University of Strathclyde
Department of Computer and Information Sciences

Assessing the Effectiveness of Direct Gesture Interaction for a Safety Critical Maritime Application

by
Frøy Birte Bjørneseth

A thesis presented in fulfilment of the requirements for the degree of

Doctor of Philosophy at the University of Strathclyde

September 2010

Signed: Date:

Dedicated to my loving family
who has supported me and nourished my curiosity for knowledge.

Acknowledgements

A few years back, doing a PhD seemed like reaching for the stars, something that was almost unreachable. Today, the book is complete with a glossy cover page, figures, tables and many chapters filled with hours, days and years of work. It is filled with knowledge that has been gathered from many fields with the aim of making a difference. Even though the journey of finishing a PhD must be completed alone, the environment surrounding me has everyday ensured me that I should not feel lonely and it has encouraged me to keep up the work even though it sometimes felt endless. Without the support of my employer, my supervisors at the University of Strathclyde, my family and friends, completing this degree could have been a different story.

I would first of all like to thank my employer Rolls-Royce Marine AS for making this PhD a reachable goal. Thank you for all your support, both financially and as a workplace that inspires to great thoughts through providing a fantastic work environment filled with great colleagues and exciting projects.

I would like to thank my supervisor Dr. Mark D. Dunlop. He has offered me fantastic support, advice, inspiration, help, tips and hints. The weekly phone calls to Scotland have been a rock throughout the three years of being an overseas student. For this I will be forever grateful. I would also like to thank Dr. Eva Hornecker who has, as a second supervisor, given great advice when I was writing my research papers, doing my studies and writing my thesis. I would also like to thank Dr. Andrew McGettrick for great advice and support during my annual reviews. In addition, I would like to thank Dr. Paul Marshall at The Open University for wonderful help of explaining me the world of statistics in an understandable format.

I would like to thank Aalesund University College for great help during my user studies, providing access to using the ship motion simulator and forwarding messages to the test participants. In addition, a big thanks to the students who participated in my studies and helped me with setting up equipment and programming the visualisation of the simulator.

The maritime human factors environment has welcomed me into their circles and I thank Margareta Lützhöft (Docent at Chalmers University of Technology) for introducing me to so many great people.

To the LadyGeeks (Michelle, Emma and Christine), who have given me great support and help with proof reading and advice through long lunches in Glasgow.

I would like to thank my loving family who has since I was a child supported my development and learning. Thank you mum and dad, who planted the seeds of knowledge for them to grow and develop into curiosity and a desire for more learning. Thank you for your endless support when things felt tough and for always reminding me that *'knowledge is power'*. I would like to thank my brothers, Gisle and Torje, for giving me my interest for technology and gadgets, and always filling me in on the latest technology news.

Finally, to Raymond, who has endured my nights and weekends of working and kept my feet on the ground when I have been stressed. You are my rock, my love and best friend.

Abstract

Assessing the effectiveness of direct gesture interaction in a safety-critical maritime application, hence a Dynamic Positioning System is an assessment that is novel to the maritime domain. The traditional interaction techniques used to manipulate a vessel at sea, such as joysticks, levers and buttons, have in the later years been challenged by touch displays. Physical buttons are being replaced by graphical buttons and menu structures, where the operator interacts with the system's graphical user interface. In many cases, the design of the interfaces and placement of the equipment is poorly fitted to suit the users' needs, which leads to an increase of cognitive load and physical strain on the operator. In the commercial market even newer interaction techniques such as using multi-touch and hand gesture interaction, have become much used in everything from mobile phones to computers. The interaction seems to be carried out seamlessly and naturally, and aims at giving the user an easy access to operating different interfaces, hence lowering the user's cognitive load. The technique has yet to become available in industrial software applications that often control safety-critical systems.

The research described in this thesis aims at lowering the operator's cognitive load when operating the safety critical dynamic positioning system by utilising direct gesture interaction. Cognitive load can shortly be explained as how hard the brain has to work when carrying out tasks. If the brain has to work very hard to carry out a task, this can cause stress and as a consequence more likely lead to more errors. The investigation addresses the questions concerning if the novel interaction technique can make the interaction safer by reducing error count, more efficient by reducing task completion time and making the operator feel more in control of the operation by enhancing the overall interaction experience. By completing five user studies, the findings from the comparisons between traditional touch button and menu interaction versus direct gesture interaction were used to answer the above questions. In addition, the different techniques were evaluated in both a moving and a static environment, to investigate how motion affected performance.

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Abbreviations

2D- Two Dimensional

3D- Three Dimensional

ANOVA- Analysis of Variance

API – Application Programming Interface

DOF – Degrees of Freedom

DP – Dynamic Positioning

DV – Dependent Variable

FIR – Finite Impulse Response

GUI – Graphical User Interface

H - Hypothesis

Hi-Fi – High Fidelity

HMI – Human Machine Interaction

HW – Hardware

IIR – Infinite Impulse Response

ISO- International Organization for Standardization

IV- Independent Variable

jME – Java Monkey Engine

Lo-Fi – Low Fidelity

PSV – Platform Supply Vessel

ROV- Remote Operated Vehicle

SMS – Ship motion simulator

SW – Software

TED – Technology Entertainment Design

1 Introduction

The maritime environment is deeply rooted in traditions and has over the last few years experienced an interesting and user-challenging technological development from suppliers of maritime equipment. The automation systems are continuously growing more advanced and the mariners have to keep up with technology. The demand of increased computer and technology related knowledge can for some people feel overwhelming, while for others it feels natural and a part of everyday life. The division is often, but not exclusively, age related with the younger generation of mariners feeling more comfortable with technology than the older generation (Paul and Stegbauer, 2005).

The increasingly advanced automation systems controlling modern vessels lead to increasingly advanced and complex user interfaces. Furthermore, a typical operator must interact with many different systems, often with different interface styles, during an operation. On Dynamic Positioning (DP) vessels, which is the key focus of this research, the operator's situation can become stressful as (s)he must interact with at least three different systems concurrently– each with its own graphical user interface (GUI) and display. A DP vessel is a vessel running a system called the DP system which is operated by the DP operator. This system maintains the vessel's geographic position without using anchors. Such vessels are most often utilised for offshore tasks in the oil and gas industry. This will be further explained in chapter 2. In addition to interacting with several systems concurrently, the operator must lead the radio communication, have an eye on the propulsion system and maintain constant observational awareness of the environment around the vessel. This can be a challenge both mentally and physically and the cognitive load can increase if presented with too much information (Lazet and Schuffel, 1977). The physical strain also affects the operator if the equipment is poorly ergonomically placed (Galliers et al., 1999). Depending on the ship owner, the shipyard and the suppliers of equipment, the composition of the equipment in the operator station can vary considerably and is often ergonomically sub-optimal.

Human Machine Interface (HMI) work has a long history in maritime settings, but is often given low priority due to perceived increased development time and economic pressures. The economic aspects play an important role in a vessel's lifecycle and issues concerning HMI and usability are in many cases not a part of the discussion until late in the cycle when it is often too late and expensive to make vital changes to obtain an optimal solution (Sillitoe et al., 2009). Today's trend is moving towards a more noticeable awareness around HMI issues, but is still not always properly accounted for. An overall increased mental load when using a system is both tiring and leaves less mental capacity for handling safety-critical events. Such events are not prominent in every-day operation, but when they occur a high mental load can reduce the operator's experience to the level of a novice (Redmill and Rajan, 1997). Poorly fitted equipment combined with low usability causes a long–term problem for the operators. Unlike personal consumer equipment, which can often be easily replaced if the consumer is unhappy with the interface or usability, equipment installed on vessels typically lasts many years and will not be replaced before its operating time has ended. The overall aim of maritime HMI research is to lower the operator's cognitive load and make the workflow more efficient by introducing interaction techniques known from other HMI domains, such as mobile technologies and personal computers, while also assessing them by using usability methodologies. These will be listed in section 1.2. In safety-critical situations a lower cognitive load will require less attention on how to operate the system and enable more focus on the actual operation.

Within this research the focus is directed towards multi-touch interaction[1] – a form of interaction that was popularised by Apple on the iPhone range but which has existed in research laboratories since the early 1980s (Lee et al., 1985). Multi-touch interaction will be further discussed in Chapter 2. There has been a discussion around the definition of multi-touch - whether it is being more than one or more than two touch points recognized.

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[1] Multi-touch is a human computer interaction technique together with the hardware that implements it. This allows the user to interact with the computer without using the conventional input devices. Multi-touch consists of a touch-display that can recognize more than one point of touch and there is a range of different technologies that implements it (Buxton, B., 2007) (Lee, SK., 1985).

In terms of this research all interaction involving one point of touch will be referred to as single touch, while when there is more than one point of touch on the display surface, it will be referred to as multi –touch. When the user interacts with the interface using a set of predefined movements (hence gestures) with more than one touch point on the display surface (multi-touch), this will be referred to as direct gesture interaction.

Multi-touch interaction seems to have a great potential for bringing the interface physically closer to the user, hence having the display interface in front of the operator in a worktop-like position. This eliminates the necessity to stretch to reach the touch interface and the user can rest his/her hands on the worktop's (display) surface. Natural conservatism concerns must be born in mind through the rest of this research. However, none of the observations done contradicted the original idea and design. This research investigates multi-touch interaction on DP-systems and in particular if it is possible to carry out the tasks faster and more safely when operating the Rolls-Royce Icon DP system using multi-touch interaction. The hypothesis is that the user interface will be brought physically closer to the operator by enhancing the operator's possibilities for directly interacting with the interface of the maritime software application by using multi-touch gestures. This ties the advanced maritime interfaces together with its increasing resemblance to modern technological consumer products where multi-touch has introduced a new dimension of interaction techniques.

In this thesis the discussion revolves around the methodologies used: an iteration of creating prototypes and assessing their usability through user studies. The key contribution of the thesis is to assess using direct gesture interaction in a specific safety-critical environment. This is supported by five different studies; one observational study (see figure 1.1) and four different iterations of user studies. An overview of background and technologies used will initiate this thesis, followed by a description concerning prototyping on different levels. Lastly the studies will be described. The initial study is based on a paper prototype where the aim was to investigate which gestures felt natural to use when operating a DP system. The second study was based on the results from the initial study, but where the aim was to investigate the efficiency of using multi-touch gesture interaction versus traditional touch button and menu interaction when operating the DP system in a laboratory environment. The two last iterations of studies concerned a pilot study where the aim was to investigate how motion affected task performance when doing tasks using multi-touch gesture interaction and a main study. The main study investigated operating the DP system in a moving and static environment while comparing the usage of gesture interaction versus touch button and menu interaction when operating. For each study the motivation for the methods chosen will be outlined together with the key results and lessons learned.

1.1 Research Agenda

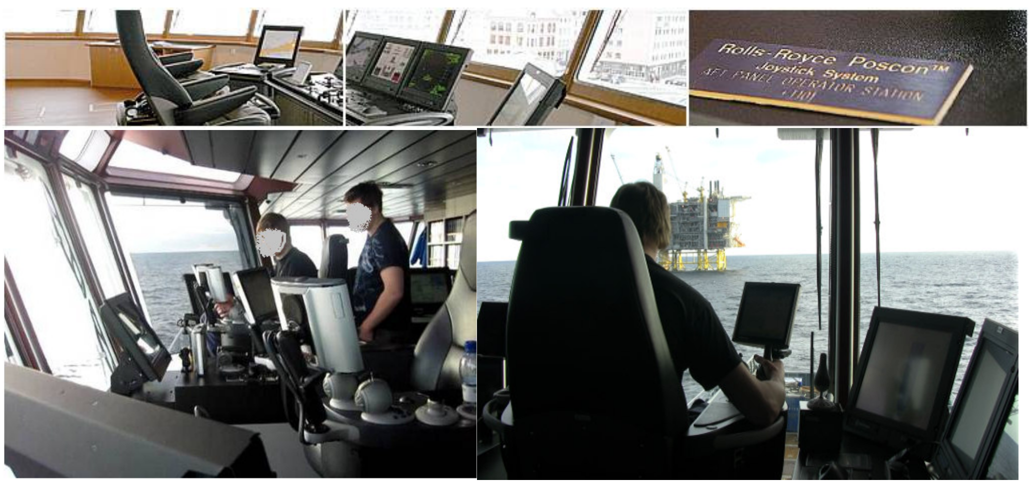


Figure 1.1: Top: DP operator station. Bottom Left and Right: DP operation in the field.

Researching human factors (HF) in the maritime domain has been well documented through many years of research by scholars. The psychological as well as the physical aspects of how the human is affected by motion and stress on board has been a topic of interest since early times. However after oil and gas became one of the most important export and import merchandise we have, the search for fossil fuels offshore in oceans with both great depths and harsh environments, have developed a market for a fleet of specially equipped vessels that can stand these environments and support offshore operations. The equipment with its software has in many cases been directly transformed from strictly button based interaction to becoming more based on direct interaction between the user and the graphical user interface (GUI), often touch screen based. The software has been developed by engineers often with little thought about how the operator's state of mind is at different stages through the operation where the operator must navigate through forests of menus to find what they are looking for. This prolongs the operation and in a safety critical situation time can be vital. Little research has been done on developing new interaction techniques that can replace or support the traditional touch button and menu interaction. In the last few years new technologies have emerged that supports direct interaction with the displays using the hands and gestural interaction. This is only commercially available today in consumer products where it has had great success and is seen as the new way of interaction with computerised systems. There is little doubt that in its right shape this technology can also be utilised in the industrial world and in this case the maritime realm.

This thesis attempts to address the challenges around developing multi-touch interaction techniques for maritime software applications where the focus is directed towards dynamic positioning (DP) systems. Here an empirically grounded investigation of the usage of direct gesture interaction to operate a safety–critical maritime system is presented. During this research it has been investigated through studies (observation and usability) and prototypes on different levels of fidelity which gestures would feel natural to use when operating the DP system. The gestures found were utilised in further studies to investigate the efficiency and accuracy of gesture interaction versus touch button and menu interaction in a static versus a moving environment. The studies were carried out in a controlled laboratory environment (static) and a moving environment in a ship motion simulator (SMS). The SMS presented a more realistic setting that included realistic audio of sounds on a vessel at sea, realistic visualisation and movement. Finally the results from the studies were compared and a conclusion drawn where the results answered three hypotheses and gave an interesting pointer to which issues to address and pay attention to when developing direct gesture interaction based applications for the maritime environment.

1.2 Aims and Objectives

The overall aim of this thesis is to investigate an interaction technique that could possibly lower the operator's cognitive load and make it possible to carry out the tasks faster and more instantly when operating the DP system. The user interface will be brought physically closer to the operator by enhancing the operator's possibilities of directly interacting with the interface of the maritime software application by using direct gesture interaction. In safety-critical situations a lower cognitive load will require less attention on how to operate the system and enable more focus on the actual operation.

The three main hypotheses/objectives of this thesis are as followed:

H1: Direct gesture interaction will enhance safety in DP- operations.
This will be tested by measuring error rate per task and reaction time to distraction tasks in an initial study in a usability lab setting and latterly in a ship motion simulator setting. These studies were based on the results from an observation study.

H2: Direct gesture interaction will enhance efficiency when using the DP system.
This will be tested by measuring task completion time in three separate user studies where one was carried out in a ship motion simulator setting.

H3: Direct gesture interaction will enhance the user's feeling of control when operating the DP system.
This will be tested by analysing qualitative data collected from an observation study and from questionnaires and post-experiment discussions during user studies.

1.3 Approach

The research methodology employed in this thesis is based on an attempt to combine methods used for previous research done within the traditional human computer interaction domain and methods used in human factors research in the maritime domain. The starting point of the investigation was to gather as much information as possible about multi-touch technologies, previous research done in the field and collect knowledge about the maritime environment. In addition to investigate the literature revolving around what was beneath the umbrella term "human factors in the maritime domain". The book 'Human Factors in the Maritime Domain' written by Grech, Horberry and Koester (2008) gave useful insight into the topic and provided a good summary of what literature to investigate more thoroughly. Issues around human error (Dekker, S., 2006) (Reason, J., 1990), the human element (RINA, 2009) (Hutchins, 1995) and safety-critical systems (Redmill and Rajan, 1997) were investigated. In terms of multi-touch literature, multi-touch and bi-manual interaction has been around since the early 1980's. An example from early work is the studies done by Buxton and Myers (Buxton, W. and Myers, B., 1986). These studies were investigated to gain insight in the first attempts of multi-touch interaction with a computerised system even before the computer mouse was introduced to the markets. Further on literature concerning testing of different gestural techniques (Balakrishnan and Hinckley, 1999; Ball et al., 2007; Benk et al., 2006; Chatty, 1994; Epps et al., 2006; Forlines et al., 2007; Gingold et al., 2006; Hancock et al., 2007; Kabbash, Buxton and Sellen, 1994; Latulipe et al., 2006; Owen et al., 2005; Yee, 2004) gave useful knowledge to avoid designing a set of too many or too complicated gestures.

The next step was to take the knowledge and ideas gained from literature and previous research and do studies that involved prototyping. Knowledge of prototyping and the iterative design process, was gathered from the book by Dix, Finlay, Abowd and Beale (1997). A low-fidelity prototype made of cardboard and paper was the first stage of prototyping. All iterations of prototyping supported the throw-away approach, where the prototype was used to test a principle and not to be used in any final products. In the maritime domain all equipment used on board has to be thoroughly tested in different environments and conditions by maritime classification societies such as Lloyd's Register or DNV (Det Norske Veritas). They issue certificates that the equipment is safe for usage on board vessels. The second and third iteration of prototypes were hardware and software based where the test participants in the user studies could realistically interact with the DP system.

This research has a combined qualitative and quantitative approach. In the initial study where the paper prototype was utilised, only qualitative data was collected. This data was further used for designing the next prototype that were, as mentioned, hardware and software based. For this iteration both quantitative and qualitative data were collected. The quantitative data was collected in the shape of timing the tasks done in different conditions and doing a simple statistical analysis to see if there were any significant effects between them. The following user studies involved a pilot study and a main study. More variables were added to the experiments and the effect of how motion affected performance was investigated. This resulted in a more advanced statistical analysis and a comparison of the results with previous research done in the field of motion (Doubie, 2000) (Wertheim, 1998) (Stevens and Parsons, 2002) (Holmes, MacKinnon, Matthews, Albert and Mills, 2008).

1.4 Publications Related to Thesis

From this thesis two research papers have been published. The first paper, Dynamic Positioning Systems- Usability and Interaction styles (Bjørneseth, Dunlop and Strand, 2008), concerns the initial study where the user study using the paper prototype was discussed together with its findings. This paper was published at the ACM conference, NordiCHI'08, for a human computer interaction audience. The paper went therefore more thoroughly into the topic of DP systems to give the audience a better insight into the maritime challenges. In addition it gave a good overview of the field of multi-touch research and gesture interaction. This paper has been published in ACM's Digital Library. The second paper, Assessing the Effectiveness of Multi-Touch Interfaces for DP Operation (Bjørneseth, Dunlop and Hornecker, 2010), was published at an all maritime human factors conference called Human Performance at Sea. This conference gathers the core of the environment of maritime human factors researchers and the paper discussed an overview of the doctoral work, which studies had been conducted including the observation study and four iterations of user studies, the methods chosen and a summary of some of the results. This paper gave a more thorough outline of the human computer interaction field due to the audience coming from a maritime environment. In addition to the above a small article, Maritime Software Development-Keeping HMI in Mind, has been published in an internal global Rolls-Royce magazine hosted by the Software Centre of Excellence. This article discussed the importance of human machine interaction (HMI) when developing maritime software applications.

Subsequent publications are planned on the observation study (chapter 4) and the final experiment (chapter 7).

1.5 Chapter Overview

This thesis is structured into eight different chapters where chapter 2 starts with giving a background investigation to the maritime realm and dynamic positioning systems. Further on it continues with discussing human factors, human error and giving an overview of research done connected to multi-touch and gesture interaction.

Chapter 3 gives a description of the initial study where a paper prototype was used to investigate which gestures felt natural to use when operating a DP system. The results found gave the basis for further iterations of prototypes and resulted in three hypotheses that formed the base of this thesis.

Chapter 4 gives a thorough description of the life on board a platform supply vessel where several different DP operations were observed (night and day operations). These gave a good insight in how the operation and the procedures around the operations were carried out.

Chapter 5 describes the different types of technologies used for this research. Two different display technologies to obtain multi-touch input was utilised in addition to three different programming languages. Network communication and practical issues will also be discussed.

Chapter 6 concerns the second iteration of user studies where both quantitative and qualitative data was collected. The prototype used was hardware and software based technology and the user study gave a comparison between using touch button and menu interaction versus gesture interaction to operate an authentic DP system. The results gave the basis of the two next iterations of studies.

Chapter 7 describes the two last studies in this research. Here a pilot study and a main study gave results that corresponded with previous research done in ship motion simulators (SMS). It was desirable to test how motion and cognitive distraction tasks affected performance using two different input techniques, gesture interaction and touch button and menu interaction. The findings gave the basis to compare with the previous studies done by others and conclude to find issues that are important to consider when developing multi-touch and gesture based maritime applications.

Chapter 8 is the last chapter which gathers all the threads together and gives a final conclusion. There will be an outline of the contributions and the experiment results given, implications for design of maritime systems, a future work section and a summary with a thesis conclusion. This marks the end of this research.

Following chapter 8 are appendices that contain published, unpublished paper, articles, questionnaires used for user studies, notes written and different items from the observation study (map of bridge movement). The last section is a bibliography that gives an overview of all literature read and utilised in this research.

2 Background and Related Research

2.1 Introduction

Throughout history the boat has been vital to the development of the society we have today. From the early beginning of mankind we have travelled by various types of boats using small wooden canoes, Viking ships, rafts and other types of vessels to carry load and people up rivers and across oceans. The forward driven force of the vessel went from force created by human strength, wind- driven force, steam and various combinations of the previous mentioned, but the breakthrough for maritime industry came with steam and the invention of the combustion engine. This introduced more efficient and rapid ships, which sparked the need for petroleum related products. The search for "black gold", oil, became more excessive and in the late 1960's Norway, today one of the world's leading countries within petroleum industry, discovered oil on the Norwegian continental shelf and drilling commenced in the 1970's. This was the introduction of what is called the Norwegian offshore adventure and offshore vessels were constructed to supply the oil rigs situated in the North Sea. Norway was not the only country benefitting from export of fossil resources and oil prospecting became one of the more important activities in countries where oil was discovered. The petroleum industry had been present for almost 100 years before drilling in the North Sea commenced, but oil did not gain any real percentage of the fuel market before the usage of coal declined in the 1950's.

With extended offshore activity worldwide, new equipment was needed to be able to carry out the different operations related to oil prospecting and drilling. This included among other factors the oilrig itself, supply vessels, anchor handling vessels and tankers. The North Sea can in certain areas have a maximum depth of around 700 meters (2300 ft), whereas in other drilling areas the depths can increase notably from this figure. The captains and mates on offshore vessels operating on deep waters were in need of more advanced technological equipment to maintain safety and also to carry out rapid, cost efficient offshore operations. With large depths it is impossible to use anchors to maintain position and new innovations were necessary, this introduced the first dynamic positioning systems.

With more advanced systems and technology, the complexity of the equipment has increased and in parallel the difficulty of operating the new equipment has also increased. Human machine interaction became an issue on large vessels, but the usability seemed to be a less important chapter in the development of much needed new safety critical technology. Today many vessels still struggle with poor usability of the equipment and maritime software, and the operators work in an environment with too many buttons and switches. This may lead to extended safety issues in combination with poor focus on usability from the suppliers of maritime equipment.

Commercial technology, like mobile phones and laptops for non- industrial use, have developed at an exponential pace during the past decades, where all types of simplified and advanced technology are available for personal use. Technology for industrial use has also sped forward, but there seems to be a trend that slows down the simplification of the equipment. The operator is often not prioritised when the products are designed. This is not the case for all industrial equipment, but in the maritime sector it has been an issue. The systems designed, often seem to be stuck in an old track with low aesthetics and too many buttons and switches to deal with. Whether the level of difficulty is at this point because the operator has extended training and education, is unknown.

With this research it is desirable to approach the issues around the dynamic positioning system and investigate a new interaction technique that can ease the DP-operators' work style when operating large vessels using dynamic positioning. In addition it is desirable to present a concrete set of recommendations that can function as a guideline to software developers developing multi-touch and gesture applications for the safety-critical industry. The aim is to provide the operator with a simple system that feels natural and intuitive to use and also maintains safety. The basis of this research will be Rolls- Royce Marine AS's dynamic positioning system.

This chapter will give the basis for understanding this research and will start by giving an introduction to the technology and principles behind dynamic positioning systems and connect the maritime realm with human machine interaction (HMI). Further the issues behind human error and human factors in a safety-critical environment will be outlined. The chapter will close with a chapter summary, summarizing the most important features of the chapter.

2.2 Dynamic Positioning

After Dynamic Positioning (DP) systems were invented and came into use, it has made deep water drilling possible and simplified the offshore operations significantly. Today many operations are dependent on the possibility of using dynamic positioning and new areas of use have emerged. The offshore petroleum industry has been one of the world's leading industries for almost 50 years. Today there are pipelines and installations embedded on the ocean floor that supplies the different refineries in all parts of the world with necessary natural gas and oil. This crude petroleum is essential to produce the different well- known petroleum products that are used by a majority of the world's population every day. Here dynamic positioning introduces a whole new spectre of possibilities to offshore industry where a high density of subsea installations, very deep water and other relevant problems make mooring and/or anchoring not possible.

Dynamic Positioning (DP) can be defined as:

- *A system which automatically controls a vessel to maintain position and heading exclusively by means of active thrust* (Bray, 2003).

Definitions like the above are not always sufficiently descriptive and needs further explanation.

To simplify the definition further we can define a DP as:

- *A computer controlled system to automatically maintain a ship's position and heading by using her own propellers and thrusters (Kongsberg, 2010).*

Dynamic Positioning developed from Cuss 1 (see figure 2.1) in 1961. Cuss 1 was a drillship equipped with four manually steerable propellers that kept the vessel in position above the well and could drill at a depth of 948 meters. The same year, Shell launched their new drill vessel Eureka, which was in contrast to Cuss1, equipped with an analogue control system that interfaced with a taut wire. The first DP vessel was now in operation and from one DP vessel in 1961 it has grown to over 1000 modern DP vessels worldwide today (see figure 2.2).

Figure 2.1: The first drillship Cuss 1[2]

[2] In courtesy of Offshore Magazine: http://www.offshore-mag.com

Figure 2.2: Modern drillship (Island Wellserver) [3]

A Dynamic Positioning system is not only a piece of software or hardware installed on the bridge of offshore vessels, but a complete system that includes everything from operator stations, position reference sensors, gyro compasses and a range of different sensors that give feedback to the operator about the ship's position and the forces that influence the vessel's direction. The system is connected to the vessel's thrusters and propulsion systems and will, on signal from the sensors, manipulate the vessel to maintain its position and not drift off. The DP system will include all the vessel components which contribute to the function of the station and the heading keeping. This includes also the power supply, the propulsion facilities and other factors included when dealing with special ships like e.g. pipelay vessels. On vessels that operate in hot weather conditions, air conditioning must also be taken into consideration to cool the DP control computers. The DP- system can therefore be described as a packet the ship owners buy, which contains a great variety of components that needs to be adapted to the vessel's specifications (see figure 2.3). The Kalman Filter shows the different components that need to be adapted to the vessel's specifications.

[3] In courtesy of : Norwegian Petroleum Safety Authority: http://www.ptil.no

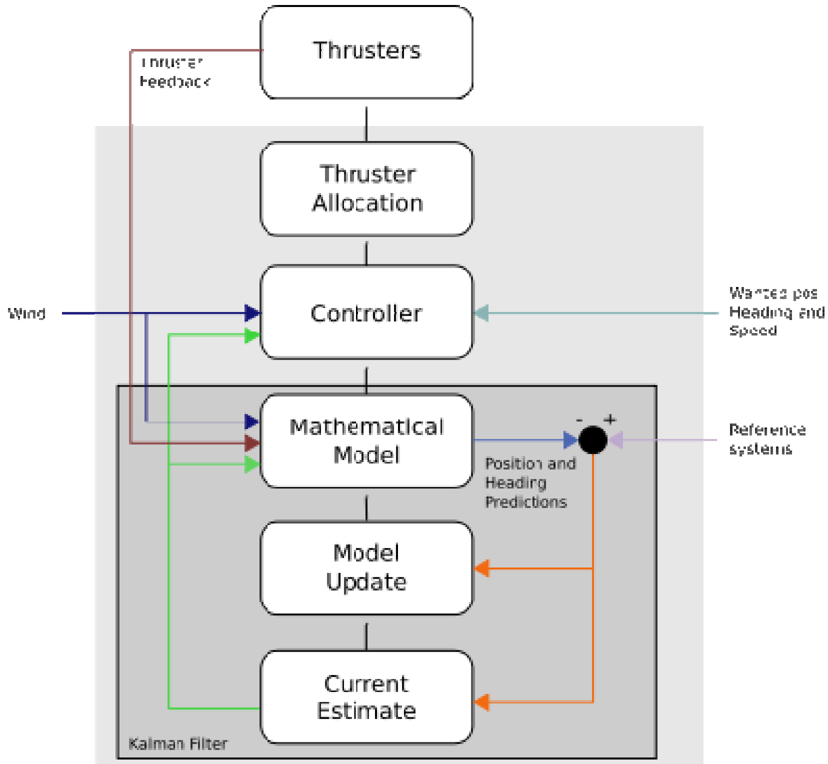


Figure 2.3: Example of Kalman Filter (Bray, 2003) utilised in DP systems.

2.2.1 Degrees of Freedom

A vessel has 6 degrees of freedom (DOF) which enables it to move around three axis, the x-, y- and z –axis (see figure 2.4). This give three rotations and three translations, which can be described as roll, pitch, yaw, surge, sway and heave. The main priority of a DP system is to maintain position and heading, where a variety of subtasks can be included, such as target- tracking or weathervane modes. Heading and position is however crucial and by manipulating the degrees of freedom this can be maintained. Surge, sway and yaw are the three DOF's which concern dynamic positioning systems. Surge and sway alters the position of the vessel, while yaw is concerned with the vessel's heading. From the illustration it is possible to visualise how the vessel moves when surge can be described as forward or backward direction along the x-axis, sway can be described as movement in sideways direction either port or starboard, along the y-axis. Yaw is best described as rotation around the z-axis to turn the vessel around or change its course in a different direction.

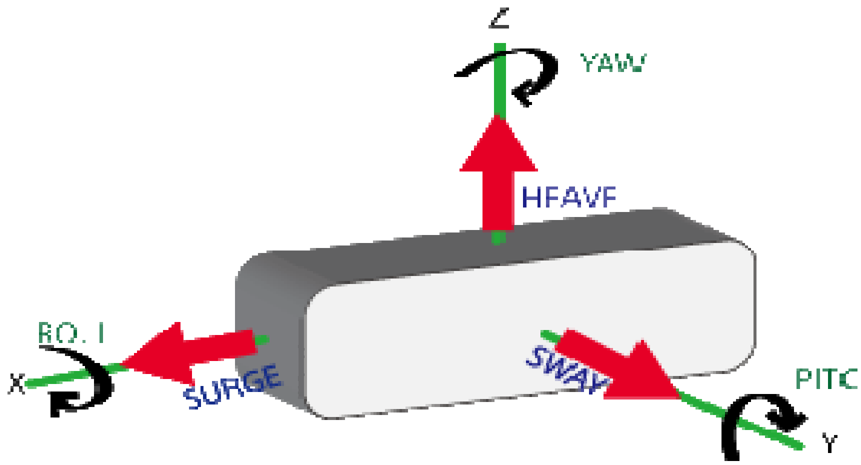


Figure 2.4: Six Degrees of Freedom (DOF)

The DP's main task is to keep the vessel in the correct position and maintain heading. This is controlled by the setpoint values input by the DP operator. In each case of input the variable must be measured to obtain feedback values. This is obtained from different sensor systems on the vessel, where the information is fed into the system and provides the ability to manipulate the vessel in an accurate manner.

The position is determined by receiving information from one or a range of position reference or navigation systems. The feedback that determines the heading is provided from one or more gyro- compasses. A gyro compass is a compass that finds true north by using an electrically powered fast-spinning wheel and friction forces, in order to exploit the rotation of the earth. The difference between the feedback from the system and the setpoint set by the operator is called the error offset. The DP system operates to reduce the error rate or keep it at a minimal level. To be able to control the position and heading, it is crucial that all sensors are enabled and give feedback to the system to allow correct measuring. The three axes of movement, x- , y-, and z-axis are kept separated to allow them to be controlled individually and also automatically. This is a feature that can vary from different suppliers of DP systems, where there is the possibility to manipulate the surge, sway and yaw movements in various combinations. The system can operated in three different states; MANUAL, AUTO or JOYSTICK, where there is also the possibility to change heading using a rotate control.

The rotate and joystick control is called the “PosCon” function which is present on many DP vessels, especially in the offshore sector. When the operator uses the joystick and rotation control (heading wheel), he or she is able to take advantage of all the thrusters available on the vessel. In addition thruster- output is often integrated in the controls in many DP- systems. This allows, for example, surge and sway to operate in auto, while heading (yaw) can be operated manually by using the joystick and rotate controls.

During an operation it is important that the vessel maintains position and heading to ensure that all operations are carried out safely and in a controlled environment. External forces such as wind, waves and current will on a permanent basis try to shift the vessel out of its setpoint position. The DP- system must therefore use thrust forces in the correct direction to counteract and induce compensating surge, sway and yaw vectors to maintain position and heading. Some forces are measured directly, with real-time feedback to the computers to apply instant compensation. Rotation is introduced as the most vulnerable movement due to wind forces upon asymmetric shapes such as the vessel’s hull and super structure configurations. The wind forces are measured by wind- sensors located on different places on the vessel, which determines the wind speed and direction.

All forces which are not directly measurable, such as current, waves, swell and errors in the system go into one unified category labelled “current”. The forces in this category are all assumed to be current, but are in reality a combination of the different forces mentioned above. To be able to get a correct input to the system, forces in the “current” category have an offset which is deduced over a period of time, allowing an average value of compensating thrust to be applied. In addition to maintaining a steady position and heading, the DP system can automatically change position, heading or both. This is applied by the operator through the graphical user interface of the system, where the speed is also set. The most frequent unit used is meters per second (m/s). When the operator acknowledges the change, the vessel takes up the new position to the speed specified. If change of both heading and position is acknowledged, this can happen, if preferred, simultaneously.

