IADIS International Journal on Computer Science and Information Systems
Vol. 16, No. 2, pp. 77-89
ISSN: 1646-3692

DESIGN AND PROTOTYPING OF WEB-BASED SUPPORT FOR SHIP-HANDLING SYSTEM VIA MOBILE WIRELESS COMMUNICATION

Tsuyoshi Miyashita[1], Ryota Imai[1], Masaki Kondo[2] and Tadasuke Furuya[3]
[1]Graduate School of Marine Science and Technology, Tokyo University of Marine Science and Technology, 2-1-6, Etchujima, Koto-ku, Tokyo, Japan
[2]National Institute of Technology, Toba College, 1-1 Ikegamicho, Toba, Mie, Japan
[3]Tokyo University of Marine Science and Technology, 2-1-6, Etchujima, Koto-ku, Tokyo, Japan

ABSTRACT

Now, in Japan, the coastal shipping industry has problems reducing the seafarers and aging. The closed sea areas in central bays and ports in Japan are navigated by many ships. In these waters, an inexperienced ship operator may make a mistake in judgment due to extreme tension, which may cause a marine accident. The authors made a prototype to provide ship operators on board with maneuvering assistance from shore to solve the problems. We developed a prototype by using wireless and mobile communication, VPN, and web browser. We conducted an actual ship experiment in the natural sea as a verification, discussing its effectiveness. It was shown that maneuvering about the same level as onboard as possible. As a result, it was confirmed that this method could be effective by future improvements.

KEYWORDS

Ship Handling, Filed Work, Computer Application, Information Support

1. INTRODUCTION

Approximately 85% of the marine accidents of cargo ships in Japan were caused by human factors such as inadequate lookout and improper maneuvering (Japan Coast Guards, 2019 Status and Countermeasures for Marine Accidents, 2020). Also, 54% of accidents were attributable to human actions (European Maritime Safety Agency, Annual Overview of Marine Casualties and Incidents 2020, 2020), illustrating a similar trend in other parts of the world. In addition, the steady increase in the world's marine transport volume suggests that the number of seafarers worldwide will become tighter in the future.

Under these circumstances, the spread of Automatic Identification System (AIS) for tracking ships and Electronic Chart Display and Information System (ECDIS) for displaying nautical charts, as well as rapid advances in maritime broadband communication, IoT, AI, and big data processing technologies, especially in Europe, have stimulated efforts to realize autonomous ships. MUNIN (MUNIN, 2016) and AAWA (AAWA, 2016) have conducted conceptual studies mainly as part of an industry-academia-government collaboration project. At the same time, the primary corporate efforts toward practical application include SVAN (SVAN, 2018) by Rolls-Royce Commercial Marine (now Kongsberg Maritime), Yara International, and Yara Birkeland by Kongsberg.

In Japan, on the other hand, the Ministry of Land, Infrastructure, Transport and Tourism's roadmap for the commercialization of autonomous ships indicates that Phase II will proceed after 2020 (Ministry of Land, Infrastructure, Transport and Tourism, follow-up to June 3, 2016, report, 2018). A feature of Phase II autonomous ships is that, while the final decision-maker will still be the ship's crew, they will be more closely linked to shore and will be able to directly operate onboard equipment as well as monitor it from shore. In addition, the onboard computer and network environments will be further enhanced and integrated. The amount of data collected by various sensors is expected to be greater than that of Phase I autonomous ships.

The closed waters of Tokyo Bay and other significant bays and harbors in Japan are navigated by many ships. It is a crucial traffic area where incoming and outgoing vessels and shipping routes intersect. In addition to the complex submarine topography and narrow waters, many fishing grounds are in the bay. These waters can quickly become a source of maritime accidents for inexperienced navigators due to maneuvering errors and carelessness caused by tension and stress. Navigators are trained over a long period through joint work and instruction on board with knowledgeable and experienced navigators. However, coastal shipping faces a severe problem of an aging seafarer population and a shortage of seafarers. They do not have as much time to work together and teach as before. To ensure navigation safety and provide a place to gain experience, the authors are researching ways an older but more experienced person can assist an inexperienced navigator onboard a ship from shore.

There has been much research on autonomous ships and remote control of ships from shore, as described above. The goal of these studies is to develop autonomous ocean-going vessels. While this is ideal, there are problems with the cost of construction, modification, and operation. For example, even though AIS is becoming more and more popular, many small vessels are not required to be equipped with AIS. Satellite communication, which can cover the entire ocean, has the problem of high communication costs. Under these circumstances, rather than aiming for autonomous ships, it is more practical and effective to provide ship handling support from the shore for safe navigation while constantly exchanging and providing information through two-way communication with vessels within the range of mobile communication.

