Recent Trends and Issues for Practical Application of MASS

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1. INTRODUCTION

As many of the readers of this paper already know, active research and development, including demonstration experiments, with the aim of practical application of the ships called maritime autonomous surface ships (MASS), unmanned ships and autonomous ships are underway in countries around the world. The author will offer his own definitions of the differences among MASS, unmanned ships and autonomous ships in the following. However, in this paper, these various types of ships will be referred to collectively as MASS.

In spite of some differences in the level of interest in each country, the purposes of research and development of MASS can be classified as “improved safety of ship operation,” “reduction of workload on seafarers,” “response to shortages of seafarers,” “reduction of environmental impacts,” “reduction of ship operation costs,” and “technical interest.” Although it is currently difficult to conduct field surveys in other countries because of restrictions on overseas travel due to the COVID-19 pandemic, there is a real feeling that the problems faced by other countries are the same as those in Japan in many cases. Put another way, if technologies that solve the problems confronting Japan are developed, there will be many opportunities to market those technologies to other countries.

On the other hand, various other countries are not simply promoting technology development, but are also proactively engaged in activities for developing standards and rule-making from the stage of technology development. Likewise, in Japan, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) established “Safety Design Guidelines of Maritime Autonomous Surface Ships” [1] in December 2020, and the Japan Ship Technology Research Association conducted a “Safety Evaluation of MEGURI 2040 (Unmanned Ship) Project” with the support of the Nippon Foundation. As part of that work, activities aimed at international standardization were also begun, including “summarizing the safety requirements considered necessary for realizing unmanned ships, and development of a draft of guidelines unifying the levels of automated and remote operation, and automation” [2]. Needless to say, since many members of ClassNK are participating in these projects, Japan has created a system for communicating not only information related to technology development, but also the development of legal systems to other countries.

In view of this social situation, this paper will introduce major trends in research and development on MASS technologies in Japan and other countries, and will describe what the author considers to be the technological issues and necessary research and development items.

2. WHAT AREMASS?

2.1 Definitions of Maritime Autonomous Surface Ships (MASS) and Other Terms

First, the author’s definitions of maritime autonomous surface ships (MASS), unmanned ships, autonomous ships, an automated navigation ship, an unmanned navigation ship and an autonomous navigation ship will be presented. The reader should understand that these are not generally recognized definitions, but are simply defined by the author using these various terms to enable easier understanding of the trends in technology described in this paper. The reader should also note that the official definition of MASS and the meaning used in this paper may differ, as definition of MASS is still under study in ISO/AWI 23860 in the International Organization for Standardization (ISO) [3].

2.1.1 Automated Navigation Ship, Autonomous Navigation Ship and Unmanned Navigation Ship

“An automated navigation ship” means the entirety of a ship which utilizes some type of automatic control function and is capable of sailing without direct human operation of devices related to navigation, such as the rudder and propellers. Heading

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control and course tracking, which are already installed in many existing ships, are examples of automatic control functions, and a ship that navigates by using these functions is also an automated navigation ship. As described below, an autonomous navigation ship and an unmanned navigation ship also use automatic control functions, and thus are types of an automated navigation ship.

"An autonomous navigation ship" refers to the automated navigation ship in which the actions of recognizing objects in the waters around a ship using various types of sensors, judging whether those objects pose a danger of collision or not, taking action to avoid the objects if a danger of collision exists, and then returning to an appropriate course toward the set destination after completing the evasive action can be performed automatically without the intervention of human judgment. Although the heading control and course tracking control do not have the cognitive judgment function of recognizing and avoiding obstacles, an automatic control system that includes this cognitive judgment function is an important feature of ships and has become a target of technology development. However, this definition only refers ships which possess functions that are capable of performing judgments and operation related to steering without human intervention, and is not related to whether seafarers who can perform manoeuvring operations actually go aboard the ship or not.

"An unmanned navigation ship" is a ship which does not carry a crew, and thus is a type of the automated navigation ship. This type of ship is either equipped with the functions of the above-mentioned autonomous navigation ship, or navigates based on manoeuvring commands transmitted from a human controller at a remote location to the ship by some means of communication. Although the definition of this type means the ship cannot carry seafarers, it can carry passengers. Considering the possibility that communications with the remote control center may be interrupted, it is hoped that this type will be equipped with the functions of the autonomous navigation ship. However, a ship which is not equipped with autonomous navigation functions, but is controlled remotely by transmission of navigation commands related to operation of the rudder, propellers, etc. can also be classified as an unmanned navigation ship, provided it does not carry seafarers who can perform manoeuvring operations.