Some DP vessels are assigned to follow a pre-set track. This concerns pipelay vessels, cable lay vessels, dredgers and barges, amongst others. The vessel's operation (task completion) is complicated by the weather and seas that imply big forces on the boat. Some vessels must maintain a fixed position, while others must follow a moving target, such as a submersible remotely operated vehicle (ROV). This is expensive and a safety critical operation where system redundancy is imperative. This has led to three redundancy categories, DP, DP2 and DP 3, which can also be described as single, dual and triple configurations. The vessels are equipped with DP systems that correspond to the level of redundancy needed to carry out the operations the specific type of vessel is set to do. To maintain the highest level of control of the DP operations, the DP stations are most often situated on the aft bridge (the rear facing part of the bridge). This gives the operator a good overview of the deck. For the system to be able to keep the vessel set to one specific setpoint, while simultaneously subjected to forces of nature such as wind, waves and tidal movements as well as forces generated from the vessel's own propulsion system, a complex mathematical model is used. This feedback system (see figure 2.3) is continuously calculating the response from the position reference system, wind sensors and gyros to find the suitable output to the thrusters to maintain position and heading.

Together with the complex information from the DP system, the DP operator plays an important role in the system. The system must be monitored and the operator must at all times be alert to any irregularities or changes that can be a hazard to vessel or crew. DP- operations (see figure 2.5 and 2.6) are often carried out close to oil rigs and expensive equipment where there is no room for errors or unexpected and sudden events. To be able to carry out the operations as safely and efficiently as possible, it is important that the operator has a comfortable work environment supported by a good graphical user interface (GUI) to visualise the ongoing processes in the DP-system. The GUI should supply the operator with the information needed and allow little doubt as to which buttons to press, handles to turn, alarms to acknowledge or displays to look at. In the maritime world this is unfortunately not always the real- life situation. GUI's together with an illustration of the DP GUI will be given in section 2.3.2.3.

Figure 2.5: DP operation close to offshore installation (view from operator station)

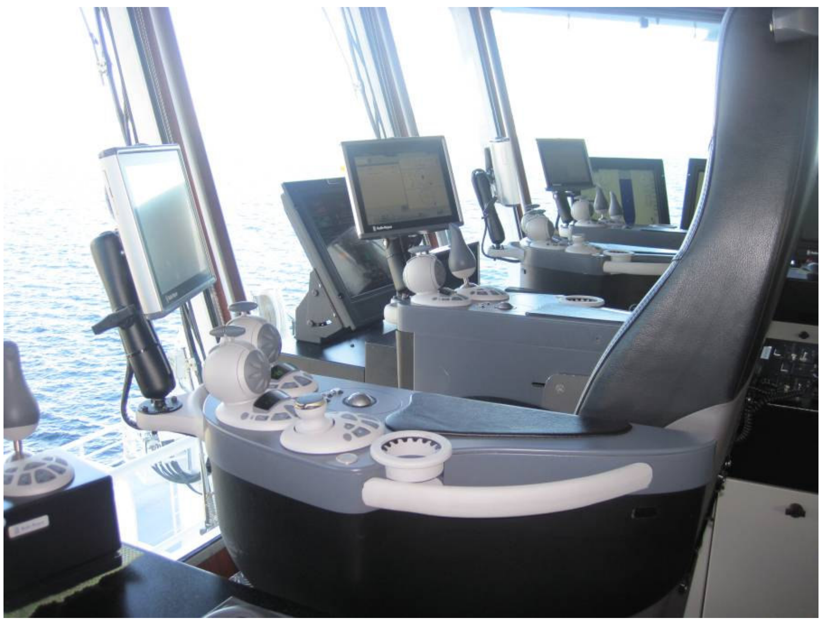


Figure 2.6: DP Operator stations on aft bridge of platform supply vessel

2.2.2 Safety-Critical Systems and Environments

Every day we encounter situations or are in touch with environments that can be categorised as safety-critical. The drive to work, to catch a flight, traffic or railway signalling or when you are under surgery in the hospital can all be safety critical environments to different degrees due to that they can cause a danger to your safety and propose a risk to your life. Redmill and Rajan (1997) argue that safety is a state in which human life and well-being and the environment are not endangered. A common denominator for all safety-critical environments is that they often have a computer controlled system running in the background to ensure safety and that your car does not speed off on its own, your flight does not crash, there is no car or train passing when your light is green or that the equipment the medical personnel use during surgery does not fail when monitoring your heart rate. These computer controlled systems are what we can call safety critical systems; hence systems that are there to make sure that safety- critical situations do not occur. The formal definition for a safety-critical system is:

"a computer, electronic or electromechanical system whose failure may cause injury or death to human beings. E.g. an aircraft or nuclear power station controls system. Common tools used in the design of safety-critical systems are redundancy and formal methods."(cited from die.net) [4]

The safety-critical system is today in most cases running on a computer and is automated (machine driven). However the computer itself is not the system, it is only the host of the system. Inside the computer, safety-critical applications are running. These software applications are the core of the system and are defined as 'a software that contains safety-critical functions' (Leveson, 1986). A question easy to ask is: What happens if the computer crashes? If there is a fire? Or an earthquake? This is where redundancy plays an important role. A redundant system is a system that continues to run on a parallel system in a protected location, even if there is a fire or another type of emergency. There are many levels of redundancy and single, double and triple redundancies are the most common. Triple redundancy is for example

[4] Definition sited from: http://dictionary.die.net/

utilized on DP vessels where a drift off position or unexpected shutdown of the system can put lives in danger, e.g. if the vessel has divers in the water working on the seabed.

No systems can be 100% fail safe and neither can it be fully automated. It has to be monitored by an operator. Bainbridge (1987) stated that the degree of automation and complexity that systems are reaching, can expand problems rather than eliminate the problems that operators encounter during their interaction with the system. The systems are becoming more advanced and higher demands are required from the human being monitoring the system. A system difficult to understand that does not support the operator in taking the right decisions during high risk/safety-critical situations, represents a failing safety-critical system where accidents are more likely to occur. The human element plays the leading part and is often the easiest target to blame after an accident.

2.2.3 The Human Element's Role when Accidents Occur

When a large accident occurs, everyone searches for what went wrong and who can be blamed. A common denominator behind each answer found under or during an accident investigation, is the emerge of other questions that connect the human error to other human actions. Frequently it is discovered that these human actions causing the error were not isolated, but the end of a chain of human factors (Redmill and Rajan, 1997). One error triggers the next which causes an increased mental/cognitive load on the operator. The system does not support the operator's stressed mental situation and the operator could eventually make the wrong decision leading to disaster.

The cognitive load is referred to as the load on the human's working memory and Sweller's (1988) cognitive load theory can help put the consequences of increased cognitive load leading to errors and accidents into perspective. An individual's base of knowledge is built up of structures that are recognized as schemas. The schemas hold structures of knowledge that are built and created when we learn and store experiences and impressions in our memory. The more experience we have (i.e.

knowledge gathered over a lifetime of learning), the more advanced our schemas become. Here the difference between an expert and a novice shows a clear division, both in terms of handling situations and keeping calmer in stressful situations. A novice has not yet been able to build the schema necessary to be categorised as an expert. For a schema to develop the novice must gather experience and change the mental structures to fit with new knowledge obtained. By acquiring more knowledge, tasks that before were difficult become easier and are handled more efficient. The novice has now reduced the load in the short term (working) memory, due to the knowledge moving over to the long term memory. An example from the transport sector of the consequences of high cognitive load (cognitive strain) is when a Delta Airlines DC 31 struck the seawall bounding the runway at Boston's Logan Airport in 1973 where 89 people were killed. The reason behind the crash was according to the cockpit voice recorder, a problem the crew had experienced with the Sperry Flight Director while attempting an unstabilised approach in rapidly changing meteorological conditions. The accident report concluded that the accumulation of minor discrepancies deteriorated in the absence of positive flight management in a relatively high risk manoeuvre. A large contributing factor was the crew being preoccupied with the information being presented by the flight director to the detriment of paying attention to altitude, heading and airspeed control (Smith, Salvendy, Harris and Koubek, 2001).

The human element must be kept in mind during development of maritime equipment. Keeping the cognitive load low is an important factor to consider when designing well fitted user interfaces.

2.2.4 The Human Element in a Maritime Context

In recent years the human element has been considered more important when it comes to the design and development of new equipment and vessels. However, there is still a long way to go. In general poor usability is a major negative factor on board vessels. It causes fatigue and strain, which can lead to loss of attention and accidents. Lloyd's Register's World Casualty Statistics (Lloyd's Register, 2007), shows little or no improvement in the period 1995 to 2007 in total loss of lives during total loss incidents (the vessel is lost). Squire (2009) states that the human element embraces anything that influences the interaction between a human and any other human, system or machine aboard a ship. In most cases the vessels are designed and engineered by people with little to no experience or interest in the field concerning human factors. The vessel is built as cost-efficient as possible and the crew is rarely involved in the process. The typical “mindset of an engineer” is often present: when designing the equipment, the necessary features to operate the vessel are present, but, the only person who can understand how to operate the equipment without extensive training, is the engineer who created it. If the operator’s cognitive load is on a quite high level from trying to operate the system during a standard operation, the load can then easily become excessive when the stress level increases. The operator will in a safety critical situation, in most cases, fail in taking the right decisions, due to already present difficulties operating the system. Sillitoe, Walker and Earthy (2009) sum up common ship operator reactions to addressing the human element. In general the shipyard likes to do things the traditional way and argue that any other method will take longer and cost more. There is a dearth of knowledge on introducing the human element into the maritime industry - ship-owners, ship yards and crew are unsure where to start and what to do. The shipyard more or less disclaims the responsibility to address the human element at all, while the equipment manufacturers agree that they could more easily compete on technology and features with a greater understanding of usability and human factors. By caring for the human element at an early stage, expensive retrofitting with varying results can be avoided. This will in addition increase safety.

2.2.5 Safety-Critical Systems in a Maritime Context

There are strict “unwritten” requirements connected to the technology we use. We must be able to understand and use it quickly, because there is no time to read the user’s manual. The difference between consumer technologies and industrial technology is often the safety-critical element. There are traditions when it comes to developing maritime equipment and both shipyards and ship-owners often state that they like to do things the way ‘they usually do it (Sillitoe, Walker and Earthy, 2009). Errors are often a matter of life and death or can at least cause serious financial damage. The safety- critical issues can often be seen as the factor that slows down the development of new technology. The shipyards and ship owners are well aware of the risks and like to hold on to the 'tried and tested' rather than risking an experiment. Maintaining safety is a positive feature, but there is a compromise between using the safe and well-known as a false security to avoid spending resources on innovative research.

According to Redmill and Rajan (1997) the design of user interfaces used for safety critical operations are centred on providing interfaces that will allow accurate assessment of present and future system states, and will control the safety-critical system to achieve desired states. In a safety –critical system a common problem is often the fact that alarms from the system are not well organized and are handed over to the operator in a concoction where it is close to impossible to extract the information needed. This is called 'alarm overflow' was the one main causes that caused the Texaco Pembroke accident. The 24th of July 1994 an electrical storm caused disruptions in the refinery in Milford Haven, United Kingdom. The triggering of an overwhelming barrage of alarms was one important factor that contributed to the explosion that lead to 26 people being injured. Other incidences that can also cause dangerous situations in addition to misinterpretation of the system's state, is when the interface is not reporting the true state of the system. This gives the operator a faulty base for making decisions. In such cases the decisions made are often the wrong ones. Operators are also put under stress during an operation: e.g. in the maritime domain for DP operators the operator on watch must maintain full overview of the aft deck at all times. This is to prevent any hazardous situations for the deck crew. However, the operator cannot maintain a high state of vigilance indefinitely, so it is important to give the operator some rest time in between. On DP vessels this is solved by having two DP operators on watch during an operation, where they swap who is in charge of the operation. When being affected by fatigue or similar conditions, they are easily confused by any kind of inconsistencies. The system must therefore be consistent throughout and the operator given enough training before being put into duty. A tendency that occurs sometimes when the operators have been given inadequate training is that they explore the system on watch which sometimes has large consequences.

When designing a safety-critical user interface and system (Galliers et al., 1999), it is important to include the user from the start of the design phase. For optimal exploitation of time resources, the human factors aspect of the design happens in parallel with designing hardware and software. There are several factors that can influence the human machine interface, which can be found in Redmill and Rajan (1997). In the starting-line of design and development the main process key factors influencing the system are (EPRI, 1984):

- What is the purpose of the system?
- Where is the system intended to be used?
- When will the system be used?
- Who will use the system?
- How safe is the system?

After investigating these factors, the work can proceed to hardware and software design, including GUIs, controls, ergonomics and background technology. Designing systems with the user in mind will in most cases reduce the risk of human errors occurring.

2.2.6 Human Error

Research concerning the nature of error has been widely investigated for decades and where an error has occurred the most natural word that springs to mind is: "why?" There is a hereditary urge to find the cause of the error to avoid doing it again. The reason behind why we make mistakes is a complex reality and a combination between mental processes, cognitive psychology and external variables, such as lack of training or poor routines (Reason, 2006). In many cases it is difficult to foresee the outcome of a situation and Mach (1905) stated that "Knowledge and error flow from the same mental sources, only success can tell the one from the other". In safety-critical industries, such as the maritime industry, coincidence is not a word that should be in the crew's vocabulary and the consequences of skipping safety routines that might seem excessive can lead to disasters. It is said that 80 % of all accidents have a human cause (Reason, 1990). A well-known offshore accident that had its cause in human error and skipping important procedures is the Piper Alpha accident in the North Sea in July 1988. Because of a maintenance error that eventually led to the initial leak that caused the explosion, 167 people died in the blaze that followed the explosion. The inquiry carried out by Lord Cullen (Lord Cullen, 1990) and Pate-Cornell (1993) presented evidence that due to a variety of organisational and technical causes, the culture in the company that owned the platform, inexperience, poor maintenance procedures and deficient learning mechanisms were the key reasons for the accident.

There are different types of errors and three definitions can be outlined, where error is the main term that can be divided into categories such as slips, lapses or mistakes.

Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency. (Reason, 1990, pp. 9)

Slips and lapses are errors which result from some failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its object. (Reason, 1990, pp. 9)

Mistakes may be defined as deficiencies or failures in the judgemental and/or interferential process involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision scheme run according to plan. (Reason, 1990, pp. 9)

Reason (1990) then discerns active failure (of front-end actors, e.g. operators) and latent failure. Latent failure originates from preceding actions, involves working conditions and load, competing demands, and is caused by designers, developers, decision-makers and managers. Latent failure is the type of failure that is frequently seen on board vessels today (Celik and Er, 2007). Active failure involves the human in the process and the operator can in some cases be blamed. Risky behavior, described in the book 'Darker shades of Blue' (Kern, 1999) and complacency (Squire, 2009) are important factors in human error, but are outside the scope of this thesis.

There are two main approaches to handle the problem of human error (Song, 2009). One approach would include increasing the number of well trained crew members. The second approach would be to look for ways to improve the working environment of the human on board ships. In a financially pressed industry the last is a more long –term solution which solves the actual problem and leads us into the field of usability and human machine interaction.

2.2.7 Usability – just a handy feature?

Just like keeping the human element in mind throughout the development and use lifecycle of the vessel, it is just as important to create a system that is usable. Even though, as will be discussed below, HMI is not always prioritised in the maritime realm, the usability of the equipment is closely connected to keeping the system safe by keeping the operator's cognitive load low. The maritime industry is more directed toward the features that the equipment holds and usability does not always sell products. All equipment suppliers, not only in the maritime domain, are dependent on selling and the extra time it takes to do good usability research is not always welcomed. This is a short-sighted approach, but often the reality due to tight time schedules. A good looking design of the product and software is often not the same as purchasing a usable product. An industrial designer has in some cases been hired to sketch up the design, but usability experts have not been consulted. In many cases the aesthetic usability effect strikes and it is automatically assumed that a product with good design is easier to use than a product with poor design (Tractinsky, Katz and Ikar, 2000). It is therefore important to consult qualified expertise to ask the crew the correct questions when developing maritime equipment and software.

ISO (International Organization for Standardization) defines usability as*: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."*

Usability should be supported both in the physical/system design and in the graphical user interface (GUI). There are three main principles (Dix, Finlay, Abowd and Beale, 1997):

- Learnability - concerns the ease with which a novice can interact with a system or interface that is unfamiliar and how quickly the user adapts to the system and can use it effectively. Familiarity is a core feature, where taking advantage of the user's previous knowledge of systems by reusing familiar features makes the system guessable and easy to understand.
- Flexibility - supports the many different ways a user and a system can interact and exchange information. Multi-tasking is an important feature that allows the user to work on several different tasks at the same time.
- Robustness – the robustness of an interaction covers the features which support the successful achievement and assessment of the goals. Responsiveness is one of the keywords that fulfills a system's robustness . Responsiveness ensures stability by providing the user with appropriate system feedback. Three other keywords are observability, recoverability and task conformance.

By obeying the above guidelines during development, one can reach far in securing both the operator's interaction comfort and take a big step towards enhancing the safety on board.

2.3 Human Machine Interaction on Maritime Equipment

In the maritime industry today there has been very little published research on human machine interaction (HMI) directed towards the electronic equipment installed on vessels, especially software interfaces. The reason behind this is yet unknown and it can be debated whether this is because the research carried out has been kept secret due to competitive interests of the different suppliers, or there hasn't been sufficient interest around the topic. The focus seems to be directed towards human factors in general and not the interaction between the operator and the graphical user interface (GUI). Mills, as one of the researchers within this sector, has published papers mainly concerning smaller vessels and fishing vessels (Mills, 1995b, 2000). Mills' research principles can however be transferred to other types of vessels, such as offshore vessels. From early history, navigation skills and maps have been crucial when seafarers were setting sail towards new destinations. As time passed, boat designs changed into being fitted to the different tasks carried out by the vessel, the vessels also grew larger and equipment was specialized to fit the operations each vessel type was set to do (Mills, 1995a, 1998). With continuous development of computer and electronic equipment, new and emerging technologies made their way into wheelhouses to simplify navigation and increase the efficiency in increasingly more complex operations. The sextant has been replaced with modern electronic navigation appliances and paper maps are supplemented with electronic maps to ease the workload for navigators and to achieve higher accuracy (Mills, 2006).

In commercial industry the electronic equipment available on the market has exploded and new features and models are being developed and released on a frequent basis. This does not concern only small electronic equipment such as mobile phones, TV's and home appliances, but also larger items like cars. Cars have developed rapidly towards giving the driver the ultimate driving experience supported by, amongst other things, "on-board" displays, GPS- navigation, sensors to measure the distance to surrounding objects and interiors which are so comfortable that they support a drive across Europe without feeling the urge to stop and stretch your legs. The question that arises is whether the commercial market has consumed all the expertise on developing new safe technology. Is the maritime industry suffering from lack of innovation and initiative and being slowed down by outdated standards and regulations, or have too many avaricious ship- owners not listened to their crew on what equipment would be preferable (Mills, 2005)?

The answer to these questions remains unanswered, but what is known is the lack of well- designed maritime electronic equipment on-board both large and smaller vessels that carry out important tasks that benefits the maritime industry. Stella Mills (2005) mentions that the sea is perhaps one of the last working environments where workers do not always have much to say about the choice of equipment they have to use. The maritime realm has not yet adopted the philosophy of participatory design, which is a philosophy that covers the whole design cycle. This will be discussed in section 2.3.1. This seems to be a valid allegation, where also the cost of the equipment is an important issue in most cases. When it comes to designing applications for any kind of area, the price tag is important and often mirrors the quality of work. In marine applications some producers seem more proficient at producing intuitively usable software than others, but the added quality may be reflected in the price (Mills, 2005), which is not, as mentioned above, always too popular with ship-owners who want maximum profits out of their fleet. Well designed equipment on-board vessels is however very important to be able to maintain safety in a safety- critical environment.

The economic aspects play, as mentioned, an important role even though the majority of accidents on board vessels are in most cases caused by human errors. According to accident reports (e.g. from Lloyd's Register) the errors are mostly due to misunderstandings during stressful (or similar) situations, and not system failure (Mills, 2005). As such poor HMI design is often blamed and there has been a trade-off between the usability of the maritime equipment and issues such as the safety-critical aspect and also the robustness. There will however always be to some extent, a compromise between the design, technical issues and maritime directives. Modern technology does become cheaper and there have been made legislations that push safety on board vessels forward (Mills, 2000). The maritime industry is conservative about novel technologies due to safety issues but in time, supported with research, the industry will most likely adopt new innovations to enhance safety.

2.3.1 Participatory Design

Including the users when developing equipment for any kind of industry can be useful. The user has extended knowledge of both the environment and the ergonomic needs and can be a valuable resource for the designers, not only as an experimental subject, but as a part of the team. However, participatory design can for many seem like a complex affair that will steal time from the project and make deadlines hard to meet. The aim of this philosophy (Dix, Finlay, Abowd and Beale, 1997) is to refine system requirements iteratively through the design process where the user is actively involved. The philosophy has three main characteristics:

- Improve work environment and task by the introduction of the design.
- Collaboration where the users feel involved in the process and can influence the design.
- Iterative process where the design is evaluated and revised at several stages.

Tools that are popular to use in a participatory context are brainstorming, storyboards (describing user activities), workshops and lastly paper and pencil exercises. Here the user can walk through the tasks step by step and give comments and add ideas.

Another advantage with participatory design is the psychological factor. The users have been involved throughout the design and development where their opinions have been taken into account. The users are at this stage satisfied with the result. If design flaws are discovered after implementation of the equipment, for example on the vessel, either it is minor and easy to correct or the users have to take some of the responsibility on their shoulders. This leaves the supplier/designers with a trump card, where they are not entirely responsible for the flaw, which can have economic and legal advantages. This could weigh up economically for the extra time spent on the design process.

2.3.2 The vessel – like a human body?

A vessel can be seen as one large system with several smaller components involved, just like a human body. The hull is the vessel's skin that protects the more delicate equipment inside, the propulsion system gives the vessel the possibility to move and the control- centre on the bridge will act as the vessel's brain, which controls all parts of the vessel by using cables and wiring, just like a nervous system. On the bridge of a boat there are several systems that control different parts of the ship; this is where the division appears.

The visual impression of a vessel's bridge, can be divided into two different parts, the physical appearance of the equipment and the GUI which is a visualisation of the system's inside. To many users, the GUI *is* the system and they relate only to the interface to understand and control it. The user has no further interest in the details of what lies behind the covers or at the end of the cables and wiring. The user's main interest is to be able to use the equipment to carry out the tasks s/he is set to do and to reach a goal with completion of the operation. A goal is usually made up of different tasks, and the designer of the interface must be aware of the overall goal and the tasks included to be able to design a good interface (Mills, 2005). The designer should hold knowledge to plot the course towards the goal and in which sequence the different tasks should be carried out, but it is vital that the user is consulted to make sure all aspects of the design phase have been covered.

2.3.2.1 Operator vs. System

A vessel can be seen as a large system where all equipment plays different, but equally important roles. The operator depends on the GUI, which again depends on the control system, which trusts the sensors, propulsion system and the ship itself. With this vision of teamwork between man/crew and vessel, both bridge design and ergonomics are crucial in addition to a usable GUI. By using this mindset it is possible to understand the interaction between all parts of a vessel and also to see the importance of a good user interface both graphical and physical. Operators of a system, such as a DP- operator, are set to carry out tasks to achieve a goal or several goals (Mills, 2005). Mills states that the goal(s) do not necessarily have anything to do with the system itself, but the system is, together with the GUI, used as a tool to achieve the goal(s). According to Mills (2005), this means that the combination between system and tool is a product which assists the users in meeting their goals. If the product is not suited the user's needs the possibility of errors occurring increase. This introduces interesting problems around how to develop well- designed equipment for the maritime environment. Product design is market driven, which supports the economic issues around good and bad design.

Faulkner (2000) emphasizes that *'knowing the user'* is of paramount importance to good design, this support the different methods used to obtain knowledge about the situation where the product is to be used. The methods are however poor substitutes to real life experience (Mills, 2005). Mills states that the best designers of maritime equipment are most likely the mariners themselves, who have experience and know what requirements the equipment must be capable of handling. A contradiction is when new equipment for maritime environment is to be designed. The user knows what goal(s) to reach, but not how to get there or which tools to use. Depending solely on the user's information can in many cases be inefficient and time-consuming. However the mariners have no expertise in design and cooperation between the designer and the mariner can be the best combination. This emphasizes the importance of utilising participatory design either in full scale or carry out frequent iterations of meetings with the mariner continuously throughout the design phase.

2.3.2.2 Operator vs. Interface

The operator's only possibility of interaction and manipulation of the system is through its interface. The interface can be categorized as both the physical appearance of the equipment (visual display units (VDU), joystick, buttons, handles or similar) and the visualization of the system also know as the graphical user interface (GUI). The bridge is the vessel's control centre where most of the interaction between humans and graphical user interfaces occur. Stella Mills (2000) discusses how bridge design has undergone many changes in the last few decades which have resulted in increased awareness of safety- critical issues on board. Simultaneously there has been pressure from ship- owners to keep the personnel at a minimum. This increases the workload on remaining crew which supports the need for good ergonomics and following certain legal principles when out at sea. Mill's (2006) summary of legal and ergonomic principles concerns mainly smaller fishing vessels, but can also, as mentioned previously, be applied to larger vessels with a slight change. The legal principles mainly concern the visibility of the equipment on the bridge, where the importance of a 360 ° view from the wheelhouse and non-occluding equipment are emphasized. For offshore vessels this is equally important, but with larger vessels the bridge's size will also increase. On larger vessels there are at a minimum two members of crew on the bridge at all times. The placing of equipment is important due to the cognitive and physical load on the operator. If the operator constantly has to move or turn to control important information, this will strain the operator and he/she will sense fatigue earlier. To ensure safety on board it is vital that the operators of the vessel are comfortable and not put under any extra strain. Mills' (2006) ergonomic principles deal with, once again visibility, but also computer related tasks. On a larger vessel, such as offshore vessels, it is highly important to the operator that he/she is presented with only the information needed. Excessive information increases workload, which can lead to the operator making the wrong decisions or decision paralysis and again unsafe operation of the vessel. It is therefore important that the information presented to the operator on the different VDU's is grouped. Related information should be placed together and information with similar appearance that handles different tasks should be placed apart, to avoid misreading of the information. This principle applies to all equipment to minimize faulty decisions and misunderstandings.

Lazet and Schuffel (1977) emphasize the fact that with too much visual information, critical information may be lost because of inattention, not being able to find the information needed in a cluttered graphical interface or simply because the operator is not looking in the right direction. This means that when decisions are to be made based on interpretation of displayed information, the presentation of data is highly important. However the most important task when discussing bridge/wheelhouse design is consistency, both concerning software and hardware. Consistency is the keyword that enables humans to recognize patterns and situations that are similar. By recognizing resemblance the operator can act by using the knowledge the brain already holds. This supports theories around using metaphors to illustrate real-life situations in GUI's (Mills, 2005).

2.3.2.3 Graphical User Interfaces – a Design Challenge

The history behind the graphical user interface (GUI) started off in the early 1960's with Sutherland's Sketchpad (Sutherland, 1963) and has developed quickly up to today where 3D and even 4D graphics are utilised to make visualisation in displays as realistic as possible. Direct manipulation interfaces (Schneiderman, 1982) where clickable objects are visible on the screen, audio and visual feedback is provided on actions, and the possibility to reverse actions is provided, were some of the features that revolutionised the GUI world. Today GUI's are seen everywhere and we interact with them everyday, which is an indication of the important place they have in our everyday lives, hence the importance of designing a good GUI. Designing a good GUI is especially crucial for safety-critical applications (such as a DP system) where the guidelines mentioned in section 2.2.7 have a key role. Users working in a stressful environment need guessable interfaces with a low threshold of effective interaction for novices. A good example from the everyday life is the relief when one could directly click on an icon displayed on the screen to enter a software application, instead of writing long lines of commands in a, for many, cryptic language. Even when the scroll wheel on the mouse was invented in 1995, it gave a new dimension of user interaction.

The next step for direct manipulation is to interact directly with the display and leave out the computer mouse and other input devices. This has become more common both on commercially available equipment and in industry. The GUIs have to be adapted to suit touch interaction.

2.3.2.4 Presenting Information in the DP GUI

The Rolls-Royce standard DP system's GUI has been designed by Rolls-Royce's maritime software development team to be suited for touch interaction. The GUI consists of different components and in a DP system (see figure 2.7), there will typically be a main overview where a graphical illustration of the vessel is visible. In addition, other relevant information is placed in menus or similar on each side and top/bottom of the display. The software component's composition (e.g. a menu) is crucial to the overall operator vs. interface experience.

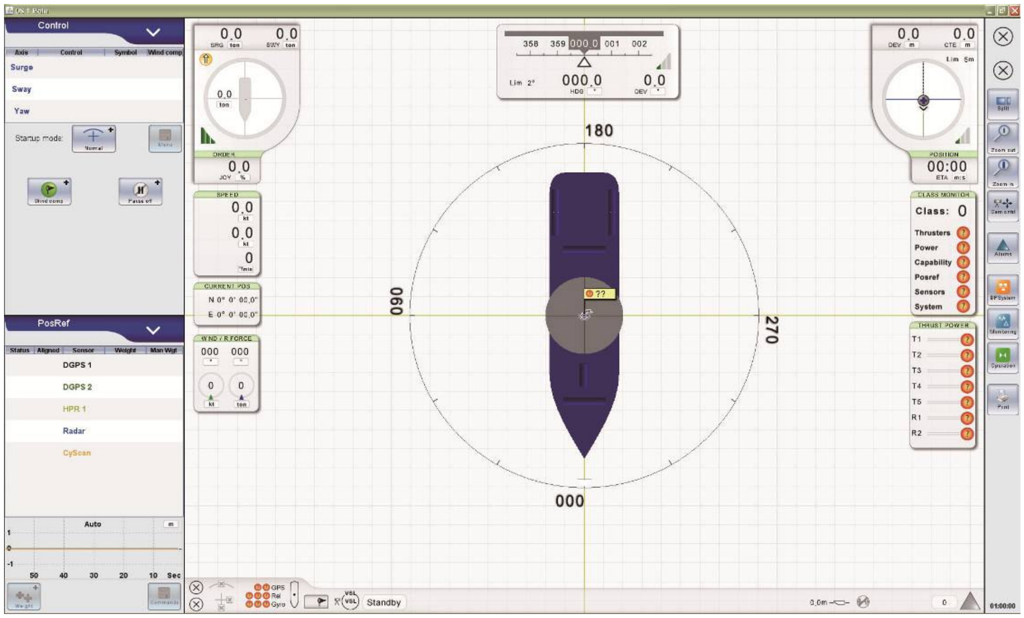


Figure 2.7: Rolls-Royce DP GUI

The symbols should be crystal clear with only one purpose and meaning (Mills, 2006) that is not possible to misunderstand. Colour use should be consistent and the same principle should be utilised for the composition of the software components. According to Mills (1998) it is considered an advantage if the operator can be presented with a 3D visualization. This is because it enables the user to easier relate to the objects visualised in the GUI. The designer must make sure that the objects are easy to learn, recognizable and realistic (Mills, 2000). Colours are often misused. Powerful colours which are naturally connected with danger or e.g. STOP, such as red, should not be used for any other purpose than actions related to the ones mentioned above. In a DP system, it is crucial that the colours support division between different states on vital parts of the system. Taking advantage of the operator's previous knowledge (Mills, 1998) when designing the GUI can improve the design and ease the cognitive load on the operator. A problem the operator can encounter while using modern maritime equipment is loss of control of the system (Mills, 2006). This works against the GUI's purpose and according to Dix, Finlay, Abowd and Beale (1997).

The user, not the computer, initiates and controls all actions.

If the user has lost his/her feeling of control, the operator will experience stress and insecurity, which endangers the operation. Leaving the user in control can be a design challenge. A solution can be to follow Norman's Stages of action as design aids (Norman, 2002) that suggests a checklist where visibility, a good conceptual model, good mappings and feedback to the user are assuring steps of design which can lead in the right direction.

2.3.2.5 Interface vs. Safety Critical Situations

Safety at sea is of utter importance when operating large vessels close to oilrigs and other offshore installations. Accidents considered small-scale can cause abortion of operations and cost large sums of money. When accidents become large- scale, the lives of crew and vessel are at danger. In many cases "human error" is concluded as the fatal cause or a factor in a series of unfortunate events. To minimize the frequency of human errors, usable equipment is, as mentioned above, the key issue. Most of the time it is hardly ever the user's fault, poor design is often the sinner (Norman, 2002). MacKay (1999) emphasizes that the design of safety-critical systems differs from that of other interactive systems: while improving productivity is important, safety remains the overriding concern. Increasing the former at the expense of the latter is simply not acceptable.

Every year numerous false alarms (Mills, 1995a) sound at rescue centres based in maritime nations, which calls for a lot of resources. In order to find a solution to false alarms, i.e. slips caused by misunderstandings and stress-related issues, the composition of the different types of equipment, where it's placed on the bridge according to the operator(s), and if the GUI is suitable for its purpose must be investigated. In a safety critical situation a button press combination can be hard to remember (Mills, 2005). The human brain gets clouded by fear of an impending accident. Depending on how critical the situation is, our mind starts re- organizing our senses, some are sharpened and others are paralyzed and put on hold. Irrational behaviour occurs when something unexpected happens (BHC, 2010). On board a vessel, the consequences of such behaviour are at a much higher level than on shore. This is why a clear menu structure (Murphy, 2004), grouping of equipment related to the same functions and correct usage of colours, amongst others, is of such importance. Under extreme stress, an experienced user mirrors the behaviour of a novice or less experienced user. A clear and concise system will bring the operator back into his/her position as an experienced user (Redmill and Rajan, 1997).