LTE and 3G wireless communications are available in coastal waters within a few kilometers of land. The signal strength and status of mobile communications in Tokyo Bay have been continuously surveyed (Ohshima, 2015, Kuroda, 2020). From the results of these surveys, it has been confirmed that there are areas where high-quality communications are not available. It is currently challenging to ensure stable and sufficient communication speed at sea. Since the final decision-maker is the navigator on board the ship, if the disruption of mobile communications is temporary, the navigator on board can navigate the vessel with authority to steer. We believe that a work-around is possible, in which the ship's navigation rights are transferred to shore when communications are restored.

This study designed and fabricated a prototype system that can transmit ship handling assistance and steering signals from shore. Mobile data communication is used for communication. Navigational information, engine information, and ship circumference images are displayed on a web browser. Maneuvering instructions are also given via the web browser. The system enables ship handling support with the Internet and a Web browser without being restricted to a specific location or device. In addition, we verified the remote control of the rudder (heading) and CPP (speed and velocity) on an actual ship sailing in Tokyo Bay and examined its effectiveness.

2. WEB-BASED SUPPORT SYSTEM FOR SHIP-HANDLING

We constructed our prototype system between the training ship "SHIOJI MARU" owned by the Faculty of Marine Engineering, Tokyo University of Marine Science and Technology, and the Number 3 Research Building on the Etchujima Campus of the same university and tried to display the voyage/engine data of SHIOJI MARU during the voyage and to realize remote ship handling support. This chapter describes the configuration of the prototype system.

Figure 1 shows the outline of the prototype system. The upper part of the figure is the SHIOJI MARU side, and the lower part is the land side. The data collection program of the experimental server of the prototype system (hereinafter referred to as the ship server) placed on SHIOJI MARU side in the figure collected AIS, GPS (Global Positioning System), ARPA (Automatic Radar Plotting Aids), voyage/engine data, etc., and sent them to the experimental building via WebSocket communication using mobile data communication. In addition, the image of the surroundings of the ship acquired from the camera, the image of radar echo, and the image of ECDIS were transmitted by HTTP streaming. A total of about 155 kbps data (Oishi, 2016), 144.6 kbps video data JPEG-compressed with a frame rate of about 15 fps and a resolution of 1500 x 300, 2.7 kbps voyage/engine data, and about 6.8 kbps AIS received data, were transmitted from the ship to land.

On the contrary, WebSocket communication was also used to send the hull control message for maneuvering from the experimental building to SHIOJI MARU. Mobile data communication in this case is consumer mobile data communication. The transmission speed is about 150 Mbps for downlink and 50 Mbps for uplink according to the catalog specifications, and there is no bandwidth guarantee due to the best effort method, communication restrictions, and communication regulations.

SHIOJI MARU is equipped with a measurement control server PC that aggregates the information measured by the navigation instrument and can control the rudder angle, CPP, and thruster (hereinafter referred to as a measurement control PC). By connecting this measurement control PC and the server of the prototype system via LAN and performing UDP communication, the state variables of the hull and the response values such as rudder and CPP required for maneuvering can be input to the ship server. Conversely, by sending a control message (64 bytes binary data) including the rudder angle and CPP control values from the ship server to the measurement control PC, the rudder of SHIOJI MARU can be controlled since the rudder angle and CPP can be input to the steering panel of the bridge via the measurement control PC.

