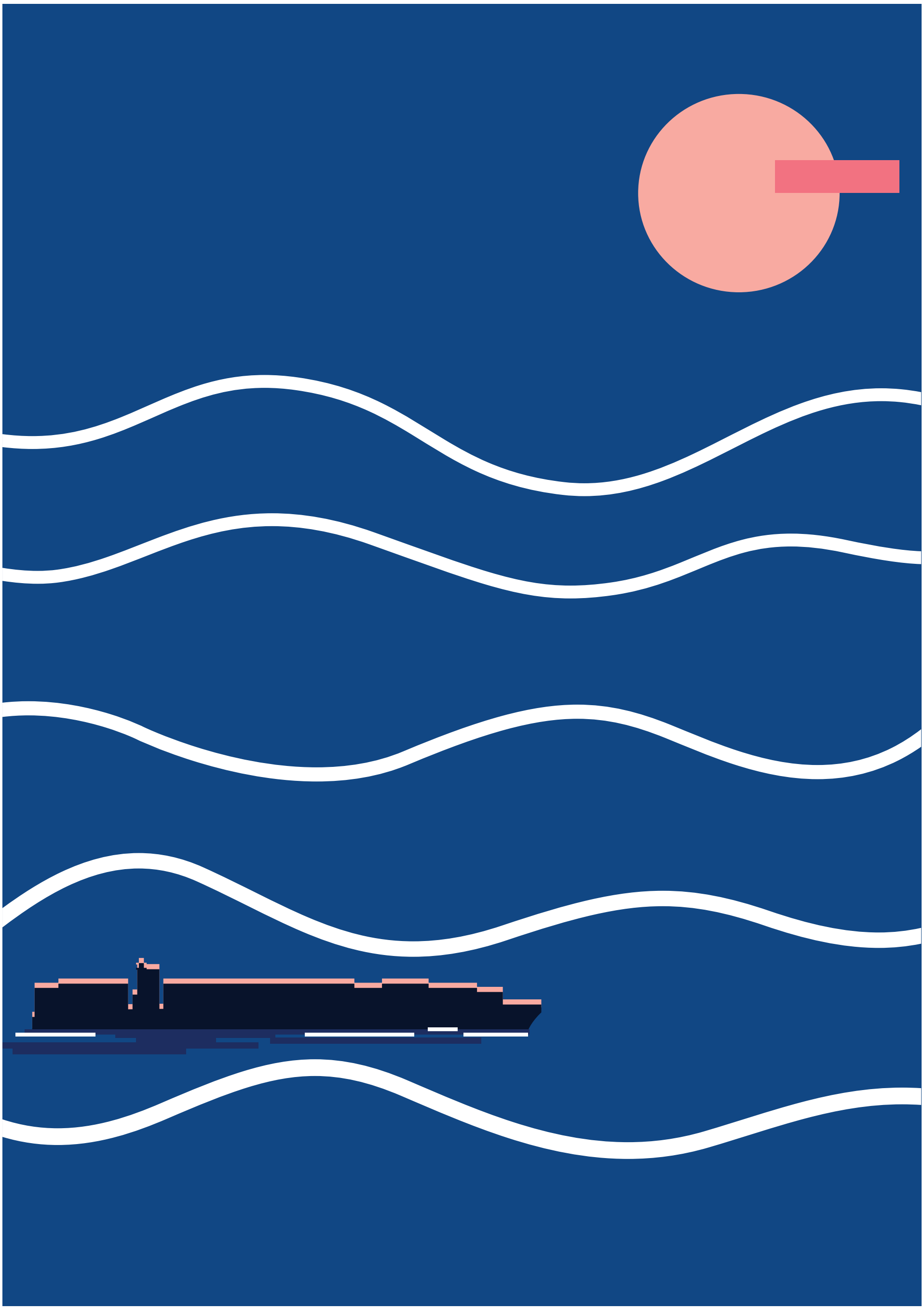
Sailing with a Ghost Ship

Design Guidelines for Developing Supervisory Control Interfaces for the Semi-Autonomous Cargo Vessel System



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Abstract

Rolls-Royce Marine is currently developing a semi-autonomous cargo vessel. The semi-autonomous cargo ship operation is a supervisory control task, in which the human operator is receiving information from a remote semi-autonomous vessel and instructing it through supervisory control interfaces. Thus, it is necessary to have supervisory control interfaces to carry the operation. But, the design guidelines for the interfaces are unclear, because of the lack of semi-autonomous cargo ships.

The thesis presents design guidelines for developing supervisory control interfaces for the semi-autonomous cargo vessel. The research question answered in this thesis is: "How to design a supervisory control interface for remote semi-autonomous cargo vessel system to enable intuitive and precise instruction of the course plan?" The author answers the question through a research and design process that consists of the problem and solution spaces.

The problem space suggests design requirements through a literature review and experts interviews. The literature review gives contextual and theoretical knowledge to design supervisory control interfaces. The expert interviews with video gamers and autonomous ship experts present potential user needs and design considerations. The findings from the problem space combine and formulate design requirements.

The solution space ideates and prototypes a supervisory control interface prototype by applying the design requirements. The prototype has been evaluated in usability tests with sailors and autonomous ship expert. The findings from the usability tests are linked to the design requirements to evaluate how the designed solution fulfils design requirements.

The thesis contributes to the design of semi-autonomous cargo vessel supervisory control interfaces by answering to the research question. In the conclusion part, the author answer to the research question by suggesting three design themes, which are synthetics of the design requirements and analysis. The design themes are: providing situation awareness, intuitive manipulation, and collaborative control.

With these design themes designers will be able to develop supervisory control interfaces, which present intuitive and precise course planning capability to the operators. At the same time, the findings of the thesis will provide several directions for further research, such as researching an unmanned surface vehicle supervisory control interface.

Keywords: Supervisory control interface, Autonomous surface vehicle (ASV), Human-automation interaction, User-interface design, Co-design, Prototyping

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Helsinki, 16th May 2017,
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Introduction

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Introduction

1. Introduction

Recently, the marine industries have shown an increased interest in developing an autonomous cargo vessel. And a number of companies and research organisations around the world are trying to make the idea into reality. Rolls-Royce Marine, one of the leading firms of this inevitable change in sea freight industry, also doing research and development on autonomous ship technology.

The ultimate goal of the company is to bring the vision of the robotic vessel to the real world. However, before the day of unmanned and fully autonomous shipping comes, we will encounter with the semi-autonomous ships, which are remotely monitored and controlled by the human operators at the shore remote operation centre. Rolls-Royce Marine predicts to see such semi-autonomous ships on the high seas by 2030.

Development of the semi-autonomous vessel requires designing new kinds of tools, work roles, and environments. And, there is a need for specially designed supervisory control interfaces for semi-autonomous cargo ship operation. Because of the nature of semi-autonomous cargo ship operation, conventional monitor and control methods might not be applicable anymore. But, the design guidelines for the interfaces is unclear, since there is no commercially available semi-autonomous vessel and its operator.

Through the research and design process, the author will suggest a semi-autonomous ship supervisory control interface design concept, which could show design directions for further development.

1.1 Background

We are living in the constantly evolving world where the autonomous vehicles become commonplace. The rapid development of sensor technology, artificial intelligence, and communication solution made this technological advance happen. And soon we will see the autonomous cargo ships on the waterways around the world.

The unmanned autonomous vessels bring several benefits to the freight shipping. With having no crews on-board and crew supporting system, for example, sewage, air conditioning, and electricity, the vessels could have improved fuel efficiency, carry more cargo, and increase revenues (Wahlström *et al.*, 2015). Also, the unmanned ship could slow down speed and save fuel while having a long-distance operation (Rødseth *et al.*, 2013). However, in the beginning, the autonomous vessels might still have a minimum number of crews on-board.

Before we encounter the fully autonomous vessels on the sea, transient type of ships will appear, which are remotely controlled and monitored semi-autonomous cargo ships. The remotely operated semi-autonomous ships have their own benefits. Such a semi-autonomous ships are tele-operated by the remote operator ashore; harms from the sea could be removed (Manley, 2008). Also, the remote operators will not have physical damage or seasickness anymore (Wahlström *et al.*, 2015).

Although the remote operators of the semi-autonomous ship would not directly see the vessel, they will monitor the sailing and voyage of the vessel using the network connection (Wahlström *et al.*, 2015). Specifically, the human operator at the remote operation centre will monitor the semi-autonomous vessel through the monitor interface, which is connected to the ship by means of satellite, 4G or other network connections. The remote operator will receive and utilise series of information from the ship includes video feeds, vessel speed, rudder angle, position, and rate of turn to perceive the state of the ship and the environment around (Wahlström *et al.*, 2015).

In an ordinary situation, the semi-autonomous ship has to autonomously undertake the operation without human supervision to make sure safe operation when the connection is lost or is limited, and to lower the workload on the operator (Rødseth *et al.*, 2013). The autonomous ship controller on-board will take control over the vessel, and the human operator will cooperate with it (Rødseth *et al.*, 2013).

However, safety critical or complicated operations need to be performed by the human operator with remote control (Rødseth *et al*., 2013). Thus, the remote operator should be able to take over control at any time, whenever the manual control overrides autonomous control is required (Rødseth *et al*., 2013). Because of the demands for manual remote control, it is necessary to have a control interface at the remote operation centre.

Porathe *et al*. (2014) identified three levels of control for autonomous vessels including:

a) Indirect control - the operator is updating the plan for journey while passaging,
b) Direct control - the operator is instructing specific manoeuvres to the vessel,
c) Situation handling - the operator is controlling rudder and thruster directly.

1.2 Framing of the Project

The autonomous vessel that Rolls-Royce is currently developing is a semi-autonomous cargo vessel, which still requires human supervision. And, it is necessary to have supervisory control interfaces include monitor interface and control interface at the remote operation centre to monitoring and controlling the voyage of the semi-autonomous vessel from a distance.

The author of this thesis assumes that "Dedicated supervisory control interface for semi-autonomous cargo ship system could support the human operator to effectively monitoring and controlling the vessel in order to accomplish the mission". Through the project, the writer will research and design a supervisory control interface for the semi-autonomous cargo ship system to establish directions for further development.

The project aims to design a supervisory control interface for direct control level within "the levels of control for autonomous vessels" identified by Porathe *et al*. (2014).

The author will review works of literature to acquire contextual and theoretical background knowledge in order to understand requirements to design a supervisory control interface. The review investigates two study areas, which are supervisory control of the autonomous vehicle and supervisory control interface design for the autonomous vehicle.

To design a successful user interface it is crucial to understand the users of the particular system and their interaction with the system. Thus, the writer will conduct series of interviews with participants who are using human-computer interfaces. At the same time, the author will interview some remote autonomous ship experts.

However, there is no commercial autonomous cargo shipping yet (Wahlström *et al*., 2015). And, that makes it harder to involve experienced remote operator of the semi-autonomous cargo ship system to the study. The author found similarities between supervisory ship controlling and video gaming. In both activities, the operators or gamers are monitoring and controlling object through monitor and control interfaces without actual interaction with the physical object or environment. Hence, in this thesis, the writer will include video gamers as participants together with remote autonomous ship experts.

Findings from the literature review and expert interviews later form a set of design requirements that will be employed to ideate solutions and guide following steps of the design process. Prototyping will realise ideated solutions and subsequently tested for evaluation. In the end, feedbacks from the evaluation stage will be discussed with other findings from the project to show conclusion.

1.3 Thesis Structure

The thesis structure roughly follows the double diamond model of Design Council (2015). The research and design part is consists of two spaces, which are the problem space and the solution space and each space forms a diamond (Figure 1). In the beginning of the problem space the research scope become larger with the progress of the literature review and the expert interviews. In the later part the design requirements will be generated by analysing findings from the research. Then in the first part of the solution space the author will diverge ideas from the design requirements. A design concept will be generated based on the ideas created and realised by prototyping. Finally the author will evaluate prototype by conducting user test.

The thesis is composed of four major parts includes:
a) The introduction,
b) The problem space,
c) The solution space,
d) The conclusion.

1.4 Research Question

The purpose of this thesis is to establish directions for the design of supervisory control interface for semi-autonomous cargo ship system. Especially the author focuses on designing a supervisory control interface for direct control level. The idea behind the topic is to achieve an intuitive and precise instruction of the course plan to the remote semi-autonomous vessel through designing a dedicated supervisory control interface, which could support the remote operator and automation to accomplish successful sea freight operation.

The main research question of the thesis is as follows:
"How to design a supervisory control interface for remote semi-autonomous cargo vessel system to enable intuitive and precise instruction of the course plan?"

