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Overview of the Development of Ship Manoeuvring and Control Technology

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Abstract

With the development of China's shipping trade, the maritime cargo transportation industry chain is becoming increasingly complete, and the requirements for ship safety and efficiency are also increasing. As an important factor affecting ship safety and efficiency, ship maneuvering and control technology has become a key issue to comprehensively grasp. Firstly, this article analyzes and summarizes the development status of ship maneuvering and control technology both domestically and internationally, and elaborates on the relevant theories of ship maneuvering systems; secondly, the four stages of the development of autopilots are summarized for the control methods of ship maneuvering rudder; finally, prospects were made for the development trend of ship maneuvering and control technology. It is of great significance for promoting the development of ship maneuvering and control technology, and for promoting the development of China's shipping industry.

Keywords

Maneuver System; PID Autopilot; Control Technology.

1. Introduction

With the development of the shipping industry, ship safety and efficiency have become an undeniable issue, and ship maneuvering and control technology, as an important factor affecting ship safety and effective operation, has also become a focus of attention. It is very important to study the development of ship maneuvering and control technology. This study aims to continuously improve and innovate ship operating systems to enhance the maneuverability, safety, and efficiency of ships. Studying ship maneuvering and control technology can not only enhance the safety and efficiency of ships, but also provide support for cultivating professional talents, ultimately achieving the goal of promoting the development of the shipping industry.

At present, there are many studies on ship maneuvering and control technology [1-3], mainly in the field of autopilot [4-5]. Among them, Zhu Liyan et al. proposed an adaptive fuzzy control algorithm for intelligent ship autopilot systems, considering input saturation, unknown rotational angular velocity, and specified performance [6]; Shen Chuanjun et al. designed a portable debugging and adaptation device for autopilots to address the issue of a lack of portable analog servo actuators [7-8]; Li Zhongjie conducted research on the hardware and software design of ship autopilot monitoring and alarm systems based on ship autopilot monitoring technology, in order to further promote the development of autopilot monitoring and alarm systems. However, there is even less comprehensive research on ships and control technology [9].

In this case, this article summarizes the current development status of ship maneuvering and control technology at home and abroad, elucidates the relevant theories of ship maneuvering systems, summarizes the development history of ship autopilots, and makes an overall grasp of the development trend of ship maneuvering and control technology. This will help promote the

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development of ship maneuvering and control technology in China, and promote the ethical development of shipping trade.

2. The Current Development Status of Ship Maneuvering and Control Technology

Ship maneuvering and control technology refers to the use of various control and technical means to achieve the requirements of ship maneuvering, navigation, safety control, and energy management during ship operation. Ship manipulation and control technology involves the mechanical and electrical equipment, communication and navigation equipment, control systems, data processing and analysis of ships. The application of ship maneuvering and control technology can improve the safety, reliability, and efficiency of ships, meet the requirements of current environmental protection and sustainable development, and also reduce the operating and maintenance costs of ships.This article mainly compares the current development status of ship maneuvering and control at home and abroad from the following three points, as shown in Fig. 1.

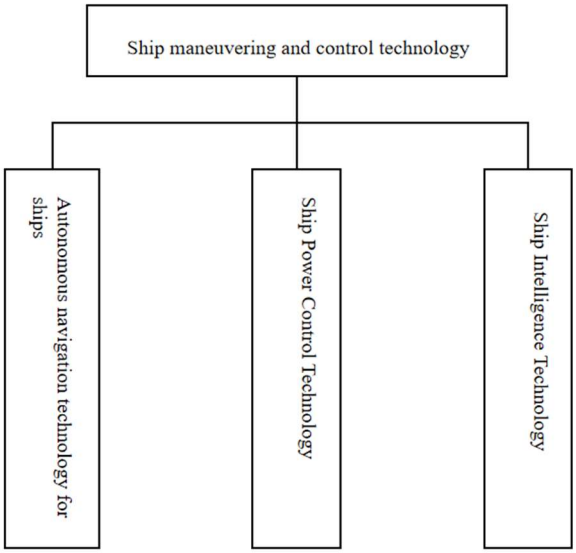

Fig. 1 Ship maneuvering and control system

2.1. Current Situation Abroad

In foreign countries, ship maneuvering and control technology is also an important field in the shipping industry, and a series of progress and innovations have been made [10-11].