2.3.2.6 Visual Display Units (VDU) and Input- devices

Maritime equipment installed on a vessel's bridge has today numerous different displays and input- devices available. Some are operated by using touch- panels where the operator can, directly on the display, press different choices on the menu or similar. Usage of joysticks, trackballs, buttons, keyboard or a computer mouse is also widespread and seen more frequently than touch- panels. The size of the VDUs varies from system to system. A typical DP system can include two operator stations on aft bridge and one on each wing. This is also dependant on the supplier of the DP system. In this research a Rolls-Royce DP –system (see figure 2.7) is used as the base of experiments and further investigation. The two operator stations on aft bridge can typically include one large and two smaller displays. The smallest displays are placed on the armrest of the operator's chair (see figure 2.8) while the larger is placed to the left on a consol desk. The wing stations (situated on the port and starboard side of the bridge) include a middle sized touch- panel supported with a joystick and a position device. The input devices will depend on the system's design and usage, which also applies to the displays. The sizes of the displays are determined by the distance from the operator to the display. The usage of touch – panels simplifies the development process of new user interfaces.. It opens a new spectrum of possibilities when it comes to upgrading the system (i.e. soft-buttons vs. fixed buttons). This introduces new possibilities both in terms of operator control/ physical user closeness to the equipment and new interaction styles.

Figure 2.8: Rolls-Royce DP operator station

2.4 Multi-Touch and Bi- Manual Interaction

In 2007 a simple form of multi-touch was popularized by Apple through iPhone and iPod Touch. Although Apple was first to popularize it, multi- touch and bi-manual interaction have been a topic since Jeff Han spread interest with his first public presentation of multi-touch interaction on the TED conference in February 2006[5]. This demonstrated his principle of Frustrated Total Internal Reflection (FTIR) (Han, 2005), which is low-cost multi-touch sensing. The interaction with both GUI and software seemed surprisingly easy and natural, with flowing movements and easy gestures. The demonstration was presented by using a large rear-projected display in front of the user, like a workbench-like installation. This inspired this research with the thought of implementing multi-touch/bi-manual interaction into maritime equipment, specifically a DP system due to the direct control these interaction techniques use. This can enhance the DP operator's feeling of control when using a DP system, which is described below and was one of the aims of this research. The majority of DP systems available on the market do not have advanced 3D graphics

[5] http://www.ted.com/index.php/talks/view/id/65
Accessed: 31.08.2010

implemented. The Rolls-Royce DP system is however based on a 3D engine and makes new types of user- interaction possible. With use of 3D, multi-touch and gestures, the original three degrees of freedom can be extended to six. This means that the user will be able to control the camera (term used in 3D graphics development when viewing an object in 3D from different angles) in the 3D scene by using gestures in three additional DOFs (Hancock, Carpendale and Cockburn, 2007), which are referred to as pitch, roll and heave in the maritime industry. The three original DOF's were surge, sway and yaw. This can lead to the user feeling closer to the system and more in control. The aim for this research is to investigate if direct gesture interaction can enhance user control, interface interaction and closeness to the system.

Multi-touch is a human machine interaction technique together with the hardware that implements it. This allows the user to interact with the computer without using conventional input devices. Multi-touch consists of a touch-display that can recognize more than one point and there is a range of different technologies that implements it. Multi- touch, gestures and bi-manual interaction are not research that suddenly appeared with Apple and Jeff Han. It has been researched for over 25 years and the story started with keyboards. From the early 1980's, the University of Toronto was a pioneer in researching multi- touch technologies (Buxton, 2007) (Lee et al, 1985). At the same time the topic grew in two different directions: multi-touch technology and multi-touch interaction. Some found interest in the technology itself, while others used the scarce technology available to research the human aspect around using more than one point of input. From then and towards today there is still very little commercially available equipment on the multi-touch market.

2.4.1 Manipulation of a 3D object

Using two hands can in theory make it possible to perform the same tasks using half the number of steps and also perform different tasks simultaneously (Zeleznik et al., 1997). When selecting an object through direct manipulation with a single touch, the object has initially three degrees of freedom (DOF) if the point of contact is in the centre of the object. Hancock, Carpendale and Cockburn (2007) introduced a project where an algorithm provided 2 DOF's for each touch- point. With three touches, six DOFs could be implemented and it proved that with a higher number of touches, both performance and user preference increased. If gestures in addition to more than one point of direct interaction were introduced to DP systems, this would provide the operator with three extra DOFs. This will give the operator the opportunity to use the original three DOFs to directly move the vessel using direct gesture interaction and the last three DOFs to orientate in the 3D scene by panning and zooming. The operator can directly manipulate the vessel using the GUI around six axes (x- y and z- axis)..

2.4.2 Gestures

A gesture is a form of non-verbal communication. In the terms of multi-touch, a gesture is non-verbal communication, as described above, but supported with action on a display. The human mind cannot remember an unlimited amount of taught movements without training. To be able to take advantage of the knowledge the mind already possesses, indicating how a certain object is to behave when moving it should feel easy and natural. The purpose is to ease the user's workload and to enhance the feeling of control. By using 3D graphics and multi-touch gestures, testing the efficiency and accuracy when using the DP system is possible.

2.4.3 Efficiency and Accuracy using Multi – Touch vs. Single touch

Efficiency and accuracy are key elements in designing a successful touch interface, especially in systems with real-time feedback and for usage of touch in safety-critical applications. Early studies done in the field of multi and bi-manual interaction confirms the increased efficiency and also the need for increased accuracy when using the multi-touch interaction technique.

One of the initial studies of two- handed input was presented by Buxton and Myers (1986) where two experiments was carried out. The first experiment concerned positioning and scaling, while the second concerned navigation and selection. They concluded that the users were capable of simultaneously providing continuous data from two hands without a significant overhead. The experiment also showed that the speed of the tasks performed was strongly correlated to the degree of parallelism employed. The second experiment involved the performance of a compound navigation/selection task. It compared a one-handed versus two-handed method for finding words in a document. The two-handed method outperformed the one-handed technique which was most commonly used in 1986, when the experiment was conducted, and also is today. This early research supports the results of numerous other research projects, amongst others Balakrishnan and Hinckley (1999), Chatty (1994), Forelines et al (2007), Kabbash, Buxton and Sellen (1994) and Owen et al. (2005) which all have come to the conclusion that bi- manual interaction, either using both hands or multiple fingers, is more efficient than using only one hand or a single-touch technique. Interestingly what is shown from the experiments carried out is the fact that poor design can make interaction with two hands worse than with one (Hancock, Carpendale and Cockburn, 2007). It is however unclear if occlusion and reaching over the tabletop (display lying on the table, hence tabletop) can counteract the benefits of such interaction (Forelines et al, 2007). This will increase the need of well- designed GUI's especially in a maritime environment where safety is of utter importance.

Precision and accuracy when operating a large vessel close to an offshore installation, is crucial. If a DP system is to be operated using multi-touch and bimanual interaction, the gestures must be accurate. What should be taken into account is how the vessel is influenced by outer forces such as wind, waves and current. These forces can move the vessel vigorously and operations must have a GUI that supports the possibility of the operator being "tossed" around. In DP systems all actions that move the vessel physically must be acknowledged by the operator by either pressing a button (not always a physical button) or similar. This confirmation is noted down in the rulea and regulations for maritime safety and is present to prevent accidental moving of the vessel.

2.4.3.1 Gesture styles

The common features with gesture- research is firstly the usage of the index- finger and secondly the thumb. Wu and Balakrishnan (2003) developed the *Roomplanner* where a set of 10 different gestures were introduced. Four combinations included the index finger and six included a combination of one or both hands, taking advantage of the palm and the side of the hand. Similar techniques are used in SmartSkin (Reikimoto, 2002), where also the index finger on the dominant hand is in focus. In SmartSkin the “pinching- gesture”, well- known from iPhone and iPod Touch, is introduced. In contradiction to how we know “the pinch” today, as a zooming gesture, SmartSkin uses “the pinch” for picking up an object. Two fingers move towards the centre of an object and the object is picked up and moved to another location. To drop the object, the opposite movement is used, fingers sliding away from the object’s centre. In 2004, Malik and Laszlo (2004) presented their Visual TouchPad where “the pinch” is presented as we know it today, zooming in and out. Fingers (thumb and index finger) slide apart, represents zooming in and the opposite zooming out. Nishino et al. (1997) designed an interactive two-handed gesture interface where a range of various gestures were tested. The shapes defined by the gestures were geometrical, in combination with an illustration of sign language and user defined gestures. There was proof found for increased efficiency when using two hands, but in some cases the rate of recognition was found to be too low and the test objects were also confused by the variety of gestures available.

This returns to the initial issue, as mentioned earlier, which concerns the amount a human mind can remember without mixing it together or filter out what may seem unimportant or irrelevant. If multi-touch and bi- manual interaction were to be implemented on, for instance a DP system on an offshore vessel, the gestures must be designed to be natural and intuitive. In a safety- critical moment with significant strain on the operator, the gestures should be remembered and carried out correctly.

Topics concerning symmetric and asymmetrical behaviour while operating multi-touch equipment will not be emphasized in this thesis.

2.5 Chapter Summary

This chapter has summarised the main theory behind this thesis. The technology and history behind the DP system has been outlined followed by an introduction to the field of human factors and keeping the human element in mind when designing safety critical systems. DP systems are considered safety-critical, due to the hazard inflicted on the surrounding environment if the system fails. This emphasises the importance of following the correct procedures where the human factors must be closely investigated throughout the design process to reduce the possibilities of human errors. Human errors are the main cause of 80% of all accidents (Reason, 1990), mainly due to design faults or lack of adequate training rather than operators sleeping on watch. Making interaction between the human and the computer/machine more streamline leads to looking at the vessel as one entity rather than separate parts. The operator interacts with the main system and the interfaces of the sub-systems where information is presented in GUIs. The way the information is presented is vital for interpretation of the vessel's status and if too much information is present or the operator misinterprets it, this leads to safety-critical situations. In addition the placement of the equipment, hence displays and input devices, is important for the interaction between the operator and the equipment. There are several methods to interact with a system on board a vessel, where the main technique is through joystick and physical buttons. In the later years touch displays have become more frequent on board which introduces new possibilities of interacting with the GUIs. Using direct gesture interaction, multi-touch and bi-manual interaction can bring the interface itself physically closer to the operator and possibly reduce the amount of equipment present on a bridge in addition to reducing the cognitive load. This will be discussed in the following chapters where investigations of direct gesture interaction to operate a DP system will be outlined.

3 Paper Prototyping: Initial Investigation of Using Direct Gesture Interaction

3.1 Introduction

This chapter concerns an investigation based on a small initial user study involving eight participants. The aim of this study was to investigate which gestures felt natural to the participants to use when operating a touch screen DP system. The investigation was built on the theories and research presented in chapter 2 where a discussion of the topics multi-touch and bi-manual interaction was connected to the maritime realm. It was desirable to compare the results from this study with results from previous studies and research done by others, to confirm the necessity of a small and compact set of gestures. The experiment was conducted in a laboratory environment using a cardboard/paper prototype (low fidelity) and the total duration of the study was approximately 1.5 hours (10 – 15 minutes per participant) including the briefing of the participants and a post-task discussion. As an initial test, gestures were studied in isolation from other influencing factors, such as the surrounding environment and other activities a mariner might be occupied with during operation of a vessel. These factors will be included and looked at in the context of a maritime environment in later studies described in chapter 4 and 7. The results were then be utilised in future user studies which are discussed in later chapters (chapters 6 and 7). The tasks concerned moving a cardboard vessel on a cardboard surface according to the set of tasks given. The participant could select any preferred method to meet the goal of the task. From this study a set of four different gestures were prominent and were utilised as a basis the rest of the user studies were built on. The chapter opens with giving a short theoretical background concerning related research and connected topics and proceeds by discussing the results of the study together with post-task discussions. The chapter closes with a summary of the main features and findings. Relevant material (published paper on the study, user study material etc.) can be found in Appendix A.

3.2 Background and Related Research

To merge commercially available multi-touch technologies with the maritime environment it was necessary and useful to consider previous research done on the topic to investigate pros and cons of the technologies and methodologies. For this initial experiment, low fidelity prototyping gave valuable insight and an easy access to issues that saved development time when designing which gestures to implement in a software based multi-touch system. Even though lo-fi prototyping can be insufficient in terms of providing enough detailed data (Liu and Khooshabeh, 2003), for this research it gave just the data needed to gain a larger understanding of using direct gesture interaction for DP interfaces. The gesture based research investigated in this study is supported by previous knowledge that gives advice on how to avoid the most obvious mistakes of developing too many or complicated gestures. Below in the following sections, the topics concerning quantitative research using lo-fi prototypes will be discussed.

3.2.1 Quantitative Research using Lo- Fi Prototyping

Prototype development is a well known technique for testing concepts and designs (Dix, Finlay, Abowd and Beale, 1997). There are several different levels of prototyping varying from lo-fi (low fidelity) prototypes made using low-cost and easily accessible material, such as the one created for this study, to working prototypes made out of hardware and software where a GUI builder can be utilised to create a dummy application where the user can click and test. This hi-fi (high-fidelity) prototype does not provide any functionality. The lo-fi prototype is typically the first one created to test the basic functionality and to study which direction to follow before investing heavily in software development. A good initial study can save resources and prevent obvious errors during product development. The close to full functioning prototype is created in the last stages of the development and demands a larger amount of resources. Each prototype goes through an iteration of usability studies to discover errors and faulty design decisions. This is called iterative design where the design can be modified and redesigned to correct any false assumptions that were revealed in the testing. The initial prototype used here utilizes the throw-away approach, i.e. the results from the testing are used for next iterations, but the prototype itself is discarded and is not to be used as the final product (Dix, Finlay, Abowd and Beale, 1997). There are six steps in a throw-away prototype approach:

1. Write preliminary requirements.
2. Build the prototype.
3. Evaluate the prototype by doing user studies.
4. Is the prototype adequate? Define new requirements and repeat if necessary.
5. Write the final requirements
6. Develop the final product to be put out on the market

The throw-away approach is often used in rapid or revolutionary prototyping. This implies that the prototyping itself is quickly done, but cannot be used for the final product. It will give interesting pointers towards how to proceed with developing the final product.

The above steps can be illustrated as in figure 3.1:

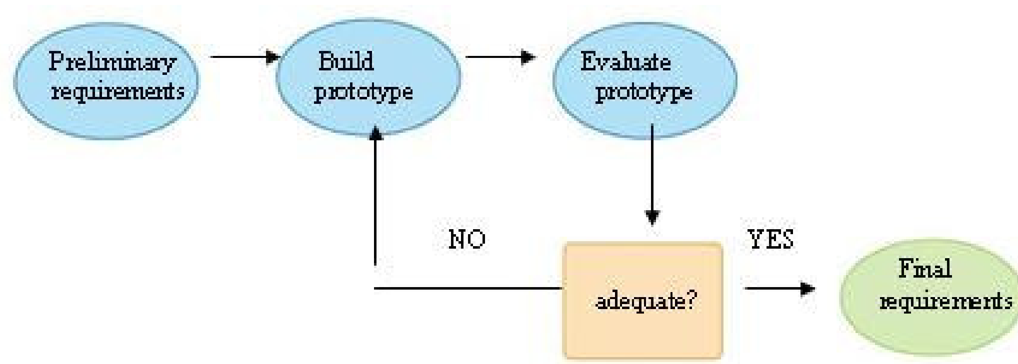


Figure 3.1: Throw-away prototype model (Dix, Finlay, Abowd and Beale, 1997)

For this initial study, no statistical data was collected and it can be categorised as a qualitative study. The information of interest was gathered through interviews and observations. The observation of the participants interacting with the prototype was carried out in a laboratory environment, recorded on video and notes were taken. The fact that the observer did not ask any questions during the observations fulfilled the requirements of it being a passive and formal observation. In this case carrying out an informal observation where the user was observed doing tasks in the field was difficult. This was due to the interaction technique being novel in the maritime domain such that the technology was not yet implemented.

3.3 Design of Study

The purpose of this experiment was to identify which gestures a panel of eight experienced users would use when operating a touch-screen DP system. A cardboard prototype was used where the participants moved a cardboard vessel on a paper surface, illustrating the graphical user interface of the screen DP system. Normally the main DP operator-display is placed vertically to the left or right side of the operator (ref. figure 2.8). However, this research is targeting a horizontally mounted display placed in a desk-like position in front of the operator. This is to suit the possibility of using both hands for interaction without any additional strain on the operator's shoulders or arms. This would be feasible for usage in a real life situation and will only demand minor changes to the DP system's graphical interface such as size and orientation. The cardboard model was in A3 format and simulated the vessel normally visible in the GUI. The test was conducted in a 2D environment, in contrast to the 3D environment, available in the real- life system. This led to testing the three main degrees of freedom (DOF); yaw, surge and sway. In addition there was one task that concerned the last three DOFs that investigated which gestures were preferred by manipulating the camera in the 3D scene. The term "manipulating the camera in the 3D scene" is used as an illustration of which angle you watch the object in the 3D environment from. Figure 3.2 illustrates the 6 DOFs that inflict the vessel's movements. Surge, sway (sideways) and yaw (rotate) are movements the operator can inflict on the vessel. Pitch, roll and heave are virtual movements that must be carried out within the frames of the 3D scene in the application, purely for orientation and to get a more nuanced overview of the object (the vessel) in the scene.

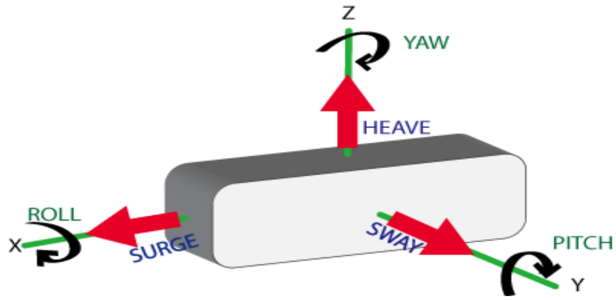


Figure 3.2: Illustrating the vessel's 6 degrees of freedom (DOF).

In the centre of the printed GUI interface a grey boat was visible. The DP system has a colour scheme with three different colours to reflect the different states of the vessel to indicate when it is in position, between positions and in an indicated preliminary position. The blue coloured vessel (see figure 3.3) signalise that the vessel is in position and is not moving. In the paper prototype this was illustrated by using a small boat cut out from cardboard. On top of the small vessel a blue print-out from the authentic system was glued on top of it. The users moved this cardboard vessel when conducting the tasks given. The yellow state was not possible to recreate in the paper prototype (see figure 3.4). The three colours (that indicate the three states) utilised to indicate movement of the vessel in the DP system is a dynamic shape. When the operator operates using the joystick or enters values into the GUI to move the vessel the yellow colour appears as a yellow shadow, giving an outline of the vessel's new and preliminary position (figure 3.4). The colour turns to grey when the operator applies (press the apply button either on the joystick or in the GUI) and accepts the indicated position (figure 3.5). When the vessel takes the yellow colour it is possible to abort the move and cancel the set values. The grey coloured vessel (see figure 3.5) signals that the vessel is in a transitional state between two positions and the move has been applied to the system, hence the vessel's propulsion system has been given an order to move in the indicated direction. When the vessel has reached the designated position, the outline of the vessel indicated in grey colour is now totally covered by the vessel and then turns into a blue colour (figure 3.3).

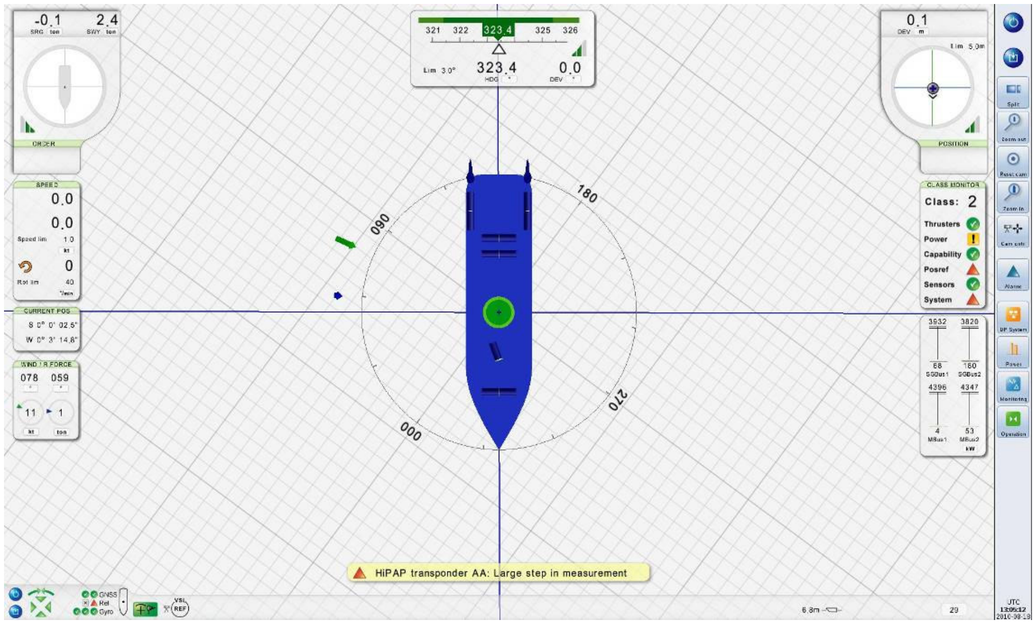


Figure 3.3: Blue colour indicates vessel in position.

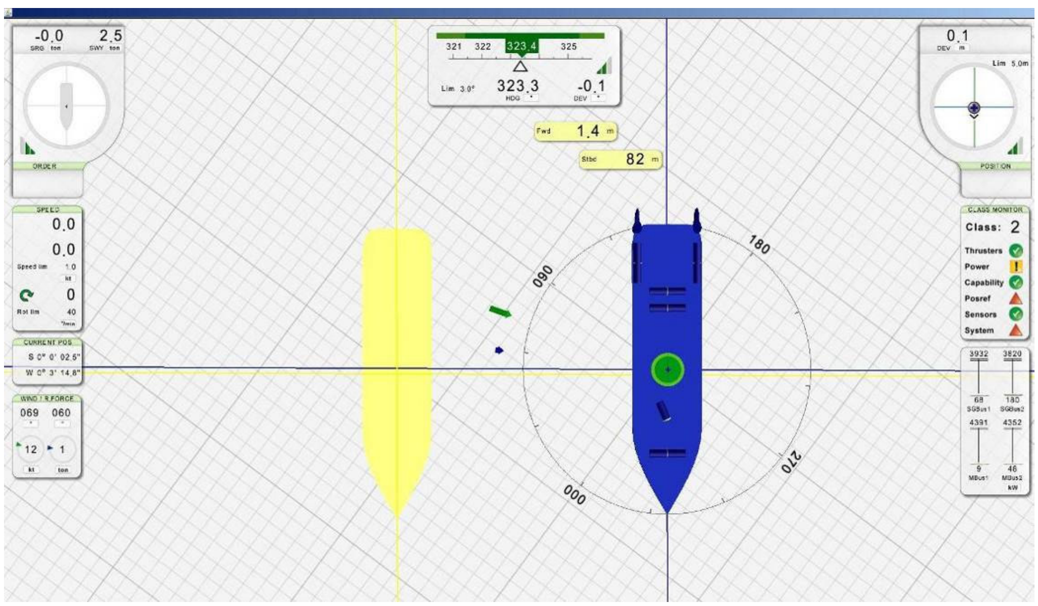


Figure 3.4: Yellow colour indicates the operator's suggested position of the vessel.

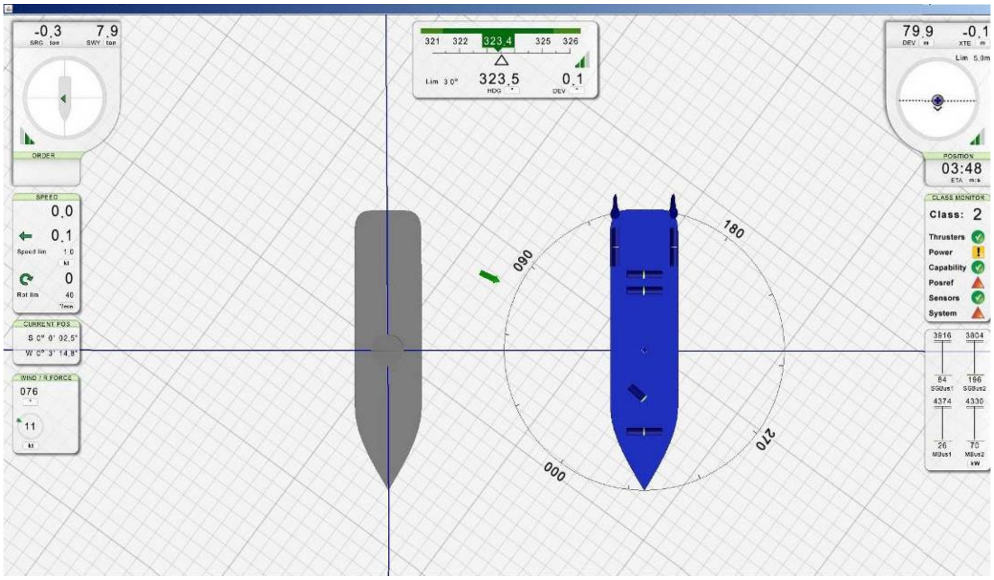


Figure 3.5: Grey colour indicates vessel in a transitional state between positions.

A video camera was used to record the movements on the surface of the prototype. Each of the participants was given the same nine tasks, but in a randomized order. Before the tasks were carried out, the participants were encouraged to move the vessel in any way found natural, using one or two hands or touching the prototype display with more than one point. The tasks given were to move the vessel in all linear directions and to change the vessel's heading by rotation. Lastly the participants were asked to suggest methods on how they would zoom into the 3D scene, pitch and roll the vessel. The last minutes were spent on a post-task walkthrough in addition to a general discussion regarding which gestures were preferred. In this experiment no quantitative data was collected and there were no hypotheses or experimental variables. This was due to it being a small experiment where the aim was not to compare different interfaces, but to investigate the possibilities within an interface.

The usability method used to obtain the results needed from this study was to utilise the low fidelity (lo-fi) prototype (figure 3.6) to do the simple tasks with a small collection of participants with knowledge about DP systems and maritime processes. Their knowledge was utilized to get a wider picture of why the hand gestures suggested could be usable in a DP system. In this case the advantages of using the paper prototype for early studies (Snyder, 2003) were important when selecting a prototype method. Following Bailey's (2005) summary, paper prototypes work just as well as software prototypes. This is especially based on Sefelin et. al's (2003) research where using software based prototypes were compared with using paper based prototypes. The outcome from this study shows that even though the participants preferred using the software based prototype, the prototypes produced essentially the same quantity and quality of critical user observations of the system tested. From this research a set of recommendations advised that paper prototypes are to be used when software based prototyping tools do not support the ideas that is to be implemented. For this research, multi-touch/direct gesture interaction was not yet available for computers, hence selecting using a paper based prototype. The negative issue with selecting a paper based prototype was the lack of feedback to the user when moving the cardboard vessel. This will however be attended to in later hi-fi prototypes described in chapter 5.To make the most out of the small experiment, the post-task walkthrough supported the results with the participants' thoughts on the different gestures selected. Video and audio recordings were useful tools to review the data and as backup details were noted down throughout the experiment. The combination of the above gave results worth building a new study on to investigate the impact of hand gesture interaction further. The outcome provided four hand gestures that the users felt natural to use when operating the touch-screen DP system by directly manipulating the vessel in the system's 3D scene. These gestures created the basis for developing new and more advanced prototypes, with the gestures implemented. This made it possible to do user studies to investigate the pros and cons of using direct gesture interaction in maritime graphical user interfaces (GUIs). These will be discussed in later chapters (chapters 6 and 7). The limitations of paper prototyping are that because of their simplicity, paper prototypes do not support the evaluation of fine design detail. Due to the use of paper and a human operator, this form of prototype cannot be reliably used to simulate system response times (Retting, 1994).

Figure 3.6: Lo-fi paper prototype

3.4 Participants

The participants were eight Rolls-Royce employees with experience of developing DP systems. They did not hold DP certificates (a maritime certificate that allows a person to operate a DP vessel), but had extended knowledge of DP from development and manoeuvring vessels during Sea Acceptance Trials, where the DP system undergoes fine tuning to be adapted to the vessel's characteristics. The participants do in average spend 15 to 20 days at sea per year, divided into separate trips visiting different vessels with duration of 3 to 5 days per trip. This gives users with a diverse experience in comparison with mariners who are employed at one vessel only. There were not given any guidance on how to proceed through the exercises or what gestures to use. This was due to the desire to investigate if it was possible to find common suggestions for movement/gesture for each task across participants.

The study lasted for duration of approximately 90 minutes, where each participant had about 15 minutes each. The participants were kept separate and carried out the experiment without discussing it with each other. A video camera was used to record the movements on the surface of the prototype.

Initially the participants indicated how well they knew Dynamic Positioning and operating DP systems. This was indicated on a scale from:
Little knowledge – Average knowledge – Good knowledge.

The participants' age, sex and official title/education was also registered (table 3.1).

DP knowledge	**Age**	**Gender**	**Title/education**
6 Average	**2** users 50+	**7** male	**6** DP software developers with MSc, BSc
2 Good	**6** users 24-44	**1** female	**2** Technical Product Managers (MSc, 50 +)

Table 3.1: Overview of details about the participants

3.5 Experimental Setup

Each participant entered the room and got a short briefing of what was going on by reading the introduction sheet where the details were described, followed by reading and signing the consent form where age, gender and education/background were registered. It was emphasized that the personal details would only be used for administrative purposes and to categorize the participants.

The participant sat in a regular office chair behind a desk with the paper prototype lying on the desk in front of the participant. The tasks were read from a task sheet by the participant,as mentioned, the tasks were given in a random order to each participant. The participant was not given any directions on how to perform the tasks. The only direction given was to move the vessel on the paper surface. On the desk was also a camera recording audio and video of the experiment. Only the participant's hands working on the paper surface were recorded. After the tasks were carried out, the participant was asked questions by the facilitator concerning how the participant experienced the experiment and if any concerns or suggestions had arisen during the experiment that he/she would like to share.

There were no experimental parameters in this experiment and the only aim was to find out if there were any common gestures suggested by the participants. Concurrent notes were taken throughout the experiment.

Schedule

- Participant enters the room
- Participant reads introduction sheet
- Participant signs consent form
- Participant takes place behind the desk
- Participant reads tasks
- Participant carries out tasks
- Participant finishes tasks
- Post-Task discussion initiated by the facilitator
- Participant leaves the room

3.5.1 Experiment Tasks

The test participants were given the same nine tasks, but in a randomized order. After completion of each task, the vessel was moved back to its initial position, shown in grey colour. Before the tasks were carried out, the participants were encouraged to move the vessel in any way they found natural.

The participants got the opportunity to read through the tasks in advance, but not the opportunity to practice. For moving in surge and sway direction the participants were instructed to move a ship's length instead of a fixed amount of meters as it is done in the real DP system. This was due to feedback from the system. In the real DP system 10 meters forward would be indicated in the GUI, the participant would receive no feedback using the paper prototype and would not know when 10 meters was reached. To avoid confusion the general term 'a ship's length' was utilised. The tasks given were:

1) Move the vessel a ship's length forward (surge).
2) Move the vessel a ship's length aft (surge).

3) Move the vessel a ship's length starboard (sway).

4) Move the vessel a ship's length port (sway).

5) Change the vessel's heading (rotate) to 90° starboard (yaw).

6) Change the vessel's heading (rotate) to 180° starboard (yaw).

7) Change the vessel's heading (rotate) to 90° port (yaw).

8) Change the vessel's heading (rotate) to 180° port (yaw).

9) Which movements would you use for the 3 remaining camera angles: heave (zoom), roll, and pitch?

The participants used approximately 10 minutes on the tasks and five minutes on a post-task walkthrough together with a general discussion regarding which gestures would be preferred.

3.6 Findings

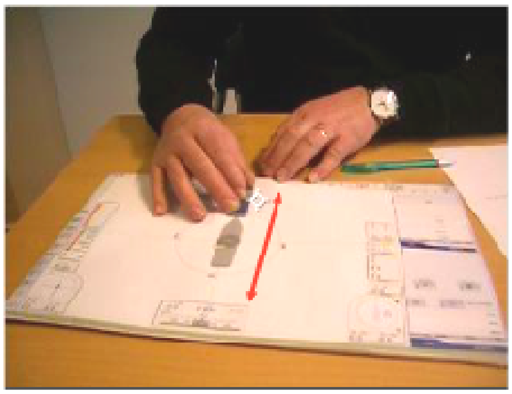
The tasks carried out showed an extended use of the index finger on the right hand. All the participants were right-handed and the majority used their right hand index finger (RI) and the thumb on the same hand to perform most of the tasks. The tables and illustrations in the next sections, show the division between which fingers used and how the vessel was moved. If there is no indication in the table concerning which direction the vessel is moved, the same method (fingers) was used in both directions.

3.6.1 Surge: Task 1 and 2

The results from task 1 and 2 (see figure 3.7) illustrated that with few variations the same fingers were used to move the vessel both forward and backward. From the table (table 3.2) only one user (user 6) used left index and two users (user 3 and 8) changed their method between the tasks. This indicates that right index finger is in most cases the dominant finger (all participants were right handed except one), while the thumb is used as a support. It is worth noting that the texture of the paper prototype could initially influence the users' choice of method if they anticipated that the cardboard vessel would be difficult to move.

3.6.2 Sway: Task 3 and 4

Tasks 3 and 4 (see figure 3.8) gave, as expected, similar results as the first two tasks. This was due to the similar type of motion required to move the vessel. The difference is however that none of the users changed their method between the tasks. There is an almost equal division between the users who only use the index finger and the users who in addition used their thumb (see table 3.3).