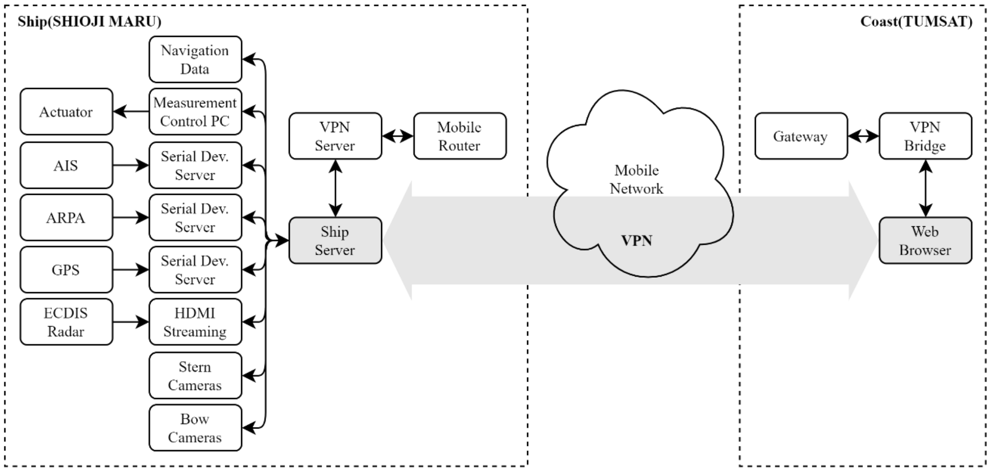

Figure 1. Configuration of remote ship handling support system

2.1 Interface

When maneuvering a ship, it is necessary to know the data on which the decision is based. If you are a ship officer, you will monitor various navigation instruments inside the bridge. Of these, data essential for remote monitoring and decision-making during maneuvering is selected and displayed. A general Web browser is used for the display. As one of the communication standards for computer networks called WebSocket (IETF RFC6455, The WebSocket Protocol, 2011), it was newly added in HTML5 (HTML Living Standard: 9.3 Web sockets, The WebSocket Protocol, 2019) and is supported mainly by recent Web browsers. By using this communication standard, two-way communication between the server and client is possible in real-time. This communication is conditional on use in a VPN environment to prevent attacks from the outside to intentionally damage the browser.

HTTP communication from the Web browser is used for the initial request processing. The subsequent processing is handed over by WebSocket and used for the sequential display of voyage/engine data. Currently, it is not necessary to reload the screen of the Web browser each time. In addition, there will be a screen where the land and ship can send canned messages to each other to let each other know what is going on, and a screen that displays a real-time graph of the round-trip delay time of the ping to keep track of the current communication status. Figure 2 shows an example of a web browser screen for remote control support. The top row is a browser screen displaying images of the ship's surroundings taken by a camera. The middle row's right is a browser screen displaying navigation and engine data, which collects information measured by various navigation devices. To the left of this is the browser screen used for ship handling instructions. For example, by selecting or inputting the rudder angle and CPP and clicking on the button on the browser, the control signals for rudder angle and CPP are sent to control the ship. Finally, the bottom row shows the ECDIS and radar screen streaming.

