Development of Advanced Safety Berthing/Unberthing Assistance System Aimed at Achieving Zero Vessel Accidents in Ports

In ports, which are congested with ships and require sensitive vessel maneuvering, many accidents are caused by human factors, and a higher level of safety is required. Taking advantage of our product technologies for marine propulsion systems and general marine machinery, we are working with Kawasaki Kisen Kaisha, Ltd. and Kawasaki Kinkai Kisen Kaisha, Ltd. to develop the world's first advanced Safety Berthing/Unberthing Assistance System that supports maneuvering in port, berthing/unberthing, mooring operations, and mooring management in an integrated way. We are conducting research and development by using Kawasaki Kinkai Kisen coastal vessels in actual service conditions, aiming for social implementation by 2025.

Introduction

In recent years, expectations have been increasing for the practical application of autonomous navigation technology for ships; this has been driven by aims such as the further enhancement of maritime safety, improved onboard working environments, and increased industrial competitiveness and productivity. To move toward social implementation of autonomous navigation technology, various approaches are being implemented across diverse sectors in Japan as well; for example, in 2018, the Ministry of Land, Infrastructure, Transport, and Tourism formulated the "Roadmap for the Practical Application of Autonomous Ships." In addition, in 2020, Class NK (the ship classification society) published the "Guidelines for Automated/Autonomous Operation of Ships—Design, Development, Installation and Operation of Automated Operation Systems/Remote Operation Systems."

Moreover, in the International Maritime Organization (IMO), the implementation of the MASS (Maritime Autonomous Surface Ships) Code, a framework of international rules, continues to be studied; the Code is planned to come into force in 2028.

1 Background

Despite advancements in navigational instruments and the development of IoT (Internet of Things) technologies, the number of maritime accidents has not decreased. For coastal vessels in particular, more than half of accidents occur in coastal areas, including in port facilities. To address this challenge, there is a need to improve safety during ship entry and exit.

Therefore, with the aim of achieving zero accidents during maneuvering within ports, Kawasaki Kisen Kaisha, Ltd. and Kawasaki Kinkai Kisen Kaisha, Ltd. are jointly working with our company on technological research and development concerning the advanced Safety Berthing/Unberthing Assistance System. This is the world's first system to support maneuvering in port, berthing/unberthing, mooring operations, and mooring management in an integrated way. As its primary feature, the system realizes comprehensive support from vessel entry to mooring operations and mooring management during berthing by means of coordinated control between the propeller and mooring-winch.

2 The aim of the three companies' joint development of the advanced Safety Berthing/Unberthing Assistance System

At present, berthing and unberthing operations in ports are carried out by crews who are well-versed in vessel

maneuvering techniques and who have a deep understanding of the characteristics of ship-specific maneuvering and mooring equipment features. However, with the increasing size of vessels leading to advanced navigation requirements and the shortage of maritime personnel, which has become a social issue, there is growing demand to further enhance safety management in ship navigation and mooring operations. It is expected that this system will assist in safe berthing and unberthing maneuvers using cutting-edge technologies such as AI, thereby leading to skill simplification and helping to resolve challenges in berthing and unberthing operations. In the research and development toward practical application, we aim to integrate the abundant navigational expertise of our two collaborative development partners with Kawasaki's system integration technologies for propulsion systems and mooring assistance technologies cultivated through our many years in the marine machinery business; this will enable us to address various challenges in berthing and unberthing maneuvers and to ensure a higher level of safety in mooring operations.

3 The technology developed to realize the safe berthing/unberthing assist system

(1) Maneuvering in-port

Maneuvering in ports is characterized by low ship speeds as illustrated in **Fig. 1**. It is challenging due to the influence of external disturbances, such as weather and sea conditions, including wind and tidal currents. Therefore, there is a need for operators to decide judiciously to ensure safe vessel maneuvering under such conditions.

Technologies developed to address this include "vessel maneuvering assistance information technology," which incorporates sensing technologies to accurately recognize a ship's own maneuvering and the surrounding conditions, and ship state prediction technologies, which utilize the vessel motion model. Such technologies have made it possible to obtain both accurate information about the relative relationships with other vessels and quay walls within the port and highly accurate information related to ship motion predictions, such as the future course, speed, and stopping position for the ship's commander, in addition to future hazard prediction information based on such information. This information is displayed on a Human-Machine Interface (HMI) device. These technologies thus realize vessel maneuvering assistance that enables even less-experienced operators to make appropriate decisions on navigation safety.