Ship autonomous navigation technology: Developed countries such as Europe, Japan, and the United States are in a leading position in ship autonomous navigation technology. Japan has launched the "Automated Ship" program, aiming to apply autonomous navigation technology to various types of ships and achieve commercial operation of unmanned vessels.

Ship power control technology: Developed countries such as Europe and the United States are also in a leading position in ship power control technology, and have developed many new power control systems. Among them, ABB in Europe and GE in the United States have strong capabilities and technological advantages in the field of ship power control technology.

Ship intelligence technology: Developed countries such as Europe and the United States have also made significant progress in ship intelligence technology. Among them, the Fraunhofer Federation in Germany has launched the "Maritime Internet of Things" project, aiming to apply IoT technology to ship operations and achieve intelligent management and control of ships.

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In summary, foreign ship maneuvering and control technology is in a leading position in autonomous navigation technology, ship power control technology, and ship intelligence technology, making important contributions to the development of the global shipping industry.

2.2. Domestic Situation

With the continuous development of China's marine economy and the implementation of the national "the Belt and Road" strategy, China's shipping industry is undergoing a new transformation. In this context, ship maneuvering and control technology, as one of the core technologies in the shipping industry, is also constantly developing and innovating. In China, ship maneuvering and control technology has been widely applied in the design, construction, and operation of various types of ships. At present, the main applications of ship maneuvering and control technology in China include the following aspects:

With the continuous development of global positioning system, radar, inertial navigation and other technologies, China's autonomous navigation technology for ships has made significant progress. At present, China's autonomous navigation technology for ships has been widely applied in the navigation and operation of various types of ships, which can greatly improve the safety and efficiency of ships.

Ship power control technology is one of the core aspects of ship maneuvering and control technology, mainly including engine control, thruster control, servo control, etc. In China, ship power control technology has been widely applied in the design and construction of various types of ships, which can greatly improve the economy and environmental protection of ships.

Ship intelligence technology is one of the important development directions of ship manipulation and control technology, mainly including artificial intelligence, Internet of Things, big data, and other aspects. In China, ship intelligence technology has been applied to the management and operation of various types of ships, which can greatly improve the intelligence level and management efficiency of ships.

In the future, with the continuous development of technologies such as artificial intelligence, the Internet of Things, and big data, China's ship maneuvering and control technology will be further upgraded and improved, making greater contributions to the development of China's shipping industry.

3. Ship Maneuvering System

Ship maneuvering system refers to the system and equipment used to control the movement of ships. Its specific components are shown in Fig. 2.

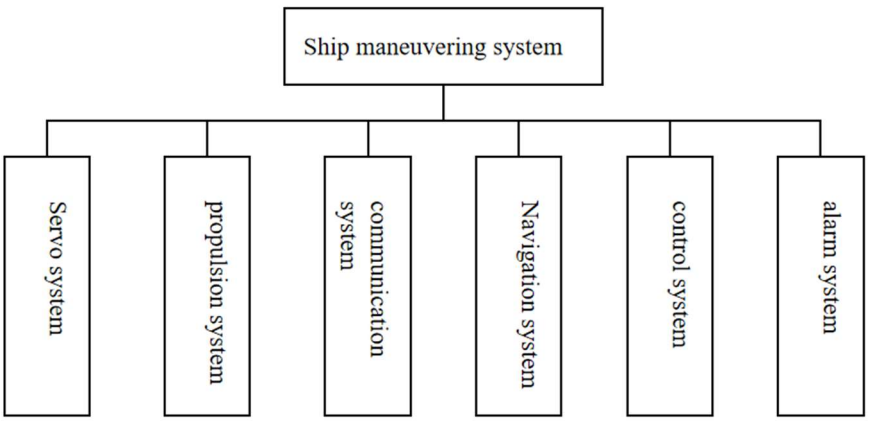

Fig. 2 Ship maneuvering system

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Servo system: The servo system is the most important part of the ship's control system. By controlling the steering of the servo, the ship's heading can be changed. Modern servo systems typically use electronic, hydraulic, pneumatic and other technologies to achieve precise control and rapid response.

