

Development of Telexistence on a Ship by Using Satellite Communication

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ABSTRACT: Nowadays shipping industry has problems such as reduction of mariners, aging of mariners, and labor expenses. To solve the problems, One Person Bridge Operation was developed as navigation supporting system. However, One Person Bridge Operation remained technological problems and one man error. Therefore, in this study, telexistence on a ship was proposed by using satellite communication. Telexistence on a ship is a concept of maneuvering between land and ship with at least two mariners such as navigation officer and helmsman. Navigation officer works on ship as usual and helmsman supports ship from land. In this paper, remote maneuvering system was developed as the first step of telexistence on a ship. For evaluating the effectiveness, ship experiment was carried out. From the result, navigation officer and helmsman could alter ship's course to 20 degrees within 60 seconds and less than 5% overshoot in the proposed remote maneuvering system.

1 INTRODUCTION

Ship supports human life by transporting many things such as product, passenger, and energy resource. Shipping industry is very important and close to our life. However, the shipping industry has many problems such as reduction of mariners, aging mariners officer, and labor expenses (Fukuto et al. 2007, Nishii et al. 2014).

As previous study, One Person Bridge Operation had been developed for improving the problems. One Person Bridge Operation had been aimed at controlling ship by one mariner (Imazu et al. 2010). However, One Person Bridge Operation remained technological problems and one man error (Shimono et al. 2009, Shimono et al. 2010, Yabuki et al. 2016). On the other hand, recently, information about unmanned ship has been announced by Rolls-Royce (Rolls-Royce 2016). However, unmanned ship also

has problems such as law, insurance, autopilot, and shipbuilding cost. Therefore, it takes more time to build unmanned ship.

In this paper, the concept of telexistence (Tachi 2009, Tachi et al. 2010, Tachi et al. 2011) is adapted to ship from another aspect to solve the problems of shipping industry. The concept of telexistence on a ship is to maneuver a ship between land and ship by at least two mariners such as navigation officer and helmsman (Sasaki et al. 2016). Navigation officer works on a ship as usual, and helmsman supports ship from land. Therefore, the telexistence on a ship is one of the solution for reduction of mariners, aging of mariners, and labor expenses. Moreover, the problems of One Person Bridge Operation and unmanned ship such as one man error, technological improvement might be solved. Therefore, as the first step of telexistence on a ship, remote maneuvering system considering communication delay was

developed by using satellite communication. Then, ship experiment was carried out for evaluating the effectiveness of the proposed remote maneuvering system. As the result, total time of 20 degrees altering course was within 60 seconds in the less than 5% overshoot in the proposed remote maneuvering system.

In this paper, first, ordinary maneuvering and remote maneuvering is described in Section 2 and Section 3. In remote maneuvering, communication delay influences maneuvering a ship. Therefore, remote maneuvering system considering communication delay is proposed in Section 4. Then the effectiveness of the proposed remote maneuvering system is indicated from experimental result in Section 5. Finally, future work for telepresence on a ship is indicated as consideration in Section 6, and conclusion of this study is described in Section 7.

2 ORDINARY MANEUVERING

In ordinary maneuvering, navigation officer usually maneuvers a ship with helmsman (Ito et al. 2012). Navigation officer orders rudder angle, then helmsman steers following navigation officer's rudder order (Kobayashi et al. 2012). In this section, ordinary maneuvering by navigation officer and helmsman is described.

2.1 Ordinary Maneuvering

Sea transportation does not exist visible route like land transportation. Therefore, navigation officer uses nautical chart and writes down course line from present port to next port as objective course. Navigation officer maneuvers a ship while recognizing the course line, and then navigation officer sometime alters ship's course in the situation such as winding in cape and bays, and avoiding other ships (Hashimoto et al. 2012).