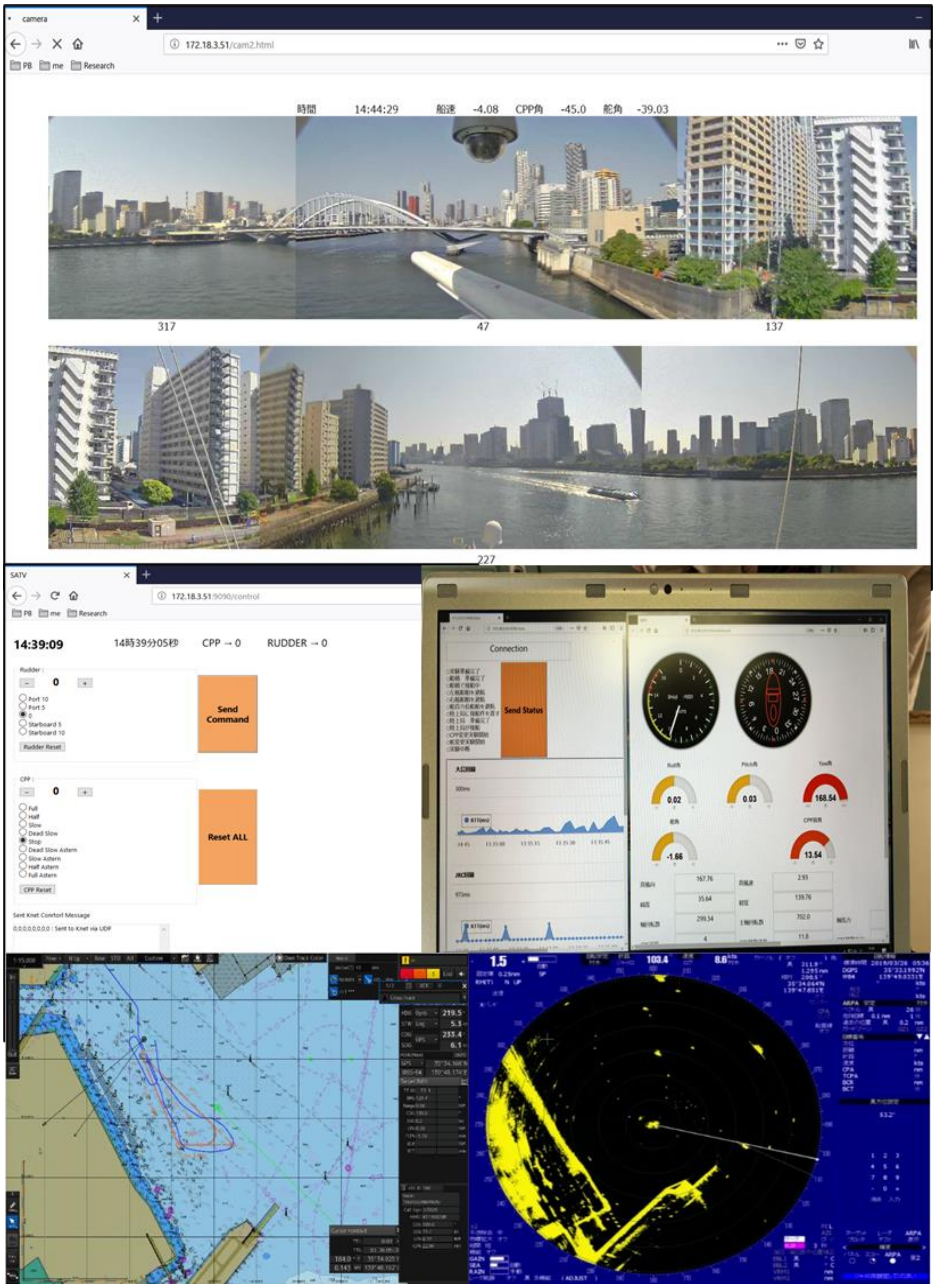

Figure 2. Example of a browser screen used during remote ship operation

On the actual bridge, the navigators must approach each instrument on board to obtain information. Sometimes, they observe the movements of other ships that they can watch windows. Therefore, multiple navigators are active on the bridge. However, consolidating information on one console makes it possible to navigate a ship with a few navigators. Building an interface with a computer screen with steering and watching the ship is necessary to transition from traditional operations less cumbersome for the navigator. We created and modified the interface based on interviews with experienced captains. In addition, in a real ship, the navigator can feel the effects of sway and wind. Therefore, we have created a visual interface that allows the navigator to understand the ship's state intuitively, which cannot be felt in remote areas.

2.2 Maneuvering

The proposed system enables remote maneuvering in an emergency. We are using bidirectional communication between the server and client made possible by WebSocket. The hull is controlled by sending a fixed-length binary message of 64 bytes, including control values such as rudder angle and CPP to the actuator command program of SHIOJI MARU measurement control PC from a Web browser. Communication to the actuator command program to control SHIOJI MARU hull is limited to 64 bytes fixed-length binary messages by UDP to a specific port according to the manufacturer's specifications.

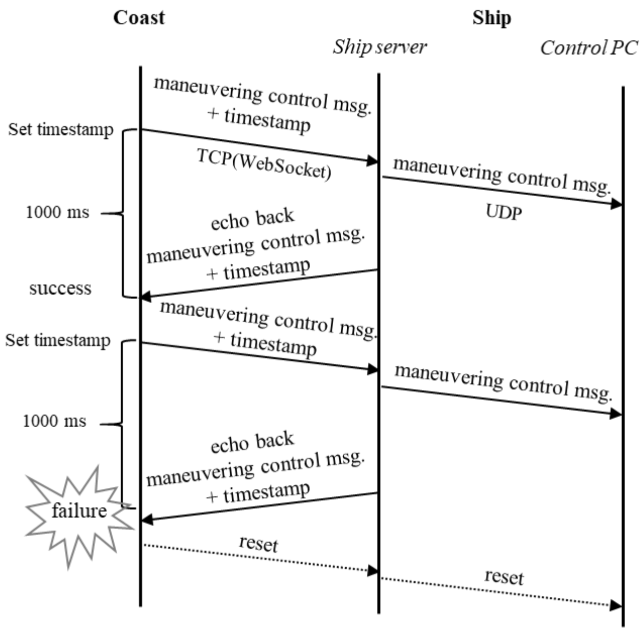

Figure 3. Configuration of remote ship handling support system

Communication interruption cannot be ignored when using mobile data communication at sea, depending on the ship's position. In particular, we must take care of a communication interruption during the transmission of a control signal. Therefore, keepalive messages are exchanged between ships and land. If land cannot receive the response within a certain period, it is judged that the communication is interrupted, and the reconnection process is performed.

Furthermore, to ensure that the control message reaches the experimental server at the application layer, the control is shown in Figure 3 is implemented. First, the control message is sent with a timestamp generated by the client's JavaScript. The experimental server returns the received control message and time stamp to the client as an ACK. If the client gets the ACK within 1 second, it considers it successful and prepares to send the following control message. If ACK is returned for more than 1 second, a control message with all zeros is sent, and the browser displays an alert. The ACK restriction is set to 1 second or less because we found in the experiment that the average round-trip delay time of the control message was about 0.3 seconds in Section 3.3.

2.3 Networking

Currently, it is common to use mobile networks on ships. Mobile networks can use them near the sea surface in Tokyo Bay (Ohshima, 2015). Also, seafarers are empirically familiar with where they can use communications. However, they are disconnected when no signal is available from the cellular base station. Satellite communications with comprehensive coverage are also becoming available at a flat rate and relatively low cost. Some merchant ships have installed VSAT (Very Small Aperture Terminal) that uses the Ku band. Even with VSAT, the connection is broken when passing under a bridge in the bay. The communication speed is limited compared to mobile networks, with a maximum of 1Mbps from land to ship and 512kbps from ship to land. It has become cheaper, but it is still more expensive than MVNO (Mobile Virtual Network Operator) SIM cards.