2.1.2 Automated Ships, Autonomous Ships and Unmanned Ships

The common feature of the three types of ships in the previous section is some form of automation (or remote control) of the navigation function. However, ship operation is not limited to the navigation function defined as "sailing on a set course at a certain speed while avoiding obstacles." Ship operation also includes various other types of work such as "deberthing (leaving the pier/quay)," "accelerating/decelerating," "transitioning from a sailing condition to an anchored condition by dropping anchor offshore," "transitioning from an anchored condition to a sailing condition by weighing anchor offshore," "berthing (mooring at a pier/quay)" and taking on passengers or cargo, and unloading. Moreover, the work of shipping companies does not end with the work on shipboard, but includes cooperation with land-based equipment and also requires coordination with the operations of multiple other ships, and not simply the operation of one ship. Considering the fact that ship operation is realized by the totality of all these tasks, in this paper, the system that performs all of these tasks is called "operation." In this paper, if automated navigation ships use automation technology to perform this type of ship operation, the operated ships are called "automated ships." Similarly, autonomous navigation ships which perform ship operation are called "autonomous ships," and unmanned navigation ships are called "unmanned ships." Because autonomous navigation ships and unmanned navigation ships are types of automated navigation ships, autonomous ships and unmanned ships are also categorized as automated ships.

2.1.3 Marine Autonomous Surface Ships (MASS)

The term maritime autonomous surface ships (MASS) has not yet been defined in Japan, and also remains to be defined in other countries. At international conferences on MASS, the participating marine equipment companies, communication technology companies and startups have made presentations focusing on application of technologies developed by the respective companies themselves, but in any case, a ship equipped with autonomous functions is assumed, as can be understood from the word "autonomous." Therefore, in terms of the definitions in section 2.1.2, "autonomous ships" is the closest approximation to MASS. At present, however, autonomous functions are still in the development process, and experiments are largely limited to automatic control devices for which only some autonomous functions have been developed. Thus, under the present conditions, it would be more appropriate to call MASS "automated ships." In this paper, MASS are referred to simply as "automated ships."

2.2 Hardware Configuration of MASS

The hardware configuration of MASS which is the target of research and development is shown in the illustration in Fig. 1.

Basically, the hardware consists of multiple autonomous ships, a remote control room (Control Center), which remotely monitors multiple autonomous ships from a remote location and issues instructions corresponding to their conditions, and a communication system for exchanging information between autonomous ships and the Control Center. Because monitoring and observation equipment for observing the condition of the waters where the autonomous ships are navigating and weather and maritime meteorology conditions are installed in ports, on buoys and so on and are also useful for information sharing, a system configuration which can be linked with this monitoring and observation equipment is desirable.

For safe use of MASS, implementation of functions for recognition and judgment of conditions and navigation are required in the ships themselves. Therefore, a ship which is to be used as MASS must be an autonomous navigation ship.

Regarding the Control Center, general control centers which perform operation control are also used by railways, in which automated operation technology was applied earlier in the sense that an operator is not onboard the train. It is necessary to create an analogous system for ships to enable monitoring of ships at sea from land and transmission of commands from a remote location whenever necessary.

It is also necessary to construct a cable and wireless communication environment for use in exchanges of information between the autonomous ships and the Control Center and remote observation devices.

2.3 Purposes of Development of MASS

Although there are some differences depending on the country, the purposes of research and development for MASS are as follows.

2.3.1 Improved Safety of Ship Operation

To mention a development in the automotive field, collision damage reduction braking control devices (automatic brakes) will be legally required on new automobiles in Japan beginning in November 2021 [4], as the incidence of accidents can be reduced by installing this type of automatic control device. Since there is concern that humans may overlook dangerous conditions due to fatigue and other factors, resulting in poor judgment, the development of automatic control devices that assist human judgment is required in order to reduce these kinds of accidents.