By leveraging environmental perception sensor technology, which enables recognition of surrounding conditions by combining signals from multiple sensors (sensor fusion), and rapidly processing a vast amount of sensor data, the following information can be acquired on the vessel in order to assist the vessel operator:

- Accurate information on the position, orientation, and movement speed of the vessel itself, other vessels, and obstacles such as floating buoys; and
- Accurate information on the relative relationships between the vessel and the quay walls.

Figure. 2 shows an example of sensor fusion recognizing the quay wall section from laser distance measurement and image information. Furthermore, by estimating the influence of disturbances such as weather and sea conditions not captured by sensors and calculating future movement predictions (**Fig. 3**) utilizing the vessel motion model, it becomes possible to provide the vessel

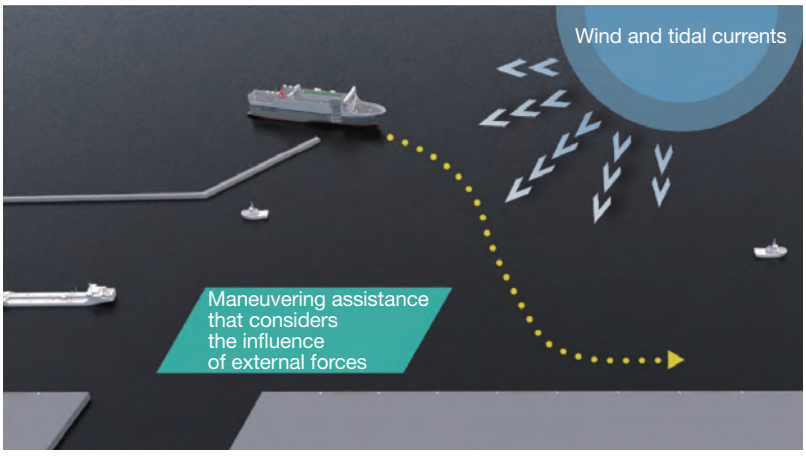

Fig. 1 Maneuvering in port and berthing/unberthing

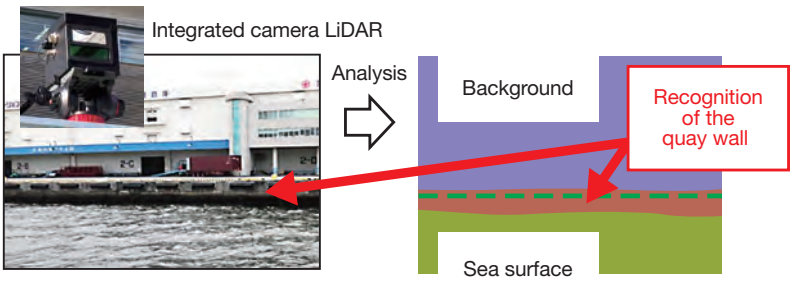

Fig. 2 Berth detection by LiDAR/camera fusion

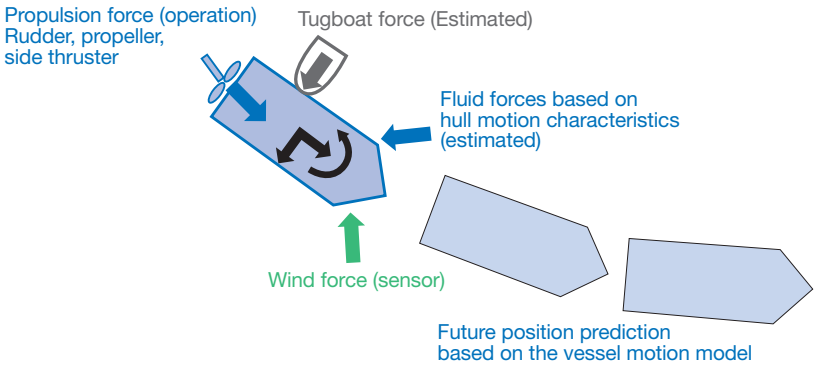

Fig. 3 Ship movement prediction that takes disturbance into consideration

operator with information such as the parallelism between the vessel and the quay wall during berthing, changes in the angular velocity, the approach speed to the quay wall, and the vessel's predicted future position.

(2) Berthing/unberthing operations

In berthing/unberthing operations close to the quay wall, vessel operators must simultaneously perform tasks such as appropriately reducing speed towards the target stopping position and maintaining both distance from and parallelism to the quay wall while considering the effects of disturbances, including weather and sea conditions. This is an extremely burdensome task for operators, so there is a need to reduce their workloads.