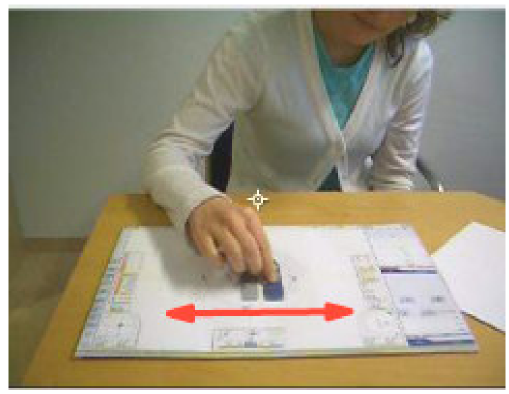


Figure 3.7: Left: Moving vessel in the surge direction using right index finger and thumb

Figure 3.8: Right: Moving vessel in the sway direction using right index finger and thumb

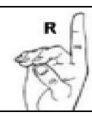
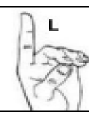
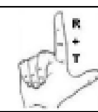
			
User 1	**X**		
User 2	**X**		
User 3	**X (aft)**		**X (fore)**
User 4	**X**		
User 5	**X**		
User 6		**X**	
User 7			**X**
User 8	**X(aft)**		**X(fore)**

Table 3.2: Summary of the fingers used to move the vessel in surge direction (R = right index finger, L = left index finger, R+T = right index finger and thumb)

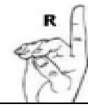
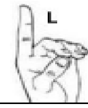
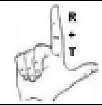
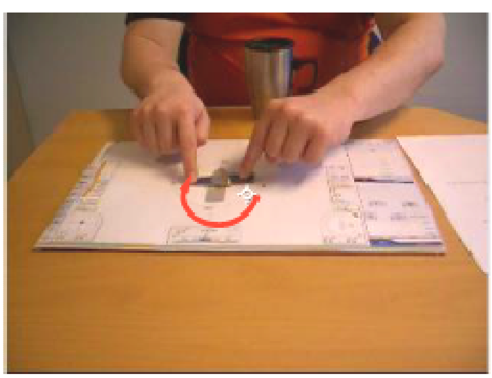
			
User 1			**X**
User 2	**X**		
User 3			**X**
User 4	**X**		
User 5	**X**		
User 6		**X**	
User 7			**X**
User 8	**X**		

Table 3.3: Summary of fingers used to move the vessel in sway direction (R = right index finger, L = left index finger, R+T = right index finger and thumb)

3.6.3 Yaw: Task 5 – 8

The result showed more variety when it came to the yaw- direction (see figure 3.9), where rotation techniques of the vessel had some correspondence, but with different variations. Four of eight participants changed their method between the tasks. This was due to the problems of rotating 180° where the hand gets in an awkward position. The participants could rotate the 90° tasks by using only one hand (see figure 3.10), while the 180° tasks where either done in two separate operations using one hand (90° + 90°, see figure 3.11) or by using two hands and both index fingers to rotate 180° in one movement (see figure 3.9). From the rotation tasks it seems like the most natural gesture would be to use both hands' index fingers to rotate the vessel in one continuous movement (see table 3.4).



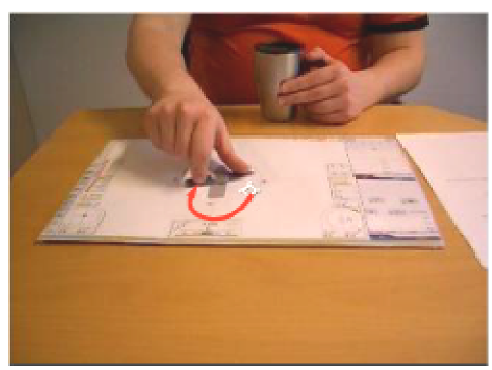


Figure 3.9: Left: Moving vessel in the yaw direction using left and right index finger

Figure 3.10: Right: Moving vessel in the yaw direction using right index finger and thumb

Figure 3.11: Moving vessel in the yaw direction using left and right index finger around the center point

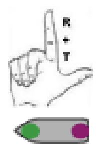
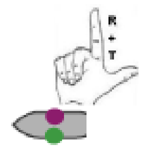
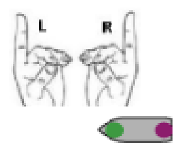
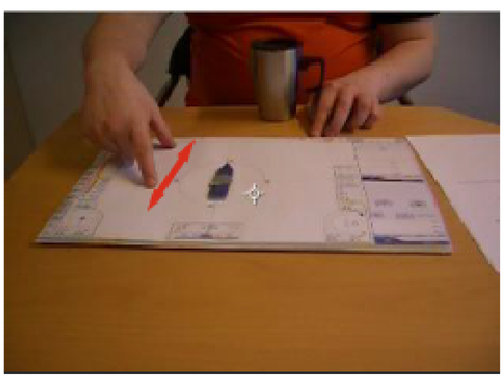
				
User 1	**X**			**X**
User 2				**X**
User 3	**X**	**X**		
User 4		**X**		**X**
User 5		**X**		**X**
User 6				**X**
User 7			**X**	
User 8			**X**	

Table 3.4: Summary of the fingers used to move the vessel in the yaw direction (R = right index finger, L = left index finger, R+T = right index finger and thumb)



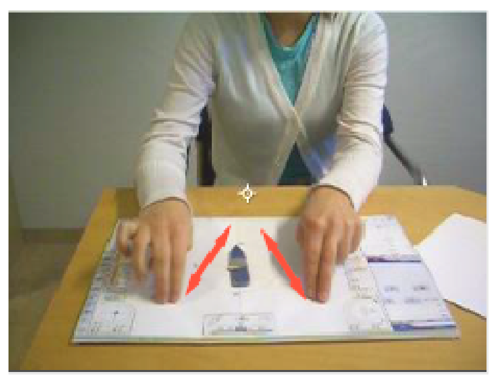


Figure 3.22: Left: Moving vessel in the heave direction using the pinching gesture

Figure 3.13: Right: Moving vessel in the heave direction using a diagonal v-shaped gesture

3.6.4 Heave: Task 9

The three remaining degrees of freedom, pitch, roll and heave, were more of a challenge. Heave equals movement along the z-axis (up and down) and cannot be implemented physically to move a vessel. It is however possible, as mentioned, to simulate heave using gestures to zoom in/out. Some of the participants tried different gestures for zooming. The pinching gesture was popular (figure 3.12), which corresponds with the familiar gesture implemented by Apple in some of their products or in the Windows 7 operating system. The gestures that arose from the zooming (see table 3.5), implies a close relation between the pinching and the diagonal slide, which is the same gesture apart from using one hand when pinching. Five out of eight participants preferred the pinch or the corresponding diagonal slide, while the remaining three suggested different movements. The v-shaped gesture is illustrated in figure 3.13.

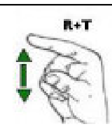
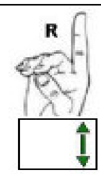
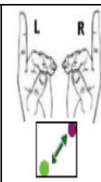
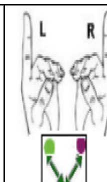
				
User 1				**X**
User 2		**X**		
User 3	**X**	**X**		
User 4			**X**	
User 5	**X**			
User 6			**X**	
User 7	Suggested a magnetic finger. Move finger away from the display, zoom out, towards display, zoom in.			
User 8	**X**			

Table 3.5: Summary of fingers used to virtually move in HEAVE direction, hence zooming in and out (R = right index finger, L = left index finger, R+T = right index finger and thumb).

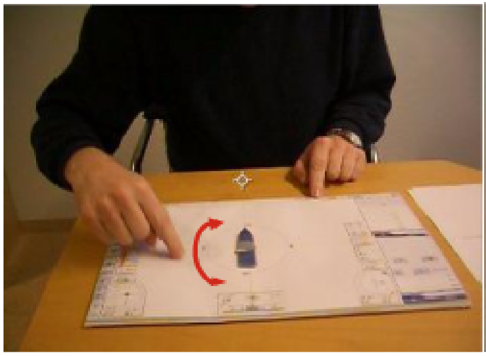
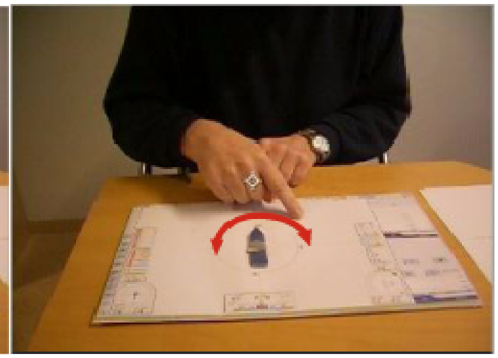
 

Figure 3.14: Left: Moving vessel in the pitch direction using a vertically curved gesture

Figure 3.15: Right: Moving vessel in the roll direction using a horizontally curved gesture

3.6.5 Pitch: Task 9

The last two degrees of freedom, roll and pitch, experienced more variation and creativeness. Pitch is a DOF where movement happens along the y- axis. It can in correspondence to heave, virtually be implemented into the system, by manipulating the angle in the 3D scene of the GUI. To illustrate movement along the y-axis, half of the participants found it natural to use a vertical curved gesture using their right index finger (see figure 3.14). An interesting issue that arose from the experiment was the fact that some of the same gestures suggested for zooming, were also suggested for pitching the vessel, which can become an issue if the users mix up the different gestures. User 7 had the most original suggestion where pressing either end of the vessel to make it "tip over" in the direction the user wished for. This shows however that the vertical curve along the y-axis seems to be the most natural choice of gesture for most of the users (see table 3.6).

3.6.6 Roll: Task 9

When the participants tried to roll the vessel, similar gestures as the ones mentioned for pitching the vessel appeared. Rolling happens along the x- axis and can be simulated by manipulating the angle in the 3D scene. The gestures suggested indicated a connection between pitch and roll, and it is natural to believe that using the horizontal curve around the x-axis (see figure 3.15) is a corresponding gesture to the pitch gesture (vertical curve around the y-axis). Three of seven (user 8 had no suggestions for roll gesture) participants (see table 3.7) indicated that the horizontal curve around the x-axis was the best alternative and two suggested a vertical curve around the y-axis. This can cause misunderstandings if mixed together.

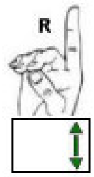
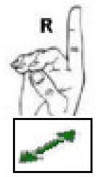
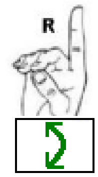
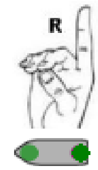
				
User 1	**X**			
User 2		**X**		
User 3		**X**		
User 4			**X**	
User 5			**X**	
User 6			**X(RI+ thumb)**	
User 7				**X**
User 8			**X**	

Table 3.6: Summary of the fingers used to pitch the vessel

					
User 1	**X**				
User 2	**X (LI)**				
User 3				**X**	**X**
User 4		**X**			
User 5		**X**			
User 6		**X (RI + thumb)**			
User 7			**X**		
User 8	**No suggestions**				

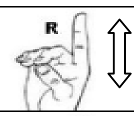
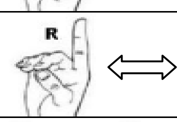
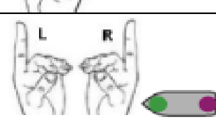
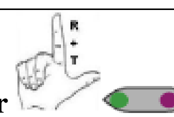
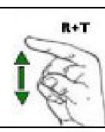
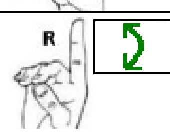
Table 3.7: Summary of the fingers used to roll the vessel

3.6.7 Post-Task Discussion

The post-task discussion gave insight into what concerns the participants had, when using mainly gestures to operate the DP system. Overall the participants' opinions were positive, especially when using dual or multiple input points. A concern arose around the display placed in front of the operator in contrast to the left or right hand side where it is placed today, where the operator's attention would be too focused downwards and not towards the aft of the vessel where the real life operations are happening. Solutions to this were suggested and included transparent displays or window projection, where the GUI was projected onto the window of the vessel. This can however disconnect the user from feeling close to the system and in control. Another important issue was heat that arises from a device on the operator's lap, response time to get out of the seat in case of an emergency situation on board and a place to rest the arms while operating the DP system. Further limitations were the lack of tactile resistance and haptic perception (Hall, Hoggan and Brewster, 2008), which will be further investigated as the research proceeds.

3.7 Experiment Conclusion

The key results from this study gave a set of gestures that stood out as a result of the tasks carried out (see table 3.8 below in section 3.8): a finger moved in a straight line for movement in the horizontal plane, a curved gesture for movement in the vertical plane, a circular gesture for rotating using either index finger and thumb or both index fingers to change the objects heading, and a pinch gesture to zoom in and out on the object. To investigate the gestures further, they were implemented in a real DP system where the aim was to compare direct gesture interaction and traditional touch button and menu interaction using single touch. This will be further discussed in chapter 6.

Tasks	**Gesture Number**	**Gesture illustration**
1 and 2: Surge	**1**	
3 and 4: Sway		
5,6, 7 and 8: Yaw 90/180	**2**	 **or** 
9: Heave	**3**	
9: Pitch		

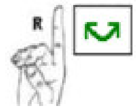
9: Roll	**4**	

Table 3.8: Summary of the set of four gestures

When changing the current methods used for DP operation, i.e. by moving the display from a left and upright position to a centred and horizontal position, issues like occlusion must be taken into account (Wu and Balakrishnan, 2003). This concerns if the display occludes any important views when placing it in this position. In addition concerns arise around the gestures' accuracy in rough weather, when the operator's hands are not steady. All these different questions add up to one common topic, which is safety. In a safety-critical situation, the GUI, interaction techniques, the system and the operator's mind must function optimally. The safety-critical aspect must be investigated and tests will be carried out in a ship simulator environment using a motion platform (ship motion simulator - SMS). This is to investigate if there is any decrease in level of performance when operating in a moving environment (Dobie, 2000) (Wertheim, 1998). These tests will be discussed in chapter 7 where the system was tested in standard offshore operation where the participants were distracted by cognitive distraction tasks (Hockey, 1997).

From the post-task discussion it became clearer that people's interpretation of HMI (Human Machine Interaction) is in general focused around HMI on consumer goods, such as PC's, mobile phones and similar equipment, which we encounter every day. The equipment is expected to be easy to use without training or extended knowledge of the product's design and/or construction. If the product is hard to use it is quickly considered useless and replaced with another product in the same category. In industry, equipment with bad usability is not as easily replaceable and the operators' complaints are often ignored due to the economical consequences of bad investments. The development has moved towards touch operated panels controlling the machines, which can replace physical buttons with soft buttons, and can therefore be more cost- efficient and enhance usability due to it being easier and less costly to re-design the GUI if usability issues are found after implementing it in the field. Physical panels are expensive and time consuming to redesign and it is very rarely done. Redesign of the software's GUI is easier if the operator's preferences are taken into account during the development process. Touch operated displays (both single and multi-touch) can suffer from limitations such as bad design, dirt on the display, lack of tactile resistance and haptic perception. To get a clearer overview of the DP operator's working environment on the bridge to take the above mentioned issues into account, an observation study offshore was needed. This study will be further discussed in the next chapter, chapter 4. The ideal setting would be to do the observation study before the initial study; however this was difficult due to practical circumstances. There were problems to get access to come on board a vessel and in addition their schedule can be unpredictable. Due to bad weather conditions the pre-study attempts to come on board were cancelled. The research had to proceed and participants that did trips offshore to attend DP issues on a regular basis were selected.

3.8 Chapter Summary

This chapter has reported the results of the initial study for this research where the aim was to investigate which gestures would feel natural to use when operating a touch screen DP system using a lo-fi paper prototype. Eight experienced users participated in an experiment consisting of nine different tasks and a post-task discussion. The results that emerged were four different gestures that stood out as prominent. When moving the vessel in surge direction the participants used their fingers to push the vessel forward or backward. In sway direction the same method as used for surge was utilised to push the vessel in port and starboard direction. For changing the vessel's heading (yaw), the participants used two fingers to rotate the vessel the amount of degrees given from the task sheet. Interestingly the participants found it difficult to rotate more than 45 degrees without the fingers getting in an awkward position. This was solved by either using two hands to rotate, hence left and right hand index finger, or doing the rotation in two operations, moving 45 degrees each time.

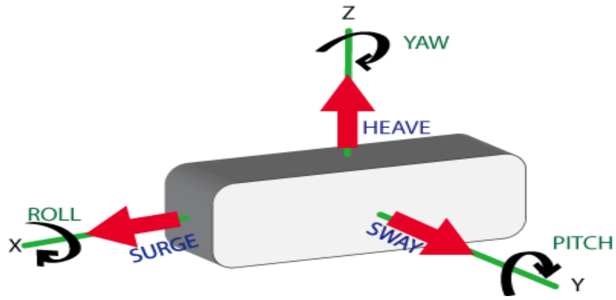


Figure 3.16: A vessel's 6 degrees of freedom (DOF).

The last three DOF's concerned heave, pitch and roll (see figure 3.16). These are directions which the vessel cannot be manipulated physically (due to heave, pitch and roll being forces imposed on the vessel by external forces such as wind, waves and current), but can be manipulated in the 3D scene of the DP's GUI for the operator to orientate in the GUI by panning and zooming like normally done in map applications and similar. For zooming in and out (heave direction) the participants used their fingers to pinch, hence sliding two fingers apart to zoom in and together to zoom out. When pitching and rolling the vessel a curved movement with the fingers in the horizontal plane for rolling and the vertical plane for pitching were utilised. The post-task discussion gave insight in the participants' opinions and concerns, where occlusion of the display caused by the hands and possible lack of haptic/tactile feedback were some of the issues that appeared.

4 Observation Study On Board Platform Supply Vessel in the North Sea

4.1 Introduction

This chapter describes an observation study where the purpose was to investigate how a DP-operator operates the DP system in its authentic environment to support the knowledge gained from the initial user study presented in chapter 3. Previously two other DP operations have been studied by utilising recorded material collected by Rolls-Royce employees. It was however desirable to obtain more real-life knowledge of the environment and situation around the operator's workplace on the bridge both during and in between operations. It was also desirable to investigate if any specific movement patterns were present between the different equipment situated on the bridge that was not clearly revealed from recorded operations. The study was conducted over a period of three days in early February 2010 on board the Platform Supply Vessel (PSV) Havila Foresight (figure 4.2). During that period, seven DP-operations at four different oil rigs were carried out where five of the operations were observed and analysed. The observations are anchored in the guidelines given in the paper written by Jordan and Henderson (1995) concerning interaction analysis and the book Social Research Methods by Alan Bryman (2008). The chapter starts with a summary of the key features of the main theory behind doing observation studies and ethnographical research. It continues with a description of the different parts of the observations carried out and ends with a conclusion of the observation with a chapter summary that sums up the main features and findings. All relevant material (bridge map, questionnaire, etc.) can be found in Appendix B and published material in Appendix C.

4.2 Background and Related Research

Observing the user in his/her natural habitat is the best method for providing authentic information about the environment of interest. As with most methods this also has its drawbacks, therefore there are several different approaches on how to observe. In many cases it is necessary to blend in and become a member of the environment observed, with or without informing the environment about the observations being done. For usability studies and gathering knowledge around processes connected to carrying out specific tasks, smaller studies combined with interviews of users are more beneficial to collect information and are commonly used. As mentioned earlier, "knowing the user" (Faulkner, 2000) is important, but it is often difficult for users to express their views and put these in the context of wider HMI work. The benefit of being an outsider when observing the users is that the observer might question issues the user may never have thought of. This gives a wider angle to finding the most suitable solutions while still grounding them in the end users' actual use of the systems and his/her environment. Below a summary will be given of the main features of doing an observation study.

4.2.1 Ethnography, Participant Observation and Micro-Ethnography

Ethnography and participant observations are, according to Bryman (2008), difficult to distinguish. Both the participant observer and the ethnographer join a group for a period of time and spend a large amount of time observing the behaviour and listening to conversations. The ethnographer also conducts interviews and asks questions while the participant observer simply observes. For the research described in this chapter there have been both observations of the participants and interviews with the participants. It can therefore be categorised as an ethnography study. However, ethnographic studies for social research often involve the observation of a group or environment for months or even years, where the ethnography is the main part of the research. When the observations are only a small part, like in the research described in this chapter, where the results are needed to gain a fuller insight in how a specific environment functions so information can be utilised to develop products or similar matters, it can be described as micro –ethnography (Wolcott, 1990). Wolcott (1990) describes "a short period of time" as a couple of weeks to a few months. This implies that a study with duration of three days is even smaller than a micro-ethnography. However, the structure of the study is identical despite the short period of time spent on observing compared to longer observations. A DP operation is based on routines where checklists are followed and most operations are very similar and the three days felt sufficient to acquire the information needed.

4.2.1.1 Entering the Environment Under Cover or Out in the Open?

With respect to an environment to observe, an approach on how to extract as much interesting information as possible must be selected. Depending on the environment, the researcher can either use covert ethnography where he/she does not mention to the selected environment that he/she is a researcher and is “under cover” or an overt ethnography where the environment is aware that there is a researcher present who is observing, but strictly for research purposes.

In addition to the covert and overt ethnographies, there are also different settings the researcher can be a part of, hence open/public settings and closed settings. In open/public settings the researcher can either be overt, such as in Taylor’s study of intravenous drug users (Taylor, 1993) where the researcher was studying the environment and was not a drug user, or a covert, such as Patrick’s study of violent Glasgow gangs (Patrick, 1973) where the researcher infiltrated the environment and gained access as a gang member. Such studies can cause ethical problems for the researcher if he/she has to become engaged in crime to not “blow his/her cover”. This discussion is however out with the scope of this thesis, but is described by Bryman (2008). The second type of ethnography involves entering a closed setting. Here the researcher studies a closed environment such as a company or other types of closed environments such as a police force. Also in this setting the research can be overt as done by Coffey when studying a UK accountancy firm (Coffey, 1999) or covert as done by Holdaway when studying a police force (Holdaway, 1982, 1983). The researcher was in this case already a policeman.

For the research described in this chapter the observer took an overt role in a closed setting and was invited to join the crew of the vessel as a guest. The crew were used to having guests on board, such as students, maritime inspectors, crew from the ship yard and HSE (Health Safety and Environment) inspectors. This seldom caused any distractions from the normal routine. It is often normal to have a key informant who initially gives the observer access to the group and also key information. In this case the key informant was the Chief Officer who invited and informed the observer throughout the observation. For covert research the key informant is also often the access point to the group. This can be the gang leader or similar members of the environment. This is out of the scope of this thesis, but can be further investigated in Bryman (2008).

4.2.1.2 Helping Out or Staying Passive: The Different Roles

The researcher can take on different roles when carrying out an ethnographic study. There are according to Gold's classification of participant observer roles (see figure 4.1) (Gold, 1958), four different roles. There is the:

- complete participant: who is a fully functioning member of the environment and social setting. The researcher's identity is not known to the members of the environment.
- participant-as-observer: the same as the first role, but the members of the social setting or environment are aware of the researcher's identity and role as a researcher. The researcher is involved in the daily routines and work.
- observer-as-participant: is a role where the researcher is mainly an interviewer. Observations are carried out, but there is very little participation.
- complete observer: here the researcher does not interact at all with the environment and is basically a "fly on the wall" and the members of the environment do not have to pay any attention to the researcher at all.

For the current observation study described in the next sections, the researcher took a role as observer-as-participant, where there was interaction with the crew in shape of observations and interviews. There was no participation in the daily practical routines on the vessel, but participated in discussions on board. The crew was well aware of the researcher's role and that the observations were to be used strictly for research purposes. It was not possible to participate in the routines of the vessel as this requires one to be fully trained as a mariner. It is therefore possible to imply that the researcher in this case entered the third role described by Gans (1968) as a total researcher which concerns observation without involvement in the situation.

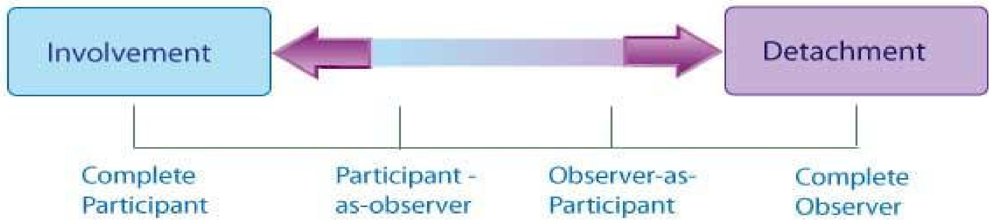


Figure 4.1: Gold's classification of participant observer roles

4.2.2 Collecting Information: Semi-Structured Interviews and Interaction Analysis

To gather as much information as possible regarding issues related to being a mariner and working offshore, semi-structured interviews were carried out in addition to observations. This is an interview technique that encourages the natural flow of a conversation instead of a fixed setup with the interviewer asking questions and noting down or recording the answers (Bryman, 2008). In this case the interview guide, which held the topics of the interviews, was memorized and incorporated into normal everyday conversation. Semi-structured interviews often give longer and more supplementary answers. In addition throughout the whole observation study, concurrent field notes were written. Field notes play an important role when the study is to be analysed and similar sections are coded/organized and labels given to component parts that seem to be of potential theoretical significance (Bryman, 2008). In addition to the procedures around how to carry out the observation, the guidelines given by Jordan and Henderson (1995) were utilized to plan what to look out for, which questions to ask and how to structure the video recordings of the operations.

For the current observation study, selective use of video recording was employed to investigate how the DP operator operates the DP system in its authentic environment. In addition, it was interesting to find out which tasks were more frequent during the different operations. The situation around the operator's workplace on board was also analysed and it was investigated whether there were any specific movement patterns between the different equipment situated on the bridge.

4.3 Design of Study

The participants in the observation study were the crew of the PSV Havila Foresight (figure 4.2) (including DP-operator(s), captain, officers, midshipmen, engineers, cook and deck crew) and two representatives from Rolls-Royce Marine AS. The vessel's work tasks for the three day period were to deliver drilling equipment, food and different liquids contained in the vessel's tanks below deck to four different platforms situated in the North Sea in Norwegian waters. The platforms were situated in the stretch of sea between the supply base/oil refinery Mongstad, 66 km north of Bergen, and Stavanger situated 207 km south of Bergen (figure 4.3). Permission to come on board the vessel was obtained from the shipping company, Havila Shipping ASA that is based in the small town of Fosnavaag on the north-west coast of Norway. Havila Shipping ASA is a company that has a fleet of 25 vessels in total where nine of the vessels are operating as platform supply vessels. Their business is in providing maritime support functions for international offshore oil and gas production, to own and run the assets regarded as necessary or desirable for this, and to provide associated services (www.havila.no). In addition, to get permission from the crew and course coordinator, contact was established with the chief officer of the vessel Havila Foresight, who provided us with further information and scheduled a time for us to come on board.

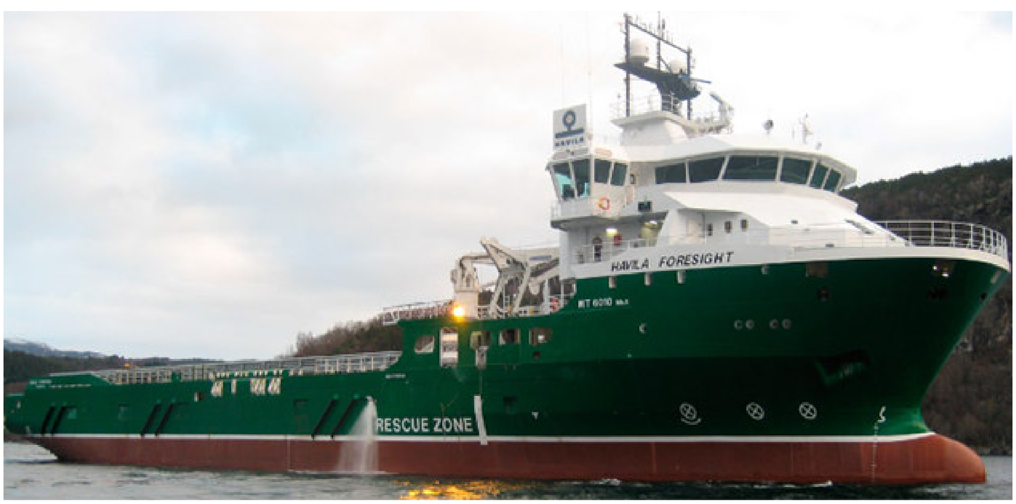


Figure 4.2: Havila Foresight

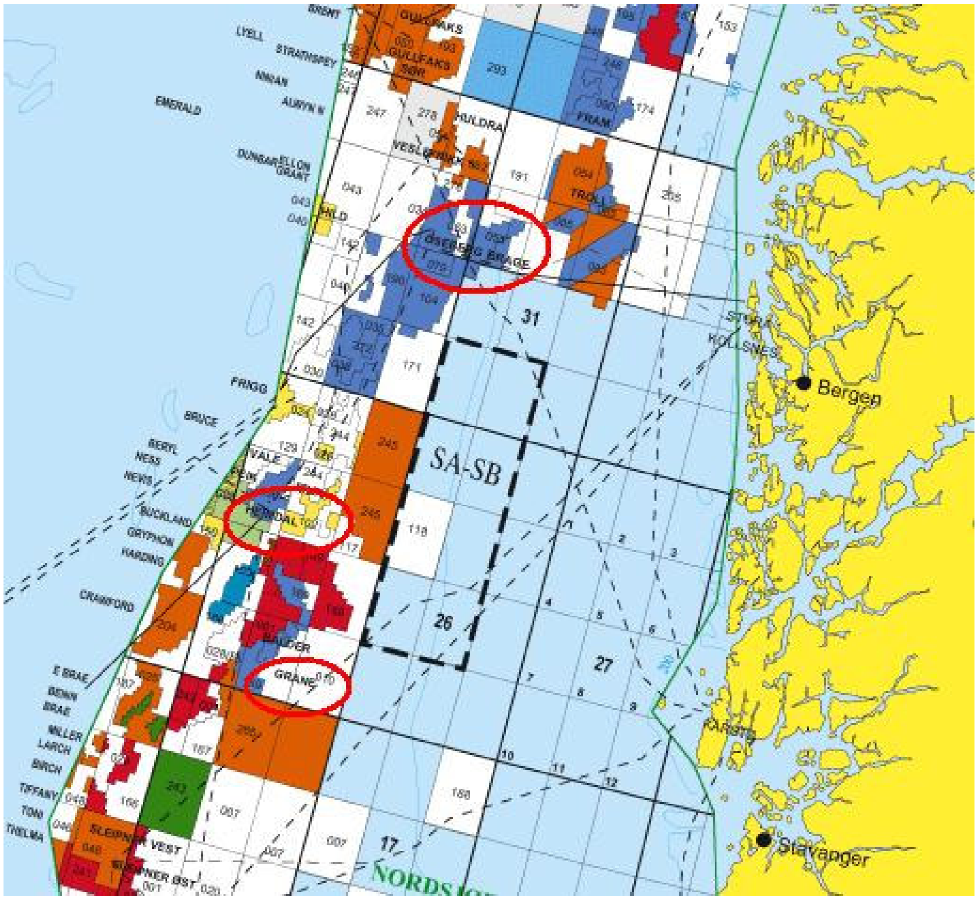


Figure 4.3: Assigned Supply Area for this observation study. Top circle: Platforms Oseberg and Brage. Middle circle: Platform Heimdal, Bottom circle: Platform Grane

4.3.1 Scheduled Tasks

Initially three observations, one interview and the handing out of one questionnaire were scheduled based on steaming (travelling) to and from one platform and one DP operation (see table 4.1). On supply vessels the sailing schedule and tasks are determined just before loading the vessel with cargo, this meant that after we arrived in harbour they informed us that we were going to visit four platforms and perform at least four DP operations. After three days, four DP operations were observed and the crew was also observed when steaming to the oilfield, between the platforms and also from the oilfield going back to shore (see table 4.2). One DP operation was recorded on video. This was because the DP operations are very similar and the deviation lies in the length of the operation and how much cargo they need to load or offload by the platform. In total 7 observations were conducted.

Initial Schedule
- Arrive at place of departure and embark vessel
- Meet the crew on board
- Give the crew a short briefing about the plans for the next few days
- The vessel leaves the harbour heading for the Troll Oilfield
- Observation 1: Observe crew on bridge (see description below)
- Prepare for arrival at Troll Oilfield
- Activate cameras and keep them running through the whole operation
-Observation 2: Observe crew/DP-operators during DP operation (loading/offloading next to the oilrig, see description below)
- Take additional concurrent field notes
- Interview and hand out questionnaire to the DP operator after DP operation (loading/offloading next to the oilrig, see description below ended operation (see description below).
- Un-mount cameras and prepare for leaving oilfield
- Observation 3: Observe crew on bridge (see description below).
- Arrive in harbour
- Leave crew and vessel

Table 4.1: Initial Schedule planned pre-embarking vessel

Fixed Schedule
- Arrive at place of departure and embark vessel
- Meet the crew on board
- Give the crew a short briefing about the plans for the next few days
- The vessel leaves the harbour heading for the oil platform Brage
- Observation 1: Observe crew on bridge when steaming towards Brage (see description below)
- Sleep (2 hrs)
- Prepare for arrival at Brage
- Observation 2: Observe crew/DP-operators during night DP operation at Brage (loading/offloading next to the oilrig, see description below)
-Sleep (3 hrs) The vessel visited the platform Oseberg C and did one DP operation during these three hours.
- **Observation 3:** Observe crew/DP-operators during DP operation at oil platform Heimdal (loading/offloading next to the oilrig, see description below)
- Observation 4: Observe crew on bridge when steaming towards the next platform Grane (see description below).
- Prepare for video recording the first operation at Grane (see description in section 4.4.3)
- Activate cameras and keep them running through the whole operation (60 minutes)
- Observation 5: Observe crew/DP-operators during first DP operation at Grane (loading/offloading next to the oilrig, see description below)
- Take additional concurrent field notes
- Un-mount cameras to keep them out of the way
- Interview and hand out questionnaire to the DP operators after DP operation (loading/offloading next to the oilrig, see description below) ended operation (see description below). Questions were asked during all periods of slack time.
- Observation 6: Observe crew/DP-operators during second DP operation at Grane (loading/offloading next to the oilrig, see description below)
- Observation 7: Observe crew on bridge when steaming back to base (see description below).

- Sleep (7 hours)
- Arrive in harbour
- Leave crew and vessel

Table 4.2: Fixed Schedule prepared after embarking the vessel

4.3.2 Respondents and Participants

The participants that were observed were recruited from the crew on the bridge, the captain, the first officer, two second officers and one midshipman. For the semi-structured interviews the captain and the first officer participated. This seemed natural as they were the highest ranked officers on board and also the spokesmen for the rest of the crew. The semi-structured interviews were carried out in the form of a normal conversation, where the captain and the first officer were asked questions when they were on duty on the bridge. The crew's routines will be discussed in the section concerning findings. An interview guide (see appendix B) was created and memorized, so that the conversation would flow as naturally as possible. The questions were asked during free periods between operations or when steaming towards a goal, i.e. an oilrig.