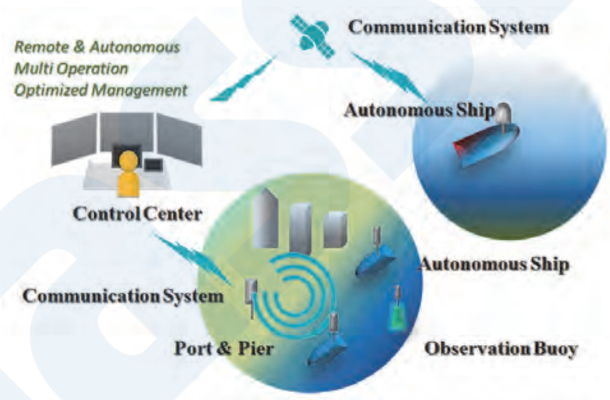

Figure 1 Hardware configuration of autonomous ships

2.3.2 Reduction of Workload on Seafarers

In the current environment, the use of the heading control function reduces the workload of manual rudder operation to maintain the target course, allowing seafarers to put greater effort into watching the surrounding area. If autonomous ships can be realized, a further reduction of the burden of watchkeeping work will also be possible.

2.3.3 Response to Shortage of Seafarers

The work of seafarers is sometimes seen as a 3K (hard, dirty, dangerous) job in Japan and as a 3D (dull, dirty, dangerous) job in other countries, and as a result, the number of young jobseekers in this field has declined. Particularly in coastal navigation, since the percentage of seafarers aged 50 years or older is approximately 46 % [5], it is easy to imagine that labor shortages become even more serious in the near future.

2.3.4 Reduction of Environmental Impacts

Although autonomous ships do not contribute directly to reducing environmental impacts, if unmanned navigation ships can be realized, the problem of long working hours of seafarers will not arise. As a result, it will be possible to reduce the sailing speed of ships, which will reduce fuel consumption and thereby contribute to reducing the load on the environment.

2.3.5 Reduction of Operating Costs

If unmanned ships can be realized, it will be possible to reduce the cost of hiring seafarers and the cost of meals and other incidental costs during voyages. It will also be possible to increase the volume of cargos by eliminating crew living space in ships.

2.3.6 Technical Interest

Because research and development on self-driving technologies is progressing, particularly in the automotive field, research is also being promoted from the viewpoint of the pure technical interest of engineers, focusing on the question of whether self-driving technologies can also be used in ships.

3. EXAMPLES OF TECHNOLOGIES RELATED TO MASS IN JAPAN AND OTHER COUNTRIES

3.1 Overview of Trends in Related Technology Development in Japan and Other Countries

It goes without saying that a large investment of several $100 million will be necessary in order to develop MASS. Although presentations on technologies which are still under development is unavoidable for raising funds from investors, there are many projects in which a grand presentation of the concept using a computer-graphic promotional video is made before the ship is actually constructed and demonstration experiments are carried out, or even assuming ship construction has been completed, before any significant progress has been achieved in developing the software needed for automatic operation. Although this paper includes some slightly older ships, here, we will introduce representative examples of demonstration experiments, with the focus narrowed to automated operation ships using comparatively large-scale ships in actual service, with the aim of developing MASS.

3.2 Examples of Related Technologies in Other Countries

3.2.1 Rolls-Royce

In December 2018, Rolls-Royce and Finferries carried out a demonstration of a ship classified as an autonomous operation ship, as defined previously, in which fully autonomous navigation was achieved between Parainen and Nauvo by the car ferry *Falco* (length overall, LOA: 53.8 m). Figure 2 shows automatic berthing by the *Falco*. The ship was equipped with an obstacle detection system which integrated sensors and AI and avoided obstacles based on information from this obstacle detection system, and also performed automatic berthing under fully autonomous navigation control with absolutely no operation by seafarers [6]. Sea trials with a total time of about 400 hours were conducted as part of system development. It may be noted that Kongsberg acquired the merchant ship division of Rolls-Royce Commercial Marine (RRCM), which had carried out this SVAN Project (SVAN: Safer Vessel with Autonomous Navigation), from Rolls-Royce by Kongsberg in April 2019 [7], and there have been no notable press releases concerning the SVAN Project since that time, presumably because the members of the Rolls-Royce team responsible for research and development of the autonomous ship established Groke Technologies [8].