Propulsion system: Propulsion system is a system used to control the propulsion force of a ship. The main engine is the core component of a ship's propulsion system, and through its control, it can achieve operations such as acceleration, deceleration, and stopping of the ship. Modern ship propulsion systems typically use power equipment such as turbines and diesel engines, combined with propulsion components such as propellers and thrusters, to achieve efficient propulsion effects.

Communication system: The ship communication system is used to communicate with ports, other ships, or maritime organizations. Modern ship communication systems include various communication methods such as VHF, SSB, GMDSS, etc., which can ensure safe communication of ships at sea.

Navigation system: The ship navigation system is used to determine the position and heading of the ship. Common ship navigation equipment includes radar, GPS, compass, etc. These devices can provide accurate ship position and direction information, helping crew make navigation decisions.

Control system: The ship control system is used to control the operation of various components of the ship, including electrical control systems, hydraulic control systems, etc. These systems can accurately control the operation of various components such as servos, thrusters, and berth equipment, ensuring the safe operation of ships at sea.

Alarm system: The ship alarm system is used to detect the status of various components of the ship, and will issue an alarm in case of any abnormal situation. Ship alarm systems usually include various types such as fire alarm, leakage alarm, wave alarm, etc., which can detect and handle various problems in a timely manner, ensuring the safe operation of ships.

4. Control Methods for Ship Rudder Control

The development of autopilot can be roughly divided into four stages: mechanical autopilot, PID autopilot, adaptive autopilot, and intelligent autopilot. As shown in Table 1.

Table 1. Development stage of autopilot

stage	time	type
Phase 1	2020s	Mechanical autopilot
Phase 2	2050s	PID autopilot
Phase 3	2060s	Adaptive autopilot
Phase 4	2080s	Intelligent autopilot

In the 1920s, Sperry from the United States and Ansuchz from Germany independently developed mechanical autopilots [12], marking the birth of the first generation of autopilots and achieving automation in ship maneuvering. Subsequently, the development of electronics and servo mechanism theory led to the emergence of the second generation of autopilot, namely PID rudder [13], which achieved breakthroughs in the 1950s. In the late 1960s, with the advancement of adaptive theory and computer technology, scientific and technological personnel from Nordic countries such as Sweden promoted adaptive rudder from laboratories to actual ships, forming the third-generation automatic rudder [14]. Adaptive rudder has made certain achievements in improving control accuracy and reducing energy consumption, but its physical implementation cost is high and parameter adjustment is difficult, especially affected

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by ship nonlinearity and uncertainty. The control effect is difficult to ensure, and may even affect the stability of the system. Despite facing these challenges, skilled helmsmen can effectively control ships with their steering experience and intelligence. Therefore, starting from the 1980s, people began to seek methods similar to manual steering and proposed the concept of the fourth generation intelligent rudder [15-16].

4.1. Mechanical Autopilot

Mechanical autopilot is an automation system used to control the direction of ships. Mechanical autopilot senses the direction and attitude of the ship through mechanical devices and sensors, and automatically adjusts the rudder angle according to preset heading instructions to keep the ship in the desired heading. The core component of mechanical autopilot is the servo. The rudder is connected to the ship's rudder control system and can control the rotation of the steering wheel. The servo is commanded by the autopilot system to automatically adjust the rudder angle based on the current direction difference of the ship, allowing the ship to return to the predetermined heading. In order to perceive the direction and attitude of ships, mechanical autopilots typically use sensors such as compasses and gyroscopes. A compass is used to determine the direction of the ship's compass, while a gyroscope can detect the ship's attitude and rotation.Mechanical autopilot usually consists of the following components, as shown in Fig. 3.