2.2 Altering course

In altering course, first, navigation officer orders rudder angle to helmsman. The helmsman repeats the rudder angle after understanding what navigation officer ordered. Then the helmsman steers while obeying the rudder order. After confirming ship's rudder angle, the helmsman reports to the navigation officer. For example, in the case of taking rudder of 10 degrees on the starboard side, navigation officer orders as "starboard 10" to helmsman. Next, the helmsman repeats "starboard 10" to the navigation officer, and then the helmsman steers of 10 degrees on the starboard side. Finally, after confirming rudder angle, the helmsman reports to the navigation officer as "starboard 10, sir" because ship's rudder does not change instantly. This procedure is shown in Figure 1. In Figure 1, t1 indicates time when navigation officer ordered, t2 indicates repeat time of ordered rudder angle, t3 indicates time when helmsman steers, and t4 indicates time when helmsman confirms ship's rudder angle and reports to navigation officer. For instance, when navigation officer alters ship's course

to 20 degrees from present course, the navigation officer orders rudder angle in several times to helmsman. First, navigation officer orders rudder angle as "starboard 10" for turning to the target course. Second, the navigation officer orders rudder angle as "midships" reducing rate of turn on starboard side at the time when the ship's course has been changed to 15 degrees. Then the navigation officer orders rudder angle as "port 5" for stopping turning on starboard side at the time of changing ship's heading to 19 degrees. Finally, the navigation officer orders rudder angle as "midships". In the altering, helmsman steers, repeats and reports while obeying rudder order from navigation officer.

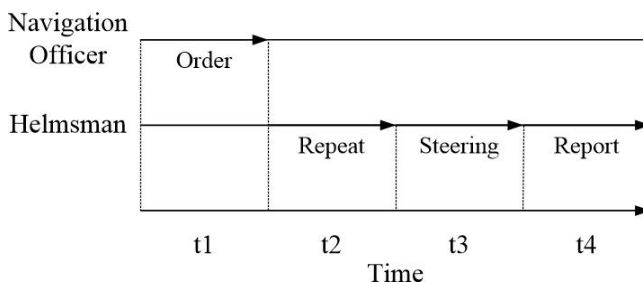


Figure 1. Procedure of ordinary maneuvering

3 REMOTE MANEUVERING

Ordinary maneuvering is conducted by navigation officer and helmsman as shown in section 2. Navigation officer orders rudder angle, and helmsman steers while obeying what navigation officer ordered. Navigation officer and helmsman also need to maneuver a ship as usual in remote maneuvering. Therefore, in remote maneuvering system, master system and slave system are set up in land and ship respectively, and connected by satellite communication as shown in Figure 2. Navigation officer orders rudder angle on the ship in the remote maneuvering. On the other hand, helmsman steers and checks the ship state on land by observing information which is sent from the slave system by satellite communication.

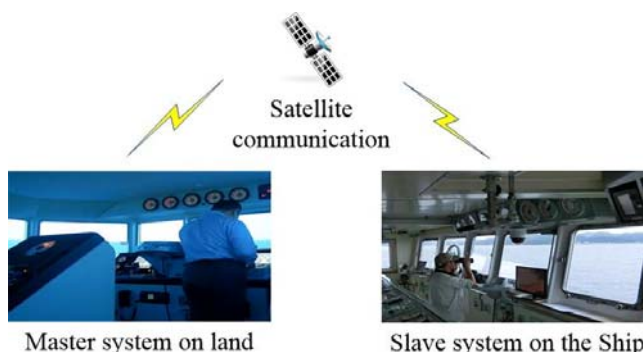


Figure 2. Satellite communication between land and ship

3.1 Configuration of Remote Maneuvering System

Configuration of remote maneuvering system is shown in Figure 3. The remote maneuvering system is consisted of master system on land and slave system

on a ship, and the master system and the slave system are connected by using satellite communication. The master system is consisted of handle for steering, microphone for voice input, speaker for voice output, and host PC for managing information. On the other hand, the slave system is consisted of microphone for voice input, speaker for voice output, client PC for managing information, and ship measurement control server for observing and controlling ship. For teleexistence on a ship, a robot is necessary as one of the slave system for supporting navigation officer and obtaining various information. However, remote maneuvering system is only consisted of host PC and client PC for communicating ship information because this paper is focused on maneuvering as the first step for teleexistence on a ship.

