Analysis of Situation Awareness of Remote Ship Operator Using Simulator

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ABSTRACT

Remote ship operation has received substantial attention as an approach to operate autonomous ships in the future. It is crucial to adequately comprehend states of the ship and environment for remote ship operators to control ships from remote locations; however, remote ship operations are not well understood. This paper proposes a method to analyze the information related to situation awareness during remote ship operation via simulation-based experiments using a remote maneuvering simulator. The situation awareness during an emergency system breakdown is analyzed on a pilot basis using modified situation awareness global assessment technique (SAGAT), which observes behaviors and eye-gazes of remote operators and conducts interviews with subjects. Results include that the detailed information on situation awareness of remote ship operators.

1. Introduction

Autonomous ships have received significant attention in preventing maritime accidents caused by human errors and reducing the workload of onboard seafarers. There are different types of autonomous ships, including manned-autonomous ships with partially automated tasks, remote-controlled ships operated from remote locations, and unmanned-autonomous ships with fully automated operation. It is difficult to operate unmanned autonomous ships because legal systems have not been developed to operate the ship. Thus, there are still some phases to achieve before operating the ship, such as organizing the role of seafarers, including the method of situation awareness, designing automated tasks and remote-control schemes, performing risk assessments, and implementing demonstration experiments of automated maneuvering and remote operation on manned ships. Recently, there has been an increase in the studies related to them (Bolbot, 2022; Dittmann, 2021).

Regarding remote ship operation, several ideas have been proposed for remote monitoring and control. With reference to the practice on manned bridges, it is considered that there are two main methods of ship control for remote operations. First is to directly steer the ship. The second method is to specify a waypoint or course and have an autopilot or track control system to steer the ship. The control methods that specify the waypoints are considered to be combined with methods such as automatic voyage planning to create a set of waypoints, condition detection to locate conflicting ships, and collision avoidance by manipulating the waypoints based on the detection results. In such waypoint maneuvering, remote operators would be gradually freed from collecting and analyzing detailed and sequential information. Thence, in the future, it is assumed that the role of the remote operator will shift to monitor to ensure that the entire system is correctly operating and respond only when an emergency situation arises for some reason.

To realize such an operational concept in the future, it is necessary for remote operators to comprehend states of the own ship and environment that are usually analyzed by seafarers to control ships, which are known only empirically and are not well understood. In particular, during an emergency failure of a remote system, it is crucial to determine the states based on adequate information and analysis. To investigate the states, it is useful to analyze the situation awareness (SA) of the remote operator, which indicates how to collect information, discriminate significant information, and analyze future conditions. This study proposes a method to analyze the information related to SA during remote operation via simulation-based experiments using a remote maneuvering simulator. The experiment considers the events that occur when a remote operation system suffers an emergency breakdown during automatic navigation. As an initial analysis, SA of the remote operator in the emergency is analyzed using the situation awareness global assessment technique (SAGAT), which is modified in this study to observe the behaviors and eye-gazes of remote operators and to conduct interviews.

2. Method to Analyze Situation Awareness

SA is the first stage in dynamic decision-making process that comprises three stages, namely SA, decision, and performance. SA is further classified into three levels, which are perception of elements in the environment, comprehension of the situation and its significance, and projection of future status and action (Endsley, 1995). To make decisions in a dynamic environment, it is critically important to analyze the SA at each level.

SA has been focused on in various domains to analyze the abilities of operators or practitioners. This chapter briefly highlights some previous studies on the SA of control operators and the proposed method, which involves analyzing the SA of the operators.

2.1 Situation Awareness in Previous Studies

In the domain of Air Traffic Control (ATC), Sethumadhavan (2009) examined the SA abilities of experimental subjects in different automation levels of ATC via simulation-based experiments using SAGAT (Endsley, 1988), which is a global tool to assess the SA across all its elements based on the comprehensive assessment of operator SA requirements. Moreover, Karikawa et al. (2013) evaluated the process of visualization interface of ATC tasks through simulation-based experiments and showed effectivity that the process supports trainees comprehensively understand the practical knowledge of ATC officers. In vessel traffic control, Song et al. (2018, 2021) analyzed the SA of vessel traffic service operators experimentally using a simulator. An educational method was developed for training of inexperienced operators, and its effectivity was reported.

2.2 Method to Analyze Situation Awareness

In this study, the SA of remote operator is analyzed via simulation-based experiments using a simulator for remote maneuvering. Additionally, behaviors and eye-gazes are analyzed to combine with SA and interpret the information related to SA required for remote operation.