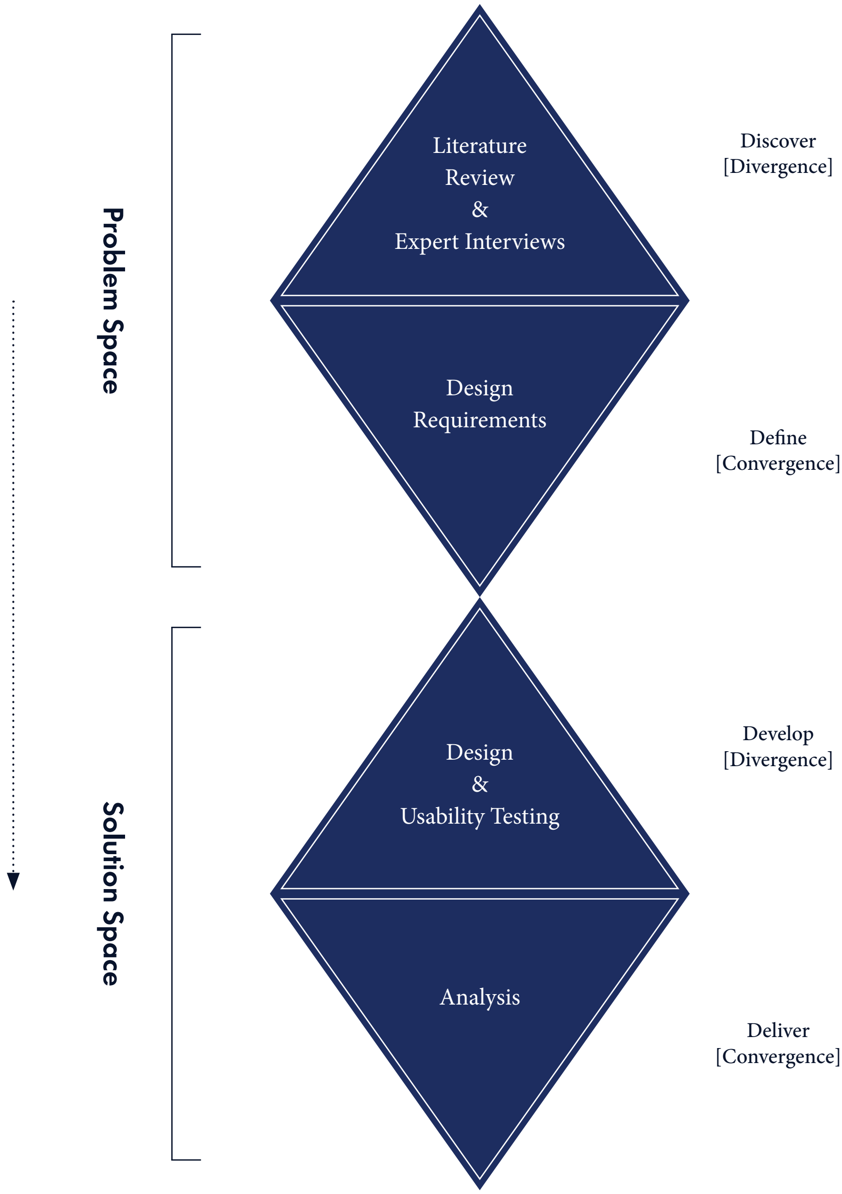

Figure 1. Thesis Structure

Problem Space

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Problem Space

2.1 Literature Review

In this chapter the author of the thesis reviews series of articles related to the supervisory control of the autonomous vehicle and the supervisory control interface design for the autonomous vehicle. The whole chapter is divided into eight sub-chapters, which are the supervisory control tasks, the human-automation interaction, the situation awareness, the trust in automation, the level of automation, the general supervisory control interface design, the control interface design, and the monitor interface design respectively.

2.1.1 Supervisory Control of the Semi-Autonomous Vehicle

2.1.1.1 Supervisory Control Tasks

Sheridan (2002) defined the supervisory control as "one or more human operators are intermittently programming and continually receiving information from a computer that itself closes an autonomous control loop through artificial effectors and sensors to the controlled process or task environment". By analogy with the definition, the remote semi-autonomous cargo ship operation is a task where the human operator is instructing and receiving information from an autonomous vessel, which means that the remote semi-autonomous cargo ship operation is also a supervisory control task.

As stated by Sheridan (2002), in the supervisory control tasks, the human operators take series of responsibilities including:

a) Planning the process before the autonomous system is activated,
b) Teaching the autonomous system to operate in a specific way,
c) Monitoring the autonomous system to make sure it performs as instructed,
d) Intervening if the autonomous action has to be corrected or adjusted,
e) Learning from the operation outcomes and the performance of the autonomous system to make better planning for later tasks.

The automation enhances the performance of the operator in the navigation-related tasks (Wang *et al.*, 2009). The performance could be improved by intelligent collaboration between the human and the automation (Chen *et al.*, 2011). However, the introduction of automation in the remote control operation brings a set of issues to the operator. For example, when the remote operator is supervisory controlling the semi-autonomous cargo ship he might experience information overload, lack of perceive of the vessel, mishaps during handoffs and changeovers, boredom during operation, delays in monitoring and controlling, continuous re-adaptation to new tasks, and need for comprehending object distinction and native knowledge (Wahlström *et al.*, 2015). The designer of supervisory semi-autonomous vessel control interface should apprehend and consider above issues to design a successful solution.

2.1.1.2 Human-Automation Interaction

As noted by Chen *et al*. (2011), the supervisory control could be defined as a coordinated interaction between the automation and the human operator. Hence the understanding of human-automation interaction is obligatory to design an effective supervisory control interface. In this part, the author will review works of literature about human-automation interfaces.

In general, automation partially or fully carries out functions that were previously carried out by a human (Parasuraman *et al*., 2000). But, in the supervisory control operation, automation will not simply replace the human operator. As mentioned by Parasuraman *et al*. (2000), the introduction of automation will change human activity and induces new coordination requirements to the remote operators. Finding cooperative needs of human-automation interaction will be worthwhile to design an effective supervisory control interface.

The supervisory control could be designated as human-agent teaming (Chen *et al*., 2011). The system should be capable of flexibly supporting the human-automation team in rare and unexpected situations, not just in ordinary circumstances (Dzindolet *et al*., 2006). Successful development of supervisory control interface may depend on the design of a supportive system that accelerates coordination between the remote operator and the automation.

Certainly, there is demand for the guidance of how to facilitate cooperation between human and automation (Dekker & Woods, 2002). Good human-automation collaboration is observable for both human and automation and also simple to direct (Dekker & Woods, 2002). So, the observability and direct-ability of human and automation activity need to be considered in the interface design.

According to Dekker & Woods (2002), The automation activities need to be displayed to the operator in particular ways, which take advantage of human abilities. And, when the human operator or automation can effortlessly instruct each other, team players are directable (Dekker & Woods, 2002). Thus, the designer of the supervisory control interface should deliberate about how to show the current and future activity of automation in a human centred way, and how to enable the human and automation to easily recognise a need to arbitrate and efficiently redirect each other.

2.1.1.3 Situation Awareness

According to Endsley (1995), designing an interface that supports effective decision-making in the complex environment is likely to be achievable by understanding the situation awareness. Thus, the author of this article would like to have a look at what the situation awareness is.

Endsley (1988) defined that "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". In the supervisory control operation of the semi-autonomous cargo ship, situation awareness might be a remote operator's state of knowledge about a vessel and its surrounding or the system.

Adequate situation awareness helps the operator to make the right decision and have a good performance in dynamic systems (Endsley, 1995). And, maintaining appropriate situation awareness of autonomous vehicle and task environment is the key to achieving successful supervisory control of the autonomous vehicle (Chen *et al*., 2011). Therefore, the design of supervisory control interface should help the operator to obtain and maintain a high level of situation awareness.

Endsley (1995) explained three levels of situation awareness. The first level is discernment of the task environmental elements. The second level is understanding of the present status. The third level is future situation prediction. These three levels of situation awareness demonstrate what the interface should provide to the remote operators. The goal of interface design is not just to show the vessel on the sea. Rather, it is to help the remote operator to understand the current and future status of the ships, its surroundings and system to accomplish the operation.

The sea is the dynamic environment where the condition is constantly changing in complicated ways. Increasing complexity in the dynamic environment causes troubles to operators and systems to achieve and maintain situation awareness (Endsley, 1995). There are two leading causes of increasing complexity; one is that the tasks are dependent on real-time analysis of the environment, and another one is that the operator needs to make a large number of decisions within limited time space (Endsley, 1995). So, the system should analyse up to date information of the vessel and its surroundings and provide an essence of parsed data to the remote operator through the interface in comprehending manners.

The introduction of remote controlled semi-autonomous cargo ship brings three situation awareness related issues. When the captain is on the vessel he can directly feel the movement of the vessel and easily achieve good situation awareness (Porathe *et al*., 2014). However, in the remote autonomous ship operation, the operator has no physical connection with the vessel and cannot sense the bodily movement of the ship (Porathe *et al*., 2014). Moreover, the mental model used for controlling manned ships cannot be directly applied for manoeuvring remote autonomous ship (Porathe *et al*., 2014). Furthermore, the situation awareness is a constantly developing output of the ongoing process (Porathe *et al*., 2014).

As a consequence, above challenges request designers to figure out what could be the way to feel the movement of the ship without the physical connection, what would be an intuitive mental model for manoeuvring remote autonomous ship, and how to maintain situation awareness of the constantly changing environment.

2.1.1.4 Trust in Automation

Designing a trustable solution is a fundamental element to succeeding in the new generation of automation technology development (Lee & See, 2004). As stated by Rovira *et al*. (2007), trustable automation system improves decision-making performance. Hence, the supervisory control interface should be trustable to the remote operator. In this part, the writer will examine the trust in automation.

While the human-automation cooperation, humans often regard the automation as a team member (Chen *et al*., 2011). However, if the human operator cannot get benefits from the automation or cannot trust it, the human-automation team will breakdown (Rovira *et al*., 2007). Thus, to improve the teaming between human and automation in supervisory control tasks the autonomous aids should be beneficial for the operator.

Creating a good user experience with the autonomous control system could build trust between the operator and the automation. According to Chen et al. (2011), the human operator's decision on whether he should trust the automation or not depends on his attitude towards to the automation. And his attitude develops with his operation experience (Chen *et al*., 2011).

A number of researchers revealed that human operators show tendencies of both over trust and mistrust automation (Chen *et al.*, 2011). And, these propensities are potential causes of situation awareness degradations or loss of operation skills (Chen *et al.*, 2011). Indeed, it is important to design an autonomous system reliable. But, on the contrary, the system should not let the operator over-rely on it.

The interface should clearly show the algorithms and processes of the autonomous system to make the automation more understandable to the operator and build an appropriate level of trust (Lee & See, 2004). To deliver information in clearer manners, the designer could apply a number of data and algorithm visualisation methods to the interface design. Consequently, this application would help the operator to build an adequate degree of trust towards the automation.

The observations by Bagheri & Jamieson (2004) indicate that showing information of the automation reliability in a context sensitive manner could reduce the performance decrement. Also, providing context sensitive information increases the detection performance of the automation failure significantly (Bagheri & Jamieson, 2004). Hence, the interface needs to show context related system information to the operator.

Lee & See (2004) identified seven considerations to design a trustable supervisory control system:

a) The design aim should be an appropriate trust, not a complete trust.
b) The interfaces need to display the previous performance of the automation.
c) The interfaces should show the algorithms and process of the automation at the halfway point in an understandable fashion.
d) The system should provide simplified algorithms and information which are more comprehensible to the human operator.
e) The interfaces need to exhibit the purpose of the autonomous system, basis of the design and application range in a context related manners.
f) The operators should be trained regarding presumed reliability of the automation, intended use of the system, and behaviour determining mechanism.
g) The anthropomorphising of the automation needs to be attentively evaluated to ensure the adequate level of trust.

Above considerations might be applicable to construct design requirements and test evaluation criteria of the supervisory control interface prototype.

2.1.1.5 Level of Automation

In supervisory control interface designing it is crucial to determine the level of automation that provides challenging yet manageable tasks and presents a sufficient degree of situation awareness to the remote operators (Chen *et al.*, 2011). In this part, the author will discuss about the level of automation.

The table below indicates ten levels of automation, which is revised from the "Table I" showed on Parasuraman *et al.* (2000).

High	10.	The automation acts autonomously, makes every decision and ignores all requests from the human operator.
	9.	The automation informs the human operator only when it decides to.
	8.	The automation informs the human operator only when it is asked to.
	7.	The automation performs automatically and informs the human operator as inevitable.
	6.	Before the automatic execution, the automation allows the human operator to reject within a limited time.
	5.	The automation performs suggestion when the human operator confirms.
	4.	The automation suggests an alternative option.
	3.	The automation sorts selections out to a few.
	2.	The automation provides a complete selection of action or decision choices.
Low	1.	Human operator makes all decision and the automation gives no assistant.