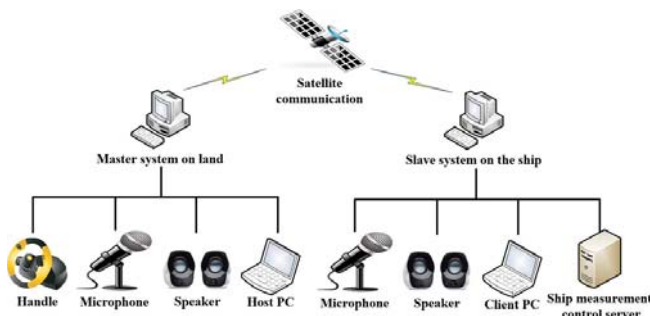


Figure 3. Configuration of remote maneuvering system

3.2 Altering Course in Remote Maneuvering System

Altering course in remote maneuvering system is basically same as the ordinary maneuvering in section 2. First, navigation officer orders rudder angle to slave system. The rudder order is recognized by voice recognition at slave system, and the rudder order is changed to simple code for reducing packet size. Then the code is sent to master system by using satellite communication. At the master system, the code is changed to voice output for helmsman. After helmsman recognized the rudder order of voice output, the helmsman repeats the rudder angle, steers, and reports to navigation officer. The signals of repeat, steering, and completion report are also sent from the master system to the slave system by using satellite communication. The procedure of remote maneuvering by navigation officer and helmsman is shown in Figure 4. In Figure 4, t_1 indicates time when navigation officer ordered, s_1 indicates time of voice recognition, satellite communication, and voice output from the slave system to the master system, t_2 indicates repeat time of ordered rudder angle, t_3 indicates time when helmsman steers after repeating rudder order, t_4 indicates time when helmsman confirms ship's rudder angle and reports to navigation officer, and s_2 indicates time of voice recognition, satellite communication, and voice output from the master system to the slave system. Here, t_1 , t_2 , t_3 , and t_4 are same process as ordinary maneuvering, and s_1 and s_2 are communication delay of remote maneuvering system. s_1 and s_2 might make navigation officer feel stress and might be difficult for navigation officer to maneuver a ship as usual.

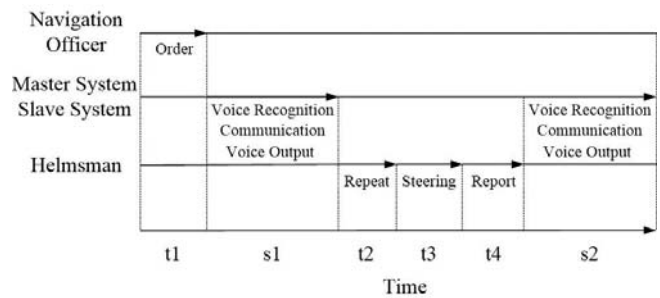


Figure 4. Procedure of remote maneuvering

4 REMOTE MANEUVERING SYSTEM CONSIDERING COMMUNICATION DELAY

In remote maneuvering system, communication delay of voice recognition, satellite communication, and voice output might influence maneuvering. Therefore, assistance functions are added to the remote maneuvering system for considering communication delay. In this section, the assistance functions of repeat, steering and completion report are described.

4.1 Overview of Assistance Function

In the remote maneuvering system, the system of the operation side is defined as master system. On the other hand, the system which is operated by master system is defined as slave system. Therefore, helmsman is regarded as master system side, and navigation officer is regarded as slave system side. However, rudder order is ordered by navigation officer at the slave system. Therefore, the problems of communication delay are also considered from the aspect of navigation officer.

The remote maneuvering system mainly has three problems. The first problem of communication delay is repeat from helmsman. The second problem is steering. Rudder angle from helmsman might be delay because of satellite communication. The third one is completion report from helmsman. In this study, assistance functions for repeat, steering, and completion report are added to the slave system for considering communication delay.

4.2 Assistance Function of Repeat

Navigation officer expects that the repeat from helmsman comes back instantly because navigation officer confirms that helmsman understood correctly. However, in the remote maneuvering system, communication delay which is voice recognition, satellite communication, and voice output, influences the repeat time. Therefore, assistance function of repeat is added to the slave system. The assistance function performs voice output of repeat when rudder order from navigation officer is recognized by voice recognition at the slave system. The details of the assistance function of repeat is indicated in Figure 5. In Figure 5, δ_0 indicates voice code of rudder order from navigation officer. Voice output of repeat is performed by voice code δ_0 at the slave system while sending voice code δ_0 to the master system.

Therefore, navigation officer can focus on maneuvering instead of waiting for repeat, and understanding that rudder order sends to helmsman correctly. However, navigation officer might make a mistake of rudder order to helmsman, or helmsman might make a mistake of repeat. In ordinary maneuvering, the mistakes are usually noticed and improved because navigation officer and helmsman point out the mistakes each other. Therefore, confirmation function is also added to the slave system as one of the assistance function of repeat. $\delta\gamma$ which is repeat of rudder order from helmsman is compared with voice order δ_o , and if $\delta\gamma$ and δ_o are different, voice output of confirmation is performed to navigation officer at the slave system.