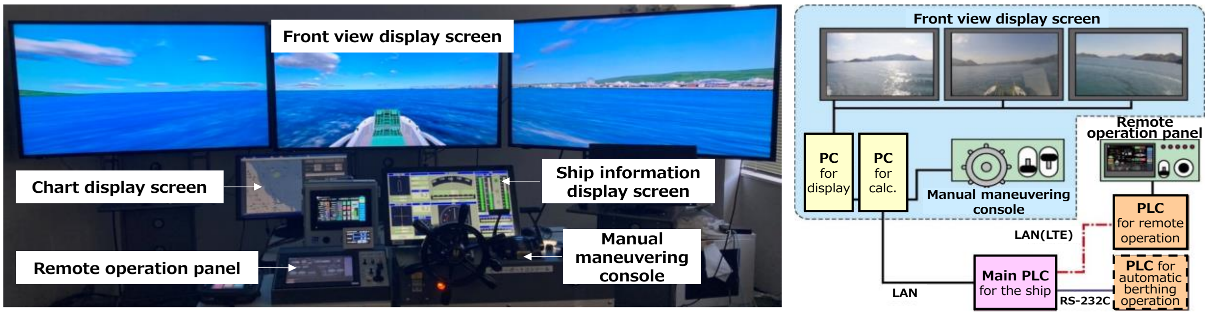
3. Remote Maneuvering Experiment Using Simulator

The simulation-based experiments are conducted using the remote maneuvering simulator owned by National Maritime Research Institute (NMRI).

3.1 Remote Maneuvering Simulator

3.1.1 Overview of Simulator

Figure 1 shows the (a) overview and (b) basic configuration of the remote maneuvering simulator. Two navigation modes of the simulator were utilized in the experiment. The first mode specifies a waypoint (WP) and employs an autopilot system to steer the ship, which is called the WP navigation mode. The WP navigation mode automatically controls and guides the rudder angle toward a WP by setting the WP of a specific location. The second mode involves steering the ship manually from a remote location, which is called the remote maneuvering mode. This mode is used as a measure such as in emergency where the ship has to evade something or when the remote operation systems breakdown. These modes have several systems to monitor the positional relationship relative to the environment using the front view display screen (Figure 1 (a)(b)), current locations of



(a) Overview (b) Basic configuration

Figure 1 Overview and basic configuration of the remote maneuvering simulator

Table 1 Information displayed on the screens (*Note*: SOG denotes speed over ground)

	Front view display screen	Chart display screen	Ship information display screen	Remote operation panel
Information content	Own ship: - Position to other ships or shore Other ships: - Visual SOG & heading (course) - Ship type	Own ship: - Location - Track Others: - Location of WP - Location of shore	Own ship: - SOG - Heading (course) - Rudder angle - Angular rate - Engine Wind: - Direction & speed	Own ship: - Engine RPM - Rudder angle - SOG - Heading - True direction - Course & distance to WP

the own ship and WP using the chart display screen (Figure 1 (a)), and current ship information of the own ship using the ship information display screen in large scale (Figure 1 (a)). Remote operators steer the own ship using the remote operation panel (Figure 1 (a)(b)) and use the joystick on the manual maneuvering console (Figure 1 (a)(b)) for manual operation. The detailed information displayed on each screen are shown in Table 1.

3.1.2 Experimental Ship

The target ship is a small experimental ship "*Shinpo*" that is managed by NMRI (Hirata et al., 2021). The length overall is 16.5 m, width is 4.6 m, and gross tonnage is 17 GT.

3.2 Method of Experiment

This section describes the experimental method, scenario, and subjects.

3.2.1 Method and Scenario of Experiment

In this study, the method to analyze SA was modified (hereinafter referred to as modified SAGAT). The original SAGAT is a method in which stops randomly occur during an experiment, an interview is conducted, and SA is analyzed based on the correct answer rate and answer timing during the interview. The change points in the modified SAGAT are to stop at predetermined points and conduct interviews about operator's thoughts.

The experimental procedure comprised five steps.

(1) The ship navigates automatically in WP navigation mode and it is monitored by a remote operator.

(2) A remote operation system suffers an emergency breakdown, and the front view display screen is not recovered. Immediately thereafter, the simulation suspends.

(3) After the interruption, the simulation resumes. The remote operator switches to remote maneuvering mode and tries to navigate the ship toward the next WP under the mode.

(4) Once the front view display screen is recovered and the ship gets back to the WP route, which connects WPs, the remote operator switches the mode to WP navigation mode and navigation continues under the mode.

(5) A remote operation system suffers an emergency breakdown again. Subsequently, the experiment is terminated.