4.3.3 Equipment Setup

The two cameras were mounted as described below, one camera in front of the operator and one behind the operator. The exact position of the cameras was difficult to fix; they had to be mounted according to what the operators believed was a suited position according to their work situation. Approximate positions for the cameras are illustrated in figure 4.4 below. A time log was kept throughout the study and a map was drawn after the same sketch as shown in figure 4.4 of where the different actors on the bridge moved (see appendix B). The mental state of operators was registered in the time log, by noting down visual signs of the operator being concentrated, stressed or relaxed.

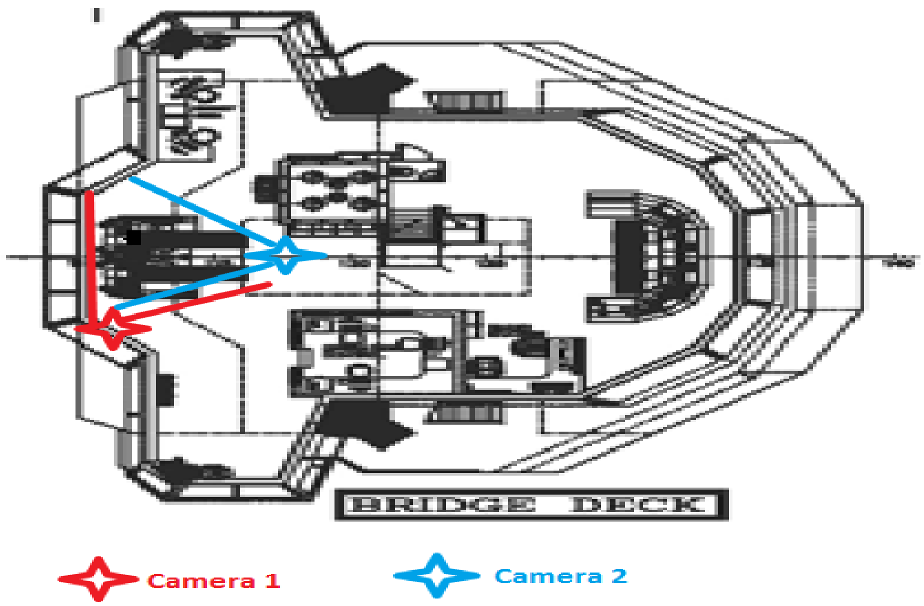


Figure 4.4: Bridge overview Havila Foresight with placing of cameras

Two cameras recorded the session. One camera recorded the operator's movements and what type of equipment he used (joystick, touch displays, emergency switches etc.). The other camera recorded the operator from the front catching the operator's facial expressions and where he placed his eyes. This camera also caught what was happening in the background. It was important that the cameras were situated out of the crew's way so that it did not interfere with the DP-operator's view out of the windows or to equipment he glanced at from time to time.

During the study, concurrent field notes were written and also events during the recording were noted down along with a timestamp. The purpose of this was to ease the work when searching for a specific event in the video recordings. Shortly after the recording finished a content log was written while the observations done were still fresh. The timeline for this study was initially not fixed, given that it would last the amount of time the operation lasted.

The map of the scene (figure 4.4) was used as an illustration and overview of the observation area. The DP-operator and additional participants signed consent forms that the video could be published and used for research purposes. Several questions were considered before and after the observations were carried out (see detailed description below in sections 4.3.4.1, 4.3.4.2, 4.3.4.3 and 4.3.4.4).

4.3.4 Observation Considerations and Categories

The observations have been divided into four categories in addition to the semi-structured interview. The first category concerns observing the crew on the bridge while steaming towards a goal (i.e. platform), the second category concerns observing the operator during a DP operation, the third category concerns observing the crew on the bridge when steaming from one oilrig to another and the fourth category concerns observing the crew while returning from the oilfield to shore. Below is a description of the different categories, which has questions that are in line with the guidelines given in the paper Interaction Analysis by Jordan and Henderson (1995). A review of the questions will be given in the section that presents the findings. A section with questions that are relevant throughout the observations is also described.

4.3.4.1 Observation category 1: Steaming towards the oilfield

This initial observation was conducted on the bridge of the vessel when leaving port and steaming towards the goal destination, the oilfield. The issues that are interesting to observe in this situation are the general movement patterns during the sea voyage from leaving harbour and entering open water, to arriving at the oilfield. Equipment used for this observation were the observer's eyes/ears and a notebook.

Questions category 1:

- Who is on the bridge?
- Who do they communicate with?
- What do they communicate about?
- Are there any movement patterns (e.g., between different installations on the bridge)(See appendix B)?
- Are there any notes/stickers/post-its on/above/below buttons/levers or switches to ease the user's mental load?

Questions Post-Observation category 1:

- Can possible patterns be shortened by placing relevant equipment closer together?
- If there are notes/stickers/post-its on/above/below buttons/levers or switches, ask the crew why.

4.3.4.2 Observation category 2: DP operation

This category concerns the DP- operation. This occurs when the vessel has arrived at the oilfield and is getting in position to move closer to the rigs to carry out tasks that concern loading and offloading supplies to and from the platforms. The vessel will use its dynamic positioning system to close in on the rig. This is dependent on weather conditions. The equipment used for this observation were two video cameras recording the operator(s) which were prepared in advance. The cameras were set to record at the same time or have a signal (e.g., sound) that indicates a point for synchronization of the two recordings.

Questions category 2:

Concerning the general overview of the operation it is important to note how the operation starts and ends:

- Is there any official start or end to a DP -operation?
- What happens during a switch between two operators?
- Are there any repetitive patterns during a DP-operation?
- How do the operator(s) communicate with the oil rig?
- Do the operator(s) communicate with others during operation?
- Are there any territorial issues between the possible two operators?
- Are there any territorial issues between the operator(s) and other members of the crew?

During the operations there are several different events happening between the official start and end:

- Is there any slack time in between different events?
- What happens during this slack time?
- Does the operator reflect on events that just happened?

- Do the crew take turns operating the DP-system?
- The activities: are they talk or instrument driven?
- Are talk and physical activities present in a turn-taking system?
- Is the DP-operator involved in several tasks at the same time (cross room communication)?

Safety-critical issues or unexpected problems can occur:
- Are there any problems?
- How do they react to problems and breach of normal procedure?
- Are there any verbal or non-verbal corrections?
- How are misunderstandings resolved?
- Does the operator occupy the space he uses in a certain way?
- Does the placing of the workstation affect interaction?
- Does the operator feel uncomfortable if people are looking at him/her? (Observed by using visual and conversation feedback).
- How does the operator interact with the system?
- Does one operator interact more than another?
- Do the operators interact with each other? In that case: How and Why?
- Who owns the territory on which actions take place?
- Are there any constraints that influence what the DP-operator does and how it gets done?
- Where are the operator’s eyes?
-Do the operators experience boredom and wandering attention? (Observed by using visual and conversation feedback.)

4.3.4.3 Observation category 3: Between platform steaming

Category 3 is conducted when the vessel steams between the platforms on the oilfield. The aim for these observations is to look for the same issues as in category 1, but investigate if there are any changes in movement patterns or behaviour of the crew. Equipment used for this observation were the observer’s eyes/ears and notebook.

Questions category 3:
- Who are on the bridge?
- Who do they communicate with?
- What do they communicate about?
- Are there any movement patterns (e.g. between different installations on the bridge)?

Questions Post-Observation category 3:
- Can possible patterns be shortened by placing relevant equipment closer together?

4.3.4.4 Observation category 4: Returning from the oilfield

Category 4 concerns when the vessel leaves the oilfield and heads towards shore and the harbour. The aim for this observation is to look for the same issues as in category 1 and 3, but to investigate if there are any changes in movement patterns or behaviour of the crew. Equipment used for this observation is the observer's eyes/ears and notebook.

Questions category 4:
- Who is on the bridge?
- Who do they communicate with?
- What do they communicate about?
- Are there any movement patterns (e.g. between different installations on the bridge)?

Questions Post-Observation category 4:
- Can possible patterns be shortened by placing relevant equipment closer together?

4.3.5 Semi-structured Interviews and Questionnaires

The interviews were focused around the DP operator and his experience. If there were any questions from the above observations that remained unanswered, the operator was asked to answer them in the interview. The questionnaire (see appendix B) contained six questions based generally on the operator's age, experience as an operator, experience with Rolls-Royce DP system and a Likert-scale question concerning the difference between Rolls-Royce DP systems and other DP systems with which they have experience. Two interviews were carried out, as mentioned earlier, where the analysis of both the questionnaire and the interviews will be discussed in the later section concerning this study's findings.

Questions:

- What is your worst case scenario?
- What can happen?
- Have you experienced any safety-critical situations?
- How do you like today's DP system?
- How do you like today's joystick and levers?
- Is there anything you would like to change or improve?
- What would you think about an interface that is physically closer to you and has a multi-touch display that enables you to directly move the vessel with your hands? (Explained to the crew in a context that was obvious to make sure they understood the meaning behind the question.)
- How did you experience this observation?
- Any comments in general?

In general

In general there are several questions that remain relevant throughout the observations.

Movement in the scene:

- What is their trajectory?
- How do they get in or out of the scene?
- Who are the human hosts?
- Is the organizational structure of the crew uniformly or hierarchically distributed? (see section 4.4.1).
- How do they function in structuring interaction?
- Are there any rearrangements of equipment?
- Are there any public display spaces?
- Who is in charge?

- Are they temporarily in the scene or stable ie, always there?
- Are things left in place across shifts?
- Is it important to be able to personalize the workspace?
- Are there any artefacts that have a specified ownership?
- Are there any artefacts and documents that function as a public display space.
- Are the displays public restricted or unrestricted?
- How does this affect the operator?

4.3.6 Post-Observation

After the study was conducted a content log (see appendix B) was created which where possible, divides the different segments into ethnographic chunks. A report was written where discussion about motivations, understandings and other internal states is supported with a reference to evidence in the video. Data was logged and analysed where analysis of the data has been password protected and accessible only by the author and the author's first supervisor.

4.3.7 Ethical Considerations

The researchers[6] were aware that their presence and actions on board the vessel can cause the crew to act differently than normal (hence video recording and asking questions). This was taken into consideration when the qualitative data was analysed. The researchers interfered as little as possible with the crew and their tasks to obtain data that is as natural possible.

The subjects were assured anonymity and were given the possibility of not attending/being a part of the observation. The researchers were objective and gave fair considerations to both sides of opinions that arose during the study.

4.4 Findings

The discoveries found after the observation study on the PSV shed more light on the differences between the usages of the DP system. Below, the different observations

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[6] The second researcher attending this study was my colleague Helene Marie Abrahamsen. She accompanied me for safety purposes and to assist in practical tasks such as setting up equipment and similar.

are described and divided into the categories they belong to as described above. The questions described in the previous section according to “Interaction Analysis” (Jordan and Henderson, 1995) will also be answered.

4.4.1 Duty Scheme and Crew Ranking

On Norwegian vessels the leadership structure is close to flat and follows the Scandinavian leadership structure where the crew as well as the higher ranked officers are Norwegian or of Scandinavian origin. The key factors in this structure can shortly be summarized as (Buus, 2005):

- Respect for the individual
- A humanistic, holistic and value based approach
- Flat and non-bureaucratic organisations
- Trust, care and concern are key values

This structure is well-known and practised in most places of employment in Scandinavia, where the distance between the manager and the employee is relatively short. The employees can freely speak their opinion, but respect and obey the managers’ decisions. This type of management varies greatly between cultures and can be impossible to maintain if the higher ranked officers are Scandinavian and the crew are for example of Asian origin where the mindset of ranking is completely different. Traditionally, from early times, the lower ranked crew was not allowed to eat in the same room as the higher ranked and it was divided into galleys and officers’ galleys. This is not the case for Norwegian vessels where all crew share the same galley facilities. For Norwegian vessels the Scandinavian leadership structure is followed, however if the lower ranked crew are from different cultures (eg, an Asian culture) the Scandinavian officers normally have to adapt and strengthen their leadership in a more formal way to maintain order on board.

On Norwegian vessels today, ranking is only visible when the shifts are distributed. Higher ranked officers get the best and most preferred shifts. The duty scheme that most frequently appears on Norwegian vessels is the six hours on and six hours off system. In this case on Havila Foresight, the captain did the shifts in the morning and afternoon/evening (6am to 12 am and 6 pm to 12 pm), while the chief officer managed the shifts in between. There have to be two members of the crew on duty on the bridge at all times. Both the captain and the chief officer have one second officer on duty with them and in addition there can sometimes be one midshipman. On the observed vessel there were 5 qualified DP operators, where the captain and chief officer were experienced and were fully qualified DP operators. The two second officers had some experience, but did not have the final certificate, which demands some sea duty before it is issued. The last operator was the midshipman who was a novice and needed guidance through the operation.

Ranking on Scandinavian vessels is based on the structure where the captain is the top manager and the chief officers come second.

4.4.2 Findings Observation category 1: Steaming towards the oilfield

This observation was conducted on the bridge of the vessel when leaving port and steaming towards the first goal destination, in this case the Brage Oilrig. The observation concerned looking for specific patterns of movement of crew between equipment on the bridge and answering the six questions found above in section 4.3.4.1, including the post-observation question. This category is divided into six sub-categories where the questions mentioned in section 4.3.4.1 are relevant for each subcategory.

The subcategories for observation category 1 are: Cast off, pull away from shore, turn vessel to desired position and start steaming, leave shore zone steaming and the last sub category is approaching the 500m safety zone around the oil platform.

The officers on watch were the captain and his second officer. In addition, one of the midshipmen and the two representatives from Rolls-Royce Marine AS (observer (author) included) were present. The officers on watch were present on the bridge during all six sub-category events. Occasionally off-duty crew came to the bridge just to get a view of the scenery and to orientate themselves and also to chat. In this case they came to talk to the observers and to the crew on watch in general. The crew claimed when asked that they normally had this habit if they were not sleeping, eating or exercising. Whether or not the frequency of the visits to the bridge increased due to the presence of the observers as guests on board is something worthy of discussion.

The communication on the bridge was in general between the crew on the bridge and on the VHF radio with the crew either on deck or on shore. When casting off and leaving shore there was extended communication with the dock labourers and with the crew on deck to get the mooring line in and to get confirmation from both deck crew and dock labourers that everything was ready and that the vessel could pull out from the quay. After confirmation, the crew on deck left to go inside and the captain turned the vessel around and started steaming. In some conditions (e.g., rough weather) they sometimes used the DP system to approach and leave the quay, but in this case it was done manually. During steaming there was little communication between the crew on watch, just random talk about the weather, private matters and estimating when arrival at the first rig would be. When reaching the end of something called the shore zone (a zone around the supply base where the vessels must check in and out. Norwegian vessels are allowed to enter without a pilot, while foreign vessels must wait at this border to await further notice on when the pilot will arrive.), they talked to the shore base (supply base) via the VHF radio and "checked out" of the zone.

The typical communication was (translated from Norwegian):
Vessel: "This is Havila Foresight"
Shore base: "Havila Foresight listening"
Vessel: "Havila Foresight checking out of shore zone"
Shore base: "Havila Foresight Confirmed"
Vessel: "Havila Foresight Received"

After this procedure was carried out, in this case it had gone dark outside (figure 4.5) and all lights on the bridge were dimmed down or turned off (except for the equipment in night mode which was showing dimmed down night colours (figures

4.6 and 4.7). This is to avoid sabotaging the crew's night vision. The crew started a 6 hour steam towards Brage oilrig and in this period of time very little happened, including minimal communication between the crew. The crew's main tasks are to observe the waters surrounding the vessel and to keep the vessel in normal operation (watch equipment reporting the status of the vessel). In this slack time the observers asked questions and performed semi –structured interviews while the officers are on watch. This will be reported in more detail in section 4.4.7.

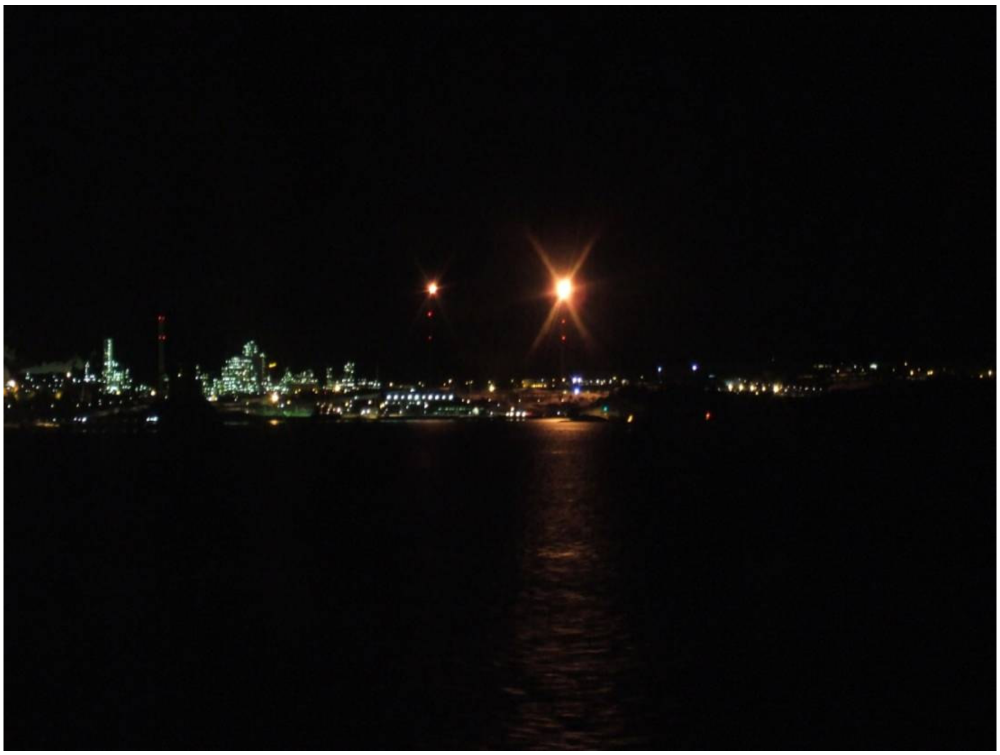
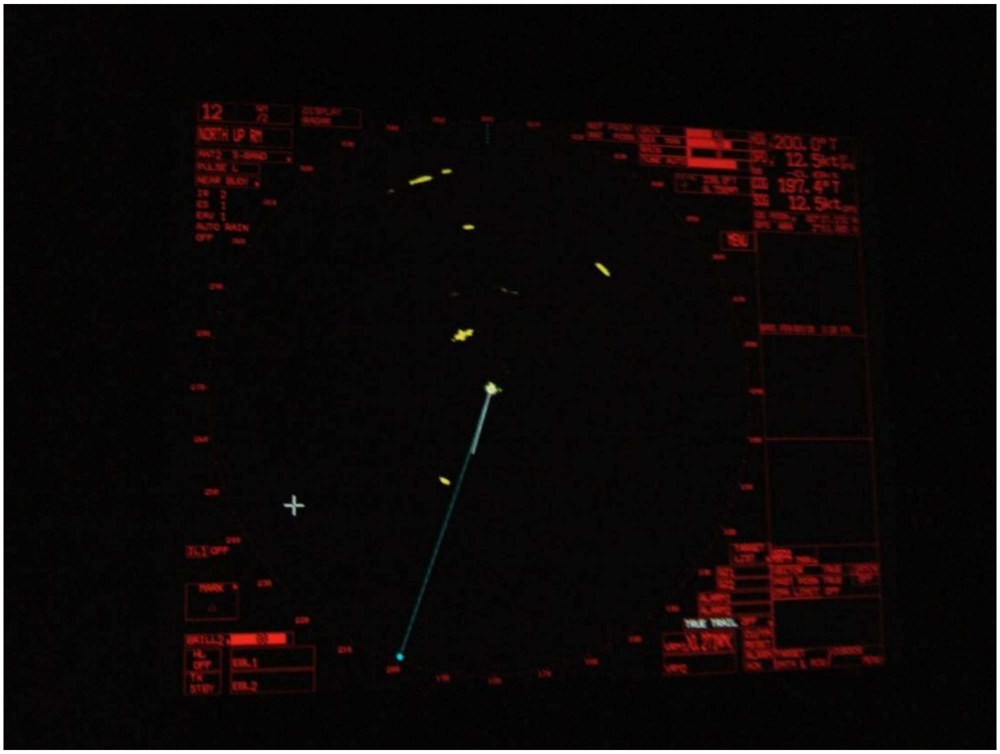


Figure 4.5: Shorebase and oil refinery Mongstad at night



Figur 4.6: Radar display in night mode (the yellow dots are vessels or oil installations).

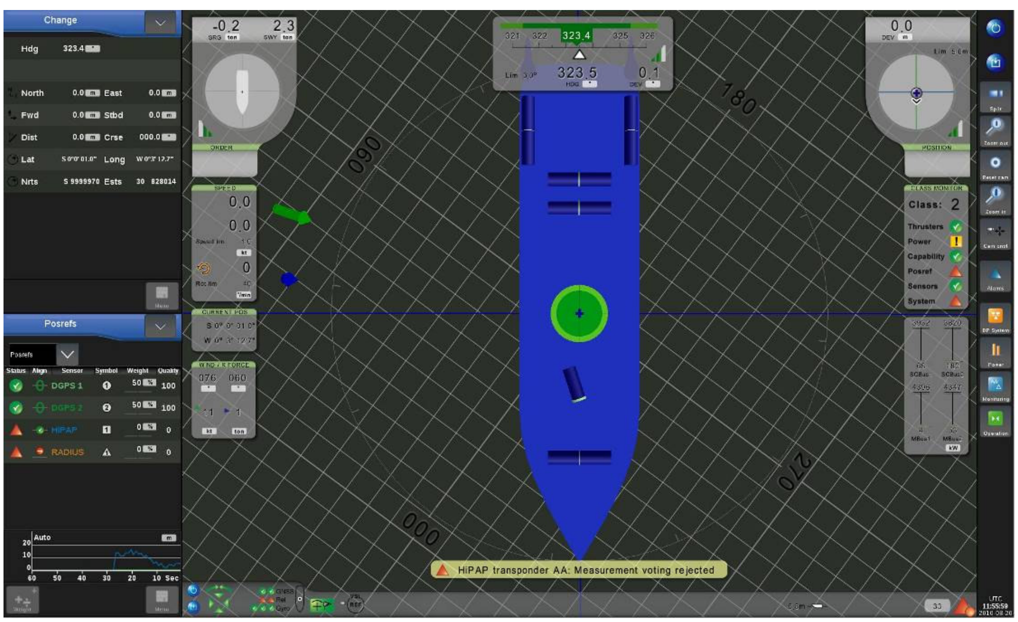


Figure 4.7: The DP's GUI in night mode

The crew on the bridge are in this period before entering the safety zone around the oil platform, mainly sitting in the chairs on the front bridge of the vessel, also called "the captain's chair". However, when they move or have the possibility of taking a small break (never leaving the bridge), they leave the chairs on the front bridge and move towards the map table where the vessel's logbook is placed. Here they enter all data they are directed to input. The logbook is not electronic and is filled in with handwriting. This is the most frequent activity that is concerned with the formal operation of the vessel. When it comes to the informal activities and small breaks, the crew often moves between the coffeemaker situated on the port side of the wheelhouse (see appendix B) and the computers with internet connection, also situated portside. The computers are used both for private purposes (only when off duty) for checking private email and social networking sites (e.g. Facebook) and for strictly operational purposes to check the latest weather forecast and North Sea news. The coffeemaker was frequently used and it was sensed that during night watch the crew had more coffee than during day watch. It may be that this is due to fatigue/sleepiness (Gretch, Horberry and Koester, 2008), but this has not been proved and is out of the scope of this thesis.

There was only one instance found of an extra "user manual" created by the crew to support the crew when operating one of the systems. The crew were in general very happy with the equipment on board, but felt they were missing a good overview of the tanks of the vessel and what they contained, whether they had been cleaned and how they were cleaned. To support this need they had a small whiteboard on the aft bridge where they drew a diagram of all the tanks available, their content and their status. This diagram was updated manually by the crew if the content in the tanks changed, the tanks emptied or if anything similar occurred. This gave the crew the extra security of having full control of the tanks' content and status.

After observing the crew from the period between leaving shore and entering the next phase and category DP operation, the question regarding rearranging equipment to shorten the crew's movement patterns emerges. This question can have various answers, but for platform supply operations such as this, the crew moves around so little that it is tempting to assume that they need this "exercise". This situation can however change if the situation gets more hectic or if they have other types of operations such as way point tracking or ROV (Remote Operated Vehicle) operations. This will be discussed in section 4.4.10.

The activity increases when the vessel approaches the oilrig and prepares to enter the 500m safety zone that surrounds the oil rig. Normal procedure is to go through the DP checklist (see appendix B), prepare for the operation and get permission from the oil platform to approach. This will be reported in the next section concerning the next observation category, DP operation.

4.4.3 Findings Observation category 2: DP operation

This category can be divided into 3 sub-categories: general overview of the operation, during the operation, and last safety critical issues and unexpected problems. The observations concern the time period from when the vessel reaches the 500m safety zone around the oil platform and goes into DP mode, gets permission from the platform to approach and starts approaching using the DP system, stabilises the vessel close to the rig, performs supply operations and lastly finishes the operation, pulls out from the rig and transfers operation from DP to normal steaming ahead. These are the five sub-sub-categories that describe a DP operation.

During this study, four DP operations were observed, where one was a night operation (figures 4.8, 4.9 and 4.10). One DP operation was recorded on video using two cameras placed in different positions as described above in section 4.3.3. Concurrent field notes were written and a transcription of all conversations between the crew and the oil rig were noted. During the observations the questions mentioned in section 4.3.4.2 were answered and if any of the questions remained unanswered, the crew answered them post-observation. Initially the general outline of a DP operation will be described, which will be more thoroughly discussed later in this section, supported by field notes and references to the video.

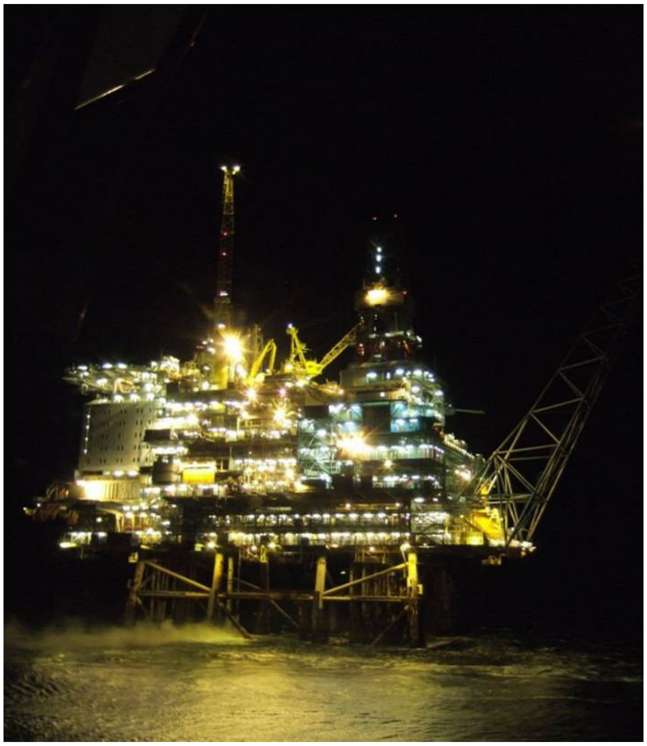


Figure 4.8: Grane Oilrig at night

Figure 4.9: Offloading cargo containers

Figure 4.10: Night operation pumping liquids to and from tanks (hose in the water on port side of the vessel. To the right of the vessel in the photo.).

4.4.3.1 General overview of the operation

Concerning the general overview of the operation, it is important to know how the operation starts and ends. In addition it's worth to make notice of the communication between the crew and the oil rig.

The official start to a DP operation is when the vessel reaches the 500 meter safety zone around the oil rig (figure 4.11), the DP operators go through the DP checklist (see appendix B) and start the communication on VHF with the oil rig. The rig addresses the vessel and decides which VHF channel they will use and suggests which side of the rig the vessel should approach due to currents, waves and wind. Normally the vessel is stabilized on the leeside of the rig. The choice of VHF channel is communicated down on the aft deck to the deck hands, so they can listen in and participate in all communication between the rig and the vessel. When arriving at the 500m border, the DP operators switch on the DP system using a manual switch. One of the operators is situated on the front bridge and one on the aft bridge.

Figure 4.11: Vessel waiting just outside the 500 meter safety zone.

Typical procedure:
OP 1 Front Bridge: "Are you ready to take over?"

Operator 1 asks to assure that operator 2 is ready to acquire command of the vessel.

OP 2 Aft Bridge: "Yes, ready."

OP 1 Front Bridge: "Giving you command"

OP 2 Aft Bridge: "Command taken"

Operator 1 walks back to the aft bridge after giving the command (control of the vessel) to the DP system on the aft bridge and the operators take place in the DP operator stations (figure 4.12), which consists of two redundant systems each with an operator station (chair and displays). There are usually always two operators surveying the operation. Normally the higher ranked and more experienced DP operator is in command of the vessel while the lower ranked is watching, learning and gaining sea experience. Sometimes the roles can be reversed such as in the DP operation described in this study, where the higher ranked officer supervised the lower ranked officer for him/her to collect more training hours towards qualifying for a DP certificate. A DP certificate proves that the operator has undergone the training necessary to operate a vessel during a DP operation. They close in on the rig using the DP system in Joystick mode, acquire the correct position references and stabilize the vessel about 10 to 20 meters from the rig. When the operator sets the DP system in Joystick-mode, the operator is then entitled to move the vessel a distance by pushing the joystick forward or sideways (depending on the vessel's position). The DP's graphical user interface visualizes (figure 4.13) the move and often the operator moves the vessel small stages at the time to be sure that to not move too much and too close to the rig.

Figure 4.12: DP operators under operation (Operator's chair: Cadet, supervising: 2nd officer)

Figure 4.13: DP GUI under operation

Occasionally the operators switch the command from the higher ranked to the lower ranked DP operator (see figure 4.12). This happens if the conditions allow it and the higher ranked officer is needed elsewhere on the bridge, has private errands (lavatory or similar) or, as described above, want the lower ranked DP operator to get more training in operating the vessel in DP. There is no formal procedure during the switch, apart from asking politely if the lower ranked operator can take command, which he confirms. On this particular vessel, there are no territorial issues which can be observed between the operators or any other members of the crew. In other professions where there are a clear demarcation of workspaces, e.g. according to roles, territorial issues can be more distinct.

During the DP operation there are few repetitive patterns, apart from following normal procedure, surveying the operation and acting on demand from the oil rig to come closer or to give more distance between the vessel and the rig. The most frequent alarm that sounds during the operation is when the system loses one of the position references. A position reference system (e.g. FanBeam, CyScan) (Bray, 2003) scans the area around the vessel for a position reference point. This is one or several reflectors mounted on the oilrig which reflects the scanning beam and returns the signal to the position reference device mounted on the vessel. In addition to GPS, position reference systems are used to ensure that the vessel stays in position if they lose their GPS signals. The position reference is easy to lose due to the vessel's movements in the waves. The alarm sounds and the operator must acknowledge the alarm and find a new reference point for the position reference system.

The communication between the operators, the oil rig and other members of the crew present on the bridge is, during operation, reduced to a minimum. The conversations have peak time in the beginning of the operation and towards the end of it. The operators discuss what happens on deck, plan ahead and also discuss how much fish the deck crew has caught during slack time (fishing is a popular hobby and is carried out whenever possible). This will be discussed in the next section. In addition, the higher ranked and most experienced DP operator tutors the lower ranked officer if a situation that demands some additional explanation occurs.

Figure 4.14: Offloading at Heimdal

During the DP operation the deck crew prepares to load and offload cargo containers and receive the hose to be connected to the tank coupling for pumping mud, water or other liquid cargo. The typical communication between the oil rig and the DP operator after finishing a pumping operation can reflect the short and concise pattern of conversation. This example is taken from the DP operation at Heimdal oil rig (translated from Norwegian). See figure 4.14.

Heimdal OP: "Our water tanks are full. You can stop pumping."
DP OP:"Confirmed"
DP operator stops the pump from one of the panels and calls for the deck crew on the VHF radio to tell them to unlock the hose from the connection.
Heimdal OP: "Confirm closed"
DP OP: "Yes, closed."
The crew has unlocked the hose and the crew on the rig can start the hoisting of it.

This leads on to the events that occur between the start and end of a DP operation which will be described in the following section.

4.4.3.2 Events during DP operation

After the vessel is in position and stabilized next to the oil rig, the deckhands prepare to start loading and offloading, plus start pumping operations either from the tanks on the vessel or to receive liquids from the platform. All platforms and vessels in the North Sea are under strict environmental regulations and are prohibited from spilling anything. This includes waste water, drilling mud, and other liquid substances. If substances are spilled it must be thoroughly reported and if they need to spill anything into the ocean, they have to seek permission from the Norwegian authorities. The normal order of loading and offloading is that they start pumping first followed by loading/offloading cargo containers and other items, this is due to the possibility of concurrently pump liquids to and from the vessel's tanks and load/offload cargo from the aft deck. During the period of time between starting the operation and ending the operation, the DP operators' responsibility is to survey the operation and the monitoring equipment on the bridge. Events the operator must respond to can be: a request from the crane operator on the rig to move the vessel closer or further away, or to take care of requests from the deckhands. A typical example of this occurred when offloading cargo containers at Grane oilrig.

The crane operator asks (translated from Norwegian):

Rig Crane OP: "Can you move 4-5 meters closer? I have the crane beam boom on full stretch."

DP OP: "That is received. Moving closer now."

Rig Crane OP: "That is confirmed."

DP OP:"Aft deck. Did you get that?"