Table 1. Ten Levels of Automation

The table shows the various degrees of automation involvement in human-automation cooperative tasks. The level of automation needs to be considered to determine when and how the human operator intervenes autonomous action or how to shift between different degrees of automation (Dekker & Woods, 2002). At the same time, to decide the appropriate level of automation the designer should consider the types and amount of human-automation interaction (Chen *et al.*, 2011).

Besides, according to Parasuraman *et al.* (2000), automation can be employed to four different stages of functions, which are data acquisition, data analysis, action and decision selection, and action execution stage. Individual levels of automation could be applied to each stage (Parasuraman *et al.*, 2000). However, since the primary goal of the thesis is to design a user interface for the autonomous system, the writer will mainly focus on the action and decision selection stage.

The author and Rolls-Royce Marine presume that the supervisory control interface which the writer designing will have level 7 of automation level under autonomous control mode. However, when the automation needs a human assistant or the human operator notices that the automation is making errors, the operator should take over control and the level of automation needs to be switched to a more manual one (Dzindolet *et al.*, 2006). Thus, when the remote operator shifts the mode to manual control the degree of automation will be calibrated to level 5.

2.1.2 Supervisory Control Interface Design for the Semi-Autonomous Vehicle

2.1.2.1 General Supervisory Control Interface Design

The remote operators are monitoring and controlling the vessel from the remote operation centre through the interfaces. The design of human-automation interface effects on perceived workload, and performance of the operator (Chen *et al*., 2011). Thus, the interface should be carefully designed to provide good usability to the operator and enable effective human-automation interaction (Chen *et al*., 2011). In this section, the author will converse about the general design recommendations for the supervisory control interface.

Understanding the state of automation is critical to the supervisory ship control task. So, the interface needs to assist the operator to understand the status of the autonomous system (Furukawa & Parasuraman, 2003). The vessel should provide all task-relevant information to the remote operator (Rødseth *et al*., 2013). However, it is important to show only necessary information in an understandable way. So, the interface should provide an adequate amount of necessary information to the operator in order to achieve effective system status awareness.

The primary task of the remote operator is to locate the vessel at the particular point at the precise moment. The primary task should not be interrupted by secondary task except in an emergency situation or when the operator has low workload (Chen *et al*., 2011). The reason is that the interference by secondary task could cause the decline of operator performance (Cummings, 2004). Intelligent management of the task could ameliorate the performance degradation (Cummings, 2004).

If the ships could form a network, then they might be able to share situation awareness data. And the interface design needs to facilitate shared situation awareness within the team by providing effective communication methods (Chen *et al*., 2011).

Below is a list of recommendations for designing a supervisory control interface, which is modified from the interface design guidelines for supervisory control of unmanned aerial vehicles, presented by Olson & Wuennenberg (2001).

a) The interface has to display predicted changes based on operator inputs.
b) The interface needs to support a quick and effortless way to re-instruct automation.
c) The behaviour of the automation should be highly visible to the remote operator.
d) Extract information from the display should be straightforward to the operator.

Moreover, following list is a set of supervisory control interface design goals, which are altered from design objectives for a human-automation interface established by Nam *et al*. (2009):

a) All of the appropriate and essential information should be shown on one display.
b) Information has to be laid out in a user-friendly manner.
c) The interface needs to display only decision-making relevant information.
d) The interface should support rapid interaction between operator and automation.
e) The interface has to facilitate dynamic role changing by providing appropriate and necessary information.
f) Interaction feedback should be provided to the operator.

The designed interface should fulfil above design goals and recommendations.

2.1.2.2 Control Interface Design

The autonomous vehicle should follow a trajectory with a certain speed designated by the operator to reach the destination at a particular moment in time (Cassia *et al.*, 2008). So, the supervisory control interface needs to support quick and precise course planning. At the same time, the operator will require to remote control functions on the vessel and the system. In this part, the author will talk through control interface design.

Rødseth *et al.* (2013) argued that with the graphical user interface, the remote operator would plot the trajectory by applying waypoint control. If the display shows the navigational chart on the background, the operator might be able to plot route on it. The interface needs to have a capability to directly send new route and speed profile to the vessel in order to enable the waypoint control (Rødseth *et al.*, 2013). When the ship receives cues, it would determine proper rudder angle and speed to follow the plan instructed by the operator (Rødseth *et al.*, 2013). Thus, the operators may not control individual rudder or thruster. Instead, they will make waypoints on display and control speed. And the vessel will autonomously control its heading and propulsion to follow the instruction.

According to Linegang *et al.* (2006), in the supervisory control tasks, the human operators need to communicate with the autonomous system when they establish mission plan. However, operators often have difficulties when they are specifying goals and constraints in the manner the automation system requires them (Linegang *et al.* 2006). Hence, the interface should be designed in a human centred way to provide intuitive course planning experience to the operator.

Dynamically changing environment effects on the pre-defined plan for the automation (Chen *et al.*, 2011). The remote operator may need to alter the plan for the semi-autonomous vessel in a timely fashion (Chen *et al.*, 2011). So, the interface should provide quick and easy ways to modify the navigation plan.

In general, the semi-autonomous ship will be autonomously operated on the open sea and manually controlled near the harbour. But in reality, the mode selection between manual and autonomous modes will depend on which alternative gives the best likelihood of succeeding in the task (Rovira *et al.*, 2007). In a study conducted by Squire *et al.* (2006), it was shown that when participants were offered a control interface which allowed to flexibly choose between waypoint control and autonomous control mode, overall operation time was reduced. Thus, the interface should provide ways to shift mode between autonomous and manual control flexibly.

2.1.2.3 Monitor Interface Design

Having a monitor interface is fundamental to controlling and monitoring the semi-autonomous ship from a distance. In the supervisory control operation, the perception of the operator is compromised since the physical environment of the scene is decoupled from the perceptual processing system of the operator (Woods *et al.*, 2004). The decoupling deteriorates affordance perception of the remote operator, and it could have an undermining effect on situation awareness and overall performance degradation (Woods *et al.*, 2004). So, the monitor interface for the supervisory control should be specially designed considering the characteristics of the particular operation.

Porathe *et al.* (2014) identified three premier tools to obtain appropriate situation awareness, which are the electronic navigational chart, the video feed, and the radar image respectively. On the electronic navigational chart, the position of the own vessel and other ships could be constantly transmitted and displayed (Porathe *et al.*, 2014). At the same time, from the ship or other sources the operator may receive various information such as radar data, AIS information, infrared and daylight video feeds (Porathe *et al.*, 2014). The operator should be able to control the camera on the vessel and the system needs to calibrate quality of the video or still camera image depending on the connection status (Porathe *et al.*, 2014).

Chen *et al.* (2011) point out that the multimodal displays could enhance the detection performance of the marine participants and decrease the cognitive workload of them. Besides, Simpson *et al.* (2005) recommended providing both visual and spatial audio feed to the operator because the spatial audio may supplement visual display when the important information is concealed or missing. The visualised information could be missed when the operator is focussing on subtasks or when in low visibility condition (Simpson *et al.*, 2005). So, the use of multimodal displays might improve the situation awareness of the remote operator and as a result ameliorate overall safety in operation.

Head mounted display or augmented reality display are considerable as a monitoring solution. According to Calhoun & Draper (2006), however, operation performance with the head mounted display was poorer than with the stationary display and joystick. On the contrary, the augmented reality display enhanced situation awareness of the remote environment (Calhoun & Draper, 2006). Moreover, the augmented reality display decreased perceived workload of the operator, minimised the negative impact of video data-link deterioration, and made the quality of communication better (Calhoun *et al.*, 2005). But, too much information on the augmented reality display would increase the risk of cognitive tunnelling (Calhoun *et al.*, 2005). Overall, the augmented reality display might be considerable as a monitor interface solution, while the head mounted display is not.

The complex system provides a significant amount of dynamic information to the operator to achieve safe and efficient operation (Parasuraman *et al*., 2000). Although a large amount of data provided by interface reduces scanning effort, the human operator has limited capability to comprehend complex states of the system (Furukawa & Parasuraman, 2003). Besides, too much information on screen could create visual mass and debase data processing ability of the operator (Chen *et al*., 2011). If the overlaid information captures the attention of the operator, critical information could be overlooked (Chen *et al*., 2011). Hence, the remote operator should be able to de-clutter massed objects on the screen and arrange objects depending on the task and the situation (Chen *et al*., 2011). Together, the monitor interface has to provide an adequate amount of information, which the operator could understand.

Supervising multiple autonomous vehicles by a single remote operator could maximise human resource efficiency (Chen *et al*., 2011). Multiple vessel control is achievable by computerising low-level functions since while the automation is conducting low-level control the operator can oversee and manage overall system (Manley, 2008). However, if the remote operator is monitoring and controlling multiple vessels on a single console the interface should automatically configure its display and provide a specific interface of a particular vessel to the user (Ebken *et al*., 2005). By providing different graphical user interface depending on vessel type or operation property and automating low-level control the multiple vessel control will be realised.

The interface needs to have a threshold-crossing alarm in order to signal to the operator when the automation or the operator taking extreme action, when the automation is having trouble, or when the automation is moving towards its limit of authority (Klein *et al*., 2004). But, the threshold is commonly crossed too early or too late in practice, and that causes the automation too sensitive or impervious (Klein *et al*., 2004). Hence, the designer should carefully set the range of the threshold when designing a threshold-crossing alarm system.

The remote operators often doubted the effectiveness and accuracy of the plans generated by the autonomous system, because they had difficulties understanding the rationales for the plan (Linegang *et al*., 2006). So, the interface should support the operator in understanding the reason behind the automated decision. And, when the automated plan cannot be trustable, the interface should provide information to the operator for manual planning (Rovira *et al*., 2007).

2.2 Expert Interviews

Five expert interviews were conducted to understand possible needs of future users of the interfaces, and supervisory control of semi-autonomous cargo ship. The chapter presents discussions of findings from the expert interviews. Because of the similarity between video gaming and supervisory ship controlling and lack of autonomous ship operators the author of thesis interviewed three video gamers. At the same time, the author interviewed two autonomous ships experts. Below is a list of interviewed participants:

a) Video Gamers (VG):
VG 1. Has played video games for 25 years,
Plays various kinds of multiplayer games on PlayStation® 4
VG 2. Has played video games for 27 years,
Mainly plays multiplayer first person shooter (FPS) games on PC
VG 3. Has played video games for 23 years,
Mainly plays multiplayer strategy games (RTS) games on PC

b) Autonomous Ship Experts (ASE):
ASE 1. Industrial Designer at Rolls-Royce Marine
ASE 2. Research scientist at VTT Technical Research Centre of Finland

All interviews were voice recorded and later transcribed. The author merged transcripts of the interviews and grouped related comments intuitively. Grouped findings from the interviews were discussed and distributed into four themes, which are essential parts of supervisory control interface design and supervisory control operation. The author comes up with these themes by apply learnings from the literature review. Key findings from each group of comments are underlined and italicised.

2.2.1 Control Interface Design

The control interface is a mandatory part of the supervisory control interface. There were some comments from the interviewees that are related to the control interface design. Findings are categorised into 15 groups and discussed below.

Group 1:

a) In cargo ship operation nowadays, you don't take the manual control, and you don't take control azimuth thruster. With autonomous cargo ship, you may need manual control much more rarely.

b) If you only plot the route for the autonomous vessel, then you will only need the route plotter.

c) If you are not going to manoeuvre the ship manually, you don't need joysticks.

The first batch of comments shows that "*the remote operation system of semi-autonomous cargo ships could have route plotter type of controller instead of having joysticks*". Autopilot function is already standard in cargo ship operation and captains are rarely taking manual control. With the artificial intelligence, manual control will become a rare thing in the cargo ship operation. The semi-autonomous cargo ship will have the ability to sense the environment and automatically control rudder or thrusters. So the ship will be able to follow the pre-made route, which is plotted by the remote operator. And if the remote operator only plots and adjusts the course, he only needs to have a route plotter.

Group 2:

a) Microsoft Surface Studio has an object on the screen.

b) People still like to have objects and control of objects and feel the actual control feeling.

c) People need some emotional feeling from control.

d) Something real, which can be touched and felt, is needed.