Procedures (1)–(3) are called Event 1 and procedures (4)–(5) is called Event 2. The interviews were conducted twice when the first emergency breakdown in Event 1 (the step (2) above) and the second emergency breakdown in Event 2 (the step (5) above) occurred.

Figure 2 shows the schematic chart of the experimental scenario. In total, there are 11 WPs, and orange plots with the number indicate WP locations. The first emergency breakdown occurs at the location between WP 2 and WP 3, and the second emergency breakdown occurs at the location between WP 8 and WP 9.

3.2.2 Experimental Subjects

For an initial analysis based on a simple experiment, three experimental subjects from NMRI (Subject 1, 2 and 3) participated in the experiment with consent. Subject 1 is a certified First Grade Boat Operator, has little

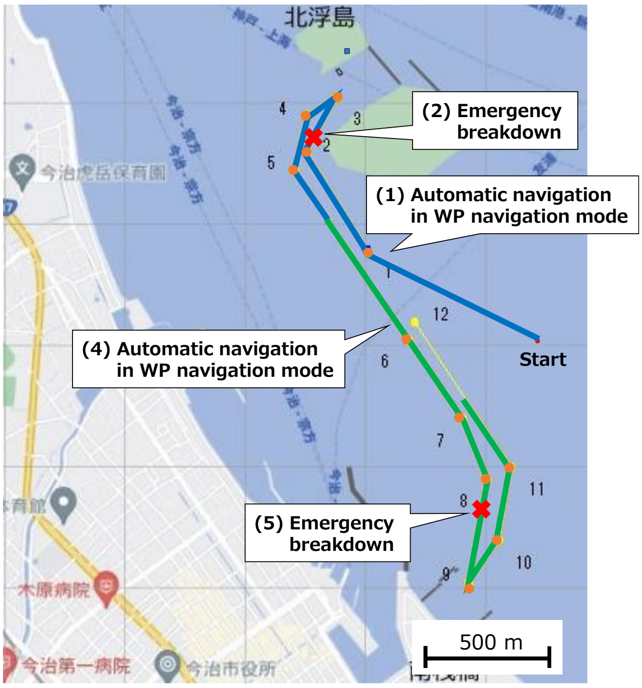


Figure 2　Schematic chart of the experimental scenario

experience navigating actual ships, and uses the simulator a few times monthly. Subject 2 has the license of the Third Grade Maritime Officer (Navigation), has experience navigating actual ships a dozen times, and has used the simulator hundreds of times. Subject 3 is a certified First Grade Boat Operator, has little experience navigating actual ships, and has used the simulator a few times.

3.3 Data Obtained in Experiment

The types of data and content of the interviews are given in this section.

3.3.1 Behavior and Eye-gaze Data

Figure 3 shows the system configuration to observe behaviors and eye-gazes of the subjects, which was developed based on Song et al. (2018, 2021). Three video cameras were installed to record the remote operation panel, front view display screen, and interview with the subjects. Recorded screen images and an eye-tracker screen were further recorded as one display screen image via the tetrameric composite device of the screen.

Subsequently, the behaviors and eye-gazes at operating unit were observed by the recorded data of the three video cameras and the eye-tracker and were arranged in chronological order in table. Table 2 shows an example of the result that is arranged in chronological order of the stat time in operating, which includes the start time, end time, and elapsed time, behavior, gaze, and information that is crucial at each operation.

3.3.2 Interview

As shown in Subsection 3.3.1 and Figure 3, the interviews of the three subjects were recorded using a camera. Table 3 shows the questions of the first and the second interviews, which focused on information required during an emergency. Subsequently, the first interview is divided into two views at this time, which are information related to perception and comprehension and projection.