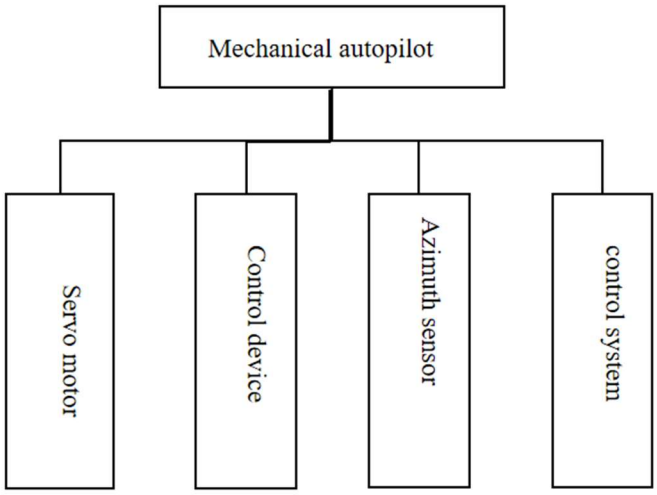

Fig. 3 Mechanical autopilot

Servo: A servo is a mechanical device used to control the rudder angle. It is usually driven by an electric or hydraulic system, which transmits the rotational force to the rudder through a transmission device, thereby changing the rudder angle of the ship.

Manipulation device: Manipulation device is a control unit on a ship, used by the captain or pilot. It is usually composed of a rudder, a tiller, or a control rod, used to change the position of the servo and adjust the rudder angle.

Directional sensor: In order for the mechanical autopilot system to maintain the predetermined heading, it is necessary to use a directional sensor to measure the ship's azimuth angle. These sensors can be magnetic compasses, gyroscopes, or other navigation devices that provide current ship's directional information.

Control System: The control system is the brain of a mechanical autopilot, which receives information from azimuth sensors and calculates the required rudder angle adjustment based on a predetermined heading target. Then, the control system sends signals to the servo through the control device to adjust the rudder angle.

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The advantages of mechanical autopilot include high reliability, suitability for various types of ships, and relatively low cost. It does not rely on electronic systems, so it can still function normally in the event of power supply interruption or electronic device failure. However, mechanical autopilots may not be as precise and flexible as electronic autopilots, as they are limited by the performance and response speed of mechanical devices.

It should be noted that with the development of technology, electronic autopilots have become the mainstream of ship automation control. Electronic autopilot utilizes advanced electronic and computer technology to control the direction of ships more accurately and flexibly. Mechanical autopilots still have certain applications in some specific maritime applications, but in most cases they have been replaced by electronic autopilots.

4.2. PID Autopilot

Ship PID autopilot is an autopilot system based on PID (proportional integral derivative) control algorithm, used to achieve automatic rudder direction control of ships. The ship PID autopilot system consists of multiple components, including the following key components, as shown in Fig. 4.

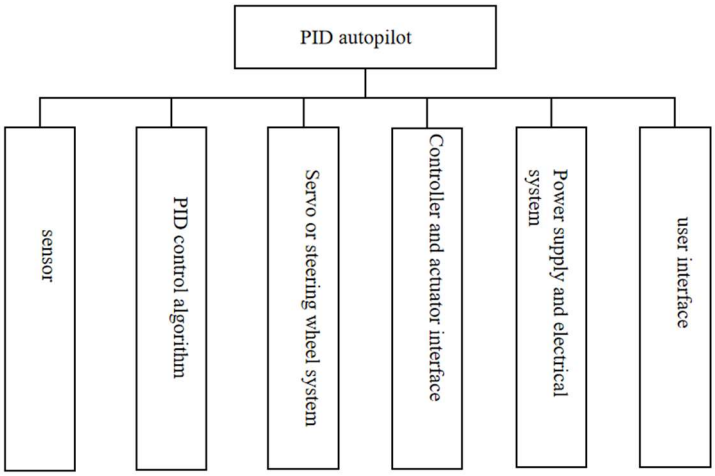

Fig. 4 PID autopilot

Sensors: Sensors are used to collect data about the ship's heading and motion status. Common sensors include heading sensors (such as gyroscopes or gyroscopes), angular velocity sensors, acceleration sensors, etc. These sensors provide real-time ship attitude and heading information as inputs to the PID control system.