Deck Hand: "Confirmed"

If there are no such events, the DP operators constantly survey the aft deck and their main view is through the floor- to- roof windows. In addition, the two deckhands who are on duty survey the operation and the rig crane operator has also a watchful eye on the loading routines. An example that shows the importance of this happened during loading a cargo container at Heimdal oilrig. The scenario occurred as follows (translated from Norwegian):

The deckhands fasten a cargo container to the crane hook and signal to the crane operator that everything is ready for hoisting the container.

Rig Crane OP: "Hook fastened?"

Deck Hand:"Fastened hook!"

The crane operator hesitates for a second and communicates on the VHF:

Rig Crane OP: "I think I'm missing something."

The deckhands turn around and walk back to the cargo. Here they realise that they have forgotten to attach one of two safety hooks to the crane hook. They fasten the hook and the crane operator hoists the container. This could have caused the open cargo container to flip around and cause a situation where the equipment in the container could have been damaged, or a possible loss of cargo overboard due to the placing of the container.

If there are breaks or the vessel is waiting for the rig to prepare cargo to be loaded, the deckhands spend their slack time fishing. There are very favourable conditions for fishing around the legs of the oil rigs and by using the echo sounder, the crew on the bridge give the deckhands instructions on where to cast the fishing line. The DP operators spend their slack time on private errands, fetching coffee or talking with the crew on the bridge. It is however important to mention that they never stop surveying the aft deck and the monitoring systems. It can happen that the vessel loses position and drifts off. This poses a big hazard to vessel, crew and rig. Only one operator at a time leaves the operator station. Another scenario that also happened when delivering to the Grane oilrig was after the operation ended (this session was video recorded and will be described in detail below), the rig operator informed the crew that they needed to pump mud (drilling mud). It would take at least an estimated three hours before they were ready to pump. The DP operator confirmed and informed the rig that the vessel would leave and wait on the 500 meter border. This was a non-scheduled task, but it seemed perfectly ok for the crew on the vessel to wait. The exact comment from the DP operator and chief officer was (translated from Norwegian): "The North Sea minutes are the lengthiest in the world. Ten minutes is most likely an hour or two. Stressing is no use. It doesn't go any faster anyway." This reflects that time is not very important as long as they get things done eventually. In this case the three hours extended to five, without the crew on board raising an eyebrow.

The operator seldom reflects on the tasks performed unless anything of interest has happened or the operator is tutoring a less experienced operator. The DP operators do, as implied earlier, take turns operating. This is to counteract fatigue, boredom if operations are very long and to give less experienced operators the chance to practise. Their interaction is instrumental (Jordan and Henderson, 1995), due to the focus not being mainly on the conversations between the operators but on the action and tasks they perform by operating the vessel and monitoring the displays. Both talk and physical activities are present in the turn-taking system. The operator in command asks the second operator to take command (as described above). The second operator confirms, takes command and the first operator gets out of his chair to do something else or remains sitting to give the second operator some practice.

The DP operator can be involved in several tasks at the same time and may experience some cross-room communication, but these are activities that have a low cognitive load on the operator. If the load increases, the operator hands over the command to the second DP operator and gives full attention to the other task or question if it is important, or if the situation is not hectic and allows it.

The DP system is a safety critical system and safety critical issues or unexpected problems can occur. This will be discussed in the next section.

4.4.3.3 Safety-Critical Issues and Unexpected Problems

The crew on board the vessel were, as mentioned earlier, happy with most of the equipment they have apart from a missing overview of the tanks' contents. In addition both the captain and the chief officers reported that the joystick used for operating the vessel in DP had an issue. The joystick had begun to get worn-out and felt wobbly during operation. In addition the joystick is too easy to push to one side by accident. The other problem that was reported was the placement of the button that turns on and off the DP system. This button is placed to the right on the panel under the operator's wrist. This has caused some incidents where the DP operator has switched off the DP system while approaching the rig by accident and has started drifting off position. This is imposing a constraint on the operators, due to them having to pay extra attention to the input device. There have not been any accidents caused by these problems and in such situations the DP operator reacts by re-enabling the system and taking control over the vessel again. In general, reactions to problems and breaches of procedure are handled by following rules and if anything happens with the vessel (e.g. loss of position/drifting) the operator takes manual control of the vessel by overriding the DP system. The crew is seldom stressed and has a high level of professionalism when operating the vessel. When it comes to misunderstandings between the members of the crew and verbal/non-verbal corrections, the misunderstandings are often cleared up by asking the person to repeat what was just said and if there still are any unclear matters, a question is asked in order to clarify. During the last but one operation at Grane oilrig, the verbal and non-verbal communication between the operators was more evident than the other operations. This operation was recorded on video and will be commented on in section 4.4.8. The verbal/non-verbal communication was clearer here, due to the midshipman being allowed to carry out the operation. He had very little experience and the second officer was standing behind him throughout the 60 minute operation to give him guidance. The chief officer was also present in case he was needed for advice or to take command. The midshipman showed in some cases clear non-verbal communication, by looking uncertain and completing this impression with verbal questions and indications on the planned action. The second officer corrected and guided him to the correct action.

The placing of the workstation is important. Workstations are placed on the aft bridge overlooking the aft deck. The windows in front of the operators run from floor to roof and present the operator with the most important view of the aft deck, and the view from this window is also where his eyes are placed most of the time apart from when he is glancing at the displays and acknowledging alarms. This view is of utter importance and it is crucial that this view is not blocked by any item. The placing of the workstations affects interaction in the way that is described above, which makes the operator have full focus on the happenings on the aft deck. In addition the displays placed around the operator (see figure 4.12) and the possibility of moving the chair electrically backward and forward, assists the operator in having an overview of the different displays. The distance between the displays could possibly be improved which will be discussed at a later stage. The operators occupy the space of the DP operating stations as follows: the DP chair to the right (starboard) is used by the operator in charge or the highest ranked officer. This is not a formal setting, but it is what is normally practiced. The operator usually sits in the chair, or if tutoring, he is often standing behind the chair, watching over the shoulder of operator being tutored.

The operators had no problem with being watched during the operation. They paid attention to the cameras in the beginning (e.g. joking, smiling, gesticulating, ducking below the camera angle), but forgot about them as soon as they got busy with performing the operation and carrying out the tasks planned. The video recorded operator who did the main part of the operation this time around was a novice and was also deeply concentrating on his tasks. When he operated the system he mainly used the input devices on the armrests on the chair, but occasionally used the small display to the left and right, also placed on the armrests of the chair (see figure 4.12). The operator interacted less frequently with the larger display placed to the right of the chair on the desk. This display was more often used for information purposes and to glance at in order to get a good overview of how the operation was mirrored in the DP system. The wind indicator and placing of the position references in the setpoint (see figure 4.13, green circle is setpoint), was the most important information for this type of operation. When it comes to which operator interacts the most with the system, as indicated in the earlier sections, this is the operator who has command of the system and can influence the DP system by imposing actions both from the GUI and the input devices. The operator who is in charge is usually the higher ranked officer who has the most experience and has the formal issues concerning the DP certificate in place. The level of interaction between the operators is low, apart from the odd private conversation and discussing interesting events during operation that need further explanation. If the higher ranked officer who also owns the territory on the bridge while on watch is tutoring, the level of interaction is much more frequent as indicated earlier.

DP operations for platform supply purposes can last for a varying amount of time. Some operations are very short while others can last for hours, depending on how much cargo needs to be handled. The longest operation observed during this study was at Brage oilrig, which lasted for about 4.5 hours. DP systems are also used for different types of operations, such as pipe laying and operating sub-sea ROVs. This will be further discussed at a later stage. If the operations are very long, the DP operators make sure that they get small breaks. They can at times experience boredom, but their attention is always directed towards the aft deck.

After finishing offloading and pumping of liquids to and from the tanks of the PSV, the platform reports via the VHF radio that they are now done. Often then the procedure mentioned earlier during pumping of fresh water to the Heimdal oil rig is carried out to close the pumps, disengage the hose and it is hoisted up onto the platform deck again. The vessel is now ready to pull out from the platform and the front bridge will take command of the vessel and prepare it for steaming ahead. The DP operator pulls the vessel sideways out from the rig to a safe distance (+/- 500 m) and the second DP operator leaves the operating stations and walks to the front bridge where he positions himself by the controls to acquire the command.

The communication between the two operators when leaving the Grane oilrig is cited below (translated from Norwegian):

1st DP OP (Captain): Are you ready to take over?

2nd DP OP (midshipman): Not yet!

Short break while the midshipman gets organised.

2nd DP OP (midshipman): OK!

1st DP OP (Captain): OK! Take her!

2nd DP OP (midshipman): Confirmed.

The vessel starts steaming towards the next platform, which will be described in the next section.

4.4.4 Findings Observation Category 3: Between platform steaming

When the vessel steams between platforms, the distance can vary greatly as, equally, can the time spent doing this. The time spent in total on steaming between platforms during this obervation was approximately eight hours. One hour between the Brage oilrig and Oseberg C, five hours between Oseberg C and Heimdal, and lastly two hours between Heimdal and Grane. The aim for observing this particular event is similar to what is described in the first category that describes steaming to the oilfield. The interesting part in this case is to investigate whether there are any differences in crew behaviour or movement patterns between steaming to and steaming between platforms. The questions described in section 4.3.4.3 will be answered.

The people that are present on the bridge when steaming between platforms are the officers on watch, the observers and members of crew coming and going to have a look out of the windows and to chat to keep the crew on watch company. The level of activity is low and as described in the first category, their task is to observe and monitor the vessel's status. The communication has an informal tone and they speak about private matters, their wives, homes and children. Fishing and leisure boats are also frequent topics. Some discussion revolves around experiences on other vessels and they also plan the route and check the monitors as to whether everything is as it should be. The crew sits in the captain chairs and walks to and from the coffee machine, the computer area and also the map table with the logbook on it. Some of the crew members are smokers. They are not allowed to smoke inside, so every now and again one of the officers opens one of the doors of the wheelhouse and steps outside to smoke a cigarette. They do not step further down on the deck, due to it being a safety hazard, especially if it is dark outside. The atmosphere is relaxed and informal.

The activity increases between the watches and the officer who has the next watch appears on the bridge approximately 15 minutes before his watch starts. This gives him time to get updated on events and statuses before he takes command of the vessel. Activity also increases when the vessel is approaching the goal destination, i.e. the next platform. The series of events rotates and what is described in category 2 is again in focus.

4.4.5 Findings Observation category 4: Returning from the oilfield

The last category describes steaming back to shore from the last oilfield. From start to end the steam back to the supply base took approximately 12 hours. The aim for this last observation is similar to the aims of category 1 and 3 e.g., to investigate if there are any differences between the steam to the platform, steaming between the platforms and returning to base. The questions mentioned in section 4.3.4.4 will be answered.

The vessel returns to base after finishing the last operation at Grane oilrig. This was to pump drilling mud from the platform after a five hour wait after the first operation (video recorded) on the 500m border. All tasks have now been completed. The atmosphere on the bridge is relaxed and informal. The crew present on the bridge is the two officers on watch in addition to one extra member of crew. He is one of the deckhands who prefer to chat with the observers and the officers for a little while before heading off to bed. The crew are, as described earlier in the related sections, seated in the captain's chairs, updating the logbook, checking email and weather forecasts on the computers, fetching coffee, going outside for a cigarette and in general watching the vessel's surrounding waters and monitoring the vessel's overall status. The subjects of conversation are revolving around the same topics as earlier e.g. homes, wives, children, cars and leisure boats. There can also be long periods of silence, where the crew just look out the windows.

In early morning the vessel approached the shore zone and reported to base that they were arriving and needed a place for berthing the vessel. This was done using the same method as described in category 1 (communication with shore base). If there had been no room by the quays, a waiting queue is organized in the fjord where the base is situated. The crew informed us that quite frequently there are several vessels waiting in line to berth. The activity on deck and on the bridge increased when the crew got ready to berth the vessel. This was also done after the same procedure describe in category 1. The observation has at this stage come to an end and the observers leave the vessel.

The vessel was not going offshore again on new assignments that weekend due to a bad weather forecast. Bad weather prevents the crew and vessel from performing the tasks given due to waves and wind. The DP system can counteract the natural forces very well, but it is not considered reasonable to head offshore in such conditions. In addition large amounts of fuel are used if the vessel has to weather out the gale before they can proceed with their tasks in the North Sea. If the forecasts are bad they prefer to stay on the supply base, to spare both money and the environment by saving fuel. Environmental issues are highly prioritised both by ship-owners and the oil companies.

4.4.6 Report of the DP operator's background from questionnaire

Two questionnaires (see appendix B) were handed out and the Captain and the Chief Officer filled them in. This was to gain more knowledge about their background and experience.

The captain is 55 years of age and has been working on offshore vessels since the 1970s. He has been a fully qualified DP operator since 2005 and has been operating the Rolls-Royce DP system since 2007. He gave the DP system a rank of 6 on a scale from 0 to 7, where he compared the Rolls-Royce DP system with other systems available on the market.

The chief officer is 27 years of age and has been working on board offshore vessels since 2005. He has been a DP operator for two years where the majority of his training has been on the Rolls-Royce DP system. No ranking was given to the system, due to him having little basis of comparison.

4.4.7 Semi-structured interviews with PSV DP operators

The semi-structured interviews were carried out during slack time on the bridge and when the captain and the chief officer had free time between watches. They were both informed that the observers would ask several questions as the trip went along, but it would not take shape as a formal interview. At one point the chief officer asked if all the information needed had been gathered, which the observer confirmed and then referred to all the questions asked during the trip.

An interview guide was created and memorised, but in addition follow-up questions were asked when it felt natural to do so. These were not initially incorporated into the interview guide. The answers to the questions were also memorised, but noted down on paper by the end of the day in the privacy of the observer's cabin. In this case it would have been better to use a Dictaphone, but was not due to a desire to prevent the interview subject feeling like he had to go through a schedule with questions and creating an unnatural atmosphere. All replies in the interviews are translated from Norwegian. The answers from the captain and the chief officer are placed underneath each other in the same section. They were not asked at the same time and had no knowledge of each other's answers.

What is your worst case scenario?

This question was asked to reflect what situation was the worst possible situation for the two officers.

Captain: My worst case scenario must be to lose one or several pods (propulsion power units). That would be especially bad during an operation. This would cause serious problems and put both the crew, the vessel and possibly an oilrig in danger. An example is actually last week on the British sector, when the vessel Far Grimshader lost propulsion power and laid for several hours thumping into the legs of the oilrig. The crew on the platform had to be evacuated, production shut down and half of the crew on the vessel was evacuated too. A major machinery of rescue operations (helicopters, nearby vessels, etc.) was set into motion followed by endless investigations. This is not a desirable situation both in terms of safety and the major loss of money for all involved parties. This however happens very rarely. The second worst case is a fire. We actually had a fire a few months back on this vessel. Luckily we were berthed, but it felt a bit dramatic at the time. The fire alarm sounded on one of the lower decks, we checked it out and there was nothing. The fire alarm went off again and we went upstairs to the wheelhouse and were met by thick smoke pouring out of all the electrical cabinets where all the controllers and equipment are wired. The whole bridge was filled with smoke. We opened the doors and quickly turned off the main electrical switches, and if possible, manage to save equipment. The crew was evacuated onto the aft deck and then onto the quay. The quay was blinking in blue with a whole fleet of fire engines from the supply base and nearby fire station. It was quite a scene, you can imagine. Smoke divers went in, including our own, but found no flames. We felt kind of small standing on the quay with smoke pouring out of the open doors and there was nothing we could do. After the firemen had investigated the scene, they found nothing that could have caused the electrical overload. We managed to save most of the equipment by switching the main power off, but some of the displays and also some of the crew's laptops had to be replaced. Still we have not received an answer to why this happened.

The Chief Officer had naturally fewer stories to tell due to his young age and less experience than the Captain.

Chief Officer: My worst case scenario is definitely to lose propulsion power during operation. That would have been slightly hectic and unpleasant. Drifting off without noticing until it is too late, is also a scenario I would like to be without experiencing.

What can happen?

This question was asked to gain more knowledge about what can happen in the North Sea when it comes to accidents and other events worth noticing.

Captain: Anything can happen really. Examples can be engine problems, illness, fires and other vessels that are distressed at sea. Luckily the North Sea is well monitored and help is not far away. There are lots of platforms in this area, almost like a village in the middle of the ocean. It is however a harsh environment.

Chief Officer: The most unpleasant thing we experienced with this vessel was finding a life raft floating around after a storm. It is our duty to investigate it and we hoisted it on board, we reluctantly opened it and to our relief there was no one in it. Life rafts can hold many people and to find eight or nine casualties on board would have been horrible. We later found out that a smaller fishing vessel had lost one of its rafts during the storm and no vessels had been lost at sea.

Have you experienced any safety-critical situations?

Captain: The closest to a safety-critical situation I have been in with this vessel, is the fire and switching off the DP system by accident. The routines are good both on handling fires and issues with the DP system. We received praise by the fire crew for our good routines after the incident with the electrical system and concerning the DP system, as long as you notice the vessel is not responding to your commands and drifting off, it is repairable.

Chief Officer: The only safety-critical situation I can remember must be switching off the DP system by accident. I have experienced that a couple of times.

How large waves have you encountered?

This question was a follow-up question in connection with the question above.

Captain: That must be like 18- 20 meters. I've heard of even larger waves, but have not experienced it. When waves are that large, we weather out the gale and waits for better conditions.

Chief Officer: I cannot remember really. Maybe like 16-18 meters? The weather can get pretty ugly sometimes.

Do you ever get scared or worried?

This question was a follow-up question in connection with the question above.

Captain: No, not really. It is fine most of the time as long as you can weather out the gale and just wait for it to pass.

Chief Officer: No. It can be pretty uncomfortable and difficult to move around on the bridge. So what is important is to be careful about it so you do not trip and fall. It is also important to not get surprised by a large wave, lose your balance, get knocked over and bump into things and hurt yourself. The cook downstairs got slammed into the wall on one trip.

Have you witnessed any accidents?

Captain: None on this boat, but one when I was a chief officer on an anchor handling vessel outside of Peterhead in Scotland (in the 1980s). One of the deckhands, an experienced man of 60 years of age, was on the wrong side of the aft deck when a wire snapped. It was over in a second, but he lost both his feet. There are safety rules on where you should stay during these types of operations and he did not follow procedure. Due to his quick-thinking colleague, the other deckhand, he stopped the bleeding from the stumps with ropes and stabilized him. A helicopter came to fetch him and they had to revive him three times. He is fine today and has prosthetic feet, but I cannot forget his last words before he got lifted into the helicopter: "Find my feet!" We searched for his feet on deck with flashlights and spent quite some time on it, but the only thing we found was a sock. These are memories I will never forget. What I have experienced is that often the most experienced members of crew make the most mistakes and slips. They let their guard down and often it is then too late.

The Captain's last comment concerning the errors made by the most experienced members of crew is supported by literature, e.g. by Gordon (1998) reporting on the contribution of human factors to accidents in the offshore oil industry.

Chief Officer:

I have not witnessed any accidents yet. Let us hope it will never happen.

How do you manage the watch arrangements sleep-wise?

The watches are divided into six hours on watch and six hours off watch, which mean that they seldom sleep over 5-5.5 hours.

Captain: It is hard in the beginning, but you get used to it. I always sleep at night when my watch ends at midnight. That is an advantage.

Chief Officer: I get used to it. It is not really a problem, but can feel strange when I come home and have four weeks off. Normally my watches are from midnight to six in the morning. So it can be hard to turn the circadian rhythm around to suit the life at home.

How do you like today's DP system?

Captain: I'm quite happy with it. The graphics are good compared to the competitors and the calculations of the algorithms are really fast. It needs much less processing time.

Chief Officer: It is good. I like it. It looks good and feels good to operate.

How do you like today's joysticks and levers?

Captain: They are ok too, but the joystick most frequently used is getting worn out. In addition there is the issue with the on/off button. That must be improved on later versions.

Chief Officer: I like them. The shape is good. There are the issue with the wobbly joystick and the on/off button though. I would like to see that improved on newer versions.

What would you think about an interface that is closer to you and has a multi-touch display that enables you to directly move the vessel with your hands?

Captain: No answer due to the question not being asked.

Chief Officer: I'm not really sure. For PSV vessels and supply operations the interaction with the system is not very intense and we usually do the tasks using the joysticks and the small touch displays on the armrests of the chair. I cannot really see why we should bring the display closer for this type of operation. However, for ROV and pipe laying it can be more interesting, due to them using the DP system to plan routes in advance and interact more with the GUI.

How did you experience this observation?

Captain: It is really good that the manufacturers of the equipment come out to see how it is used in real life and to get more ideas on how to improve things. We are in general happy with our vessel and the equipment, but naturally there are always things than can be improved.

Chief Officer: We are happy that you came on board to get an overview of our work environment. I can imagine it is interesting for you to see how things are offshore.

Any comments in general?

Captain: No.

Chief Officer: Hmm. I do not think so.

4.4.8 Reporting from Video recorded DP operation

One DP operation was recorded on video. This particular operation was selected due to one of the novices on board (the midshipman) was selected to do the DP operation to obtain training. In addition, it was a short operation that lasted for about 60 minutes. This operation was the second to last operation planned before the vessel was scheduled to return to the base. Recording an operation done by a novice would give interesting results on the video regarding what issues he felt insecure of. The comments made by the experienced operators to guide the novice properly were also of interest. After observing two operations previous to this, knowledge was gained as to what to look for and pay special attention to. All platform supply DP operations contain the same sub-sub categories as mentioned under the section that explains the DP operation (Category 2). The only difference between the operations is the length of the operations. This is determined by the amount of cargo to load and offload, in addition to there being any liquids to pump from the tanks and the quantity of these. Below a detailed description of the 60 minute DP supply operation will be reported with timestamp (clock) references to the videos. The operation was recorded with two cameras positioned according to the layout described in section 4.3.3.

Figure 4.15: Approach to Grane oilrig

The approach to Grane oilrig (see figure 4.15) starts as planned at 2 pm. The vessel is waiting at the 500m border and the cameras are activated. The vessel approaches the rig illustrated in figure 4.12 and the novice DP operator is seated in the operator chair to the right. Behind him is the second officer ready to guide him and if necessary take command if anything fails to go according to plan. Both the second officer and the midshipman are two young men.

Rig: **"**Havila Foresight! This is Grane."

Second Officer: **"**Grane. This is Havila Foresight."

They agree on VHF channel 15 and the communication between the vessel and the rig concerns which side of the platform to approach. The vessel moves in sideways and tries to get in position using the joystick. Two deckhands appear on the aft deck and get ready to start the offloading. There is a period of silence on the radio and no further instructions are given from the platform.

Chief Officer: “What are we waiting for?”

Second Officer: “Have not got a clue.”

The vessel approaches the rig slowly. There is very little communication at this point. The waves are between 2 and 3 meters and the weather conditions are good. A member of the crew comes to the bridge to have a look on what is going on.

Time: 2.16 pm

The vessel is now approximately 150m from the rig and the novice DP operator is concentrating deeply and has his eyes fixed out the window. He calms the vessel down (it almost stops heaving up and down on the waves). The DP operator and the second officer have a quiet conversation which is difficult to reproduce due to the low volume of their voices.

Time: 2.22 pm

The vessel is approximately 100m from the rig. The deck hands and the crew on the rig communicates that everything is ok, but move a tiny bit closer to the rig. There are now in total seven people on the bridge including the observers. Some comments about the recording equipment are made in a humorous way.

Time: 2.24 pm

An alarm sounds. This is the position reference system losing connection with one of the reflectors mounted on the rig. The alarm is acknowledged and a new reflector in a more suitable position is found and approved by the system. The DP operator locks the vessel in position at the same time as the deck hands are being called by the rig’s crane operator. The chains and crane hook is hoisted down to the aft deck, handled by the deckhands and the first container is hoisted off deck together with a small bag of postal mail.

Time 2.26 pm

The crane operator communicates with the DP operator over VHF.

Rig Crane OP: “Can you move 4-5 meters closer? I have the crane beam boom on full stretch.”

DP OP: “That is received. Moving closer now.”

Rig Crane OP: “That is confirmed.”

DP OP:”Aft deck. Did you get that?”

Deck Hand: “Confirmed”

In the background on the radio small talk between the crane operator and another member of crew on the rig. The Second Officer leaves for a minute and returns to continue to survey the operation and guide the DP operator.

Time: 2.32 pm

The Second officer leaves again and hands over the surveillance to the Chief Officer.

Time 2.34 pm

A blue cargo container is hoisted down from the rig on to the aft deck.

Time 2.39 pm

The vessel receives a message from the rig on the VHF radio.

Rig: "Havila Foresight. You must wait 3 hours for mud (drilling mud)."

Chief Officer: "That is confirmed"

Time 2.41 pm

New container down and a red container get hoisted up.

Time 2.45 pm

Slack time on deck and the deckhands are now fishing and the activity on the bridge is to locate fish on the echo sounder. The DP operator still looks out the window and checks the monitors if everything is ok.

Time 2.52 pm

An alarm sounds. The position reference system has lost the connection with the reflector again. The alarm is acknowledged and the reflector has been re-connected. Activity on the aft deck again and the last containers gets loaded.

Time 2.55 pm

The rig calls up the vessel on the VHF radio and informs them that this is the last cargo and they can now pull away to the 500m boarder and wait for the next operation in three hours' time. The DP operator pulls the vessel away sideways and moves 500m where he locks the vessel in position.

The video recorded DP operation is now over and the next procedure is to wait until the rig is ready to pump mud. There is no activity on the bridge apart from monitoring and the crew talking with each other. As mentioned earlier the waiting lasted for about five hours before the rig was ready to pump the liquid.

4.4.9 General Findings

In general when summarizing the whole observation from leaving the supply base to returning after all tasks were completed, there are a number of questions that are relevant throughout the observation. These questions were outlined in section 4.3.5 and will be answered in the discussion below. Referring to the paper by Jordan and Henderson (1995) it is important to notice the different artefacts presented in the scene, the actors in the scene and how they interact with each other in the scene. On the vessel the different members of crew have different roles according to their ranking and position. The crew working on the bridge are the ones observed in this case, and where the Captain, the Chief Officer, the two second officers and the midshipman who play different roles according to their rank and tasks given. They have different trajectories and act differently according to what they are set to do. Even though it is suggested earlier that the management structure is relatively flat on Norwegian vessels, the tasks given to each person are respected according to rank. This is without indicating that the distance between the captain and his crew has management-wise increased or turned more formal.

The scene is this case is the vessel's bridge. This is where most of the management happens and where there are people on watch at all times. The actors playing the different roles operate in teams that cover different six hour watches. The two teams operate identically, apart from the team that includes the captain. The captain is commander-in-chief and always has the last word if larger decisions are to be taken. This is not something that happens on a daily basis. The chief officer has been given the trust to take the correct decisions and acts according to that. When analysing this further, the basis will be focused on the team and not on the roles/actors.

A team consists of the Chief officer/captain, his second officer and a midshipman, this group can be categorised as the human hosts to the artefacts and the scene is the surrounding environment. The team's main trajectory is to maintain the vessel's safety, monitor the surrounding environment and the vessel's status. The artefacts used for this are mainly the equipment on the bridge and the logbook. These artefacts are always present on the bridge and can therefore be categorised as being stable in the scene. Depending on the situation, e.g. during DP operation the roles slightly change, but the above should always be maintained regardless of the situation.

During a DP operation the human hosts are the same actors as the team mentioned above, but their roles change and they become DP operators in addition to the traditional roles. The actor in charge is the highest ranked officer and the artefacts start to then revolve around the DP system and the DP operator stations, which are also present in the scene at all times (stable), but not used actively unless a DP operation is planned. The DP operator stations come into the scene when approaching the 500m safety zone around the oilrig and the front bridge comes into the scene when leaving the 500m safety zone around the rig and proceed on to steaming ahead. The equipment used during the DP operation is distributed hierarchically and is important when it comes to structuring the interaction. The operator firstly uses his eyes and ears to look and listen, then operate the input devices and lastly glance sporadically on the monitors. The DP operator has his hands on the input devices most of the time, while he at the same time uses his senses to get an overview and monitor the operation. It is important to the DP operators and also in general for the crew on the bridge that it remains "standard". The crew never personalizes the workspace due to it having the potential to cause confusion if artefacts, documents and required equipment have been moved or the crew does not recognize the scene setting. It is however quite difficult to rearrange or change a bridge, because the equipment is locked to one place and fixed there. Other artefacts e.g. the logbook is not fixed/locked to the desk and is a moveable object. It is however not accepted to move it due to that this is an important artefact and must stay at the same place and not be changed (i.e. swap the book to a different colour or move it to another table). If the next team on watch cannot find the logbook and note down events it is both confusing and a breach of procedure. Things are always left in place across shifts. Other artefacts that possibly can have a specified ownership must be the crew's coffee mugs. Apart from that the equipment belongs to the vessel with the captain in charge who also can be categorised as the owner of all artefacts on the vessel. The team on watch are on the other hand in charge of the artefacts present on the bridge and can then partly claim ownership of them.

The scene/the bridge has no public display spaces. The only public display space on the vessel is downstairs in the galley where on an unrestricted cork notice board, messages are being posted and social issues distributed.

The predictable placement of equipment and artefacts affects the operators positively. Their only task in that case is to perform and operate and they would not have to worry about looking for equipment, the logbook, or other important artefacts. If items were to be placed in a different cupboard every day or if the officer on watch decided to bring the logbook to his cabin, it would cause stress, resulting in an unorganized vessel. This affects performance and in a safety-critical environment, like the one discussed, it can also be a hazard for crew and vessel.

4.4.10 Comparison of PSV DP operations with Pipe laying and ROV Operations

The semi-structured interviews were carried out to build a base of comparison between using DP for platform supply operations and other types of DP operations such as pipe lying and ROV (remotely operated vehicle) operations. Pipe laying and ROV operations have a different level of intensity during the operations compared to platform supply operations, which can propose a different set of motives when it comes to interacting with the system. It has not been possible to observe such operations due to these types of vessels often stay out in the field for months and their schedule is uncertain. Therefore a general comparison between PSV DP operations and pipe laying/ROV operations will be given to gain valid information. The Rolls-Royce Icon DP system does not currently contain the features necessary to perform a tracking/pipe laying/ROV operation.

ROV is an underwater robot that is remotely controlled by the crew on board the “mother ship”. The ROV is connected to the vessel via a cable through which the signals sent from the operator are transmitted. The signals transmitted are electrical power, video and data signals. Most ROVs are equipped with lights and a video camera, while additional equipment can include for example extra arms for cutting, additional cameras and sonar equipment if the visibility is bad. The advantages of the ROVs are their ability to work at great depths where humans cannot work. Frequent tasks revolve today around sub-sea pipe laying and inspections of sub-sea installations.

When pipe laying vessels operate they usually plan the operation ahead. The DP system's tracking abilities are utilised and a pre-set route is plotted. The DP system's main task is to keep the vessel on track to prevent valuable equipment, such as the ROV or the pipes, being damaged. The pace during the operation itself is low (apart from during safety-critical occurrences), however the interaction with the DP system pre-operation has an increased frequency. The interaction with the display increases and the menu structures are central to plotting the correct route. In this case it is possible to believe that alternative interaction techniques such as direct gesture interaction can be utilised.

4.5 Conclusion Observation Study

Throughout the observations and analysis from the PSV Havila Foresight, a picture of a well-organised and formal vessel emerged. They carried out the tasks given with ease and followed procedures precisely, which is necessary on vessels working in safety-critical environments. However the personal relations between the crew members reflected an informal organisation that respected the ranking of an officer, but had an informal and cheerful tone between each other. They had an overall good working environment. The observations gave a good base of knowledge on how platform supply DP operations at sea were carried out in real life. For platform supply vessels the majority of time is spent on steaming to, from and between oil platforms and also waiting to get access within the 500 meter safety zone around the platforms. The discoveries made during this observation were that the pace on board was much lower than anticipated. This can of course vary between different types of DP vessels, but what was anticipated in this case was a more hectic scene on the bridge with lots of equipment interaction. The level of stress does increase if weather conditions are bad, but in general for platform supply DP vessels the pace is comfortable and slack time on board is often used to browse the internet, check the weather reports and fishing. The most frequently used equipment on the bridge during steaming to or from a destination was the logbook, the coffee machine and the captain's chairs on the front bridge. There were always at least two officers on the bridge, with one always being on watch. They swapped between being on watch and doing other tasks, such as filling in entries into the logbook.

During a DP operation the DP operator stations and communication equipment were the most frequently used equipment. During DP operation, the officer in command of the DP system maintained the view out of the aft windows and aft deck the majority of the time. The operator's good overview of the aft deck and the actions happening on deck during operation give an advantage in ensuring that safety on deck is maintained.

The observation provided detailed knowledge of the routines on board and of which tasks were more important than others. The interaction with the system had peak time when the operator closed in on the oilrig. The main interaction technique was using the input devices, such as the joystick and the heading wheel. They occasionally glanced at the displays placed to the left or right of the operator, an action which was sometimes followed by quick interactions with them. A problem that was highlighted by the operators was a button that could be hit accidentally. This caused a change of state without the operator being aware. This could potentially cause dangerous situations. In addition to the above, it was also interesting to observe and understand the communication patterns between lower and higher ranked officers, between the vessel and the oilrigs and also between the vessel and shore base.

The crew was asked about the possibilities of using direct gesture interaction to operate the system, but for platform supply operations they did not see why they should use it since using the input devices worked so well. It is worth mentioning that the dynamic approach to the platform such as that performed by using the joystick (meter by meter instead of punching an exact number) is a behaviour that also direct gesture interaction will mirror. Gesture interaction can be utilised as a supplement or a replacement of joystick interaction. It is still important to bear in mind the concerns of natural conservatism through the rest of this research and the following chapters. However, none of the observations done in this study contradicted the original ideas and design. Even though the operators cannot see why a novel interaction technique should be tested/utilised at this stage, the interaction techniques used today are the only techniques they are familiar with and have tried. There has been little work done on introducing new interaction techniques for vessel operation in previous research. The implications for using direct gesture interaction on a PSV will change the operator station's design and manoeuvres that can feel strenuous to the operator, such as turning their head to look at the displays to the left and right (leaning closer to get a better overview etc.) will be removed. The display will be moved in front of the operator placed above the operator's lap (mounted on a retractable arm or similar) and tilted approximately 30 degrees. This will give room for a larger display that will give a large work surface and not steal any of the important visibility. This is due to the display not reaching further in front of the operator than the operator's knees, hence only utilising the space already available. By possibly introducing a larger display more suited to direct and close interaction than they have available today, all information can be presented in one place in front of the operator instead of in several places. In comparison with other tasks where the DP system is utilised, such as ROV and pipe laying, the frequency of interaction during planning of the operation is higher and direct gesture interaction could be beneficial.