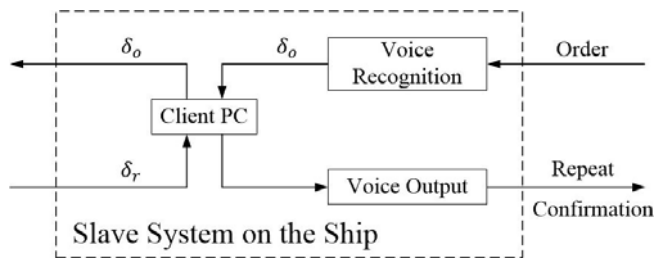


Figure 5. Assistance function of repeat

4.3 Assistance Function of Steering

Navigation officer requires that helmsman steers instantly while obeying rudder order. For example, if the response of steering is delayed, ship might face dangerous situation. However, in remote maneuvering system, after navigation officer orders rudder angle, ship's rudder does not move for a while because of communication delay. Therefore, assistance function of steering is added to the slave system. The assistance function of steering is performed while obeying rudder order from navigation officer. The detail of assistance function of steering is shown in Figure 6. Rudder order is recognized by voice recognition at the slave system, and the recognized rudder order is changed to rudder order value δ_{ov} . The rudder order value δ_{ov} is sent to ship measurement control server as control signal, and the ship's rudder is moved. In the meanwhile, rudder order δ_o is sent from the slave system to the master system. At the master system, the rudder order δ_o is changed as voice output for helmsman. Then, the helmsman steers at the master system, and the rudder angle δ is sent to the slave system via satellite communication. Finally, the rudder angle δ and rudder angle value δ_{ov} are compared at the slave system, and if the difference of δ and δ_{ov} is less than ± 1 , the rudder angle δ from the master system is input to ship measurement control server.

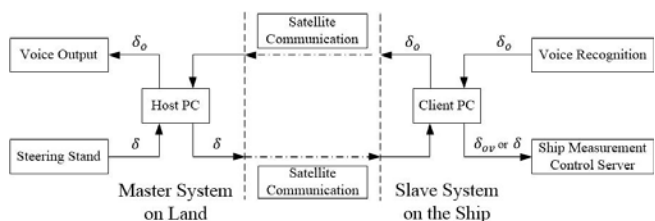


Figure 6. Assistance function of steering

4.4 Assistance Function of Completion Report

Navigation officer received completion report from helmsman after the helmsman finished steering. Then navigation officer prepares for next action of maneuvering. In the remote maneuvering system, communication delay of voice recognition, satellite communication, and voice output also influences completion report from helmsman. Therefore, the rudder angle δ and rudder angle value δ_{ov} are compared same as the assistance function of steering in the Section 4.3. Then if the difference of δ and δ_{ov} is less than ± 1 , voice of completion report is output.

5 EXPERIMENT

Ship experiment was carried out to clarify the effectiveness of proposed remote maneuvering system which assistance functions were added for considering communication delay.

5.1 Experiment Settings

Shioji Maru which is a training ship of Tokyo University of Marine Science and Technology was used for ship experiment. The principal dimension of Shioji Maru is shown in Table 1.

Table 1. Principal dimension of Shioji Maru

Length over all	49.9 [m]
Breadth	10.0 [m]
Draft	2.8 [m]
Gross tonnage	425.0 [ton]

In the ship experiment, measurement experiment of communication delay time and 20 degrees altering course in remote maneuvering were carried out. In the measurement experiment of communication delay time, each time of task in ordinary maneuvering and remote maneuvering was measured. On the other hand, in 20 degrees altering course, previous remote maneuvering system which assistance functions were not added, and proposed remote maneuvering system which assistance functions were added for considering communication delay were compared. In this ship experiment, for considering safety, master system was set to a room in the ship. The master system was connected to the slave system on the bridge by using satellite communication. In remote maneuvering system, navigation officer maneuvers a ship on the bridge by using the slave system, and helmsman steers at the room in the ship by using the master system.