PID control algorithm: The PID control algorithm is the core of the ship's PID autopilot system. This algorithm calculates the corresponding rudder angle control command based on the current heading deviation of the ship, as well as the integral and differential terms of the previous heading deviation. The PID control algorithm uses three parts: proportional, integral, and differential, to control the adjustment amplitude and speed of the rudder angle based on the adjustment parameters.

Servo or servo system: Servo or servo system is an actuator that converts the output of PID control algorithm into actual rudder angle operation. The servo adjusts the rudder angle of the ship according to the instructions of the PID controller to achieve automatic steering control of the ship.

Controller and actuator interface: An interface is required between the controller and actuator to transmit rudder angle control commands. This interface is usually a digital or analog signal

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transmission line used to transmit the rudder angle command calculated by the PID controller to the servo or servo system.

Power and Electrical Systems: The ship's PID autopilot system requires power to drive sensors, controllers, and actuators. Usually, there will be corresponding power and electrical systems to ensure the normal operation of the system.

User interface: The user interface is a part of the ship's PID autopilot system, used for crew or operator interaction and monitoring with the system. The user interface can be a control panel, display screen, or computer interface, through which the parameters of the PID controller can be set and adjusted, the system status can be monitored, and manual operations can be performed.

The ship PID autopilot system monitors the ship's heading deviation in real-time and uses PID control algorithm to automatically adjust the rudder angle to keep the ship in the expected heading. By continuously adjusting the rudder angle, the system can achieve stable heading control of the ship and make precise adjustments based on the magnitude and rate of deviation, in order to improve the ship's handling performance and navigation safety.

4.3. Intelligent Autopilot

Intelligent autopilot refers to the use of advanced technology and systems to enable ships to automatically perform navigation and rudder control operations without the need for manual intervention.

The intelligent autopilot system usually includes the following components, as shown in Fig. 5.

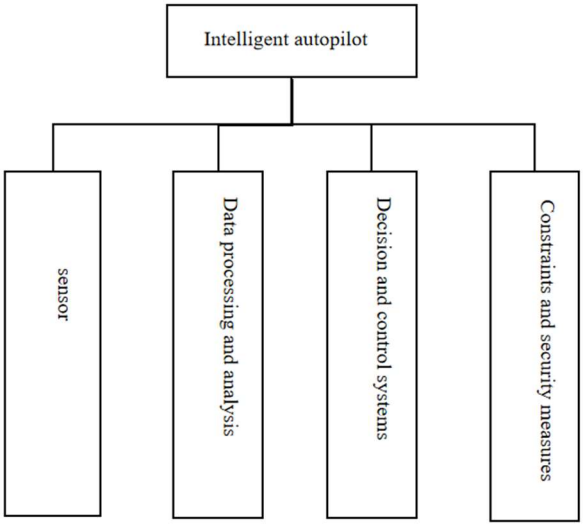

Fig. 5 Intelligent autopilot

Sensors: The intelligent autopilot system uses various sensors to obtain information about the surrounding environment of the ship. These sensors can include Global Positioning System (GPS), radar, rangefinder, ship speed sensors, etc. These sensors can provide information about the position of ships, surrounding vessels and obstacles, water depth, and ocean conditions.

Data processing and analysis: The collected sensor data will be sent to the computer system of the intelligent autopilot system for processing and analysis. These systems typically use advanced algorithms and artificial intelligence technology to process, identify, and classify data in order to understand the environment and situation in which ships are located.

Decision and control system: Based on the results of data analysis, the intelligent autopilot system will make corresponding decisions and control operations. These operations include

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rudder angle control, speed adjustment, heading maintenance, etc. The system will automatically adjust the rudder angle and thruster operation to keep the ship at the predetermined heading and speed.