In the second group, interviewees do point out that "*by touching and feeling the physical controller the remote operator could get emotional feeling*". The operator will need a realistic feeling of the controlled ship. By controlling with a physical object, the remote operator could get the sense that they are controlling a real ship. Microsoft Surface Studio has a dial type controller on the touch screen which gives more precise control, better control feeling, and easy and intuitive command. The remote control interface could also be a hybrid system of a touch screen and a physical control object.

Group 3:

a) To play a game like StarCraft, it is mandatory to have a mouse and a keyboard.

b) Playing Star Wars: TIE Fighter & X-Wing Alliance with keyboard and mouse was not easy. The game was designed to be played with a joystick.

The third group of comments shows that "*the design of interface software and hardware needs to be done together*". Many games are designed to be played with a particular type of control interface; for example, many of flight games are designed to be played with a joystick. This causes control issues when the gamers are using wrong kind of controller which is not matching with the game software design. Thus, in order to avoid controller mismatch issues the software and hardware design of the interface should not be separated.

Group 4:

a) It is critical that you know what you are playing.

The fourth group of comment shows that "*the remote operators need to know what they are operating*".

Group 5:

a) Bad control can be a variation of controls in unnatural order or a game that doesn't respond in a way you expect. It causes a lot of problems.

b) If you pressed forward button but the console could interpret signal to forward left, and that will cause your character to towards the wrong direction.

The fifth group of comments indicate that "*the control interface needs to respond in a way that corresponds the remote operators intention*".

Group 6:

a) You could hold Nintendo 64's controller in different ways. That caused some issues because you couldn't know what was the correct way of holding the controller.

The sixth group of comments shows that "*the control interface should be intuitive to hold in the correct way*". If the shape of the remote ship controller does not lead the remote operator to intuitively hold it in a certain way that will cause confusion.

Group 7:

a) When I play PC games, the quality and ergonomics of the mouse have a significant effect on gameplay and stamina. If you play a game with a really bad mouse you will end up with a sore hand or wrist within two hours.
b) Mouse size is an apparently big thing. In my experience gaming mouse should be a bit larger than standard mouse nowadays.
c) If you have a small mouse, you will squeeze it with your fingers instead of putting your fingers on top of it.
d) Gaming mice are ergonomically better than normal mice because of their bigger size and comfortable shape.
e) Your hand needs to rest on a mouse in a comfortable and ergonomic way.

The seventh collection of findings suggests that "*the control interface needs to be comfortable to hold and use*". The ergonomics of the controller might have a big effect on the ship control experience. The size of the controller needs to be large enough to rest a hand on. If the controller is not comfortable to use the operator cannot hold it for a long time, because it could cause sore hand or wrist. The controller also needs to have comfortable shape.

Group 8:

a) Controllers for gaming consoles are easy to use, they fit on hand, the functions are easy to figure out and they have enough space to move hands on.

According to the eighth group of comments "*the control interface needs to be easy to use, it needs to fit on hand, the functions have to be easy to figure out and it needs have enough space to move hands on*".

Group 9:

a) Having multiple ways to do the same thing causes me confusion in control.
b) Shooting games commonly have reloading function on a particular button. And that button is usually consistent, so the reload is always on that button.

The ninth group of comments shows that "*the control interface should give consistency in control*". Usually, shooting games have dedicated button for reloading, so the player always reloads with the same button. If the function of the button changes, the operator will get confused; and, that will lead to control mistake. At the same time having multiple ways to do the same task can cause confusion.

Group 10:

a) The mechanical keyboard has lower switch activation strength than dome membrane keyboard.
b) Mouse should have enough sensitivity and it should work well on the surface.

The tenth group of comments explains "*the control interface should be sensitive enough to work well*". An interviewee preferred a mechanical keyboard, because of its low switch activation strength. Low switch activation strength means that a switch is sensitive, so not much pressure is needed to activate it. If the control interface is a mouse, it needs to work on the surface sensitively.

Group 11:

a) Customised key layout enables gamers to reach buttons easily and that helps gameplay.
b) Usually games provide adjustment of control such as adjustment of the camera and movement sensitivity, which helps you to have more precise control.
c) If I play a game on another person's PC the first thing I do is adjust mouse sensitivity. Mouse sensitivity changes the whole control experience.
d) Setting the other person's computer with my preferences takes time and I cannot remember all the numbers of my settings.

The eleventh group points out that "*the remote operators should be able to customise the remote controller and have personal setting*". Control customisation improves control experience. It allows users to reach buttons easily and have more precise control. Games usually provide options to configure sensitivity of camera and mouse movement. The remote operators might be able to control camera movement and sensitivity of control interface too. The control interface sensitivity effects on the whole control experience. Each person has different preferred settings. Also, setting up a computer or console with personal settings takes time. So the system should memorise custom settings of each remote operator.

Group 12:

a) Mouse buttons should be pressable without having to twist or move your fingers.

The twelfth group of comment shows that "*the buttons on the remote controller need to be arranged in an ergonomic way*". Otherwise, the operator will need to twist their fingers in order to press the buttons.

Group 13:

a) Force feedback steering wheel and gas pedal for the racing game were surprisingly responsive, and it had no input lag.
b) Overwatch is on the top of the list regarding controls. How to react and give feedback is immediate and precise.
c) Poor feedback to the gamer is a distracting thing. That makes the player spend a lot of time trying to understand what has happened.
d) Compared to a dome membrane keyboard mechanical keyboard gives better haptic feedback to users.

The thirteenth group of comments shows that "*control feedback should be responsive, immediate and precise*". Poor feedback makes operator spend lots of time understanding what is the result of his command. Choosing the right type of switch is important regarding control feedback. One of the interviewees commented that mechanical keyboard gives better haptic feedback than dome membrane keyboard.

Group 14:

a) In the future, the operator might say to the computer "go to this position".

The fourteenth group of comment shows that "*the remote control interface could have a voice control function*". So the remote operators would be able to command the ship with their voice.

Group 15:

a) Mapping a lot of buttons on the keyboard usually causes me some trouble.

The fifteenth group of comment shows that "*Mapping too many buttons on the keyboard can cause trouble in control*".

2.2.2 Monitor Interface Design

Without monitor interface, having supervisory control operation is impossible. Participants commented things related to the monitor interface design. Comments are distributed into seven groups and discussed underneath.

Group 1:

a) Wrong camera angle causes challenge with control.
b) Bad perspective causes you to have wrong input and lead to false control.
c) In the first person games, the camera is fixed on the eyes of the character.
d) Player can grasp perspective and move around pretty well in the first person game.

The interviewees do point out that "*the monitor interface should show proper perspective to the remote operator*". Perspective is important in the remote ship control because the remote operator relies heavily on video or still camera feed. If the display shows the wrong perspective to the remote operator, they will have trouble controlling the ship which can lead to failure. False control could end up causing a serious ship accident. Interviewees point out that in a first person game they do not have that much perspective related issues because the camera is fixed on the eyes of game characters. So, if the ship can show first person point of view, the monitoring device will give a better perspective to the remote operator.

Group 2:

a) Poor orientation of your character causes challenge with control.
b) First person games usually don't have big orientation issues.

The second group of answers reveals that "*the monitor interface should show correct orientation of the ship*". If the orientation of the ship on display is different from reality, the operator will have challenges with control. Wrong orientation will cause confusion in control and give unnatural control feeling to the remote operator. Additionally, interviewees mentioned that first person games do not have big orientation issues.

Group 3:

a) If the screen size is too small, you need to be precise with clicking.

The third group shows that "*the display size should not be too small because it can make remote control hard*".

Group 4:

a) A game called Fatal Frame on Wii U had dual screen. You can see the game on the TV screen but you also need to look at the screen on the controller. That made the gaming experience horrible.
b) Moving focus between small and big screens causes disorientation.

The fourth group of answers shows that "*the monitor interface with multiple displays should be designed in a careful way in order to avoid disorientation issues*". If the remote operator needs to focus on different displays alternatively to understand the situation of the ship that will cause disorientation.

Group 5:

a) Now Rolls-Royce has a simulator in Ålesund, Norway. The simulation room is stationary but the picture on the screen is moving. That affects the human brain and people can feel the rocking of the ship.
b) The operator can get a feeling of ship's posture quite easily because the cameras are stationary on the vessel.
c) I think the sense of rocking is something we can't take away.
d) The camera needs to be rolling and tilting with the vessel.

The fifth group of answers indicates that "*with rocking video taken from the stationary camera on the ship the operator could understand movement and posture of the ship*". By watching a rocking video, the human can sense movement of the camera. If the camera is stationary on the ship the remote operator will be able to understand movement and posture of the ship by watching the video feed.

Group 6:

a) The operator can have 3D modelled ocean with 3D modelled ship rocking on it.
b) Lidar shoots millions of laser beams, and it builds 3D map around the ship. It can't see anything behind. With that technology, the operator can get topography data of all the islands around ship, heights and everything. It is quiet accurate. With around one minute, lidar will draw the world around the ship.

According to the sixth group of answers, it is possible to have an animated 3D ocean at the remote operation centre. Lidar shoots millions of laser beams around the ship and can get topographic data around it. By utilising lidar data, it is possible to build a 3D modelled ocean with the ship rocking on it. The remote operators are not on the actual ship, so they have limited situation awareness. "*having a 3D modelled ocean in the remote operation centre can help the remote operator understand sea condition and the situation of the ship*".

Group 7:

a) You can have a chart table, which tugs are appearing on and the remote operator could give commands on those tugs.

b) It is normal to bring AIS data on the chart now. The captain can see other vessels on the chart and their vessel type, speed and destination port.

Comments on the seventh group show the potential of the nautical chart as a remote ship controller and monitor. One of the interviewees mentioned tug controller, which is integrated with the nautical chart. If it is possible to control tugs on the nautical chart, controlling own vessel on it will be possible as well. Moreover, nowadays it is common to bring AIS data on the nautical chart. The nautical chart can show other ships and their types, speed and destination to the captain. This system could be used in the remote operation centre too. With this system, the remote operator could be able to understand other ships around his ship. Thus, "*nautical chart could be an integrated system of ship controller and monitor*".

2.2.3 The Practical Side of the Control

It is important to understand the practice in order to design a user-friendly solution. The interviewees mentioned a few remarks related to the practical side of the control. Findings are clustered into six groups and discussed below.

Group 1:

a) When a fast decision is needed, for example when another vessel is doing something unpredictable, the operator should take over control.
b) If the computer or artificial intelligence doesn't know what to do it will ask the operator to take over control.
c) If the ship is close to a harbour with heavy traffic it needs a human assistant.
d) When the vessel comes into harbour, the operator should take over control.

In the first group interviewees commented that "*the remote operator should take over control whenever it is needed*". There are three cases mentioned. Firstly, when the artificial intelligence cannot predict other ships actions, the remote operator needs to take over control. Secondly, when the artificial intelligence cannot make a decision, it will ask the operator to take over control from it. Especially when the ship comes into the harbour and there is heavy traffic the artificial intelligence will need the remote operator to handle the ship.

Group 2:

a) If all sensors fail or the weather conditions are bad you can simply stop the operation and the ship will go to DP (Dynamic Propulsion) mode and stand on the sea until the situation gets better.
b) If you have a robust DP system that will enable you to stop the ship and maintain the position until the problem is fixed.

The second group reveals that "*the Dynamic Positioning (DP) system is required to be installed on the semi-autonomous vessel as a mandatory feature and the remote operators should be able to use that function in emergency situations*". For example when all sensors fail or when the weather conditions are bad, stopping the operation until problems are solved could be the only option. With high-performance DP system the vessel could automatically maintain the position on the sea in negative conditions.

Group 3:

a) Automatic docking would be available in the near future.

The third group shows that "*semi-autonomous vessel might have automatic docking function*".

Group 4:

a) I could see that augmented reality lines could help the operator. It could show routes to go and not to go with overlaid lines. So that kind of systems also could be used in ship system.

According to the fourth group of comments "*the artificial intelligence could show route suggestion or alert the remote operator*". Overlaid lines on the display or augmented reality glasses could show the operator which way to go.

Group 5:

a) Where you have a lot of islands and a lot of different under sea level, shores and places you cannot go, or in the very tight area with a lot of traffic. In that situation, you cannot go without a pilot who knows the shore and areas where you go.

The fifth group of comments indicates that "*the artificial intelligence could provide local sea information to the remote operator*". Currently, when the ship is coming into harbour pilots give local sea information to the captains. In the future, artificial intelligence might be able to have a similar role as the pilots have nowadays.

Group 6:

a) You will still have manned vessels, which are not predictable. So, artificial intelligence probably needs to do a fast calculation on speed and movements of manned ships.

As seen in the sixth group "*the artificial intelligence could predict route of manned vessels around*". The remote operator might be able to get route information of autonomous ships easily. However, manned ships might not be able to provide information to the remote operation centre. In that case, the computer could quickly calculate expected route of the manned ship and show it to the remote operator.