Therefore, we used mobile networks in our research. In addition, we bundled the network connections provided by multiple mobile network carriers to ensure bandwidth and redundancy. By doing this, communication is possible even outside of where we know empirically that a single connection is available. We can use multiple connections simultaneously by creating VPN tunnels and using BGP (Border Gateway Protocol) to distribute packets to these tunnels. The link is considered down if a tunnel breaks and communication continues using the living tunnel. We tested the prototypes of this method in Tokyo Bay (Sakurada, 2017).

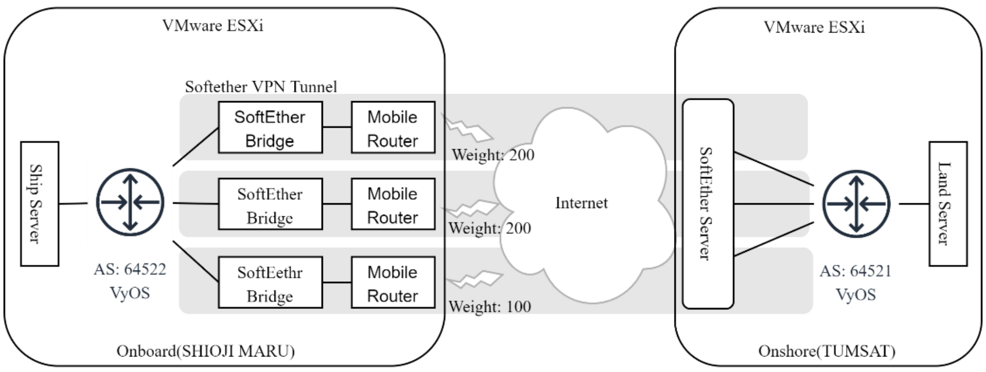

Figure 4. Network Configuration

There are two types of prototypes, one using VM and the other using Raspberry Pi3 Model B and LXC (Linux Containers). Figure 4 shows the network configuration for the VM type. A hypervisor is VMware ESXi. VPN Tunnel Software is SoftEther VPN. When the upstream line of the VPN bridge goes up, the VPN tunnel to the land-side VPN server is automatically created. VyOS is installed on each ship and land to distribute the packets to the tunnels. VyOS is a software router. BGP runs on the software routers and distributes packets to the tunnel to communicate with the opposite software router. In addition, each tunnel has weight, and the tunnel with the higher weight is used. If there are multiple tunnels with the same weight, packets are distributed to use more bandwidths. The lines with high communication costs or low speeds are not normally used. Those lines are used when all the main lines are down.

Oishi et al. (Oishi, 2016) adopted the network configuration shown in Figure 4 to transmit a total of about 155 kbps from SHIOJI MARU to TUMSAT. At this time, we used two lines of 300 kbps and one line of 500 kbps. However, this VM type configuration requires Linux Box for a general desktop with a hypervisor installed. General Linux PC is too large to be installed on a small ship. The durability of fans and power supplies is also an issue. Therefore, we replaced the Linux Box with a Raspberry Pi3 and the VM with an LXC. In the experiment, we obtained an average throughput of 10.9Mbps (min. 9.6Mbps, max. 12.0Mbps) when using two lines. In addition, we tested rerouting in the event of a communication breakdown, including VSAT in addition to mobile networks. The test shows that it takes 17 seconds to recover from all network disconnections, and it takes 5 seconds to transition to a tunnel with a different weight.

3. EXPERIMENT

In the system prototyped in this study, an actual ship experiment was conducted to examine the usefulness of remote control. The ship used for the experiment is the training ship "SHIOJI MARU" owned by the Faculty of Marine Engineering, Tokyo University of Marine Science and Technology. In this experiment, first, the left turn was performed by inputting the rudder angle by remote control, and the speed was increased by inputting CPP. It was confirmed whether the bow direction and the shipping speed changed according to the input. Next, the round-trip delay time of the ship handling control message between the ship server was measured from the Web browser between the ship and land. A seafarer's competency certificate holder carried out ship handling. Figure 5 shows the maneuvering scenery.

Figure 6 illustrates the track and route displayed on the ECDIS during remote maneuvering and the route with the course change points and course annotated. The counterclockwise experiment at point B in Figure 6 is described in Section 3.1, and the acceleration experiment by CPP from point A is described in Section 3.2.

