Research on the Control Strategy and Control Method of Ship's Automatic Berthing

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Abstract. Ship berthing and maneuvering have become one of the difficult and complex maneuvers. With the development of large-scale, rapid, and automated ships, the navigation safety and efficiency of ships have become more and more important. In this study, the control problem of automatic berthing is studied and analyzed, and the control strategy of automatic berthing is compared and analyzed. This study uses dynamic output feedback control, robust control, neural network control and other methods to automatically berth under-driven ships. In the research of berthing control, a robust adaptive control method is proposed by combining dynamic surface control technology with backstepping method for the automatic berthing control problem of intelligent ships under the influence of environmental disturbance and quay wall effect. This method solves the problem of increased computational complexity caused by the traditional backstepping method for the virtual control derivation, and effectively eliminates the chattering phenomenon of the control output.

1. Introduction
With the development of large-scale, rapid, and automated ships, as well as the reduction in the number of crew members or insufficient experience, ship berthing maneuvers has become one of the difficult and complex maneuvers[1]. Large ships have the following maneuverability characteristics: large ship type, large mass, large inertia, poor maneuverability, large stopping stroke, long time consumption, poor heading stability and rudder efficiency, and exposure to external environments such as wind currents[2]. With the increasing number of large ships and the limitation of their own maneuverability, the navigation safety and efficiency of large ships berthing should arouse great attention.

Compared with the characteristics of the deep draft of large ships, berths generally have relatively shallow water depth, which makes the turning performance and rudder efficiency of large ships worse in deep water[3-4]. When the ship is operated in shallow waters, the speed of the ship can hardly maintain the rudder efficiency, so higher requirements are put forward for the safety of berthing. Due to the shortening of the freight cycle of ships, the number of ships entering and leaving the port is increasing, so that the ships in the port are increasingly frequently berthing and unberthed, and the navigation density of ships in various ports has increased. These factors have greatly affected large ships. It is safe to enter and leave the port and berthing and unberthing. According to statistics, 70% of accidents are related to poor boatmanship in the port. Therefore, it is of great practical significance to study the automatic berthing of ships. The actual berthing of a ship is affected by shallow water, low
speed, quay wall effect, etc.[5-6]. The realization of automatic berthing can avoid accidents caused by personnel driving and improve the berthing safety and berthing efficiency of large ships.

2. Research on automatic berthing control strategy

For the automatic berthing control of ships, scholars at home and abroad have done a lot of research. The main research comparative analysis is shown in Table 1 below:

| Researcher          | Methodology                                                 | Problem solved                                                                 | Validation                      |
|---------------------|-------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------|
| Lee, et al.         | Fuzzy control, LOS algorithm, leading line visual guidance, etc. | Measurements of the boat position, navigation accuracy, the side thruster to assist berthing | 4-meter fiber plastic reinforced boat tests |
| Mizuno, et al.      | Artificial neural network, minimum-time maneuvering, predictive control, etc. | Berthing path planning, accurate ship motion tracking under uncertain interference | Actual boat tests and numerical simulations |
| Ahmed, Hasegawa, et al. | Artificial neural network PD course-keeping, BPLM algorithm, etc. | Consistency problem of the samples of which rudder angle jitters | 3-meter ship model tests |
| Tran, Im, Bui, Kim, Park, et al. | Artificial neural network, motion identification technique, adaptive backstepping control, etc. | Uncertainty in modeling the interaction force, generate the mathematical model of the propellers and side thrusters, the applicability of the berthing controller, Tin-rudder and twin-oar boat berthing under strong wind disturbance | Ship model tests and numerical simulations |

Considering the uncertain disturbance of the model and the disturbance of factors such as wind and flow, the researchers used various algorithms such as artificial neural network, sliding mode control, expert system, feedback control and other algorithms to design the autonomous berthing controller. The principle of the ship trajectory control system is shown in Figure 1. According to the above research and analysis, this research uses dynamic output feedback control, robust control, neural network control and other methods to carry out automatic berthing control research on under-driven ships. The research found that although berthing can be achieved, the spatial position, the requirements for berthing angles are high, which have limitations in engineering applications, and the maneuverability of under-driven ships is poor. A control system that uses auxiliary equipment such as tugs and thrusters to realize automatic berthing is difficult to control the speed and angle of the berthed ship during actual berthing operations, and it is difficult to ensure that the tug can accurately perform complex control operations. Automatic berthing control is performed on ships equipped with traditional propellers and thrusters. The use of side thrusters can greatly improve the safety and practicability of automatic berthing for gradually unmanned and large ships. However, due to the rudder angle and the limitation of low-speed movement results in poor maneuverability of ships equipped with traditional propellers and insufficient ability to cope with complex environments. Even if equipped with side thrusters, the maneuverability in lateral movement is difficult to meet the requirements of ships in automatic berthing movement. The flexibility of maneuverability. In addition, the quay wall effect will also have an impact on the control accuracy and control output, resulting in a decrease in the safety of the ship’s berthing. The jitter of the control output will make it difficult for the propeller to accurately execute the control command, thereby affecting the safety of the ship’s berthing.
3. Research on Optimization of Precise Position Control of Automatic Berthing