2.2.4 Communication

Communication is a crucial part of remote semi-autonomous cargo ship operation. In operation, the remote operators need to communicate with captains, ships, system, etc. Findings related to the communication are arranged into seven groups and discussed underneath.

Group 1:

a) Every network solutions evolve fast.
b) There has been an idea of floating 4G devices on the sea. The idea is to make a connected 4G sea road, which is run by energy from wave or solar power.

As seen in the first batch of comments "*the network connection issues on the sea seem to be solved in the near future*". All network solutions evolve fast and there has been an idea of a floating 4G router on the sea. Those routers will be connected to each other and make 4G sea road. They will get energy from wave and solar energy.

Group 2:

a) Data from the ship needs to be visualised so that the operator can understand at a glance whether everything is ok or not.
b) Algorithm visualisation might support the operators to easily understand the logic of automation or where the error comes from.

The second group of comments shows that "*the information needs to be visualised well to help remote operators easily understand the situation of the ship, environment and the system*". The operators should be able to comprehend the situation at a glance. The algorithm visualisation is needed to support the operators in understanding the logic of the artificial intelligence or knowing the cause of error.

Group 3:

a) Operator can have a lot of information from the ship. But the operator might get lost in the information when he gets too much information or does not get what is relevant information at that point.

The third group of comment shows that "*the system needs to show only the adequate amount of relevant information that the remote operator can handle*". The system can get a lot of information from the ship and other data sources. However, the remote operators cannot handle too much information. If there is too much information, they will be confused. The information should be relevant to the particular situation.

Group 4.

a) If the autonomous ships and normal ships could form a network and exchange information, the operator could get enough information to operate even when he cannot get any information from his ship.
b) On the network, remote operators and captains can discuss with each other to handle a problematic situation. For example, when a collision is approaching they can negotiate a way to avoid the collision.
c) One of the key issues is that how do they negotiate who is going where and how do they tell each other's intentions.

The fourth group of comments identifies that "*connected ships will enable ships to exchange information and negotiate problems with each other*". The autonomous and normal vessels could form a network. If the remote operator cannot get information from his ship, he will be able to get information from connected vessels around his ship. When there is a problematic situation, captains and remote operators within the same network could negotiate a way to solve the problem.

Group 5:

a) If the operator could see that the automation is not reliable because of an internal issue he would not trust the automation system.
b) The operator should not distrust automation system and should not try to do every control manually.
c) The operator should not over trust the autonomous system. They should not let the automation do everything it wants.
d) Depends on how much the operator could trust the automation system, level of trust should be calibrated to an appropriate level.

The fifth group of comments reveals that "*artificial intelligence needs to be trustworthy, but the remote operator should not over trust it*". If the artificial intelligence is not reliable, the remote operator will not trust it. The remote operator should not distrust artificial intelligence and try to control everything manually. At the same time, the remote operator should not over trust the artificial intelligence and let it do everything it wants. The level of artificial intelligence usage should be able to be calibrated based on how much the remote operator could trust the artificial intelligence.

Group 6:

a) No matter whether you are using a console, a PC or a Mac, it is a lot faster to just talk than type.
b) With voice chat, you talk and keep playing at the same time.
c) Voice communication is going on all the time while you play.
d) I guess the biggest goal of voice communication is that everyone is on the same level of conversation and talking about the same thing with the same term.
e) We don't communicate with sentences but words because it is quick communication.

In the sixth group, the interviewees commented, "*voice chat could be a primary communication method*". According to the comment from one interviewee communication with voice chat is faster than with type chat. And with the voice chat, the remote operator could communicate while he is controlling and monitoring the ship. Voice chat will be going on all the time during the operation. In the voice chat group, everyone needs to be on the same level of conversation. They should talk about the same thing with the same terminology. In a quick voice chat peers tend to communicate with single words instead of full sentences.

Group 7:

a) I used Emote often when I was playing World of Warcraft. With Emote your character can do actions, for example wave hand, bow, dance, sit down, point, etc. But I didn't always use them with the intended purpose.
b) In Portal2 the player can project animated images on the wall to corporate with other players.
c) In Portal2 the player can show symbols or dialogue bubbles overhead.

The seventh group of comments shows that "*emotes, symbols, overlaid images and dialogue bubbles could be used as alternative communication methods*".

2.3 Design Requirements

In this section, the author presents thirteen design requirements for developing a supervisory control interface for a semi-autonomous cargo vessel. Design requirements are an objective that must be met to solve the design issues discovered within problem space. The design problems are uncovered from data collected from the literature reviews and the expert interviews.

2.3.1 Integration of Control and Monitor Interfaces

The interface should provide the ability to control and monitor a vessel simultaneously. The remote operator is required to be plotting the course of the vessel while he is overseeing the progress of an operation. He will perceive the situation around the ship mainly through the monitor screen. Besides, it is already common to bring AIS information on the electronic navigational chart on the cargo vessel bridge. Similarly, the remote operation centre might have an electronic navigational chart which shows information from the ship or other sources on it.

This electronic navigational chart could be an integrated system of ship control and monitoring interface. In a real time simulation game the players control units on a map. Correspondingly, the remote operator could control his vessel on the electronic navigational chart. Control vessel on the electronic navigational chart will raise design challenges when the goal is to provide right perspective and orientation of the ship to the remote operator.

2.3.2 Precise Manoeuvre and Speed Control of the Vessel

With the interface, the remote operator should be able to manoeuvre and control the speed of the vessel precisely. The interface must allow the remote operator to transport vessel to the particular point at the precise moment. Plotting the desired path and controlling speed must be immediate and effortless. At the same time, control feedback from the interface should be instant and accurate. Appropriate control feedback provides precise control and reduces errors. Furthermore, the vessel should follow the plotted path with high precision.

2.3.3 Quick and Easy Revision of Plan

Revision of plan should be fast and easy. Semi-autonomous vessel follows the plan, which is organised by the remote operator or autonomous system. The plan needs to be changed whenever it is not achievable. Because of the safety-critical and real-time nature of the supervisory control operation, the interface should provide a quick and easy way to rectify the plan.

2.3.4 Understanding the Target Object of Control

When the captain is on the bridge, the controlled object is the vessel where he is on-board. However, in the remote operation centre, the remote operator will recognise the vessel he's controlling through the interfaces. Poorly designed interfaces can confuse the remote operator to apprehend control target, which could increase the chance of a control mistake. So, the interface should clearly show to the remote operators what they are controlling.

2.3.5 Providing Essential and Non-Overwhelming Information

The interface should show crucial and non-overwhelming information to the user. Human operators can handle a limited amount of information. Too much information could cause information overload, which is a cause for cognitive tunnelling. The interface should provide only an adequate amount of information that the operator could comprehend. Understanding the system status is significantly important; however, information from a complex system needs to be simplified. Also, information should be visualised in easily interpretable manner. Well-visualised information helps the remote operator to understand the situation of the vessel, the environment and the system effectively and efficiently. Furthermore, essential elements on the screen should be appealing enough so it won't be overlooked by less relevant data. Moreover, decision-relevant information should be selected from a large number of dynamic data in order to help the remote operator achieve safe and efficient operation.

2.3.6 Showing Necessary and Appropriate Information on Main Display

The way the information is presented affects the performance of the remote operator. Information distributed on multiple displays will require the user to move focus irregularly and may cause disorientation issues. Thus, the interface should show all the necessary and appropriate information on main display and relatively less important information on additional displays.

2.3.7 Ergonomically Designed Control Interface

Ergonomics should be carefully considered in control interface design. The remote operators will use the control interface for several hours at a time. If the control interface is uncomfortable to use, the remote operator might easily get tired and experience performance degradation. First of all, the size and shape of the control interface should fit on hand and guide the user to intuitively hold the control interface in the correct way. Also, to reduce the learning curve and errors the interface should be easy to use and all the functions should be easy to figure out. Furthermore, button and levers on the control interface need to be laid out in a user-friendly fashion. Moreover, the control interface should have enough free space on it to move hand or fingers on it.

2.3.8 Intuitive Control

How the interface responds and works should be matched with the remote operator's intention; in other words, the usability of control interface needs to be intuitive. At the same time, the interface should provide consistency of control to users. The way to activate a particular function is required to say the same all the time. Too many buttons on the interface cause confusion to the operator and increase the chance of error, so the interface should not have too many buttons.

2.3.9 Flexible Shift between Autonomous and Manual Control Mode

Since the vessel is semi-autonomous, the interface will have autonomous and manual control modes. In general, the autonomous mode will be activated during open sea operation and manual control mode will be used during offshore and harbour operation. However, the remote operator might need to take control whenever the automation needs human assistance. Because unexpected need for human assistance can occur, the shift between the two modes should be flexible.

2.3.10 Dynamic Positioning System

Dynamic positioning system enables the vessel to maintain its position or heading automatically. When the weather is bad or the remote operation centre cannot get enough information from the vessel, the operation cannot be continued. In certain cases stopping the vessel on the sea and maintaining its position could be the only option. Thus, the remote operator should have a way to activate the dynamic positioning function.

2.3.11 Threshold-Crossing Alarm

The interface has to signal when the vessel or the system gets into trouble, when the vessel is reaching its limits of ability or when the operator or automation is taking extreme actions. Putting threshold-crossing alarm would be an answer to these problems in interface design. The threshold-crossing alarm needs to be context-sensitive and should not cross too early or late.

2.3.12 Autonomous Prediction

The autonomous system should be able to predict a result of operator input or routes of manned ships. The system might be able to show predictions by utilising information from sensors, database or other ships. These predictions need to be provided to the remote operator through the interface during operation.

2.3.13 Primary Task Priority

The primary task of a remote semi-autonomous vessel operation is transporting the vessel to its destination. The primary task should not get interrupted by secondary task except in emergency situations or moments of low workload. Interruption during an operation causes overall performance loss of the remote operator. The system should intelligently manage incoming information and messages to lower interruptions and workload.

3

3.1 Design

The author has generated several design ideas of supervisory control interfaces for semi-autonomous cargo vessels based on the design requirements. Subsequently, the prototype has been created to realise design ideas and to evaluate the designed solution (Figure 2, 3).

Figure 2. Supervisory Control Interface for Semi-Autonomous Cargo Vessel Prototype (i)

Figure 3. Supervisory Control Interface for Semi-Autonomous Cargo Vessel Prototype (ii)

3.1.1
Display

The remote operator is monitoring the operation process through the display (Figure 4). The display shows the navigational chart on the background and indicates the location of the vessel, which is under control of the remote operator. At the same time, the remote operator can see manned and unmanned vessels or other objects around the vessel (Figure 5). The display provides necessary information for navigation to the operator, such as speed of the vessel, planned route, and areas where the vessel cannot enter.

Figure 4. Display

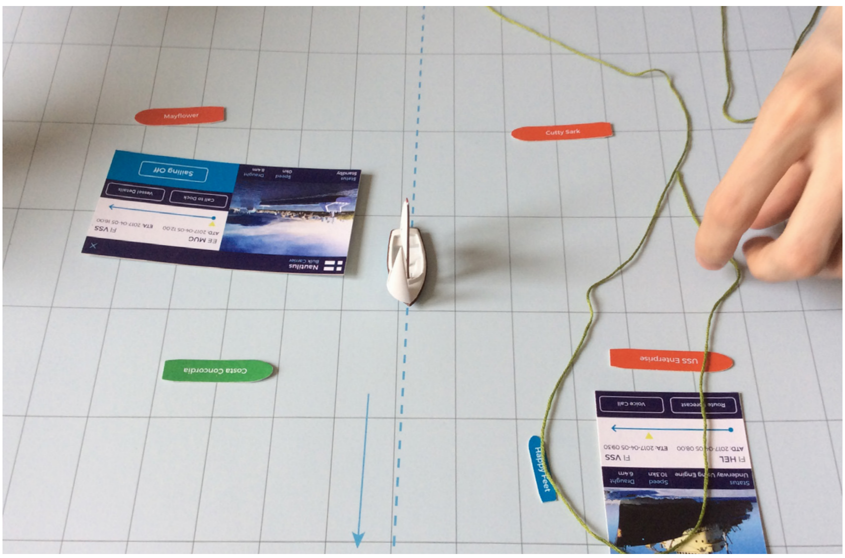


Figure 5. Operation Process Monitoring

The display is also a communication tool. If the remote operator touches a ship on the screen, the display shows basic information of the selected ship with the voice communication menu (Figure 6). Information about the other ship includes the name of the ship, type of the ship, the destination port of the ship, and the speed of the ship. When the operator selects the voice communication menu, he can have a voice chat with the captain or the remote operator of the selected ship. With the voice chat, the remote operator can negotiate to solve the problematic situation or acquire information from other captains or remote operators.