The benefits of collecting observation data such as that described above are that it provides a much more detailed understanding of the processes on board a vessel. This will provide better knowledge when developing equipment and will save both time and money when the knowledge gained can avoid the most obvious pitfalls. The most beneficial time to do an observation study is in the early stages of the research or development process. An important preparation was to read the related literature mentioned above to gather information about what to look for and which questions to ask.

The limitations of this observation study are that only one vessel has been observed in real life and that the observation was very time consuming. It did give a valuable insight and necessary supplement to operations studied previously on video, on what life at sea on board offshore vessels is like and how the procedures concerning the different operations are carried out. A platform supply DP operation is typical and most platform supply DP operations are similar. The lessons learned through the five operations that were observed were that the same tasks were repeated. If the conditions were not changed (weather or safety- critical issues), the differences between the operations were not providing any new or additional information. It could therefore be determined that one real-life observation study was sufficient to get a deeper understanding of how platform supply operations are carried out.

4.6 Chapter Summary

This chapter has described an observation study of the crew on board the PSV Havila Foresight. The vessel's work tasks for the three day period were to deliver drilling equipment, food and different liquids contained in the vessel's tanks below deck to four platforms in the Norwegian sector of The North Sea. On supply vessels the sailing schedule and tasks are determined just before loading the vessel with cargo. This meant that our schedule could not be finalised until arrival in harbour. After three days, four DP operations were observed and the crew was also observed when steaming to the oilfield, between the platforms and on return to shore. Due to similarity in operations, only one DP operation was video recorded. In total, five observations were conducted where one was a night operation (with a second night-time DP operation unobserved due to the observer's need to sleep). The participants observed were the captain, the first officer, two second officers and one midshipman. For the semi-structured interviews the captain and the first officer participated. This seemed natural due to them being the highest ranked officers on board and also the spokesmen for the rest of the crew. They were both experienced seamen, but clearly remembered the how it was to be a novice. Following a light interview script, the semi-structured interviews were carried out in the shape of a normal conversation, where the captain and the first officer were asked questions while they were on duty on the bridge. The questions were asked during free periods between operations.

The observations were divided into four categories in addition to the semi-structured interviews. The first category concerned observing the crew on the bridge while steaming towards a goal (i.e., platform) and the second category concerned observing the operator during a DP operation. The third category concerned observing the crew on the bridge when steaming between oilrigs, and the fourth category concerned observing the crew while returning from the oilfield to shore. Each category was supported with a set of questions in line with the guidelines given by Jordan and Henderson (1995). The questions concerned, briefly, who was situated on the bridge, communication and movement patterns on the bridge, and also any usability issues concerning the equipment on board. During the DP operation the official start and end of the operation was investigated, whether there were any repetitive patterns, communication between the operators, and also territorial issues. In addition the interaction between the operators and their abilities to work together was observed. The semi-structured interviews consisted of questions revolving around the operator's daily routines when on watch, whether any incidents had occurred and how they solved the issues.

The outcome of the observations gave useful insight into the routines and operations of a platform supply DP vessel. The pace on board was calmer than anticipated. This would however increase if the weather became rough while they are offshore. The weather during the three days of the observations was calm. The largest height of waves was approximately 4-5 meters. This observation study provided the knowledge needed to implement and test the direct gesture interaction discussed in chapter 7.

5 Software and Prototype Technologies

5.1 Introduction

The remaining empirical work in this thesis focuses on testing the proposed interaction technique using prototypes running a maritime application, i.e. a DP system. In the beginning of this research in 2007 the interest around multi-touch and direct gesture interaction had just started to become the subject of conversation. Han (2005) published his low-cost multi-touch sensing technology two years earlier and after his presentation at TED[7] in 2006 he sparked interest around this innovative interaction technique. The technique was, however, not novel and as discussed in chapter 2, Buxton and Myers (1986) had researched this technique for years. There was very little technology available concerning both hardware and software in the commercial and industrial market. The multi-touch installations available were in the form of a small table, such as Microsoft's Surface (Microsoft, 2003) table and other tables built by the developers themselves for test purposes. The technology required for this particular research was an optimal solution with display technology that detected more than one point of touch where all the technology needed was integrated in the display together with support for all gestures specified (rotation, zooming, moving in all directions/DOFs). The first display was obtained from NextWindow and used optical technology, but with limitations of the rotation gesture. The second display used was a Dell tablet computer that was the closest possible to the optimal solution. Using prototype hardware demanded programming that would make the software recognize the different gestures and interpret them into actions in the DP system. The programming challenges were solved by using two different programming languages and client- server communication between the interfaces. This chapter gives a description of the hardware and software technologies used in the different prototypes (described in the following chapter 6 and 7), starting with a general description of the system, an introduction to the

[7] TED- Technology Entertainment and Design. A global set of conferences with aim of spreading innovative ideas.

programming languages, prototype technologies and finally network communication. The chapter will be finalized with a chapter summary.

5.2 System Description

The system used for this research is a combination between hardware and software developed by Rolls-Royce Marine, software developed by the researcher to create an interface between the different parts of the system and a multi-touch display developed by an external provider. The DP system itself, when being equipped on a vessel, consists of hardware built up using Rolls-Royce Marine Controllers, displays, physical input devices and an operator chair (see figure 2.8 in chapter 2). In addition the software implemented in the system is divided between controller software and the GUI. During the development of the system, simulated values are fed in to the controllers to make the GUI come alive and act like a system in normal operation where the user/developer/test-participant can interact with the system and obtain the same results as when the system has been installed on a vessel. During this research simulated values were utilized, using two different types of simulation systems. The initial HW/SW prototype utilized a marine controller feeding the system with realistic values, while for the second HW/SW prototype a Python script framework was utilized to supply the GUI with data. Description of further details of the Python script language and controller software is out of the scope of this thesis.

In figure 5.1 the flow of information through the system and the most important components of the general system, have been illustrated. Initially after start-up the system displays the DP's GUI and feeds it with data so it is possible to interact with it. Embedded in the DP's software, changes were made so the DP system could interpret signals from the multi-touch display and pass the information on to the suitable class and make the vessel move according to information received. The software, developed by the researcher, was built on client-server communication where the server part, programmed in Java, was built into the DP system interpreting the input sent from the client. The client, programmed in C#, was listening to input from the multi-touch display that the operator/user/test-participants used to interact with the system.

More details will be given in the following sections where each block in the below figure (figure 5.1) will be discussed. Before going into the separate blocks, a description of the work done before the NextWindow prototype was available will be outlined.

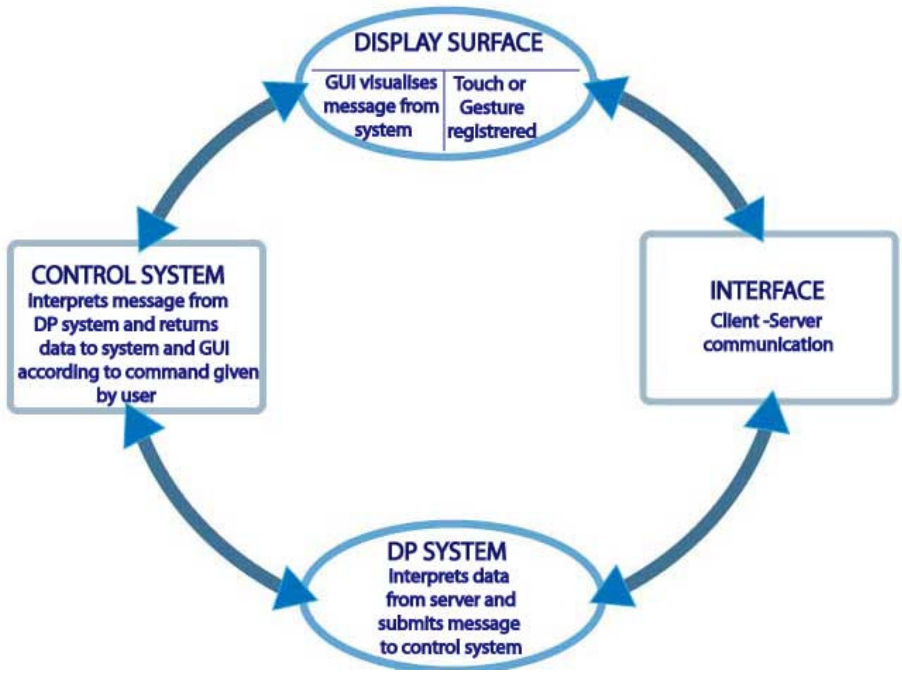


Figure 5.1: Dataflow from input to action and visualisation in the GUI. The control system section supplied the system with data automatically and was not developed specifically for this research.

5.3 Development of Pre-NextWindow Prototype

During the search for a multi-touch display prototype, software development commenced to prepare for a possible prototype where it was assumed that gestures had to be developed from scratch. Prototype software implementing gestures using single touch and the method described in section 5.3.1, were then added to the DP system. This made it possible to manipulate the vessel in four of six available degrees of freedom: surge, sway, pitch and roll. The DOFs that needed more than one point/finger touching the screen, such as zoom/heave and rotate/yaw could not be implemented. By using Java, jME (described in sections 5.5.1.1 and 5.5.1.2) and a standard touch-display, the touch-point could be tracked by inserting the coordinates into a datastructure (array). The co-ordinates were a set of absolute x and y values that introduced the vectors processed. By using a datastructure (array) and comparing the elements in it, it was possible to do further calculations to determine which gesture had been applied to the display. It was desirable to find out the length of the gesture (to determine how far the vessel should be moved), the direction (in which direction the vessel should be moved) and whether it was curved (for tilting or rolling the vessel).

5.3.1 Processing Data to Determine the Gesture

The data was processed by using standard mathematical rules for derivation and curvature as used by Moreau et al. (2007). Firstly the co-ordinates given by the touch-point were inserted into an array with room for nine values. The timestamp of each touch-point/mouse co-ordinate was inserted into a separate array of the same structure as the first containing the coordinates. The values obtained from this collection were used to calculate the first (figure 5.2) and second derivatives. The reason behind these calculations was to get the correct data to calculate the curvature of the movement.

$$f'(x) = \frac{(coord[6] - coord[8])}{(time[6] - time[8])} = \frac{\Delta coord}{\Delta time}$$

Figure 5.2: Derivation (6 and 8 equals the position of values from the datastructure).

When the values of the first derivatives were obtained the second derivatives could be calculated. This was done by using the same procedure as above, replacing the coordinate values with the first derivatives. With this information it was possible to calculate the curvature (*K*) (figure 5.3) and determine what type of gesture the user was executing (curve or straight line):

$$\kappa = \frac{|y''|}{(1 + y'^2)^{3/2}}$$

Figure 5.3: Curvature

In parallel with the calculation of curvature, the angle (Θ) between the vectors' axes and the speed vector was calculated (see figure 5.4). As used by Wu, Shah and Lobo

(2000) this method calculated the direction of movement of the touch-point, where the angles found were a result of the dot-product of the x-axis' vector, and the first derivative was divided by the absolute product of the length of the x-axis' vector and the length of the first derivative. The same procedure is followed to find the angle between the speed vector and the y-axis.

$$\theta = \arccos\left(\frac{xy}{|x||y|}\right)$$

Figure 5.4: Angle between the axes and speed vector

By using these formulae, it could be determined if the touch-point moved towards north, south, east or west. In addition it was also possible to find out if the gesture was a curve and whether the direction was either north or south. The camera in the 3D scene tilted the vessel according to the gesture initiated by the user. By using unfiltered values such as those described above, the vessel did not behave rationally, due to large variations in the values indicating the curvature. To even out the signal and remove rapid fluctuations, a filter had be added. Two different approaches were attempted, the first approach used a low-pass filter with a corner/cut off frequency, while the second was a simple FIR (Finite Impulse Response) filter.

5.3.1.1 Filtering the Signal

There are several different methods to filter the signal and even out the signal's peaks. The main goal was to smooth the signal's curve and reduce the short term oscillations. One solution to this could be to find an average value and use this as an input to the algorithms which control the movements of the camera in the 3D scene.

Low- Pass Filtering

A low-pass filter was considered due to its characteristics of passing low- frequency signals and reducing the amplitude of signals with frequencies higher than the cut-off frequency (McClellan, Schafer and Yoder, 1999). The filter does in many situations work similar to a running average filter removing fluctuations in the signal and leaving the long –term trend, which in this case was the desired output. The low-pass filter (see figure 5.5) used to filter the curvature signal took advantage of the previous filtered valued to calculate a new output.

$$F = (1 - Fc) * V0 + Fc * Vu$$

F = Filtered Curvature,

Fc = Corner/Cutoff Frequency,

V0 = Last Filtered value,

Vu = Unfiltered Value

Figure 5.5: Low- Pass Filter

The problem with low- pass filtering was finding the cut-off frequency. In this case the cut-off frequency was next to impossible to locate due to rapid fluctuations in signal and great variations in signal values. Low- pass filtering did not solve the vessel's behavioural problems and the decision for the next attempt fell on a FIR (Finite Impulse Response) filter.

FIR Filter

FIR is a filter that is used to remove rapid fluctuations in signals and is identified as a secure and stable filter in contrast to IIR (Infinite Impulse Response) filters (McClellan, Schafer and Yoder, 1999). A FIR filter removes fine scaled variations in signal, and it is possible to include a desired amount of samples into a running average filter. The output is obtained by shifting the output of the casual running average by a selected number of samples to the left. This results in a centralized running average filter (see figure 5.6) which is delay-compensated.

$$y[n] = \sum_{k=0}^{M} b_k x[n-k]$$

bk = filter coefficients

M = filter order

k = filter index

Figure 5.6: FIR Filter (McClellan, Schafer and Yoder, 1999)

With the implementation of the FIR filter as used by Shi, Taib and Lichman (2006) and Arfib, Coutourier and Kessous (2002), the vessel behaved better, but not completely satisfactorily. The above pre-prototype development was discarded after receiving multi-touch displays where some of the gestures were already implemented and adapted to suit the display. The knowledge gained was however useful in understanding the theories behind gestures and gesture recognition where the research from this point considered creating the appropriate interface between the multi-touch display and the DP system.

5.4 Display Surface: Prototype Technologies

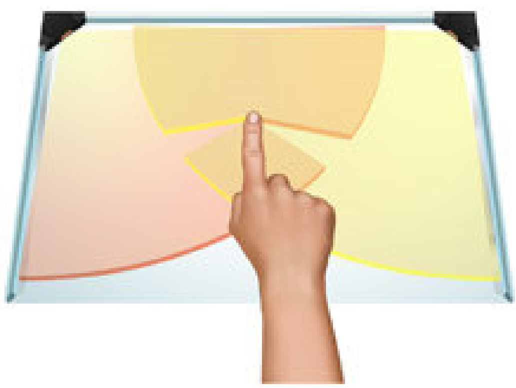
The display surface consists of two different parts in this research; the display as a surface of interaction and the technology behind the actual displays. For this research two different technologies of prototypes were utilized, the NextWindow display and the Dell Latitude XT2 tablet computer using optical and capacitive touch technology. The diversity of the prototypes is a reminder of how quickly development has grown in the multi-touch sector. In 2007 there were hardly any devices available, while in 2009 it was possible to buy a commercially produced tablet computer with all features integrated. In section 5.4.1 and section 5.4.2 the two different display technologies will be discussed, which will be followed by section 5.4.3 that describes the role of the display in the dataflow between the different blocks of the system (see figure 5.13).

5.4.1 Optical Technology using NextWindow Prototype Display

The first prototype used optical technology presented by NextWindow and was used in the user study presented in chapter 6. The displays can be found today in commercial products such as the HP TouchSmart All-in-one-Pc (Hewlett-Packard, 2010) and on other installations such as interactive commercial displays and similar (NextWindow, 2008). To give a short summary of the build of the NextWindow display is that it is basically a traditional LCD display with a glass overlay where two optical sensors are mounted. On top of this is a frame that covers the overlay and makes it look like it is a part of the traditional LCD and covers sensors and the technology needed to reflect and interpret the signals (see figure 5.7). Optical touch is constructed so that two optical sensors track the movement of any object (finger, pen, credit card or similar) close to the surface by detecting the interruption of an infra-red light source. The light is emitted in a plane across the surface of the screen and can be either active (infra-red LED) or passive (special reflective surfaces). The prototype used for this research was passive, utilizing reflective tapes around the edges of the display. The signals are then interpreted by a circuit controller board where the controller software compensates for optical distortions and positions the touch signal in the exact position. This is done by a triangulation of the touching object. There are different types of configurations available from NextWindow, however in this case optical sensors were mounted on the surface of the glass. According to NextWindow (NextWindow, 2010) the infrared light source and optical sensors are synchronized using an algorithm that also reduces the effect of ambient light. For this research a NextWindow prototype display was tested which proposed some challenges (see figure 5.8). The advantage with this technology is that it is not pressure sensitive and gives, according to the supplier, a very accurate touch. This did however seem to be a problem due to it being easy to touch by accident by brushing something against the display such as objects as small as dust and fibres from textiles.

In addition it was not possible to easily implement the rotation gesture. The NextWindow team had at this stage not added support for rotation and the attempt trying to solve the problem using software failed due to occluding touch points. The optical sensors were not able to detect the touches as two separate touch points, but only as one single touch. This occurred when the two fingers were in a linear vertical position and the reflective tape at the bottom of the display only reflected one position (vertically) and did not detect the horizontal coordinates (see figure 5.9). This caused the rotation gesture to be discarded for the first prototype-based study (chapter 6). It must be emphasized that the optical technology on products commercially available today has improved and if requested can be equipped with protection against dirt, dust and moisture.

Figure 5.7: Illustrating the layers of NextWindow's's[8] optical technology



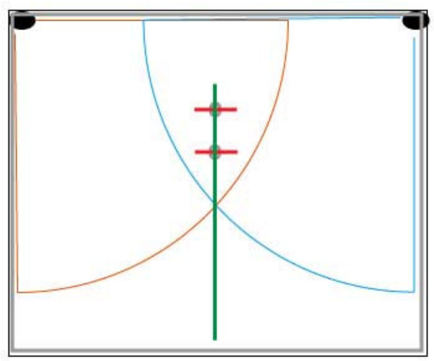


Figure 5.8: Left: Illustration of NextWindow Optical technology[9] with orange and yellow sectors showing the area covered by optical sensors.

Figure 5.9: Right: Illustration of occlusion of touch points during rotation attempt.

Orange and blue sectors illustrate the optical sensors' coverage, the grey square inside illustrates the reflective tape and the two gray circles in the middle are the touch point is the position where occlusion occurs. The red lines symbolise the direction not recognised by the NextWindow system (horizontal) and the green line symbolises the one touch point reflected by the tape and recognised (vertical).

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[8] See footnote below.

[9] In courtesy of NextWindow: http://www.nextwindow.com/optical/index.html

5.4.2 Capacitive Technology using Dell Latitude XT2 Tablet Computer

The second prototype used capacitive touch technology presented by Dell in the shape of the Dell Latitude XT2 tablet computer (see figure 5.10). This prototype was used for the pilot and main study presented in chapter 7. The reason for changing technologies was due to the test results from the first prototype-based user study (chapter 6) where the test-participants suggested a technology with less sensitivity to touch and having a larger buffer for inaccuracy. Despite the need to re-program the software previously used, this tablet computer gave a better basis for doing the next user studies (chapter 7) and it was possible to enable both the desired horizontal position of the display and rule out the usage of additional equipment such as the marine controller. This would ease the accomplishment of the future user studies (chapter 7), due to having everything integrated and running on one computer. The only item needed for obtaining the necessary information from the studies was the tablet computer and a Python framework feeding the GUI with simulated data. The drivers needed to detect input from the display were supplied by NTrig (NTrig, 2010) and had all gestures enabled, including rotation.

Figure 5.10: Dell Latitude XT2[10] tablet computer with multi-touch functionality

The capacitive technology is designed for many areas of use, but is particularly popular for touch-screens used in mobile phones, cash machines and in tablet computers. It is better suited for harsher environments due to the possibility of

[10] In courtesy of: http://www.dell.com/tablet

sealing the monitor itself; hence it is suitable for interaction with industrial applications such as the DP system or in the maritime environment in general. The technology itself works by sending a small current of electricity (see figure 5.11) across the screen, with circuits located at the corners of the screen. These are used to measure the capacitance of a person touching the overlay. A touch will interrupt the current and activates the software that controls the signals obtained from the screen.

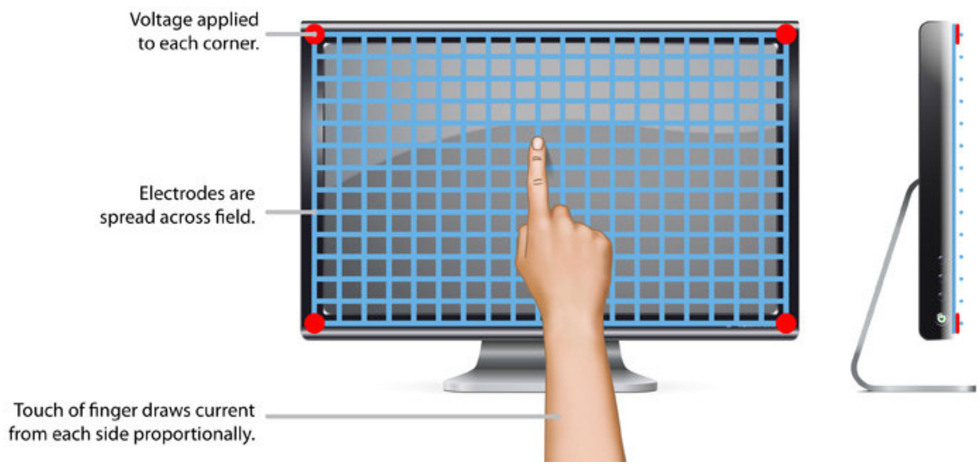


Figure 5.11: Capacitive touch technology[11]

5.4.3 The Role of the Display Surface in the Dataflow through the System

The display is where the interaction begins and ends in this research and its role is therefore illustrated as the top block of the dataflow structure (see figure 5.12). The moment the user touches the screen and starts to initialize a gesture, as in this case using the direct gesture interaction technique, the data is collected and interpreted by the touch drivers, extracted by the client and further dispatched to the server (as will be discussed in section 5.5.3.2). After the data has travelled from the display through the software interface to the DP system and from the DP system to the controller (here, a feeding system with simulated data), the controller block feeds the GUI with the appropriate data. The user experiences a reply visually from the GUI and from the system that the action is confirmed, - for example the vessel starts moving in the

[11] Illustration in courtesy of: http://www.nextwindow.com/optical/comparison.html

direction initialized by the user. The circuit restarts when the user initializes another movement and data is sent to the interface between the display and the DP system.

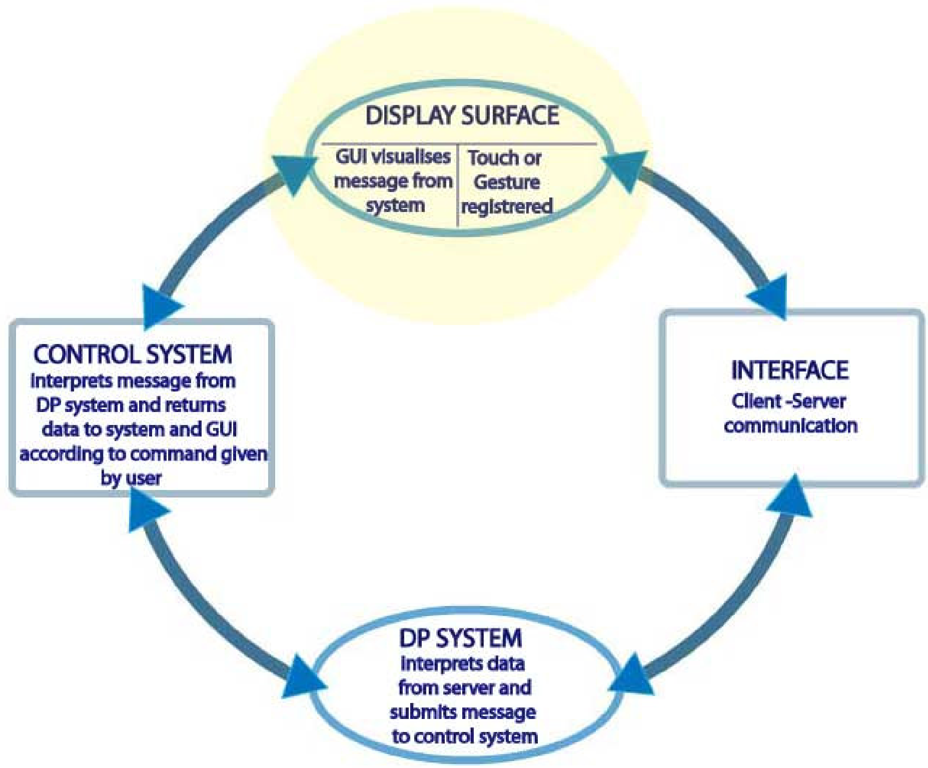


Figure 5.12: The role of the display surface in the dataflow

5.5 Interface: Client-Server Communication

The interface between the display and the DP system is based on the traditional client-server architecture where the data is in this case interpreted by using two different programming languages, Java and C#. Before explaining the role of the interface in connection with the dataflow structure, the theory behind the languages will be discussed.

5.5.1 Programming Languages

The programming languages used to develop this system were Java and C #, which are two object-oriented languages using a very similar syntax. The difference between them lies in the technical details such as running in different frameworks and runtime environments. A short description of the different languages will be given below.

5.5.1.1 Java

Java, owned and developed by Sun Microsystems today a part of Oracle Corporation, was released in 1995 and has inherited many features from previous settled programming languages such as C and C++. The developers looked at what was missing in earlier languages to create a more usable language utilizing a simpler object model with less low-level connections. The aim was to create a language where the applications could run anywhere regardless of computer architecture by using the Java Virtual Machine. Java is today one of the most frequently used programming languages and is used both in industry and for entertainment and leisure software we find and use every day on our computers and mobile phones. The language is a general purpose and object oriented language that enables concurrency and is class-based. The Java developer community is a community where many third party Java APIs and libraries have been developed and a large part of the material available is open source. Third party Java APIs have contributed to the growth of the language and it is also utilized in industrial applications, such as in this case the Rolls-Royce DP-system using Java MonkeyEngine. The Rolls-Royce components in the dataflow structure (see figure 5.13) have been developed in Java and it was therefore a natural choice to continue developing the needed software in the same language to obtain a good integration with the previously developed Rolls-Royce software (DP system's GUI). In addition to traditional Java, a third party library was utilised called the Java MonkeyEngine. The server-side of the communication was developed in Java.

5.5.1.2 Java MonkeyEngine

Java Monkey Engine (jME) is used in the DP system's GUI to create the special 3D scene where the vessel is displayed. Using 3D in the DP's GUI makes the Rolls-Royce DP system one-of-a-kind among DP system suppliers and enables the possibility of adding more functionality, such as orientation in the 3D scene (zooming and panning) and, in connection with this research, direct gesture interaction. JME is a high performance scene graph based on a graphics API to give more functionality and a full features graphics engine which was missing from the libraries developed by Sun.

5.5.2 C#

C# is a programming language that was released in 2001 by Microsoft. It runs on the .NET platform and has been developed to fill in some of the gaps that Java does not cover. C# is more easily integrated with C++ software and has been developed by studying already existing languages such as Java and Object Pascal. The language is object-oriented and is considered a multi-paradigm programming language. This means that C# supports more than one programming paradigm. The aim of C# was to be a simple, modern, general-purpose and, as previously mentioned, object oriented programming language (ECMA, 2006), where C# is also based on classes. The C# developer community has grown, but has fewer open-source libraries available than Java. This is could be due to the relatively young age of the language.

In connection with this research, the drivers for the displays used were programmed in C++ and the external suppliers also provided an API in C# to interpret the data from the drivers. C# was therefore selected as a programming language to develop the software needed. The client-side of the communication was developed in C#.

5.5.3 The Role of the Interface: Communication

The role of the interface in the dataflow structure is to maintain the communication flow between the two programming languages, the DP system and the input from the multi-touch displays (see figure 5.14). The Client-Server communication was running on the same system, where the client initiated the sessions and the server was listening. The server-side of the application was embedded in the DP system listening for input from the client which was designed to obtain the input coming from the multi-touch display. For both iterations of prototypes (NextWindow and Dell tablet computer) the communication was the same, but adapted to suit the changes of technology. For this research the session was initiated by the user/test-participant touching the display feeding the client with input. This triggered the server that held four different classes (a protocol, a receiver, a server and a small class managing the communication) to interpret and send the message further into the

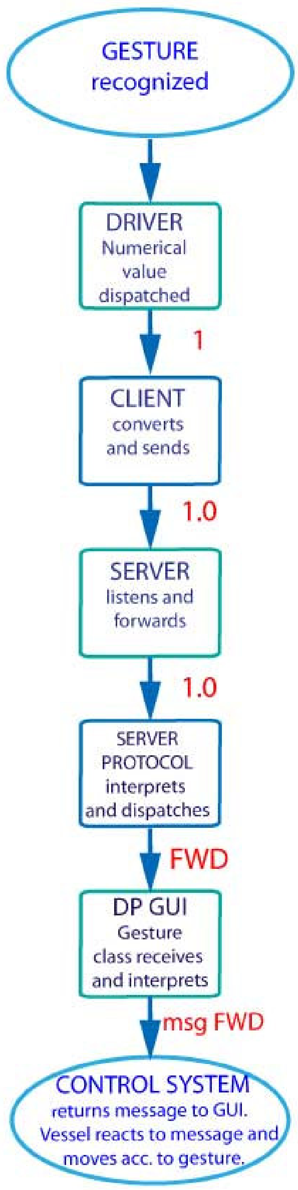


Figure 5.13: Communication flow

DP system to get the expected response. Challenges with this were to ensure rapid communication and prevent constipation where the server used threads to maintain order. The flow of communication is described in figure 5.13 where the communication starts off with the user initializing a gesture on the display as described in the previous section. The driver interprets the data and forwards it to the client.

5.5.3.1 The C# Client

The client that interpreted the input from the multi-touch display was programmed in C#. The language was selected due to the pre-programmed drivers supplied both for the NextWindow Display and for the Dell Latitude XT2 tablet computer by the external providers. The moment the user touched the display, a gesture was detected and a value set. This value was sent to the client-class that interpreted it, changed the value to a format suitable for reception by the server. The value was then forwarded through an assigned network port that the server was listening to. When developing using drivers from NextWindow, some gestures were already ready-made and could directly be interpreted by the client. However, during the first iteration of user studies using a hardware and software based prototype, the tilting gesture was not implemented and had to be programmed from scratch. For the next iteration this gesture were discarded due to it not being relevant as a task during a real DP operation.

5.5.3.2 The Java Server and Server Protocol

The DP system's GUI is as mentioned developed in Java/jMe and messages are sent from the GUI and further down in the system to trigger events. Java plays therefore an important role by interpreting the values in the server programmed in Java sent by the client. The value dispatched from the client was received by the server listening to the assigned port and was immediately sent to the server protocol. The server protocol class contained a parser that divided the data into smaller parts and pushed the messages further down in the DP system to call the correct events.

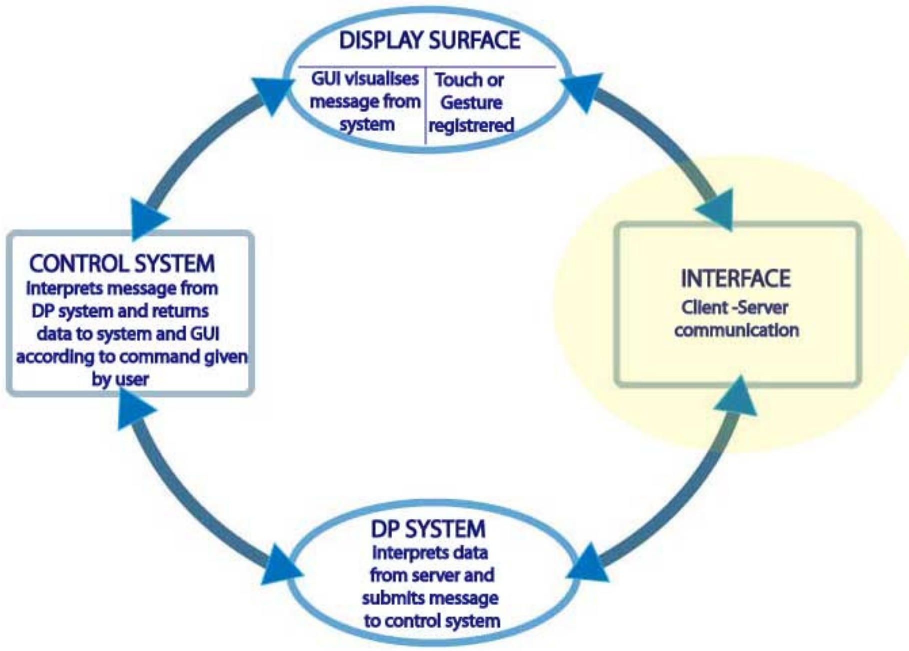


Figure 5.14: The role of the interface in the dataflow

5.6 The DP and Control System: Interpreting messages

The DP system and control system are important parts of this system. However they have not been active parts of the prototype development. The DP and controller software, in addition to the Python framework, were already available for use and served as "messengers" to make the vessel move as instructed by using direct gesture interaction. As described above, the server protocol pushed data further down in the application structure and the modifications made in the DP system by the researcher were the GestureHandling-class. The additional code belonging to the DP system and the control system will not be further discussed due to its lack of relevance for this thesis.

