collected, and the results were compared. Test conditions: The initial speed of the ship is 5 knots, the main engine speed is 600 rpm, the wind speed is 2.5m/s, and the turning rudder angle is 35°.The specific test results are shown in the figure below:

![Figure 2 The specific test results](image)

Comparing the identification value and the true value of the z-type test ship's motion trajectory, it can be seen that the trend of the motion trajectory of the two is the same, indicating that the mathematical model of the identification can meet the accuracy requirements.

6. Conclusion
This research optimizes the mathematical model of the ship's automatic berthing and unberthing, and solves the problems of large interference and difficult operation in the ship's automatic berthing and unberthing technology. The research created a mathematical model for automatic berthing and unberthing, and corrected the parameters of the created mathematical model, and performed parameter identification and analysis on the ship model. The "Zhiteng" was used to complete the corresponding actual ship test. The test results can realize automatic berthing and unberthing. The operation improves the accuracy of automatic berthing and unberthing technology operations.
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