When the error has occurred on the vessel, the interface, or the system, the display shows an error message (Figure 7). The operator can check details of the error, for example, what is the error, why it has occurred, and what is the possible solution for it. By following the instructions showed on the display the remote operator could solve the problems.

The display shows the course planned by the automation or the remote operator. While the operator is planning the course, the automation decides whether the vessel can follow the path or not. If the vessel can follow the route, it will display the route with green colour and the remote operator is allowed to confirm the action. However, when the vessel cannot follow the path, the display will show the route with red colour and the remote operator cannot confirm the action. When the action cannot be executed, the interface will display an alert.

Since the remote operator needs to monitor the rocking of the vessel, the display will show a 3D modelled ship, which pitches and rolls depending on the actual movement of the ship.

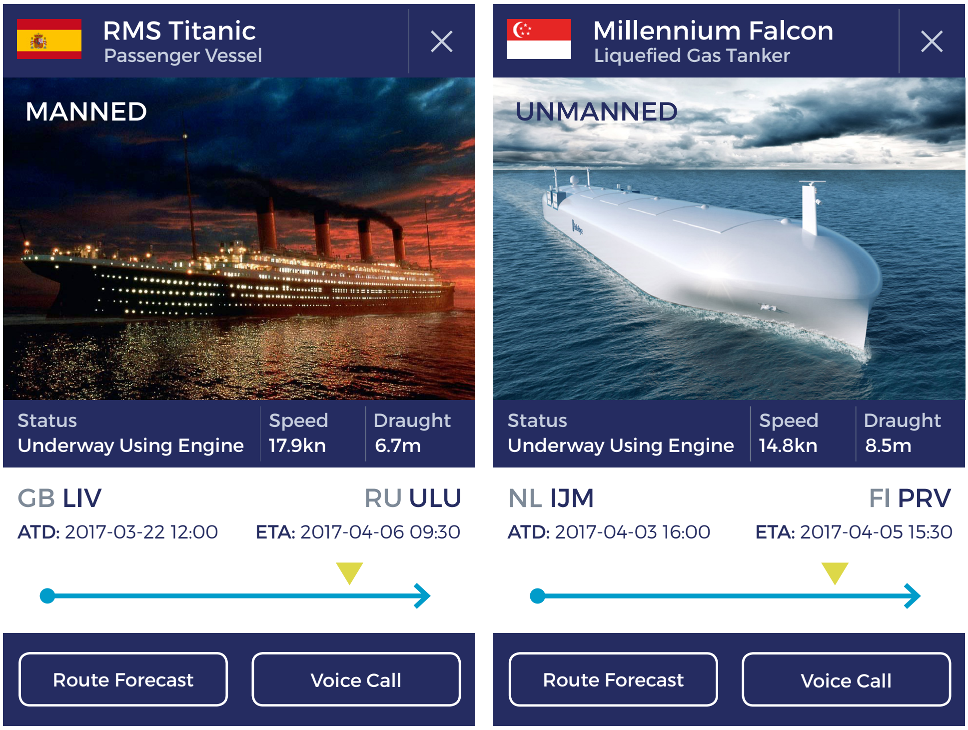


Figure 6. Ship Information Menus

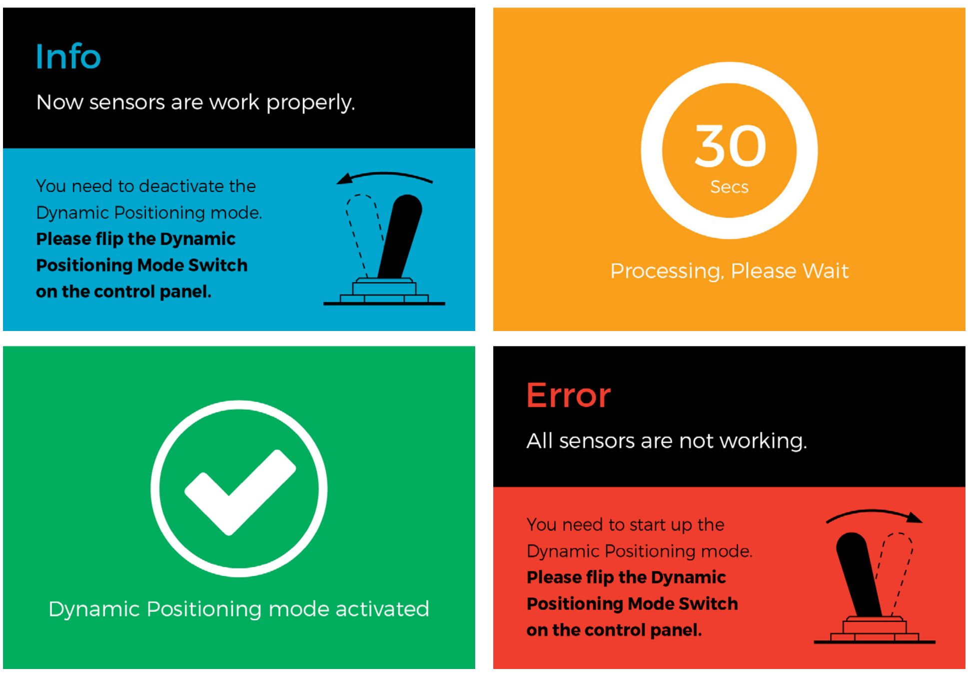


Figure 7. System Messages

3.1.2 Course Control Wheel

The course control wheel is a dedicated waypoint control device for route planning of the remote semi-autonomous vessel (Figure 8). With this control interface the remote operator can plot the course and the vessel follows the path made by the operator. The course control wheel is designed to provide easy, instant and precise manoeuvre of the remote semi-autonomous ship to the remote operator.

The course controller consists of the doughnut-shaped body part, two buttons on the top, and rotatable ring that encircles the body. The size of the whole device is 65mm in diameter and 15mm in height. The controller has a hole in the centre, which is 35mm in diameter. Centre of the hole is the point where the vessel will go. Buttons on the top side are a confirmation and an undo button respectively. Confirmation button is green coloured and on the top left side of the controller. Undo button is red coloured and on the top right side of the controller. The controller has a white coloured triangle on the top, which indicates the bow of the vessel when the vessel has reached the waypoint.

Figure 8. Course Control Wheel

The course control wheel works on the surface of the display (Figure 9, 10). When the user places the course control wheel on the display, the display will show a trajectory from the current position of the vessel, or the last waypoint confirmed to the centre point of the course control wheel. The remote operator can confirm the plan by pressing the confirmation button after which the vessel will follow the approved path. While the ship is following the course, the operator can continuously set next waypoints and ship will sequentially follow the trajectory and pass the waypoints. If the operator needs to revise the plan, he can press the undo button. When the user presses the undo button the interface will sequentially undo the actions from the last confirmed one to the first confirmed one.

Figure 9. Trajectory Planning with the Course Control Wheel (i)

Figure 10. Trajectory Planning with the Course Control Wheel (ii)

By rotating the outer ring, the remote controller can modify the course (Figure 11). When the white triangle on the top is pointing 12 o'clock position and the vessel is located at 6 o'clock position, the display will show a straight vertical line. If the operator rotates the outer ring to the clockwise direction, the centre point of the path will move towards 9 o'clock direction, and the curvature of the path will increase. In the same manner, when the outer ring is rotated to the counter-clockwise direction, the centre point of the trajectory will move to 3 o'clock direction, and the curvature of the course will increase as well.

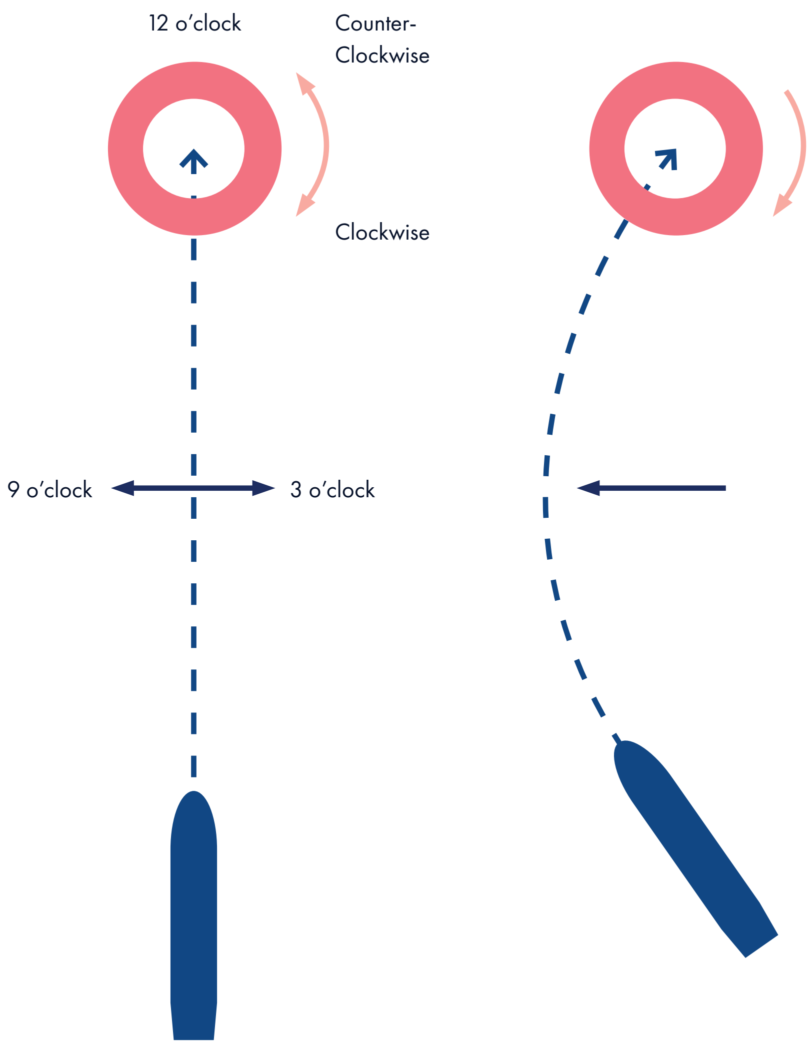


Figure 11. Path Curvature Control with the Course Control Wheel

3.1.3 Control Panel

The control panel includes the throttle for speed control, dynamic positioning mode switch, and automatic and manual mode selector switch (Figure 12).

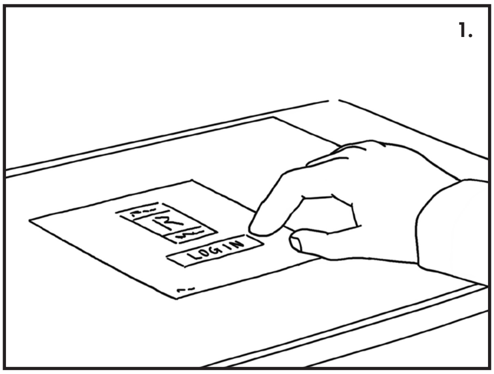
Most of the motorised vessels have throttles to control propulsion power. The control interfaces for remote semi-autonomous vessels also need to have a speed controller. In this thesis, the author is not designing speed controller. However, for a testing purpose, the control interface prototype should have a speed controller. Instead of designing a new speed controller the author will use a TWCS throttle designed for flight simulation games.

By using a dynamic positioning mode switch the operator can stop the vessel and maintain its position with the automation assistant. The remote operator can use this switch in emergency situations for example when all the sensors fail or the remote operation centre cannot get enough information from the ship. However, using this function in an ordinary situation can reduce operation efficiency. Thus, the switch is protected with a button cover.

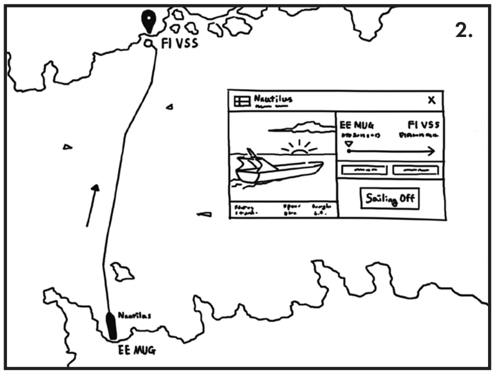
Autonomous and manual control mode selector enables the user to shift mode between autonomous and manual control flexibly. The remote operator will need to use this switch when the vessel can be autonomously operated or the automation needs human control.