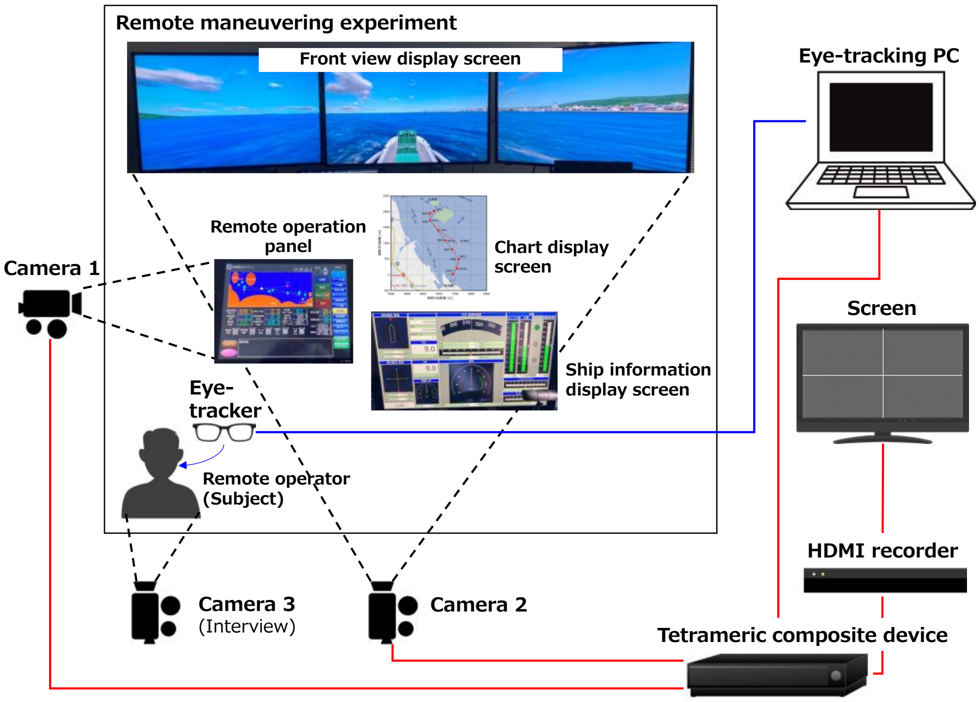


Figure 3 System configuration to observe behavior and eye-gaze

Table 2 Example of result arranged in chronological order

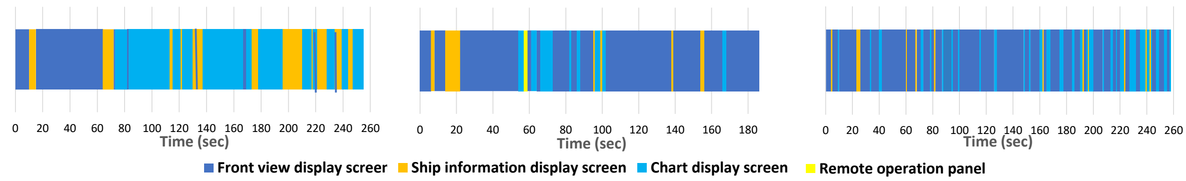
	Start time	End time	Elapsed time	Behavior	Gaze	Information
1	4:44:57	4:45:15	0:00:18	Monitored another ship that is crossing in front of the own ship during the ship goes astern.	The front view display screen.	Another ship at the front view display screen.
2	4:45:15	4:46:42	0:01:27	Checked the display screens alternately.	The chart display screen and ship information display screen.	Position to other ships at the chart display screen & course of own ship at ship information display screen
:	:	:	:	:	:	:

Table 3　Interview questions

	First Interview	Second Interview
Q1	<About ships around the own ship> Perception and comprehension: - What is the reason to pay attention to other ships? Which information was obtained? Projection: - What is the future action to evade other ships?	<About getting back in WP route> - Which information should be perceived and comprehended before breakdown? - Which information has priority during running remote maneuvering mode?
Q2	<About getting back in WP route in the next step> Perception and comprehension: - Which information is required when the own ship gets back in WP route at this condition? Projection: - What is a plan to get back into the WP route?	<About overall> - What is required to ensure safety if only remote maneuvering mode can be used in case that the front view display screen is not recovered?

Table 4　Rate of gaze time at the screens during the experiment

	Front view display screen	Chart display screen	Ship information display screen	Remote operation panel
S1-E1	30%	34%	32%	4%
S1-E2	26%	52%	22%	0%
S2-E1	92%	3%	3%	2%
S2-E2	79%	12%	8%	1%
S3-E1	72%	15%	13%	0%
S3-E2	73%	22%	5%	0%



(a) Subject 1　　(b) Subject 2　　(c) Subject 3

Figure 4　Change of behavior and eye-gaze during the experiment

4. Analysis Results and Discussions

The analysis results of behaviors, eye-gazes, and interviews describes in this chapter.