Figure 2 Scene of automatic berthing of *Falco* [6]

3.2.2 Kongsberg Maritime

In a joint project with Bastø Fosen, Kongsberg and the Norwegian Maritime Authority (NMA), in February of 2020, Kongsberg Maritime installed an automatic operation system on the car ferry *Bastø Fosen VI* (LOA: approx. 140 m), which is operated by Bastø Fosen, and successfully conducted an experiment with MASS as defined in this paper, demonstrating autonomous operation from leaving port to entering port under the conditions of normal service between Horten and Moss [9]. Figure 3 shows the scene on the ship's bridge published in a press release.

3.2.3 Wärtsilä

In January of 2021, Wärtsilä announced that it had installed its automated navigation system, Wärtsilä SmartMove Suite, on a 42 year old ship, the *American Courage* (LOA: 190 m), and performed navigation including automatic berthing and unberthing on a waterway called the "Crooked River" in Cleveland, Ohio (US). Figure 4 shows the scene of navigation by the *American Courage*. This vessel is also classified as MASS, as defined in the previous chapter. Here, it is noteworthy that automated navigation was realized in both going ahead and astern operation, as there is no space to turn round the vessel in this narrow waterway [10].

Figure 3 Scene during voyage of *Bastø Fosen VI* [9]

Figure 4 Scene during voyage of *American Courage* [10]

Figure 5 MASS of U.S. Department of Defense [11]

Figure 6 Combined dredger-and-oil recovery ship, *Kaisho Maru*

3.2.4 U.S. Department of Defense

Also in January 2021, the U.S. Department of Defense announced that MASS, as shown in Fig. 5, had successfully navigated a route of more than 4,700 miles from the Gulf Coast to the coast of California via the Panama Canal. Approximately 97 % of the voyage was performed under autonomous navigation, and one of the few situations when the vessel was operated by the small crew onboard was during traversing the Panama Canal[11]. Although the press release from the U.S. Department of Defense used the word "unmanned," under the definitions used in this paper, this vessel is classified as an autonomous navigation ship/MASS because the experiment was conducted with a crew onboard.

3.3 Examples of Development of Related Technologies in Japan

3.3.1 Japan Marine United

The combined dredger-and-oil recovery ship shown in Fig. 6, the *Kaisho Maru* (LOA: 103 m), was developed by the present Japan Marine United Corporation and is operated by the Kanmon Waterway Office of the Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). This vessel features an "automatic mooring and automatic land discharge system," in which berthing, discharge of dredged sand on land and unberthing are automated, and has performed automatic operation since April 2004 [12]. The automatic mooring and automatic land discharge system was realized by a set of functions comprising course tracking control, which follows a predetermined port entry and berthing course, and an automatic mooring system using equipment installed on the quay side [13] [14]. Since this ship utilizes an automatic control system under an environment in which crew members perform watch duty and is not equipped with an obstacle detection and avoidance function, the ship type is classified as an automated navigation ship and not as an autonomous navigation ship. However, in the sense that the berthing and unberthing operations have been automated, it can be called an automated operation ship.

3.3.2 NYK Line

Nippon Yusen Kaisha (NYK Line) installed an optimal route program on a large-scale pure car carrier, the *Iris Leader* (LOA: approx. 200 m), as shown in Fig. 7, and made a day-and-night voyage intermittently under the control of that program, while maintaining the normal crew watch system, over a test route from Xinsha, China to the Port of Nagoya in Japan, and then from the Port of Nagoya to the Port of Yokohama (the test area included Japan's coastal waters but excluded bays) [15]. Since the program also performs collision avoidance, this can be considered an experiment with an autonomous navigation ship, as defined in this paper.

3.3.3 Mitsui E&S Shipbuilding and 4 Other Companies

In May 2021, Mitsui E&S Shipbuilding Co., Ltd., Mitsui O.S.K. Lines, Ltd., Tokyo University of Marine Science and Technology, Akishima Laboratories (Mitsui Zosen) Inc. and MOL Ferry Co., Ltd. carried out a demonstration test of automatic pier docking and undocking at an actual quay in the Port of Oarai, Ibaraki Prefecture, Japan, using a large-scale car ferry owned by MOL Ferry, the *Sun Flower Shiretoko* (LOA: 190 m), successfully demonstrating automatic pier docking and undocking at an actual quay by a large-scale car ferry for the first time in the world [16]. Figure 8 shows scenes from the automatic pier docking and undocking simulation and the demonstration experiment. Since the press release did not mention collision avoidance, whether the ship is equipped with autonomous functions is unknown. Therefore, under the definitions in this paper, this can be considered to be an experiment with an automated navigation ship.