5.2 Measurement Experiment of Communication Delay

For confirming communication delay, t_1 , t_2 , t_3 , and t_4 of ordinary maneuvering in Figure 1, and t_1 , t_2 , t_3 , and t_4 of remote maneuvering system in Figure 4 were measured. The measurement result in each time of ordinary maneuvering and remote maneuvering system is shown in Figure 8. In Figure 8, the horizontal axis indicates each task of ordinary

maneuvering and remote maneuvering, vertical axis indicates each time. Black bar chart indicates ordinary maneuvering, and slash bar chart indicates remote maneuvering. Communication delay s_1 and s_2 in remote maneuvering was 1557msec and 1482msec respectively. The result showed that navigation officer waits for response from helmsman about 1.5 seconds longer in remote maneuvering.

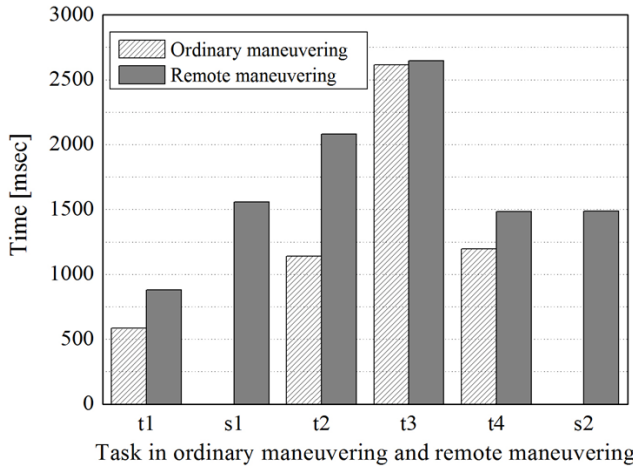


Figure 8. Time of each task in ordinary maneuvering and remote maneuvering

5.3 20 Degrees Altering Course in Remote Maneuvering

As the result of measurement experiment, the communication delay obviously influenced remote maneuvering. Therefore, for evaluating the effectiveness of assistance functions, comparative experiment was carried out by using previous remote maneuvering system which assistance functions are not added, and proposed remote maneuvering system which assistance functions are added for considering communication delay. As the comparative experiment, 20 degrees altering course was carried out. The result of previous remote maneuvering system was shown in Figure 9, and the result of proposed remote maneuvering system was shown in Figure 10.

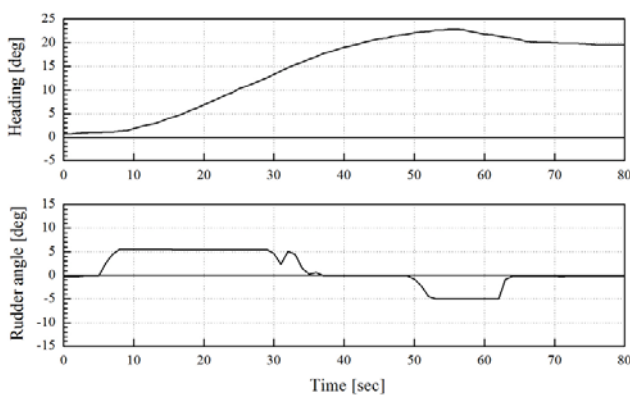


Figure 9. Remote maneuvering by previous system

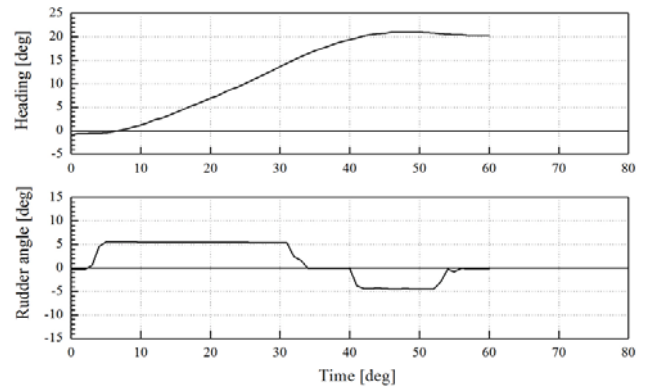


Figure 10. Remote maneuvering by proposed system

Figure 9 indicates the result of previous remote maneuvering system in 20 degrees altering course. On the other hand, Figure 10 indicates the result of proposed remote maneuvering system. In Figure 9 and Figure 10, horizontal axis indicates time, vertical axis of above graph indicates heading, and vertical axis of below graph indicates rudder angle. Starting point of horizontal axis is defined as the moment when navigation officer ordered rudder angle. In the previous remote maneuvering system of Figure 9, the total time of 20 degrees altering course was 80 seconds, and overshoot of heading was 2.8 degrees which is 14% in the target course 20 degrees. On the other hand, in the proposed remote maneuvering system in Figure 10, the total time of 20 degrees altering course was 60 seconds, and overshoot of heading was 1.0 degrees which is 5% in the target course 20 degrees. In addition, for comparing the difference of maneuvering, time series of rudder angle of previous remote maneuvering system and proposed remote maneuvering system is shown in Figure 11.