Figure 5. Remote control scenery

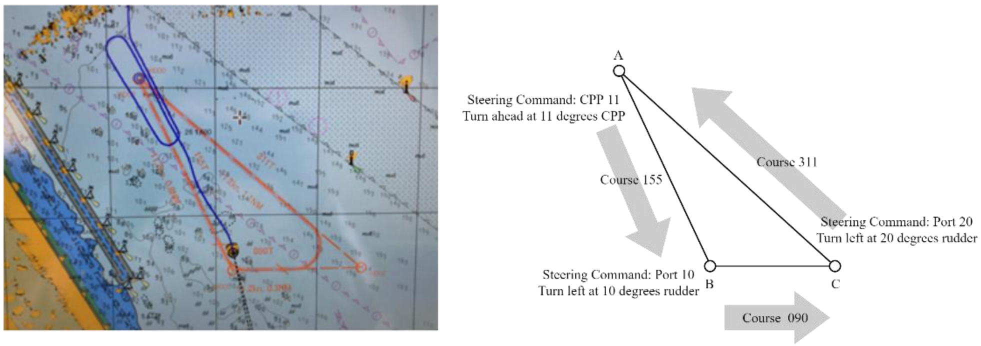

Figure 6. Routes / tracks by ECDIS and route illustrations

3.1 Left Rotation Experiment by Rudder Angle Input

In remote maneuvering using mobile data communication, a left rotation experiment using "Port 10" was conducted to examine whether it is possible to achieve the same level of rudder angle input to the steering panel inside the bridge. "Port 10" means to turn the rudder by 10 degrees to the left. IMO (International Maritime Organization) recommend "standard helm commands" for steering. "Port 10" is one of the "standard helm commands." The results of turning left are shown in Figure 7. Figure 7 shows the relationship between the rudder angle and the bow direction according to the time series on the horizontal axis. The solid bathtub line indicates the rudder angle, and the dashed line that descends to the right shows the bow direction. It can be seen from the response value of the measurement control PC that the rudder is responding within

2 seconds after the control message is transmitted when turning counterclockwise. In addition, it can be said that the direction of the bow is changing without causing any delay in the change of course itself.

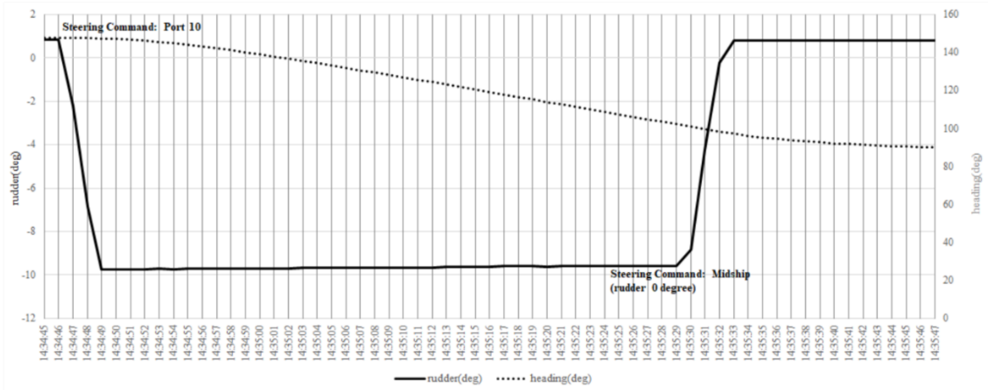

Figure 7. Rudder angle and bow direction

3.2 Acceleration Experiment by CPP Input

Next, a speed-up experiment with "CPP 11" was conducted in the manner of 3.1. CPP stands for controllable pitch propeller, and by changing the blade angle, the ship's speed can be increased or decreased. “CPP 11” means that the pitch angle of the screw propeller should be 11 degrees to increase the speed. The results are shown in Figure 8. Figure 8 shows the relationship between CPP and ship speed according to the time series on the horizontal axis. The solid line at the top shows the CPP, and the dashed line at the bottom shows the ship's speed.

As in 3.1, it can be seen from the response value of the measurement control PC that the CPP is responding within 2 seconds after sending the control message. It can also be seen that the shipping speed is also increasing in chronological order.