Figure 7 Large-scale pure car carrier, *Iris Leader* [15]

Figure 8 Scenes from automatic pier docking and undocking simulation and demonstration experiment with large-scale car ferry, *Sun Flower Shiretoko* [16]

4. ISSUES FOR REALIZING MASS

4.1 Overview of Issues for Realizing MASS

The term “ship” covers a wide range of vessels from mini-boats with a length of several meters to large ships with LOAs of several 100 meters. Moreover, differences are not limited to size; numerous kinds of ships with different shapes also exist, including pleasure boats, fishing boats, cargo ships, tankers and car carriers, among others. Therefore, the location and height of the pilothouse, the number and response of the propellers, and the types of devices installed to acquire information concerning the surrounding environment will also differ completely depending on the ship. Furthermore, even on one voyage, the length of the voyage will differ depending on the course, and the work required during the voyage will also differ greatly. On the other hand, because the universities, research institutes and companies which are engaged in research and development aiming at realization of MASS is extremely limited, even from the global viewpoint, and these organizations are promoting research and development targeting ships in which each has a deep interest, it cannot be said that research and development is being carried out with skillful coordination in the ship industry as a whole.

Therefore, in this paper, the issues which require study are arranged in terms of the functions required in MASS, the waters where those ships are used and the ship size, within the range of the author’s knowledge.

4.2 Functions Required in MASS

As mentioned in section 2.1.2, it is necessary to realize the functions of “sailing on a set course at a certain speed while avoiding obstacles.” “undocking,” “accelerating and decelerating,” “transitioning from a sailing condition to an anchored condition by dropping anchor offshore,” “transitioning from an anchored condition to a sailing condition by weighing anchor offshore” and “docking.”

The function of docking and undocking from a quay (or pier) has been realized by linkage between a car ferry and equipment on the land side, as noted in Chapter 3. On the other hand, the author was unable to find examples of research and development related to anchoring, although this may simply reflect the limits of literature research.

As technologies for avoiding obstacles while sailing, the first requirement is a function for detecting obstacles. This detection function is not limited only to detecting other ships, but also includes incapacitated vessels (vessels not under command), vessels restricted in the ability to maneuver, etc. and fishing nets and buoys, floating objects and channel buoys. A judgment capacity is also required; that is, it is necessary to judge differences in the priority order depending on the encounter situation and the condition of navigation, and determine how to avoid a collision accordingly. In the case of obstacle detection, development of systems utilizing artificial intelligence (AI) is being carried out in many countries. In Japan as well, the Japan Ship Technology Research Association launched a “Research Committee on Image Recognition Systems for Marine Use” in June 2019. This organization is collecting and organizing big data in image form for use in the development of AI for obstacle recognition at sea. The planned period of activities by this Committee is 3 years, ending in FY 2021. The Committee was set up based on the thinking that development of the image big data on marine areas and teaching data should be carried out jointly with industry, and development of the AI technology and applications should be done by systems companies or others as a “competitive area.” The work of the Committee is being carried out in two stages, Phase I and Phase II. In Phase I, the decision of the specifications of the image data and trial production of the teaching data were carried out in FY 2019. From FY 2020, this work moved to Phase II, and collection of image data, production of teaching data and image big data, including the teaching data, is now being planned to be conducted over a 2-year period [17].

4.3 Differences Depending on Waters [18]

In closed waters like those in a park or a theme park, the condition of a ship sailing in those waters and its course can be understood almost completely. In this case, even if someone unexpectedly falls overboard, the accident can be discovered easily, not only by watching by cameras installed on the ship, but also by monitoring the entire route with surveillance cameras installed separately around the body of water. At present, it is considered necessary to leave judgments of obstacles that should be avoided and obstacles that need not be avoided such as waterbirds and the like to human observers, but in the future, automatic detection by AI is expected to become possible. When an obstacle is discovered, stopping the ship before it collides with the obstacle can be considered the minimum obstacle avoidance function. Moreover, because the cruising distance is short in closed bodies of water, the necessary operating time of the propulsion system is also considered to be short. If the operating time is short, maintenance can be carried out by providing opportunities separately, and automation is easy because the control necessary for sailing is normally simple. In automated pier docking and undocking, manoeuvring control can be simplified by providing suitable piers for the automated ships.