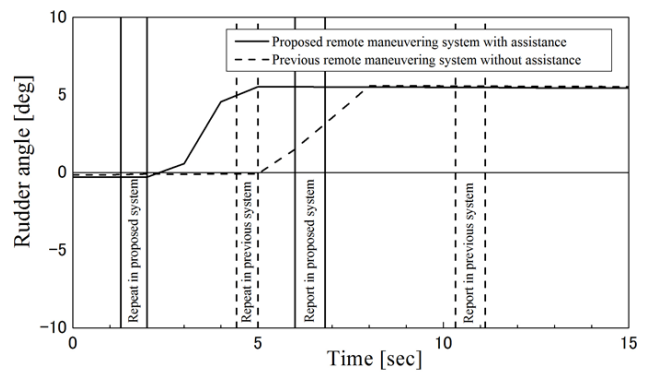


Figure 11. Rudder angle in comparative experiment

The dotted line indicates rudder angle of previous remote maneuvering system, and the solid line indicates rudder angle of proposed remote maneuvering system. Starting point of horizontal axis is defined as the moment when navigation officer ordered rudder angle. In Figure 11, the result of previous remote maneuvering system was 4.4 seconds for repeat, 5.0 seconds for steering, and 10.3 seconds for completion report. On the other hand, the result of proposed remote maneuvering system was 1.3 seconds for repeat, 2.0 seconds for steering, and 6.0 seconds for completion report.

6 CONSIDERATION

Remote maneuvering system considering communication delay was developed in this study. As the result of measurement experiment of communication delay, total time of communication delay s_1 and s_2 was about 3 seconds in remote maneuvering. In comparative experiment of 20 degrees altering course, the total time of proposed remote maneuvering system was shorter than total time of previous remote maneuvering system. From the experimental results, effectiveness of the proposed remote maneuvering system was indicated. However, from Figure 8, t_1 , t_2 , t_3 , and t_4 of remote maneuvering system were longer than t_1 , t_2 , t_3 , and t_4 of ordinary maneuvering.

The delay might show that navigation officer and helmsman feel stress by using remote maneuvering system. Therefore, the delay of t_1 , t_2 , t_3 , and t_4 will be focused when assistance functions will be developed in the future. In addition, navigation officer maneuvers a ship in many situations such as open sea, harbor, and berthing. Therefore, assistance functions are also necessary to expended to each situation because maneuvering method and nautical instrument were difference in each situation.

On the other hand, ship information service system was considered as the future work. In this study, maneuvering was focused. However, lookout is also important as another work of helmsman. Therefore, other ships information is also sent to slave system in the ship information serves system. Thus, the helmsman checked other ships, and if the helmsman found dangerous ship, the helmsman can report the ship to navigation officer who works on the ship via satellite communication. Therefore, the ship information service system will be useful for finding other ships on land, and helpful for navigation officer to find other ships in advance.

7 CONCLUSION

In this study, telexistence on a ship was developed. The concept of telexistence on a ship was to maneuver a ship by at least two mariners such as navigation officer and helmsman. As the first step of telexistence on a ship, remote maneuvering system between land and ship was developed by using satellite communication. In the remote maneuvering system, communication delay such as satellite communication and processing delay influenced maneuvering. Therefore, assistance functions of repeat, steering, completion report were added to remote maneuvering system for considering the communication delay. To evaluate the effectiveness of proposed remote maneuvering system, ship experiment was carried out. As the result of proposed remote maneuvering system, total time of 20 degrees altering course was shorter 20 seconds than the total time of previous remote maneuvering system which assistance functions are not added. In addition,

overshoot of the proposed remote maneuvering system was reduced from 14% to 5%. From the results, the effectiveness of the proposed remote maneuvering system was indicated. In the future, the remote maneuvering system will be adapted to various situations and ship information service system will be developed for lookout.

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