Constraints and safety measures: Intelligent autopilot systems usually consider navigation constraints and safety factors. For example, it will comply with navigation rules and maritime traffic management regulations, avoid collisions with other ships, and consider factors such as weather conditions and channel restrictions.

The goal of intelligent autopilot technology is to improve the safety and efficiency of navigation. It can reduce the workload of crew members, reduce the risk of operational errors, and improve the navigation accuracy and stability of ships. However, the implementation of intelligent autopilot systems for ships requires comprehensive consideration of the special needs of the ship, the complexity of the marine environment, and relevant regulations and safety standards.

5. The Development Trend of Ship Maneuvering and Control Technology

In the field of ship maneuvering and control technology, with the continuous progress and innovation of technology, there are many exciting development trends. The following are some important trends in ship maneuvering and control technology, which are of great significance for improving navigation safety, efficiency, and comfort.

Firstly, the widespread application of automation technology is one of the current main trends. Automation systems can achieve automatic control of rudder angles, thrusters, and other critical equipment, reducing the workload of crew members and improving operational consistency and accuracy. Through automation technology, ships can achieve functions such as automatic trajectory control, automatic berthing, and automatic docking, greatly improving the accuracy and safety of maneuvering. Secondly, electronic autopilot systems have replaced traditional mechanical autopilot systems and become an important development direction for ship maneuvering and control. The electronic autopilot system utilizes advanced electronic and computer technology to achieve precise control of the rudder angle through an electric servo. These systems typically have higher accuracy and flexibility, and can integrate with other navigation and control systems to achieve more advanced functions such as automatic trajectory control and power management. The development of electronic autopilot systems has made ship maneuvering more accurate and responsive. Thirdly, the application of ship maneuvering simulators is becoming increasingly widespread. Ship maneuvering simulator is a virtual simulation system used for training and research. It can simulate various ship maneuvering scenarios and provide real-time feedback and evaluation, helping crew members become familiar with ship operations and respond to various situations. Ship maneuvering simulators are of great value in cultivating the skills of new crew members, improving their emergency response capabilities, and researching new maneuvering technologies. Through the use of simulators, crew members can conduct maneuvering training in a safe environment, improve ship maneuvering skills, and reduce operational errors. Fourthly, unmanned vessel technology is one of the important trends in the field of ship maneuvering and control technology. With the development of automation technology, unmanned ships can achieve autonomous navigation through advanced sensors, navigation systems, and autonomous control algorithms, without the need for direct control by personnel. Unmanned ship technology has broad application prospects in fields such as marine scientific research, marine exploration, rescue missions, and maritime transportation. Unmanned ships can perform tasks in complex and dangerous environments, reduce personnel risks, and improve ship efficiency and flexibility. Fifthly, intelligence and data-driven are important directions for the development of ship maneuvering and control technology. By utilizing artificial intelligence and big data technology, ship operation data can be analyzed and modeled to achieve more accurate

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navigation prediction, energy conservation, and maintenance plans. Intelligent technology can help ships monitor navigation status in real time, predict abnormal situations, and take corresponding measures to improve navigation safety and efficiency.

In summary, ship maneuvering and control technology is constantly developing towards automation, electronicization, simulation, intelligence, and unmanned direction. These trends will further improve the safety, accuracy, and efficiency of ship maneuvering, bringing more opportunities and challenges to the development of the shipbuilding industry and the future of navigation.

6. Conclusion

With the development of global shipping trade, ship maneuvering and control technology plays an important role in ship safety, maneuverability and maneuverability, fuel efficiency, and environmental protection. This article summarizes the current situation of ship maneuvering and control technology at home and abroad, summarizes the development history of ship maneuvering rudder, and provides an overall discussion of ship maneuvering and control technology, which helps researchers to master ship maneuvering and control technology globally. The continuous development and application of new ship maneuvering and control technologies will help improve the sustainability and efficiency of the shipping industry, and promote the progress of navigation technology.

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