To address this need, the adoption of model predictive control utilizing vessel motion models enables prediction of the future vessel speed or attitude as well as calculation of the optimal thrust command; doing so provides optimal automatic control of the vessel speed and attitude, which are affected by constantly changing disturbance forces, such as weather and sea conditions. We have realized a vessel maneuvering assistance system that includes a function for automatically maintaining the ship's speed, thus compensating for external disturbances and ship attitude. This function reduces the workload imposed by vessel maneuvering operations, enabling operators to focus on making appropriate deceleration command decisions toward the target stopping position and sequential safety judgments for vessel maneuvering.

We manufacture and sell the KICS (Kawasaki Integrated Control System) collective control system, which can collectively control multiple types of propulsion machinery, including controllable pitch propellers, azimuth thrusters, side thrusters, and rudders. We have a wealth of experience in maneuvering various types of vessels, including ferries, supply boats, cable-laying ships, and fishing vessels[1), 2), 3)]. **Fig. 4** shows an example system configuration. Prediction of ship movements is enabled by a system configuration that combines navigation sensors—such as gyrocompasses, positioning systems, wind sensors, and log speed meters—with a control unit that incorporates a vessel motion model that represents the dynamic characteristics of the vessel. This system configuration allows the system to instantly calculate the blade angles, rotation speeds of multiple propellers, and rudder angle in response to disturbances such as wind and waves, thereby automatically optimizing the control.

(3) Mooring operations

In mooring, propeller operation at the bridge and

Fig. 4 Example of system construction of KICS-5000

mooring winch operation on the deck, as shown in **Fig. 5**, must be coordinated. In addition, there is a need to improve safety during vessel maneuvering.

The development of integrated coordination technology for propellers and mooring winches makes it possible to coordinate operations between the propellers and mooring winches from the remote bridge. In such coordinated operation, the mooring winch control system automatically controls the tension to generate the optimal tension while ensuring balance with the propeller. Additionally, this technology provides a function for using camera sensor technology to monitor whether there are any personnel near remotely operated mooring winches and mooring lines. The technology thus realizes mooring assistance that significantly reduces the risk of personal injury during mooring.

By applying the Dynamic Positioning System (DPS) technology included with KICS, which controls the heading, thrust commands for multiple propellers and mooring line tension commands for multiple mooring winches are optimally allocated to generate the desired resultant force that is balanced as the entire ship. **Figure 6** shows the control block diagram for KICS. This technology enables the position and attitude of the vessel performing berthing and mooring operations to be easily controlled, thereby realizing safe berthing and mooring at the specified position on the quay wall.