When operating on a course with good visibility and a very short distance of a few 100 meters, for example, when crossing a river or a canal, it is comparatively easy to monitor the entire route by installing surveillance cameras, as is done in the above-mentioned closed waters, and the functions required in the propulsion system are also similar to those used in closed waters. As a difference from closed waters, it is not necessary to assume that other vessels may enter the own ship's course in closed waters, but this possibility cannot be ignored if the waters are not closed. A higher-level obstacle detection function and obstacle avoidance function are required so as to discover other vessels that may intrude into the own ship's course, determine their direction and navigate so as to avoid a collision. Moreover, depending on the environment, it may also be necessary to consider the effects of tides and currents, and in this case, a more advanced autonomous navigation function is necessary.

When navigating a route which is predetermined but lacks direct visibility, for example, when sailing the length of a river or canal, in addition to the conditions of the above-mentioned very short routes, the number of obstacles that should be detected will also increase. Although the ship may stop at multiple points, the voyage time is long; therefore, a more reliable propulsion system is required.

In the case of courses such as navigation in a port, a large number of ships of different sizes are present in comparison with navigation on a river, the directions of those other ships are more varied, and detection of fishing nets and other fishing gear is also required. Improvement of the obstacle detection function is necessary under these conditions. Because the body of water is larger and the size of the waves also increases, a grasp of weather conditions and shiphandling responding to those conditions is required. Tugboats and pilot boats also present problems: Although automatic operation is conceivable, it is necessary to consider not only the simple manoeuvring of these vessels, but also the movements of the ships which they are assisting. In this case, even more advanced steering control is demanded.

In the shiphandling aspect, in cases where a ship leaves a certain port and then enters another port after a voyage of several hours to several days, if the shiphandling system is on a level that enables autonomous navigation in the port, it is considered possible to use the same system. On the other hand, improved reliability is necessary in the propulsion system so that the system can be used for several days in a completely unmanned condition, and ultimately, a maintenance-free propulsion system is needed.

Although ocean-going voyages may last from several days to several weeks, various types of ship maintenance work are required on these voyages in addition to simple operation to transport the cargo. Performing maintenance work during voyages contributes to reducing work when the ship is in dock, resulting in a longer available ship operation time. Since automation of maintenance work is extremely difficult, it is thought that maintenance will continue to rely on human labor, even assuming automated shiphandling is possible.

4.4 Differences Depending on Ship Size [18)]

Because Japan's Ship Safety Act does not require surveys of small-sized vessels with a length of less than 3 meters and output of less than 1.5 kW, and the Act on Ships' Officers and Boats' Operators does not require that an operator possessing a small craft operator's license be on board and operate the boat, experiments can be performed easily with these craft. However, from the viewpoint of the Act on Preventing Collision at Sea, care is advised, as the above-mentioned provisions do not necessarily mean that experiments are permitted. Due to the small output of craft with outputs of less than 1.5 kW, the size of the vessels and the waters where they can be used are limited, and there are also limitations on the steering performance of these craft. Thus, care is necessary when evaluating the results of experiments and the possibility of development of the experimental results to other locations.

Small-sized vessels with gross tonnages of less than 20 tons have good maneuverability and a small turning circle, but are greatly affected by waves and other conditions. When a small ship is operated manually, fine steering control from a micro viewpoint is performed, even though the ship is sailing in a straight line from the macro perspective. For example, if the wave caused by another ship is sighted, the ship operator adjusts the heading toward the wave to minimize shaking of the own ship. This means it is necessary to realize a function that not only follows the set course, but can also make this kind of fine steering adjustments. Moreover, even assuming it is possible to measure the ship's heading as it changes instantaneously under the effect of external disturbances, the ship will return to the original heading when the external disturbance ceases; thus, it is necessary to consider the maneuverability of the ship when using the measured values.

Although ships with gross tonnages exceeding 20 tons range from small vessels with LOAs of around 20 meters to very large ships with LOAs of several 100 meters, there are no names that provide a detailed classification of these ships based on size. Maneuverability also differs greatly depending on the conditions, as the draft of tankers and cargo ships may change by more than 10 meters when empty and fully loaded, and car carriers are extremely susceptible to the effects of wind due to their very large above-water structure. Therefore, it is necessary to design a control system which is suitable for the conditions, even in the same ship. Since maneuverability also varies, the distance necessary to avoid a collision after an obstacle is discovered will vary. As a result, the distance at which the sensors must detect obstacles will change and the performance required in the sensors will differ accordingly. Regarding propellers, in the case of small ships, manoeuvring is possible, preconditioned on switching between forward and reverse rotation of the propellers, as switching between forward and reverse rotation is comparatively simple. However, steering by changing the direction of propeller rotation is not realistic in ships with LOAs of several 100 meters.