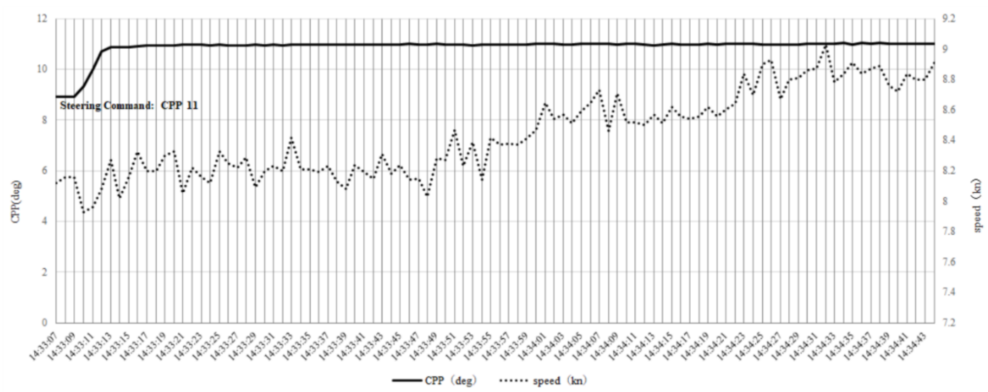

Figure 8. CPP and ship speed

3.3 Round-Trip Delay Time for Maneuvering Control Messages

To investigate the round-trip delay time of mobile data communication between SHIOJI MARU ship server from the Web browser, the round-trip delay time of the 72-bytes ship handling control message, including the time stamp at the time of transmission, as measured by the following procedure. First, the ship handling screen of the Web browser is operated to send a maneuvering control message with a rudder angle of 1 degree to the experiment server. This maneuver control message contains navigator clicked a timestamp of the time the web browser submit button. The ship server that received the ship handling control message extracts the 64 bytes required to control the hull by sending it to the measurement control PC from the received message and then sends it to the measurement control PC as binary data via UDP.

At the same time, the received message is sent back to the Web browser as it is. The Web browser records the time when the echo back from the experiment server is received as a time stamp. To determine that the echoed back maneuvering control message is the same as the one transmitted, it is determined whether or not the timestamps in the message are equal. In this experiment, the difference between the time recorded at the time of transmission and the time at which the Web browser received the echo back was measured as the round-trip delay time. iPerf3 is a benchmarking tool for round trips. Although we used iPerf3 for the measurements, we also used our measurement program to understand the round-trip delay time between the web browser and the server on the ship.

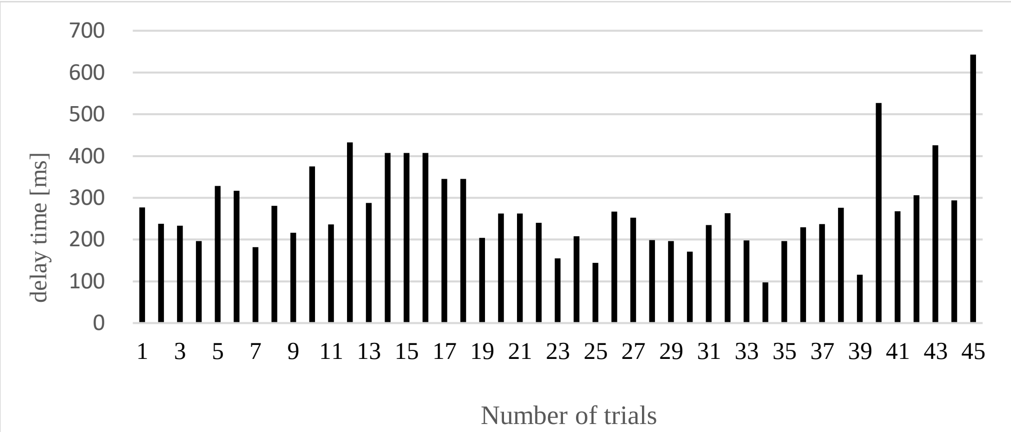

Figure 9. Round-trip delay time between ship and land

The measurement results are shown in Figure 8. The horizontal axis is the number of trials, and the vertical axis is the round-trip delay time. Around 21:00 on June 18, 2019, when trying to send and receive dummy messages 45 times between SHIOJI MARU and a web browser while anchored off Tateyama, the round-trip delay time was 0.3 seconds on average, 0.7 seconds maximum, and 0.1 seconds minimum.

4. CONCLUSION

In this research, we built a prototype system that enables advanced information sharing and ship handling support between ship and land from various locations using mobile data communication and general-purpose software such as Web browsers toward the practical application of autonomous ships. In addition, we conducted a field experiment to investigate the feasibility of providing ship handling support by issuing steering commands from the coast.

First, experienced captains who used this system evaluated it as a good interface for ship handling. They also believe that the ship operation using this interface is also good. The main functions that we specifically realized are shown below.

- A screen that allows non-follow-up steering (without using Helm)
- A screen to grasp the communication status
- Display of the bow direction together with the camera image

Next, from these experiments, the following main conclusions were obtained.

A) It is possible to transfer information necessary for navigation between land and sea using mobile data communication. However, the communication state may become unstable and interrupted due to the influence of other communications in the sea area. In the future, it is necessary to ensure good communication at all times through the spread of 5G communication and the installation of high-precision communication antennas.

B) The main navigational information necessary for ship operation collected at sea was generally reproduced on land.