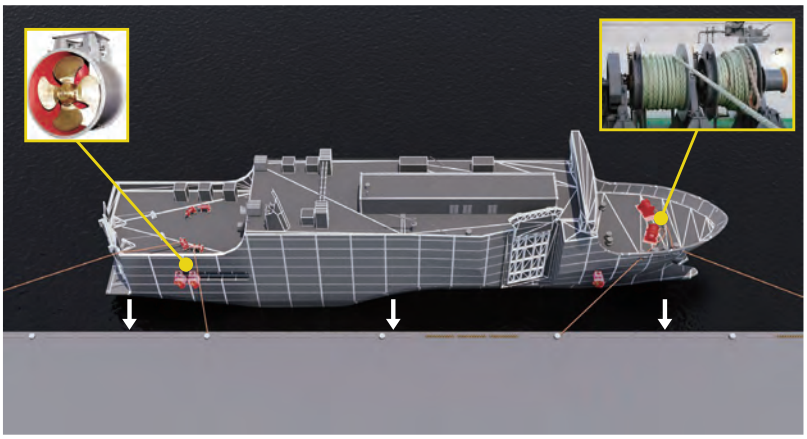

Fig. 5 Mooring operations & management

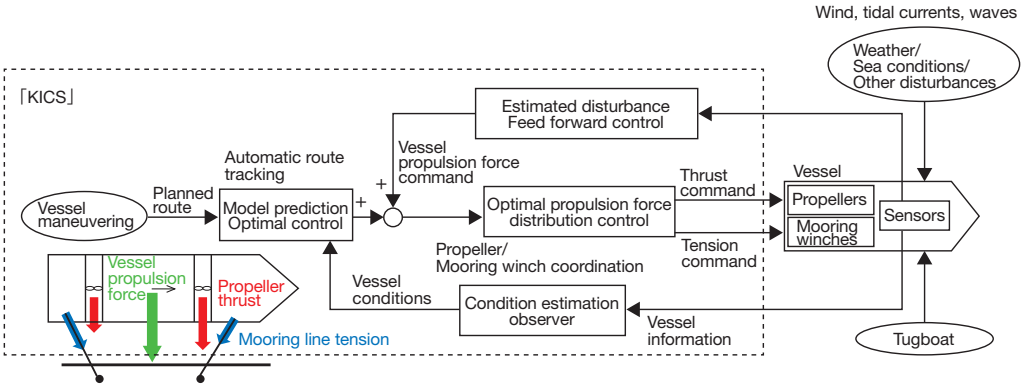

Fig. 6 Control block diagram of KICS (integrated linkage of propulsion and mooring systems)

Fig. 7 Deck machinery

(4) Mooring management

Regarding the management of mooring lines stretched from the bow to the stern of a vessel at mooring, there are needs to reduce the workload of tension state management tasks in response to factors such as tides and changes in the vessel's draft as well as to enhance the safety of these operations.

To meet these needs, we have developed a new system that can detect the tension applied to mooring lines on a vessel while it is at mooring as well as monitor the tension and stress of mooring lines in real time from any location within the vessel. Mooring lines are typically fixed to mooring bollards on the quay side through multiple shipboard fittings. Consequently, there is usually a difference in tension between the mooring winch side and the mooring bollard side. However, by utilizing our unique tension estimation model, we can detect the tension with high precision. This technology contributes to reducing the workloads of tasks such as frequent status checks and tension adjustment operations, particularly in ports with significant tidal variations or rapidly changing vessel drafts. It also enhances safety during mooring.

We have been manufacturing and selling marine hydraulic systems for steering gear and deck machinery (such as anchor windlasses and mooring winches) since we first produced a hydraulic pump for steering gears in 1916. We produce and sell products tailored to various types and vessel categories while developing hydraulic equipment and systems. In the field of deck machinery, our advanced hydraulic control technology contributes to labor saving in cargo handling and mooring operations. We have delivered our products to over 7,000 vessels to date, and they have been highly evaluated by various sectors of the shipbuilding and shipping industries, both domestically and internationally. **Figure 7** shows examples of our deck machinery.

4 Technical verification trial

While proceeding with efforts to convert key technologies into intellectual property for differentiation, we are developing a verification system for the safe berthing and unberthing assist system, aiming for social implementation. **Figure 8** shows the schedule of the

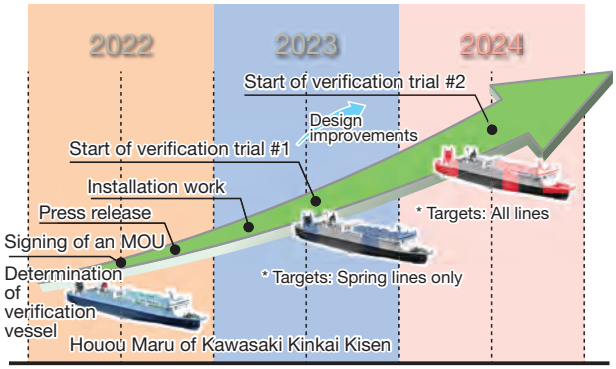

Fig. 8 Schedule of verification trial

verification trial.

For the safe berthing and unberthing assist system, the verification system has been installed on Houou Maru, a roll-on/roll-off coastal vessel that belongs to our co-development partner. We are conducting adjustment of control while collecting data on various actual vessels, including motion models of the vessels, and are scheduled to start the verification trial in October 2023.

Conclusion

We are the only domestic manufacturer capable of producing propellers, DPSs, and mooring winches, which enables us to conduct comprehensive engineering of everything from ship propulsion to mooring. KICS, which is a DPS, can provide integrated control of the propulsion propeller, side thrusters and other propulsion machinery. It comes equipped with a route tracking function that automatically navigates the planned route. To date, KICS has built up an impressive track record in automatic maneuvering technologies in Japan and abroad. Using the control technologies refined with KICS, we will further advance our research and development by utilizing DPS technology and advanced ICT, which we will do to achieve practical application of the integrated linkage of propulsion and mooring systems. Through high-level integration of the results of our research and development with knowledge of safe navigation cultivated by our co-development partners, Kawasaki Kisen Kaisha, Ltd., and Kawasaki Kinkai Kisen Kaisha, Ltd., we aim to achieve consistent safety enhancements from berthing to mooring management, as well as future autonomous vessels, all in the pursuit of marine mobility that is both safe and reliable.

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