Figure 12. Control Panel

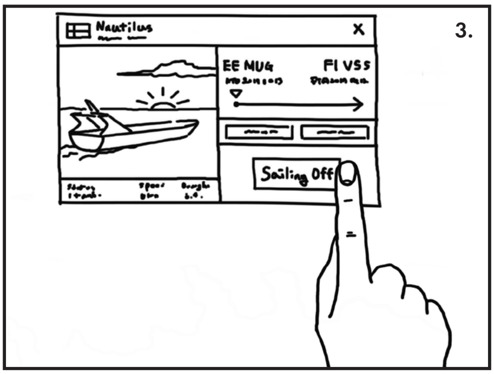
Figure 13. Instruction Manual



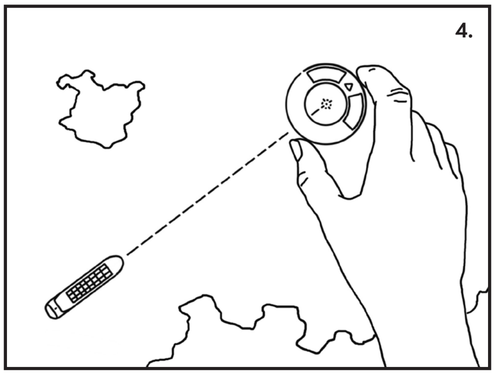
The remote operator logs into the supervisory control system.



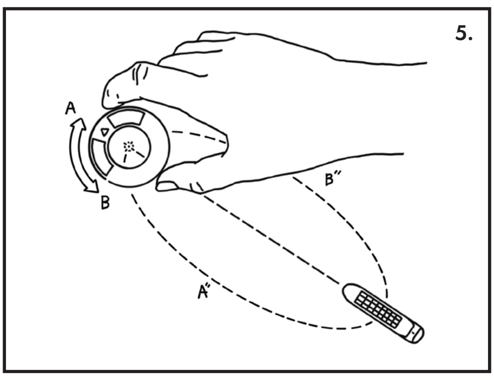
The display shows an overview of the operation and information of the ship under control.



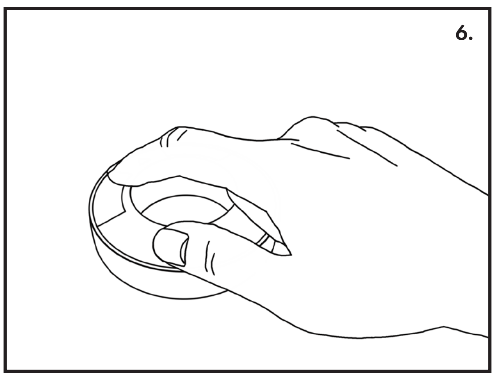
If the remote operator touches sailing off button on the screen, the operation begins.



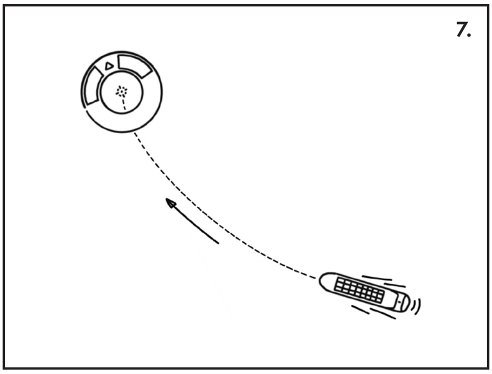
When the course control wheel is on the screen, the display shows the vessels selected path.



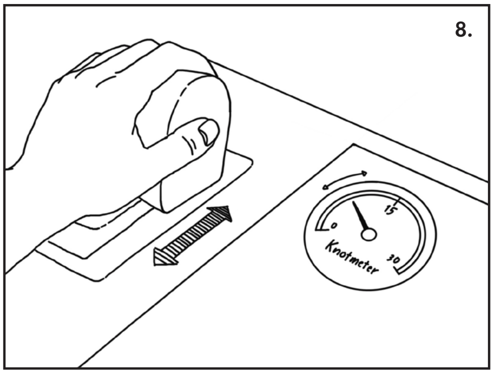
By turning the outer ring of the course control wheel the remote operator can adjust the trajectory of the ship.



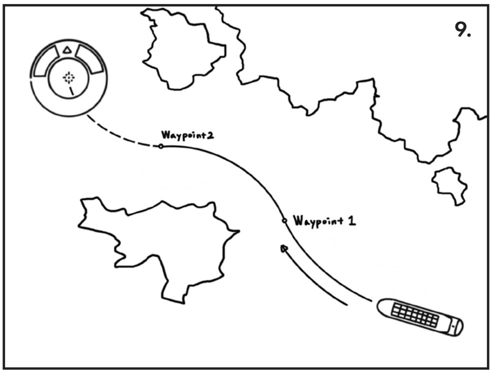
The remote operator can confirm the action by clicking the confirmation button on the top of the course control wheel.



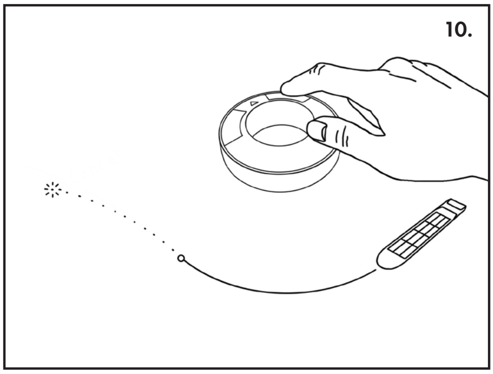
After the confirmation button is clicked, the vessel will follow the given course.



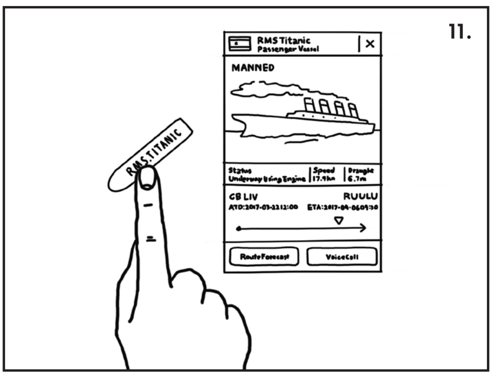
While the ship is moving the remote operator can control the speed of the ship with the throttle.



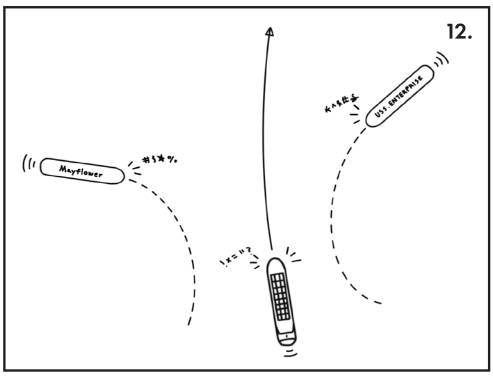
The remote operator can make multiple waypoints when the vessel needs complex manoeuvring.



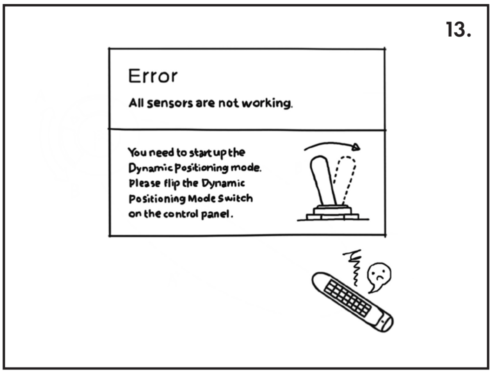
The remote operator can undo the waypoint confirmations by clicking the undo button on the top of the course control wheel.



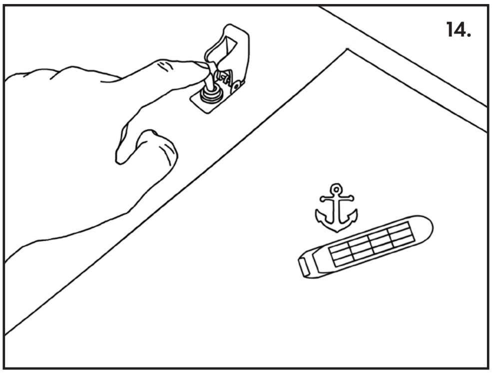
The interface shows information about the ship and voice call access when the remote operator touches ships on the screen.



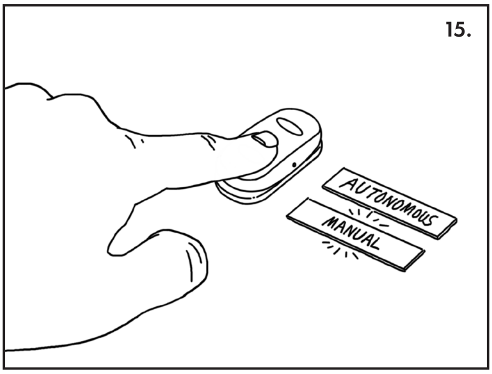
With the voice chat, the remote operator can communicate with other operators to solve minor incidents.



When the vessel or system receives/encounters an error, the display will show an error message with instructions to address the problem.



The remote operator can automatically maintain the position of the vessel by activating the dynamic positioning mode.



The remote operator can select between autonomous and manual control mode by changing the mode selector.

3.2 Usability Testing

The usability tests were conducted to understand monitor and control experience of the test participant, who utilises the supervisory control interface prototype. There were three usability test sessions in total.

3.2.1 Test Setting

On each session, the test was carried out with an individual participant. In total, three participants were selected for testing. Two of the participants were recreational sailors who have over three years of sailing experience on the sea. One was a remote autonomous ship expert. An instruction manual was created by the author to instruct the testers on how to manipulate the supervisory control interface prototype (Figure 13). During the usability tests the author recorded videos for analysis. Below is a list of test participants:

a) Recreational Sailors (RS):
RS 1. Sailed ship occasionally on the sea for 7 years
RS 2. Sailed ship occasionally on the sea for 5 years
b) Autonomous Ship Expert (ASE):
ASE 1. Research scientist at VTT Technical Research Centre of Finland

3.2.2 Tasks

The participants completed several tasks during the test sessions. The author asked every participant to undertake seven tasks that included a primary task and six subtasks. Before the test sessions, instruction manuals were given to the participants to instruct usage of the supervisory control interface prototype.

The primary task was transferring a semi-autonomous bulk carrier Nautilus from the Muuga port, Estonia to the Vuosaari port, Finland through supervisory control the ship by manipulating the designed interface prototype.

The primary task procedure is described underneath:

a) When the test starts, the display shows an overview of the mission with brief information about the vessel under control.
b) The operation begins when the tester clicks the sailing off button on the screen.
c) The participant will interpret information on the monitor interface and guide the vessel to the destination by manipulating the control interface.
d) When the vessel reaches the Vuosaari port, the test will be finished.

There were six subtasks including:

a) Conduct complex manoeuvre in the high traffic area,
b) Negotiate with other ships to determine ways to go,
c) Activate (Deactivate) dynamic propulsion mode when all sensors failed (recovered),
d) Change modes between manual and autonomous control modes,
e) Revise trajectory when following planned route is not available,
f) Report an accident on the sea to the emergency rescue service.

3.2.3 Limitations

The usability tests had limitations caused by the non-functional prototype, the short testing time, the lack of autonomous ship operator involvement, and the lack of multiple vessel control support.

The tested prototype was a non-functional mock-up, so it had no ability to interact with the test participants automatically. Within the test sessions, the author manually displayed elements on the screen depend on the user input. The duration of each test was about an hour, which is shorter than most of the cargo shipping operations. There were no autonomous ship operators within the test participants since there is no commercial autonomous cargo shipping yet. Moreover, the prototype design has not considered multiple vessel control, and the prototype only supports single vessel monitor and control.

3.3 Analysis

This section will present the analysis of the supervisory control interface design concept. The author assessed how the designed solution fulfilled the design requirements. Findings from the usability tests were evaluated against the design requirements.

3.3.1 Integration of Control and Monitor Interfaces

The idea of integrating the electronic navigational chart and the trajectory controller got positive feedback. The integrated interfaces allowed users to monitor and control the vessel simultaneously. The users could see how the ships move on the sea and could get sufficient information of the environment and the vessels around.

Because of the limited ability of the prototype the testers could not zoom in and out, or rotate the screen freely. All test participants mentioned multi-touch control on the mobile map application as an example of a solution. One subject suggested adding a mini-map showing the entire journey on the side of the screen.

The integrated interfaces helped users to plot the desired course. The testers were able to see trajectories of ships and topographical features on the display while they were planning the course. This enabled them to make a safe and efficient course plan.

During the tests the participants communicated with other ships and port control centres through the monitor interface. The testers selected ships or ports on the chart and communicated with them successfully.