C) The maneuvering control message sent from land can be received on board, and the response can be confirmed by the voyage information sent from the ship.

D) Real-time transmission of images by web cameras and radar is not possible at present because of the large data capacity. However, it was found that there was no significant problem in remote ship handling support even if images were transmitted at regular time intervals.

E) The transmission of navigational information about other ships, such as AIS, GPS and ECDIS/Radar Streaming, is good. The information displayed on the ship could be reproduced on land.

F) A left rotation experiment with rudder angle input and a speed-up experiment with CPP input were conducted by remote control, and the rudder and CPP responded within 2 seconds. Course change and speed increase can be controlled without any delay.

G) The possible effect of a delay of up to 2 seconds is when changing course; on the scale of SHOJI MARU, a course change of 10 degrees will lead to a delay in the decision to maneuver because of the fast-turning response. However, large angle course changes are not made in actual ship operations. However, large angle course changes are not made in actual ship operations, because a route with small course changes is selected. Therefore, a delay of 2 seconds is acceptable.

H) As a result of the measurement experiment of the round-trip delay time between the ship (ship server) and the land (Web browser), the average round-trip delay time by mobile data communication is 0.3 seconds. The Web browser is required to receive the arrival confirmation of the control message for maneuvering within 1 second, but since the ACK response can be received within the range, the effect on remote maneuvering is small.

The above shows the possibility of remote ship handling support using a web browser as an interface and mobile data communication between ship and shore. However, in this experiment, the rudder and CPP are mainly verified. In the future, it will be necessary to increase the number of functions to be verified in consultation with the training ship and evaluate its effectiveness.

As a future issue, adding the function to display the received AIS data on the browser can be considered. As an alternative, we are streaming ECDIS video, but we would like to eliminate this. Furthermore, AIS-equipped ship information will be superimposed and displayed on the voyage image displayed on the browser, and the display of AIS-non-equipped ships detected by image recognition will be examined in the future.

ACKNOWLEDGEMENT

We would like to express our gratitude to the crew members of SHIOJI MARU, who cooperated in the experiment in advancing this research.

REFERENCES

AAWA, 2016, Remote and Autonomous Ships The next steps, [online] Available at https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf [Accessed 25 Jun. 2021].

European Maritime Safety Agency, 2020. Annual Overview of Marine Casualties and Incidents, [online] Available at http://emsa.europa.eu/publications/reports/item/4266-annual-overview-of-marine-casualties-and-incidents-2020.html [Accessed 21 May. 2021].

HTML Living Standard: 9.3 Web sockets, 2019. The WebSocket Protocol, [online] Available at https://html.spec.whatwg.org/multipage/web-sockets.html#network [Accessed 21 May. 2021].

IETF RFC6455, 2011. The WebSocket Protocol, [online] Available at https://tools.ietf.org/html/rfc6455 [Accessed 21 May. 2021].

Japan Coast Guards, 2020. 2019 Status and Countermeasures for Marine Accidents, [online] Available at https://www6.kaiho.mlit.go.jp/info/keihatsu/20200511_state_measure01.pdf [Accessed 21 May. 2021]. (in Japanese)

Kuroda, H. et al, 2020, LTE Radio Field Intensity Investigation for Improving Multipath Communication at Sea. In The journal of Japan Institute of Navigation, Vol. 142, pp 67-78. (in Japanese)

Ministry of Land, Institute, Transport and Tourism, 2018. Initiatives to be Promoted for Deepening the Productivity Revolution in the Maritime Industry - Follow-up to the Report of June 3, 2016, [online] Available at https://www.mlit.go.jp/common/001237409.pdf [Accessed 21 May. 2021]. (in Japanese)

MUNIN Project, 2016, MUNIN Final Brochure, [online] Available at http://www.unmanned-ship.org/munin/wp-content/uploads/2016/02/MUNIN-final-brochure.pdf [Accessed 25 Jun. 2021].

Ohshima, K. et al, 2015, 3G Radio Field Intensity Measurement Experiment in Coastal Waters of Tokyo. In The journal of Japan Institute of Navigation, Vol. 136, pp 72-79. (in Japanese)

Oishi, H. et al, 2016. Navigational Data Display System between Ships and Land Using Mobile Data Communication. In The journal of Japan Institute of Navigation, Vol. 135, pp 159-165. (in Japanese)

Sakurada, T. et al, 2017. Design of a communication system between ship and land using multiple communication lines simultaneously and prototyping with small devices. In The journal of Japan Institute of Navigation, Vol. 137, pp 9-14. (in Japanese)

SVAN, 2018, Rolls-Royce and Finferries demonstrate world’s first Fully Autonomous Ferry, [online] Available at https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx [Accessed 25 Jun. 2021].