Based on the analysis of existing research, aiming at the automatic berthing control problem of intelligent ships under the influence of environmental disturbance and quay wall effect, the dynamic surface control technology is combined with the backstepping method, an adaptive law is designed to estimate the environmental disturbance. The term deals with the disturbance of the quay wall effect and proposes a robust adaptive control method. The robust adaptive control law of ship's automatic berthing can make the position of the ship converge to the desired position with arbitrary accuracy, while ensuring that all signals in the ship's automatic berthing closed-loop control system are consistent and ultimately bounded.

According to the theory of ship kinematics and dynamics, the nonlinear mathematical model of ship berthing is:

$$\eta = R(\psi) v;$$

$$M v + D v = \tau + R(\psi) b + d$$  \hspace{1cm} (1)

Among them: $M$ is the inertia matrix, $D$ is the linear damping matrix, $\tau = [\tau_1, \tau_2, \tau_3]^T$, $\tau_1$ is the ship's longitudinal control force, $\tau_2$ is the ship's lateral control force, and $\tau_3$ is the ship's bow control moment, $b = [b_1, b_2, b_3]^T$ is the unknown environmental force and moment, $d$ is the interference force of the wall effect on the ship.

Define the position error surface vector:

$$z_1 = \eta - \eta_d$$  \hspace{1cm} (2)

Among them: $\eta = (x, y, \psi)^T$ is the position $(x, y)$ and heading angle of the ship in the north-east fixed coordinate system, $v = (u, v, r)^T$ is the ship's longitudinal speed, lateral speed and bowing angular velocity in the hull motion coordinate system, $\eta_d$ is the desired position point.

$$\eta = R(\psi) v$$

$$R(\psi) = \begin{bmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$  \hspace{1cm} (3)

Suppose $\eta_d = 0$, then

$$z_1 = R(\psi) v$$  \hspace{1cm} (4)

Select the virtual control vector as

$$\alpha = -R^{-1}(\psi) K_1 z_1$$  \hspace{1cm} (5)

Where $K_1$ is a positive definite symmetric design matrix.

Based on the principle of dynamic surface control technology, the state vector $X_d$, is introduced to calculate a first-order low-pass filter for the virtual control vector $\alpha$, which is expressed as:

$$T_d \dot{X}_d + X_d = \alpha$$  \hspace{1cm} (6)

Where: $T_d$ is the filter time constant.

Define the velocity error surface vector as $z_2 = v - X_d$, perform the derivative calculation and multiply it with the inertial matrix $M$,
The design automatic berthing control law is

\[ M\ddot{z}_2 = \tau - Dv - M\dot{X}_d + R^T(\psi)b + d \]  \hfill (7)

Where: \( K_2 = K_2^T \) is the positive definite design matrix, \( \hat{b} \) is the estimated value of \( b \), and \( \tau_{rd} \) is the robust term for compensating the interference term of the quay wall effect. The adaptive law for choosing \( \hat{b} \) is

\[ \hat{b}^* = \Gamma^{-1}R(\psi)z_2 \]  \hfill (9)

Where: \( \Gamma \) is a positive definite design matrix, and the robust term is:

\[ \tau_{rd} = \hat{d}^*z_2/\|z_2\|\|\hat{d}^* + \mu_{rd}\|, \hat{d}^* = \lambda_{rd}\|z_2\| \]  \hfill (10)

In the formula: \( \hat{d}^* \) is the estimated value of \( d^* \), \( \mu_{rd} \) is an arbitrarily small normal number, and \( \lambda_{rd} \) is a positive design constant.

For ship berthing control systems affected by environmental disturbances and quay wall effects, by selecting appropriate design constant \( T_d \) and design parameter matrices \( K_1 \) and \( K_2 \), the ship can converge to the desired position with arbitrary accuracy and realize automatic berthing control. Using this method reduces the computational complexity and is easy to implement in engineering. A robust term for handling quay wall effects is added to the control law. Compared with traditional dynamic surface control strategies, it can greatly reduce the jitter caused by quay wall effects and improve control accuracy. It can achieve a satisfactory automatic berthing control effect, making the berthing process of the ship more stable and reasonable.

4. Conclusion
This research uses dynamic output feedback control, robust control, neural network control and other methods to carry out automatic berthing control research. Aiming at the automatic berthing control of ships under the influence of environmental disturbance and quay wall effects, a robust adaptive control method is proposed. This method reduces computational complexity and is easy to implement in engineering. A robust term for handling quay wall effects is added to the control law. Compared with traditional dynamic surface control strategies, it can greatly reduce the jitter caused by quay wall effects and improve control accuracy. A satisfactory automatic berthing control effect can be achieved, and the berthing process of the ship is more stable and reasonable.

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