However, one of the participants mentioned that inviting peers or leaving chat room requires too many clicks. He recommended having a dedicated communication menu that enables quick voice chat room management. Another participant said the SOS button is missing and the monitor interface must show it on the top layer.

3.3.2 Precise Manoeuvre and Speed Control of the Vessel

The participants were able to do complex and precise manoeuvre with the course control wheel. The author asked the test participants to manoeuvre the ship through high traffic archipelago. The testers made several waypoints on the navigational chart to create connected curves that the vessel follows. In each test, the vessels manoeuvred through the area without collision.

One participant suggested showing a pointer on the centre of the course control wheel. He expected that this feature could enable more precise waypoint control because the pointer would indicate the exact spot where the waypoint will be created. With the interactive screen, it will be possible to display the pointer on the centre of the course control wheel.

The participants controlled the speed of the vessel by manipulating the throttle. They were able to control the vessel speed with checking the speed through the knot-meter. However, one participant mentioned that in the future speed controller development the designer might need to consider how the ship can reach the particular waypoint in a specific moment of time.

3.3.3 Quick and Easy Revision of Plan

During the tests, the participants had not experienced such a serious issue related to the revising plan. They were able to quickly and easily remove predefined waypoints and create new ones while the own vessel follows confirmed trajectory and other ships moves around.

Although the interfaces provided a quick and easy way to revise the plan, the author found potential improvement for the plan revision function. One participant wanted to have a method that allows modifying the course without removing the waypoints. While testing the prototype he tried to pull the path with his fingers to modify it.

Since the waypoint controller creates continuous curves, modifying a part of the course may change the curvature of the whole trajectory. In the worst-case, the vessel might not be able to follow the course. The feedback shows that there is a need for a control method to change the course without undoing actions.

3.3.4 Understanding the Target Object of Control

During the tests, a scale model of the boat was used to indicate the position of the vessel. When the model ship was on the display, the testers could understand the current position of the vessel.

Knowing the position of the ship affected the interpretation of the visualised information on the screen. One of the participants misunderstood the arrival and departure port because there was no model ship on display and that caused him to confuse the destination marker and the ship position indicator on the chart.

Since the model ship is three-dimensional, it supported the testers ability to comprehend degrees of motion, for instance, pitch, roll, sway, surge, yaw, and heave. One test participant commented that showing a 3D model of the ship on the monitor interface would help the user to perceive the realistic feeling of the remote vessel.

3.3.5 Providing Essential and Non-Overwhelming Information

Participants said that the amount of the information on the display was not overwhelming. However, the author noticed that the users got a different amount of information depending on their background knowledge. Participants who had a lack of ability to read the chart missed some necessary information on the screen, for example, which area is the high sea or not and what kind of navigation rules they must follow in a particular area. While well visualised information would support operators to understand information on the screen, it is still important to train them to have enough operation related knowledge. One participant wanted to have a coordinate grid on the chart to communicate with other ships or the port control centre effectively.

3.3.6 Showing Necessary and Appropriate Information on Main Display

The participants mentioned that the display showed essential and proper information for operation. From the electronic navigational chart the testers obtained a lot of information including the trajectory of the ship, type of the waters, positions of the ships, topographical features, etc. They were able to navigate by monitoring main display and manipulating the controllers provided.

One of the participants said that the monitor interface does not give a realistic feeling of the ship. He recommended having an additional surround display that shows real-time 360-degree video from the ship. With the real time 360-degree video, the operator would get a perspective of the bridge.

The same participant also mentioned that the video feed would improve object recognition. In real operation, the remote operator will need to distinguish whether the floating objects on the surface are humans or debris when the automation asks.

3.3.7 Ergonomically Designed Control Interface

The prototype had 27-inch display, and the testers were satisfied with the size of it. The participants mentioned that they should be able to easily reach all corners of the screen with their arms to place the course control wheel on the screen. That means the screen size should not be too large. The tested prototype had a frame that is about two millimetres higher than the surface of the display. This gap caused the test participants hard to put the course control wheel on the edge of the screen to make a waypoint. In the later version development, the monitor interface has to be designed not to have such a gap.

The course control wheel is 65 millimetres in diameter and 15 millimetres in thickness. It is intended to be held with thumb and middle finger. Two participants said the device fit into their hand. Another participant commented that he would like to have a bigger one because of his larger hand size. There is a hole 35 millimetres in diameter on the centre of the course control wheel that allows the user to see through the display. The participants were able to see the screen through the hole and make a waypoint on the desired spot.

The side of the course control wheel is a rotatable ring, and it enables the user to modify the curvature of the course. The author expected that the testers might hold and rotate the outer ring with one hand, while they manipulate the throttle with the other hand. However, during the tests, the participants used both hands to hold and rotate the course control wheel. The bottom part of the course control wheel was slippery on the display, and that caused the users to hold down the inside part while they were rotating the outer ring. One tester commented that the bottom part of the course control wheel should be temporally fixed on the display when the user rotates the ring.

The course control wheel has two buttons on the top, which are confirmation button and undo button respectively. The confirmation button is painted with green colour, and the undo button is with red colour. Different colours on each button helped the participants to distinguish between them. Test participants were also satisfied with the size, shape, and arrangement of the buttons.

3.3.8 Intuitive Control

While participants were modifying the trajectory with the course control wheel, the author observed whether the author's intended usage of the course control wheel matches with the user's intuition or not. The tests revealed that intention of the author and expectation of the user matched. The participants said modifying trajectory with the course control wheel is intuitive.

Although the testers commented that the interfaces interacted intuitively, the observations revealed that they had completely different ways to direct the ship depending on their intuition. As a result of the tests, three different control styles have found.

The first participant plotted waypoints without modifying the curvature of the courses. Straight-lined paths were created between waypoints. This caused the ship to have to stop and go at each waypoint. Compared to other participants he made more waypoints when he was conducting complex manoeuvring. This control method was the least efficient one within the found control methods since it slows down the vessel and increases time and fuel consumption to finish the operation.

The second test participant first rotated the vessel on a fixed position and then increased the speed of it. When his ship was passing the high traffic area, he drew a straight-lined course that is not in contact with obstacles on the display. His vessel followed the path without slowdown. However, the vessel passed other ships too close by and nearly collided with them. In the real operation, this control method must not be applied when the vessel is passing narrow waterway.

The third tester planned courses with creating connected curves. Similar to the first participant he also made multiple waypoints when he was manoeuvring his vessel. Because the curves were continuous, the ship could keep its speed when it is passing waypoints. His control method was what the author intended the users to have, and it was the most efficient and safe course control method within the three control ways.

As the above findings revealed, only one participant intuitively employed the control method that the author intended. Although the instruction manual has provided before having tests, the participants intuitively created their style of control. The current design of interfaces seems to not effectively guiding users to follow intended usage.

3.3.9 Flexible Shift between Autonomous and Manual Control Mode

The author asked the test participants to activate autonomous control mode when the ship is entering the high sea. They changed the mode without having troubles. Switching to the manual control mode also caused no particular issues. Overall, they were able to shift control mode flexibly. However, the testers occasionally failed to perceive which control mode is currently activated. The mode indicator was not visible to the users while they focus on the display. A participant noted that if the user is trying to control trajectory or speed of the vessel in autonomous control mode, the mode should be automatically shifted to the manual control mode. The testers liked to have a physical toggle switch to change modes because it brought them a secure feeling of control.

3.3.10 Dynamic Positioning System

The author provided sensor breakdown scenario to the testers to observe how do they utilise the dynamic positioning function. The test participants successfully followed the instructions on the error message to maintain the position of the ship until the sensors are recovered. The participants enabled or disabled dynamic positioning function by toggling switch on the control panel. The cover on the dynamic positioning mode switch prevented possible control mistake.

3.3.11 Threshold-Crossing Alarm

The ideas of threshold-crossing alarm were not tested because the prototype was non-functional.

3.3.12 Autonomous Prediction

The test participants frequently used the route prediction function while they were plotting the course, especially when other ships were close by or they interfered with navigation. Although the testers found that the route prediction function is useful, two of the participants said that the way to enable or disable the function requires too many clicks. With the current graphical user interface, the operator needs to select ships and click route prediction button one by one to see the predicted routes. Two testers suggested an intelligent route prediction system that selectively shows only predicted routes of interfering ships around. One tester wanted to have a list of ships around on the right side of the screen, which shows potentially obstructing vessels on the top.

3.3.13 Primary Task Priority

The test participants were able to monitor and control the ship while they had subtasks, for instance, having voice communication or checking vessel information. However, the effect of distraction while conducting the operation has not been studied properly.

4

Conclusion

4. Conclusion

The aim of the thesis was to suggest design directions for the supervisory control interface for the semi-autonomous cargo vessel. Designing a dedicated supervisory control interface for semi-autonomous cargo ship operation is supposed to support the remote operator to attain intuitive and precise instruction of the route plan. However, the design guidelines have not been clearly defined, because there is no semi-autonomous shipping yet.

To achieve the above goal the author proceeds to answer the question: "How to design a supervisory control interface for a remote semi-autonomous cargo vessel system to enable intuitive and precise instruction of the course plan?"

To get an understanding of the problem space, the literature review and expert interviews were conducted. The literature review provided contextual and theoretical knowledge to design a supervisory control interface. The expert interviews with video gamers and autonomous ship experts helped the author to predict potential user needs and design considerations. Findings from the literature review and expert interviews were combined and formulated in the design requirements.

In the solution space, the design requirements were applied to the design of a supervisory control interface prototype. The prototype was used in the usability tests for evaluation. The findings from the usability tests were analysed against the design requirements to evaluate how the designed interfaces fulfilled the design requirements.

Combining the design requirements and evaluation of prototype provided the answer to the research question of the thesis. The author suggests three design themes for semi-autonomous vessel supervisory control interfaces design:

a) Providing Situation Awareness:

The remote operators perceive situation of the vessel and its surroundings through the interfaces. Combining an electronic navigational chart and a course planner allows users to monitor circumstances on the sea and manoeuvre the vessel concurrently. The electronic navigational chart must provide all necessary information for navigation on it so that the operator could carry out the operation without additional displays in most of the cases. The mini-map will present an overview of the entire journey. Real time 360-degree video on a surround display may improve object recognition and deliver realistic feeling from the vessel. The operators must be able to understand where their ships and other ships are located. A 3D model of the ship on the navigational chart will support users to get a grasp of the degrees of motion. Moreover, visualising data and logic of automation in a user-friendly manner is crucial. Also, users must be able to understand which control mode is currently activated while they focus on the display. The perceivable amount of information varies on the background knowledge of the individuals. Hence, operator training is as important as interfaces development regarding situation awareness.

b) Intuitive Manipulation:

The interface design should enable intuitive manipulation. Physical controllers, for instance, course control wheel, switches and levers provide direct manipulation and secure control feeling to the users. The course control wheel enables a user to plan and modify the course. Besides, it is good to have physical switches to control the critical functions. People are familiar with touch control nowadays due to the prevalent touch controlled devices. Thus, many of functions could be implied to the touchscreen (e.g., selecting ships or ports, activating or deactivating functions, sending a rescue signal, modifying courses, zoom and scroll chart). Individuals have their styles of control, and they create new control methods based on their intuition. The interface design should guide the user to follow intended usage of the designer. Enabling or disabling functions should not require too many steps to follow, and it needs to be simple and easy to perform. Furthermore, instruction on the error message helps users to solve problems intuitively.

c) Collaborative Control:

In semi-autonomous cargo ship control, human operator and autonomous system collaborate. The collaborative control has potential to improve operation performance. However, that is possible only if the interfaces are designed to assist human-automation teaming. Displaying predicted result of user input or showing expected courses of the ships around helps route planning. Intelligent route prediction function that selectively shows only anticipated courses of obstructing vessels around has to be developed. Also, the interface must alarm users if the autonomous system or the user is taking extreme action or if the ship is reaching its limit of ability. A threshold-crossing alarm is a possible solution for this issue. Moreover, the human operator has to support the autonomous system whenever it asks, and vice versa. Flexible switch between autonomous control and manual control mode is mandatory. Furthermore, when the both autonomous system and the operator cannot take control, the vessel must maintain its position with the dynamic positioning system. The interfaces must have a switch for activating and deactivating dynamic positioning function. Most importantly, the design of the interfaces should build trust between the operator and the vessel to facilitate collaboration.

Applying these design themes to remote semi-autonomous vessel development will enable designing successful supervisory control interfaces and provide intuitive and precise course planning ability to the users. The findings of this project will present several directions for future research activity, such as researching an unmanned surface vehicle supervisory control interface. The design concept still needs to be developed further. Building an interactive prototype is necessary for testing the interactive functions and understanding human-automation interaction.

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