4.1 Analysis result of Behavior and Eye-gaze

Table 4 shows the rates of gaze time at the front view display screen, chart display screen, ship information display screen, and remote operation panel during the experiment. It should be noted that the result of a subject in an event is denoted by “S No.-E No.”; for example, the result of Subject 1 in Event 1 is denoted by S1-E1. The rate of gaze at the front view display screen is longest for Subjects 2 and 3, while it is also long to some extent for Subject 1. As shown in Table 1, the front view display screen shows the positions of other ships or shore, and visual information of other ships, such as SOG and heading. To check the front view display screen is a way to intuitively perceive and comprehend the changing states of the own ship and other ships. Thus, the information is of particular importance; however, it takes relatively long time to comprehend. Moreover, the rates of gaze at the chart display screen, which shows locations of the own ship, shore, and WP, and the ship information display screen, which shows accurate own condition values, such as SOG, heading, and rudder angle, are also long, particularly for Subject 1. The information from the front view display screen leads to intuitive comprehension of the states, and digital numerical information at the chart display screen and ship information display screen is useful to accurately comprehend the own states. Therefore, it is considered effective to check this information together with the front view. Meanwhile, all subjects hardly gazed at the remote operation panel. It is considered because the information on the panel, such as SOG, heading, and rudder angle is also displayed at the ship information display screen in large scale.

For a closer look at each Event, there is a difference between Events 1 and 2. All subjects checked the locations of the own ship, shore, and WP using the chart display screen more frequently in Event 2. Following

Table 5 Results of the interview

	1st Interview	2nd Interview
Q1	<About ships around the own ship> The information to pay attention to other ships: - Position and distance to other ships on or near WP route and their heading by the front view display screen. - Ship type, especially fishing boats or pleasure boats, on or near WP route by the front view display screen. - Heading by the front view display screen. The information to evade other ships: - SOG by the ship information display screen - Position where no ships exist by the front view display screen - Fishing gear at the front view display screen - Movements of other ships shown in the front view display screen	<About getting back in WP route> The information to perceive and comprehend before breakdown: - Current conditions of the own ship, which are location, SOG, and rudder angle using the three display screens. - Position, SOG, and heading of other ships shown in the front view display screen. - Position of shore and shallows shown in the front view display screen and chart display screen. - Position where no ships exist by the front view display screen. The priority information when running the remote maneuvering mode: - 1. Current conditions of the own ship. - 2. Position, SOG, and heading of other ships.
Q2	<About getting back in WP route in the next step> The information to evade the other ships: - Shore and shallows indicated in the front view display screen and chart display screen - Fishing gear and other ships indicated in the front view display screen	<About overall> The information to ensure safety in emergency: - Rudder angle is moved to zero, and navigation is stopped.

the first emergency breakdown, all subjects tended to care the current locations.

Figure 4 shows the change of behavior and eye-gaze for each subject in Event 2, which was analyzed based on the results arranged in chronological order shown in Table 2. As shown in Figure 4, all subjects do not check for any particular information; however, some information on the three display screens alternate.

4.2 Result of Interviews

Table 5 shows the result of the interviews of the three experimental subjects. It summarizes the result focusing on information related to the SA of each subject.

4.3 Discussions

Based on the above results, the information on the current states of the own ship and environment were obtained by the front view display screen. Real-time states of the own ship and position to other ships, shore, and WP are crucial as displayed by the front view display screen. This information, which can be obtained from the front view display screen, is required for remote operation. Moreover, the location of the own ship and position to shore or WP and the current conditions of the own ship are obtained by the chart display screen and ship information display screen, and they are crucial to comprehend the current states.

However, there are some improvements in the system configuration of the simulator. The information is scattered across the three display screens, and thus it is not easy to obtain the information. As shown in Figure 1 (a), the ship information display screen is arranged in front of the rudder that is the remote operator’s place; however, the chart display screen is a little far from the remote operator. It is better to arrange the chart display screen next to the ship information display screen to easily check the both display screens; for example, the right side of the ship information display screen. Moreover, it is difficult to perceive and comprehend the information of other ships behind the own ship because the display screen in this configuration does not provide the back view. To improve this drawback, the information, including the back view is displayed compactly.

Furthermore, there are some answers to the interviews about the rudder angle and joystick operation. It is likely that operating the joystick is difficult in an environment with little physical feedback, and it would require familiarizing with adjusting the rudder angle. Steering wheel may be easier. Thus, the system needs some improvements in the future.

5. Conclusions

To realize that remote operators control ships in the future, a method to analyze the information related to

SA during remote ship operation via simulation-based experiments using a remote maneuvering simulator is proposed to comprehend information that is usually collected and analyzed by seafarers during navigation. The information in an emergency was obtained using modified SAGAT, and then the behaviors, eye-gazes, and responses of the interviews with remote operators was analyzed. Consequently, the information on current states of the own ship and environment obtained by the front view display screen is crucial during remote operation. Furthermore, several system improvements are shown to realize remote ship operation in the future.

In the future, we would like to conduct further experiments using this method to investigate in detail the information required for remote ship operation.

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