4.5 Linkage with Land-based Equipment

If all shiphandling work is performed only from the ship side, the problems are inevitably complex. For example, in mooring operation, if it is possible to provide an automatic mooring and automatic land discharge system like that used in operation of the *Kaisho Maru* introduced in section 3.3.1, the work of passing mooring lines between the ship and the land side can be eliminated. If it is possible to use a berthing method like that used in car ferries, which take on and discharge automobiles from the bow and stern, berthing control can be performed more easily in comparison with docking the ship alongside a quay.

Because the equipment in a remote control center unavoidably relies on a wireless communication network to acquire all information on the operating condition of ships and the waters during voyages, the volume of information which can be transmitted and received and the transmission speed are inevitably limited. However, depending on the waters where ships operate, installation of cameras on the land side can enable more effective monitoring of the waters than installation of cameras on every ship, since a cable transmission network can be used effectively, and it may also be possible to acquire bird’s eye information on the entire water area by properly selecting the camera installation points. In particular, using a cable communication network can be expected to have various benefits from the viewpoints of transmission volume, speed and cost.

In short, the problems that must be solved can be simplified by effectively utilizing land-based equipment, rather than attempting to solve all the problems related to ship operation from the ship side alone. Since it may also be possible to reduce costs, it is necessary to understand the status of development of land-based equipment, and to be aware of the advantages of actively utilizing these technologies.

4.6 Creation of Legal System and International Standardization

Recently, the Maritime Safety Committee of the International Maritime Organization (IMO) concluded its 103rd session (MSC 103) and completed a regulatory scoping exercise (RSE) for analysis of the effects of MASS on the existing regulatory system. As a result of this study, which began in 2018, it was concluded that revisions of treaties corresponding to the level of automation and development of commentaries will be necessary for some maritime-related treaties. Among these, however, it was concluded that revisions and commentaries will not be necessary for most treaties in the case of “automated ships equipped with automation system that support the decision making of seafarers” (Degree One automation). Agreement was also reached on the following as priority items for future study [19].

〇Planning of work to develop standards related to MASS
〇Definition of MASS and review of levels of automation
〇Development of the definitions of MASS terminology
〇Addressing high priority issues specific to MASS
(Positioning of “master,” “remote-control station/center,” etc. in MASS)
〇Development of guidelines for application of automatic navigation systems, etc.

In the future, increasingly active efforts are expected in the development of more concrete rules for social implementation of developed technologies. The Japanese side must also participate actively in these rule-making activities in order to strengthen the international competitiveness of this country’s maritime industries. In addition to the development of rules related to the developed technologies, it will also be necessary to study and create a legal system for the operation management engineers who use the developed technologies, or in more concrete terms, qualification and training for the seafarers who will crew ships using automation technologies and the personnel who will perform operational control from remote control centers.

5. CONCLUSIONS

This paper has described recent trends for practical application of maritime autonomous surface ships (MASS) as identified by the author, and the items which the author considers to be issues in research and development for practical application of MASS. Due to the extremely active publicity of other countries in connection with research and development on MASS, some may feel that the technologies of companies in other countries are more advanced than those in Japan. However, a detailed examination shows that there are no large technical differences in comparison with the technologies now under research and development in this country. On the contrary, because many overseas technologies are being developed focusing on only some problems, there are also some scattered examples of technologies that fail to satisfy the current collision regulations (COLREG convention) and others. Moreover, even assuming that MASS are applied practically, this does not mean that all ships will be MASS. Therefore, coexistence of MASS and conventional ships will still be necessary. In other words, it will be necessary to confirm the contents of various existing treaties and carry out technology development that complies with their requirements. In technologies provided from Japan, it is expected that this country plans disseminate technologies which fully comply with the relevant treaties. Moreover, since various demonstration experiments have been conducted in Japan in recent years, Japan intends to publish the results of those demonstration experiments and proactively issue rules and guidelines necessary for safe operation of MASS based on the results of those experiments so that the technologies developed in Japan will become the standard technologies for MASS .

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