5.6.1.1 The DP GUI's GestureHandling class

The messages from the server triggered events that enabled the possibility of manipulating the DP system (figure 5.15) directly through touching the display using gesture interaction, making sure that the vessel's movement stopped and started at the correct time. These messages were handled by the GestureHandling class that interpreted the data from the server and again called classes deeper down in the application/code structure. These classes forwarded the message to the control system (figure 5.15), which is the end point of this communication flow. The control system then returned the appropriate data back to the GUI and made the vessel move according to the gesture initialised.

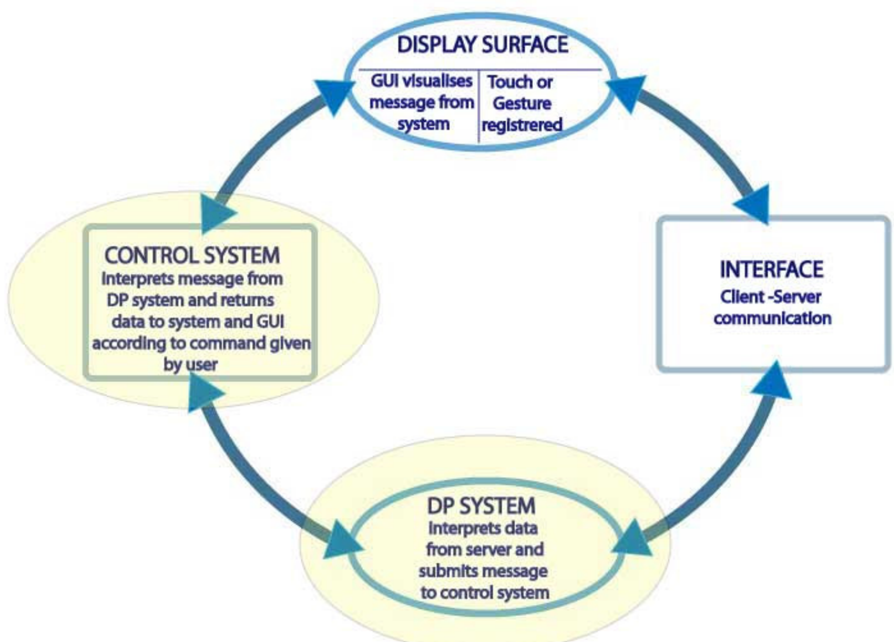


Figure 5.15: The role of the DP system and Control system in the dataflow

5.7 Chapter Summary

This chapter has summarised the hardware and software technologies used to create the prototypes needed for the user studies that will be described in the next two chapters: chapter 6 and 7. A general description of the system with pre-prototype programming gave an outline of the build, while a description of the programming languages in connection with this research gave the knowledge needed to get a clearer picture of how they interact. Optical and capacitive touch technology provided different results that were interesting for the final result of this research. These findings were based on the touch sensitivity registered by the software when touching the display. Another feature implemented in the prototype based on capacitive technology (used for the pilot and main study, chapter 7) was threading that prevented blockages of data. In addition to the threading, the general differences between the two prototypes were mainly the touch technology used and the source of providing simulated data to the DP GUI. The communication between the different parts of the system was the same, however adapted to suit the special requirements of each technology.

6 Initial System Prototyping: Investigating the Differences

6.1 Introduction

This chapter concerns an exploratory investigation of the differences between interacting with a DP system using traditional touch button and menu interaction and using direct gesture interaction. The experiment was conducted in a laboratory environment where eleven participants from the Aalesund University College's nautical studies were involved who had knowledge of DP systems, but not extended experience. This was due to the desire to find a trend using novice users. The duration of the study was approximately 4.5 hours including a plenary session introducing the test participants to the topic and a short briefing with every participant after they entered the room of the experiment. The aim of this study was to get a sense of how the gestures extracted from the initial paper prototype study described in chapter 3 functioned when being implemented in a real DP system. It was also for this exploratory investigation desirable to investigate if direct gesture interaction performed faster than traditional touch button and menu interaction. More variables will be added and tested in the next iterations of studies. The results found gesture interaction to be faster than touch button and menu interaction. The result was, however, not uniform. This chapter starts with a short introduction of the topic with background and related research, proceeds by describing the experiment, its findings and conclusion and ends with a chapter summary that sums up the main features and findings of the chapter. All relevant material (questionnaire, consent form, experimental design etc.) can be found in Appendix D.

6.2 Background and Related Research

When conducting experiments with a prototype that is to be tested on a selection of users, the prototype is designed according to where in the development process the product is. Below the fundamental features of system prototyping is outlined together with main features concerning user studies and testing. Carrying out user studies and doing user tests are topics that involve several different stages of preparation. The test participants must be selected and treated anonymously according to guidelines and ensuring that personal details are only used for categorisation. If video and audio recordings have been utilised during the experiment, such as in the initial paper prototype experiment (chapter 3) and in this current chapter, the participant must give his/her consent for the material to be used or published.

6.2.1 System Prototyping

The purpose of system prototyping is to discover errors and design faults before the final product is released. As mentioned earlier in chapter 3, prototyping is a part of an iterative design process that can be described by the use of prototypes and artefacts that simulate or animate a selection of features of the intended system. There are three main approaches to prototyping which are described by Dix et al. Dix, Finlay, Abowd and Beale (1997) as the throw-away approach, the incremental approach and the evolutionary approach. In this research project three different prototypes were created that were built on the throw-away approach.

The first hardware (HW) and software (SW) based prototype, which the experiment described in this chapter was built on, was built by using the Rolls-Royce Icon DP system and a NextWindow multi-touch display using optical technology (see figure 6.1). The standard DP system's graphical user interface (GUI) was augmented with more features in Java to support input from the NextWindow multi-touch display, while the NextWindow drivers were programmed in C++ and C#. This first generation prototype enabled a second iteration of user tests where the aim was to uncover if operating the DP system using multi-touch and direct interaction with the GUI's 3D scene could be faster and more efficient than using touch button and menu interaction. The experiences obtained from the initial lo-fi prototype were built into this software prototype to be able to test the gestures found in a working environment. A user study was carried out following standard user laboratory study procedures that are widely used in interface design (Dix, Finlay, Abowd and Beale, 1997), having been adapted from psychology experimentation methods.

To fully exploit the advantages of prototyping, the natural step between each prototype is usability testing. The experiences obtained and the results gained from this provided the base for the next prototype.

Figure 6.1: First HW/SW based prototype using NextWindow display

6.2.2 Usability Studies and Testing

Doing a usability study includes planning of the study, doing individual sessions with each test participant, thoughts about the observer's role, the outcome of the study and which tools to use to obtain data and analyse the results. The aim is to measure performance, accuracy, recall and subjective response; in this study performance was the only measured factor, due to its exploratory nature to test the gestures in a real system for the first time. More variable will be measured in the studies described in chapter 7. Usability studies give good insight into the user's response to the system and give the possibility to weed out serious faults before the final decisions towards the product are made. For maritime equipment and software, the costs of replacing equipment with bad usability are so high that it is only done if the product represents a safety hazard. The process of developing controlled experiments that can provide robust results has been described by Blandford, Cox and Cairns (2008).

For the current study that will be described below, one dependent variable and two independent variables were studied. To address the effect of confounding variables, the studies were designed using a within-subject design where all participants repeated the same, or a very similar procedure, several times with different variations of the independent variable (experimental conditions). This approach can lead to learning effects, so the experiments were balanced with an even split of which experimental condition users would first encounter. In this research the appropriate population for all user studies was participants who had knowledge of DP systems, but not extended experience. Participants with extended experience are often predisposed of habits obtained over many years of operating different DP systems, which could damage the statistical data collected. Through observing the test participants the results from this test were hoped to demonstrate the potential effect of direct gesture interaction versus touch button and menu interaction. After the above setup was selected, a procedure was fixed describing the process of what the participants were supposed to do. This procedure ensures that all participants are treated the same and also makes it possible for others to replicate the experiments. To make the experiments more robust, pilot studies are recommended. For this particular research, three user studies (described in chapter 3, 6 and 7) and one pilot study (described in chapter 7) supporting the last iteration of user studies were carried out.

Post-experiment it can be desirable to collect some additional qualitative and quantitative data. This data is collected by conducting a post-task walkthrough and make the participants fill out questionnaires, answers to which can be quantitatively measured on Likert-scales (Likert, 1932) combined with the participants' opinion on specific matters. Post-task walkthroughs and questionnaires were utilised for all the experiments in this research. To collect and safely save/keep the results of the experiments, protocol analysis can be conducted using several different methods. In this case paper and pencil in addition to video recording was used. By carrying out a user study it was possible to discover issues that concerned not only the gesture interaction, but also issues concerning the display technology. This emphasizes the advantages of doing prototyping and user- studies as an iterative design process. The drawbacks of prototyping are however the time spent on it together with not being able to test aspects such as safety and reliability. These features are often the most important, but will in a prototype be non-functional (Sommerville, 1992). The feedback from the test participants after finishing the user study and going through a post-task walkthrough led to the development of the next prototype which will be described in chapter 7.

6.2.3 Selecting Participants

The participants selected for our user studies were a mix of people with DP experience, students studying to be ship officers and DP operators on vessels and for the pilot study (described in chapter 7) students with various backgrounds. This was because the system is safety-critical and from previous research it has been proven that under excessive stress the knowledge of an experienced operator is lowered to the level of a novice (Redmill and Rajan, 1997). Before the user studies were carried out ethical considerations were taken into account to maintain the participants' trust. This was done by making all participants sign consent forms and make them aware that they could leave the experiments at any time. None of the participants were in this case particularly vulnerable (e.g. children), but some maintained their right to not have video clips or photos published.

6.2.4 Research Methods Used

The statistical method used to analyse the data collected was to conduct a two-tailed paired t-test. This was selected due to there being only one dependant variable and two independent variables. The results were supported by qualitative data collected from doing questionnaires and a post-task discussion.

6.3 Design of Study

The purpose of this experiment was to test the usage of the set of gestures found in the initial study (chapter 3) in practise and to investigate the differences between touch controlled DP systems using traditional touch menu and button interaction and direct gesture interaction. A panel of 11 test subjects used two touch screen systems, one with multi-touch functionality and one with standard single touch functionality to carry out the experiment. This was connected to a real-life DP application where a Rolls-Royce Marine Controller was used to supply the GUI with data. The GUI showed an authentic graphical user interface from a Rolls-Royce Dynamic Positioning system (see figure 6.2). The test was conducted in a combined 2D and 3D environment, where the menus were presented in 2D and the "action" happened in the 3D scene where the vessel was situated. This made it possible to test 4 of 6 available degrees of freedom (DOF); surge, sway, heave and pitch.

The participants interacted with the vessel in two different conditions: touch button and menu based and gesture based using multi-touch. The tasks were identical for both conditions, but the methods used to interact were different. In the touch button and menu based condition tasks were carried out in the traditional manner used on vessels today, by using menus and button key-pads to manipulate the vessel in the GUI's 3D scene. The second set of tasks utilized the multi-touch functionality and the possibility of directly manipulating the vessel in the 3D scene. The test subjects used their hands to perform different gestures that changed the vessel's direction.

Figur 6.2: Equipment setup of first HW/SW based user study. From left: Rolls-Royce Marine Controller, Dell Laptop, Next Window multi- touch display and Rolls-Royce touch display.

Initially the participants declared how well they knew Dynamic Positioning and operating DP systems, which was indicated on a scale from:
Little experience – Average experience – Good experience.

The experiment consisted of four parts: plenary session, introduction, series of tasks and a post task discussion. The students were briefed in plenary in a lecture. After the participant entered the room of the experiment and was given an introductory sheet that included consent, (s)he was then instructed to do the tasks according to the task sheet after a short briefing. All tasks were videotaped and the timestamp for each operation was recorded by the camera. Six participants started with the button-based procedure, while five started with the multi-touch procedure. The post –task discussion was carried out after the participants finished their respective tasks. They were given a £15 voucher as a sign of appreciation of their effort.

Schedule

- The participant enters the room of the experiment
- The participant is seated behind a table with the equipment in front of him/her
- The participant is given a short briefing of what is going to happen
- The participant signs the consent form with information about utilising audio and video recordings
- The participant starts the test
- The participant changes condition and does the same tasks again in the same order with a different condition
- The participant finishes the tasks
- The participant answers questions read by the facilitator
- Post-task discussion
- The experiment session is finished
- The participant leaves the room

6.3.1 Participants

The participants were 1st year nautical students with little experience using DP systems. This would make it easier to recognize a trend when operating the system using the different methods, because experienced/expert users can be influenced from other DP systems, which could distort the result of the experiment. Future studies will involve experienced operators. Of the eleven participants, two stated that they had average knowledge of DP systems. This was due to their previous career on board DP vessels as lower ranked crewmembers. They had observed a DP operator during a DP operation, which gave them limited insight into how the system was operated and also into sensing the reactions from the vessel when commands were given. The age distribution concentrated around eight participants between 19 and 21, one participant was 25 years of age and two were 27 years old. The information concerning age and gender was only used for categorisation of the participants, not for data analysis.

6.3.2 Prototype

The prototype consists of a regular Dell Precision M65 laptop running both the server and client side of the application. The server-side consists of the DP software developed by Rolls-Royce Marine's DP department, but with adaptations by the author to receive and process the data coming from the client also developed by the author. The server- side is programmed in Java, while the client-side is programmed in C#. The client-side receives multi-touch information from the NextWindow display (technological details can be found in chapter 5), which is processed and recognized as gestures. This is sent to the server, which calls the appropriate methods in the DP application. A Rolls-Royce Marine Controller is used to supply the system with live data, so that it is possible to authentically operate the DP system. The NextWindow display utilizes optical technology.

6.3.3 Experimental Parameters

For this experiment one main hypothesis was selected based on the experiences gained from the first study using the paper prototype. The aim in addition to testing the gestures was to measure if task performance was faster using gesture interaction versus using traditional touch button and menu interaction. The experiment was in this iteration carried out in a controlled laboratory environment where movement was not taken into account. Movement will be added for later studies described in chapter 7. Each test participant was situated on a static chair behind a table with the different equipment in front of him/her (see figure 6.2).

Hypothesis

H1: Tasks will be conducted in less time using gestural interaction

To be able to test the hypothesis they were supported by one dependent and one independent variable. The dependent variable was measured and the independent variable was manipulated, the independent variable had two levels of values.

Independent Variable

IV1: Interaction style

- Conditions: multi-touch gesture and buttons

Dependent Variable

DV1: Average time spent on each task

6.3.4 Experimental Setup

Each participant had about 20 minutes total. 15 minutes were used to perform both sets of tasks and the last 5 minutes for a post-task discussion/walkthrough. A camera recorded the movements on the surface of the touch-displays. The participant was seated at a conference table with two displays in front of him/her, one traditional Rolls-Royce embedded touch display and one display with multi-touch functionality from NextWindow (see figure 6.2). It is important to emphasize that for this study the aim was to only test direct gesture interaction in a real DP application to investigate performance times. Studies in a more realistic environment will be described in chapter 7. Participants were randomly allocated to start with one of the experimental conditions (balanced for number only). All participants were given the same 9 tasks to complete twice in each condition, in order to measure learning between first and second attempt. The tasks consisted of four tasks that changed the vessel's position and five tasks that oriented the camera in the 3D scene.

The tasks given (in execution order) are listed below and shown in table 6.1 with the associated gestures.

1) Zoom out (heave) from the vessel in the 3D scene.
2) Move the vessel 5 meters forward (surge) and accept movement.
3) Move the vessel 5 meters aft/backward (surge) and accept movement.
4) Move the vessel 5 meters starboard/right (sway) and accept movement.

5) Move the vessel 5 meters port/left (sway) and accept movement.
6) Zoom in (heave) on the vessel in the 3D scene.
7) Tilt the vessel downwards.
8) Tilt the vessel upwards.
9) Reset the vessel to its original size.

In this experiment, due to limitations in technology, rotation was not possible to test. This is due to occlusion of touch points when using the optical technology of the multi-touch display for detecting touch points. The users were furthermore constrained to using two fingers in all tasks in opposition to using one finger for some tasks and two for others as suggested in the prototype study (chapter 3). This was due to technical constraints in the hardware (display driver) and it could not handle swapping between detecting one and two touches. This did however not seem to have any influence on the user's performance.

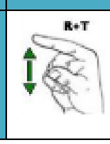
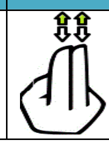
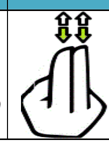
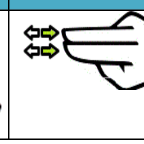
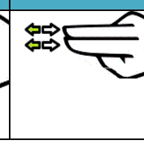
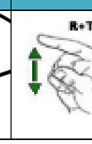
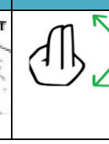
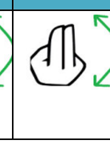
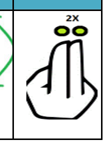
Task No	1	2	3	4	5	6	7	8	9
Gesture									

Table 6.1: Tasks with corresponding gestures

After completing the tasks, the last five minutes were spent on a post task discussion where the following questions were asked:

1) How do you like the system in general without thinking of a specific method?
2) Do you find the GUI easy or hard to understand?
3) What is your overall impression of the two presented methods?
4) Which method did you prefer?
5) Which method did you find most intuitive?
6) Do you think multi-touch can increase the efficiency of a DP- operation?
7) Do you think multi-touch will increase the feeling of system control during a DP operation?
8) Would you consider multi-touch in DP operations a safer alternative?

9) Do you think tactile feedback from the multi-touch display would increase or decrease the feeling of control when operating the system?

6.4 Findings

The users did nine tasks two times (summarised: 18 tasks in total) using direct gesture interaction and likewise using touch button and menu interaction. Overall, users of the traditional button/menu interface took on average 6.52s per task (averaged over all tasks) with a high standard deviation of 6.09s. Users of the direct gesture interface achieved 4.98s mean (SD 3.37s). This difference was significant ($p<0.01$, two-tailed paired t-test ($p\approx0.0013$)) and shows that direct multi-touch interaction performed faster overall. However, as shown in figure 6.3, the benefit of direct multi-touch interaction was not uniform. Between the first and second attempt the users improved in both interactions techniques by around 30%. The traditional button/menu interaction improved by 29% from first to second attempt, while multi-touch improved by 32%, with a statistically significant difference in time taken for both conditions.

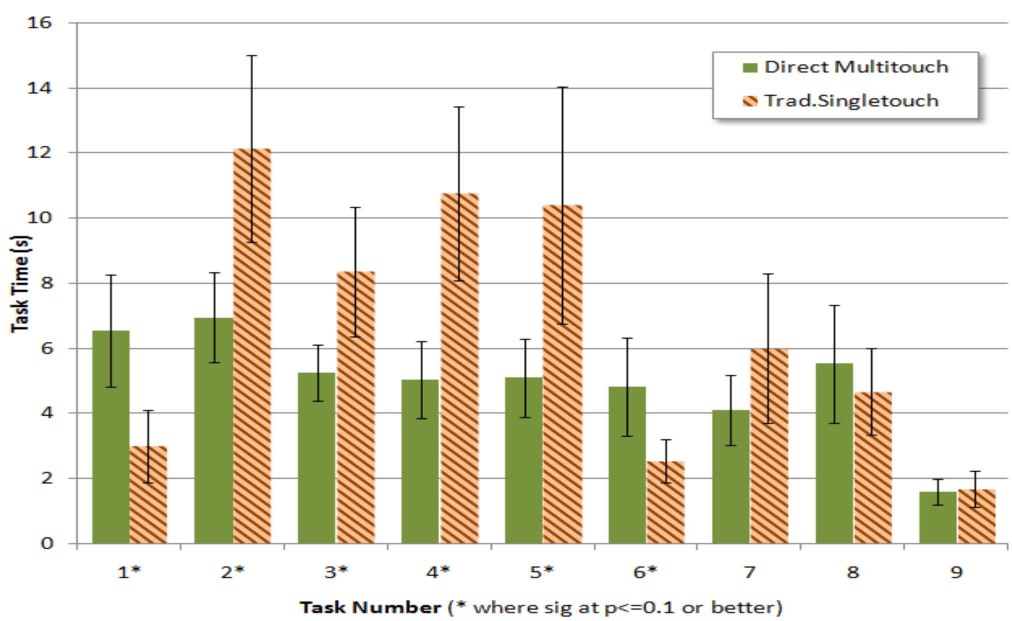


Figure 6.3: Average task times (gesture interaction (direct multi-touch) versus traditional touch button and menu interaction) with 95% confidence intervals.

6.4.1 General Observation of Interaction

During the tasks that were carried out, it became clear that when interacting with the system using direct gesture interaction, the participants hesitated less when performing the tasks. They went straight into moving the vessel: while when using the traditional menu/button based interaction, they were searching longer, on average approximately 3 seconds, for the right button/menu, even though they had been briefly shown where to find the different functionalities. During their first attempt using the system (regardless of technique used), they needed some guidance on how to perform the tasks correctly. The second attempt went faster and little to no guidance was necessary.

Only one of the eleven participants was left handed. He performed all tasks well, but when using the menu/button bases technique he found it easier than the right handed participants. This was due to the menus being locked to the left side of the GUI. The right handed participants experienced that their own right hand occluded the view of the 3D scene when pressing the buttons and menu selections to the left of the display. This problem was eliminated when using the direct gesture interaction, because the menus were removed.

6.4.2 Task 1 and 6: Heave (Zoom)

Figure 6.4: Zooming in and out (heave)

These tasks were carried out well using both methods and concerned navigating the camera in the 3D scene. However, in both cases traditional single touch interaction was faster (significant with $p<=0.01$ for task 1, $p<=0.05$ for task 6, paired t-test). The gesture used was the pinch-gesture which in this case was chosen as a result from previous tests where this gesture was most commonly used to zoom in or out (figure 6.4). The differences that could appear in time were how long they decided to hold the "zoom out"-button or held their fingers in the "zoom out"- gesture position. The tendency was that they pressed once or twice on the "zoom out"-button, while their held their hand longer in the "zoom out"-gesture (figure 6.4). The same occurred for zooming in on the vessel. Some participants also zoomed in and out to get a comfortable size on the vessel. A general trend when performing this task, using the direct gesture interaction, was that they mixed up which gesture was zooming in and which was zooming out. This resulted in confusion and also indicates that using the pinch as a zooming gesture might not be ultimate or that the participants needed more training to get this right.

6.4.3 Task 2 and 3: Surge (Forward and Backward)

Figure 6.5: Moving vessel forwards and backwards (surge).

Task 2 and 3 were tasks where the participant was given a specific distance to move the vessel forwards or backwards (figure 6.5) and then accept the movement. In both cases direct multi-touch interaction proved faster ($p<=0.01$). The participants were accurate with a difference of +/- one meter. The participants improved on accuracy between the first and the second attempt.

Using the direct gesture interaction, an additional tap using two fingers on the screen was the gesture used to accept the movement. First the participant drags the vessel, using two fingers, to the desired position then taps once and the vessel starts moving. When moving the vessel the GUI indicates this with a yellow “shadow” (see figure 6.5). The vessel is shown as a blue boat in the middle of the 3D scene: when the participant moves it; a yellow boat appears and moves to the selected position. When the action is accepted, the vessel indicating the new position (the yellow boat) turns grey, and the blue boat starts moving towards the grey and eventually fully overlays the grey boat. If the user wanted to abort the movement to the new position, the system automatically leaves the vessel in its original position if no actions are being carried out. When the participants moved the vessel using the direct gesture interaction, the fingers had to be slightly apart for the system to recognize the gesture. A few of the participants slid their fingers across the screen and the fingers shifted to some extent in direction during the gesture. This either caused the vessel in some cases to tilt or zoom. The system has a 10% “tremble” limit between the gestures and in these cases this limit was exceeded. It is therefore possible to imply that the system is too sensitive when it comes to recognizing the gestures – an issue that may be of more concern in real ship operation. This is also mirrored in some of the participants finding it difficult to strike the exact position of 5 meters. To solve this problem, it is possible to implement tactile feedback (Hall, Hoggan and Brewster, 2008) to improve the software sensing the gestures, by say indicating every meter.

Figure 6.6: Entering position on keypad using touch button and menu interaction

When using the traditional menu/button interaction, accepting the movement happens after the participant has entered the correct number in the “keypad” (see figure 6.6). After the yellow boat has moved to the desired position, an accept-button gets activated and it is possible to either accept or cancel the movement. For the accept button to be activated, it takes approximately one second. The participants in the user tests wanted instantly to press accept after entering the correct distance. This caused them to press the button several times, or they thought that everything was OK and left the vessel unintentionally in its original position. This is an issue that possibly can be solved with training, but in this case the participants felt that it was easier using the direct gestural interaction due to its more instant reaction. The participants found the traditional button/menu interaction difficult at times, because they had problems with pressing the correct buttons and were unaccustomed to the delay of the accept-button. When interacting with gestures they found accuracy easier to maintain, but here they also experienced a deviation of +/- one meter on the exact distance. This improved from first to second attempt using direct touch gesture interaction.

6.4.4 Task 4 and 5: Sway (Sideways)

Figure 6.7: Moving the vessel sideways (sway)

When moving the vessel in the sway (sideways) direction (see figure 6.7), for the direct gesture interaction, the same gestures as in the above tasks were used, but perpendicular to the ship's main axis. In both tasks multi-touch interaction was again significantly faster ($p<=0.01$ for task 4, $p<=0.05$ for task 5).

Two fingers slightly apart in the horizontal direction made the vessel move as desired. The same drawbacks as mentioned in task 2 and 3 also apply to these two tasks. In addition, some participants twisted their hand in an awkward position. Instead of changing the angle of how to hold his fingers, one participant shifted the position of the whole arm and lifted the elbow up from a position close to the body to a 90 degree position in front of the display. This indicates that when using this gesture, it would be better to have the display lying on the table as a work surface than being set up like a standard display in front of the user.

When using the traditional button/menu interaction, the participants had the same issues as with the previous tasks 2 and 3. The accept-button was programmed with a delay which caused them to press the apply-button several times before it was activated. This sometimes lead to the user unintentionally not accepting the movement due to that they thought they had pressed the button earlier. This is however unlikely to change the overall result, due to the delay being only 1 second and when using direct gesture interaction the participant paused equally long to check if the vessel was in the correct position before they tapped to accept.

6.4.5 Task 7 and 8: Pitch

Tilting the vessel was for some of the participants very easy and for others hard, without a consistent significant difference between the two interaction styles. Here the same issues concerning zooming in and out on the vessel appear where the length of the gesture or the amount of button presses determined the amount of time spent on the tasks. Some of the participants left the vessel after a small tilt, while others spun the vessel around to an upside down position. This was the case for both interaction techniques.

When using the direct gesture approach the gesture used was two fingers slightly apart doing a curved vertical movement (see figure 6.8). To tilt the vessel down, the participants slid their fingers in a downward direction on the display as described above, and the vessel tilted downwards. For upwards tilting, the gesture was the same, but in the opposite direction. This gesture was the least preferred gesture by the participants. The majority found it awkward and hard to do. This may be for the same reason as with the gesture used to move the vessel sideways, which means that the gesture would benefit from having a work surface that was lying on the table.

The traditional menu/button based interaction was in this case preferred, but here the participants tilted the vessel the wrong way. For tilting downwards they tilted upwards and opposite. This happened for many of the participants. This can be due to the design of the icon on the tilt buttons. One participant misunderstood the symbols and rotated the vessel instead of tilting it, while another tried all the buttons in the camera control menu.

Figure 6.8: Tilting the vessel

6.4.6 Task 9: Reset Size

Resetting the vessel was a short and easy task with very few misunderstandings on how to do it and no significant or likely difference between interaction styles. When executing the operation by either double tapping the display or pressing the reset button in the camera menu, the camera in the 3D scene snaps back into position and the 3D scene shows the 3D model of the vessel. The task took in most cases approximately 1 second with small variations. The variations appeared when either the participant could not locate the reset-button or when using direct gesture interaction, the multi-touch display didn't recognize the gesture instantly. This task was the task which showed the smallest difference between the two interaction techniques.

6.5 Post-Task Discussion

The post task discussion gave answers to nine questions where the participant had to comment on different aspects on how they liked the two different interaction techniques.

6.5.1 Question 1: General System Attitude

How do you like the system in general without thinking of a specific method?

The overall opinion concerning the system in general was that it was easy to understand and all of the participants thought the system was a system that appealed and were excited about the GUI and its usability. Even with very little experience, the participants found the system user friendly even though they did not understand all the details of the application such as specific maritime terms and units.

For the traditional menu/button interaction, one of the participants found the overview of the vessel in the 3D scene too cluttered with menus and the 3D part of the GUI too small. Another participant felt the angle on the traditional touch display to be awkward. This was due to that he didn't hit the buttons and menus as consistently as he wanted to. He suggested it would be better if he stood right above the display.

For the direct gesture interaction with the display using multi-touch functionality the display sometimes was too sensitive to touch. Friction on the display was also an issue, participants with very warm/moist hands finding it particularly difficult. The tilting gesture was also mentioned as a gesture which felt uncomfortable to use.

6.5.2 Question 2: Mental Demand

Do you find the GUI easy or hard to understand?

When answering this question, all the participants agreed that the GUI was easy to understand. Two agreed that after trying it four times using two different methods, it felt easy when taking the lack of experience into account.

6.5.3 Question 3: Overall Impression

What is your overall impression of the two presented methods?

The overall impression of the two different interaction techniques was that both were pleasant to use. Some participants seemed to like the efficiency of the direct gesture interaction, but the majority were concerned with the accuracy of gestures. They felt they sometimes had to wriggle back and forth to get the correct distance when moving the vessel. However, two participants disagreed and found it much more accurate – these users had particularly large fingers (which are not uncommon amongst seamen) and were observed to struggle to hit the correct buttons when using the traditional button/menu interaction.

In conclusion on the overall impression of the two presented techniques, the traditional button/menu interaction proposed some problems to some of the participants when it came to accuracy and hitting the correct buttons. Even though there were concerns with accuracy using direct gesture interaction also, the rest of the group found using direct gesture interaction a more instant ans easy way of interacting with the system. A positive feature with direct gesture interaction was a less cluttered GUI with menus removed which gave a more visually open and better looking 3D scene.

6.5.4 Question 4: Preference

Which method did you prefer?

Subjects were split between the two presented techniques on which were preferred. Five of the eleven participants preferred the traditional button/menu interaction, due to that it was more accurate. They could enter the specific amount of meters they preferred to move and in a real-life situation this would lead to them feeling safer when close to offshore installations. When using direct gesture interaction they pushed the boat e.g. forward and the counter counted to the amount of meter they aimed at reaching. However the participants felt that it was difficult to hit the exact position, hence they preferred to enter the number exact using touch button/menu interaction. The tilting gesture was considered too slow or difficult to carry out when using the direct gesture interaction. One of the participants was not happy with the delay on the accept button, and wanted it to happen much faster. Four of the participants preferred the direct gesture interaction. This was due to that it was quicker and felt more efficient. The traditional button/menu interaction was hard to perform satisfactorily when the buttons were hard to hit. The last two participants preferred the direct gesture interaction if a new and better suited multi-touch display were presented, that had reduced the drawbacks of high friction and too sensitive gestures. Accuracy concerns are the key to our overall aim within this project so these comments are concerning and will be investigated further in future studies.

6.5.5 Question 5: Intuitiveness

Which method did you find most intuitive?

This question provided very interesting feedback. Eight participants found direct gesture interaction to be more intuitive if a task were to be carried out instantly, e.g. in a safety-critical situation, if the technology were optimal. One participant misunderstood the question and suggested methods to improve the traditional button/menu interaction. One participant thought that both techniques were good, but preferred the less cluttered GUI of the direct gesture interaction interface. The last participant found the traditional button/menu interaction more intuitive, because you just enter the amount of meters desired for the move of the vessel and press apply.

6.5.6 Question 6: Increased Efficiency

Do you think multi-touch can increase the efficiency of a DP- operation?

Nine of eleven participants think that multi-touch and direct gesture interaction technique can increase the efficiency of a DP operation. The participants suggested that this was clearly the most efficient method for doing tasks quickly, and not have to go into a menu to select the correct choice and then proceed into another menu to select the target. Again it was mentioned that tilting of the vessel using gestures was the lengthiest part of the gestures. One of the participants was unsure what to answer because he felt he had too little experience and had not tried it using the third possible way to manipulate a vessel, with joystick and heading wheel. The reason for not comparing with joystick/heading wheel interaction is because it was desirable to compare the two display interaction techniques available, touch button and menu interaction versus and direct gesture interaction. The last participant was also unsure, but suggested that with some training to get the “feeling in your fingertips”, it would possibly be more efficient.

6.5.7 Question 7: Increased System Control

Do you think multi-touch will increase the feeling of system control during a DP operation?

Also here, nine of the eleven participants agreed that using direct gesture interaction would increase the feeling of system control during a DP operation. According to the participants, this technique would be just as good as using the traditional button/menu interaction and also possibly the third method, using joystick and heading wheel if tested and compared. However there were some constraints with the quality of the current multi-touch display and one of the participants suggested that the traditional button/menu interaction would give a better feeling of system control for now. One participant disagreed and thought that the traditional manoeuvring would be better suited and provide better control. The last participant agreed that for young and newly educated seamen/DP-operators direct gesture interaction would give a stronger feeling of system control, but that for the older generation who are not used to iPhones and have never heard of multi-touch, the traditional techniques would possibly be better.

6.5.8 Question 8: Safer Alternative

Would you consider multi-touch in DP operations as a safer alternative (if the system was optimal)?

Eight participants were positive that direct gesture interaction would be a safer alternative to traditional interaction techniques if the system was optimised This was anchored in the comments that it was quicker to go straight to the task in a safety-critical situation and when it was easier to understand the system, it would also be easier to avoid errors. Two participants are unsure due to the poor display and the last participant was counting on the traditional interaction techniques. This was because he was concerned with the older generation of seamen, which he meant had computer anxiety and trembling/unsteady hands. This could be the case for some seamen, but it is not possible to assume that this concerns all aging seamen (Paul and Stegbauer, 2005). There is a lot of technology on board vessels today but some seamen favour the traditional and mechanical way of working.

6.5.9 Question 9: Tactile Feedback

Do you think tactile feedback from the multi-touch display would increase or decrease the feeling of control when operating the system?

Tactile feedback was a feature that was welcomed by the participants. All participants, apart from two that did not answer the question, thought that tactile feedback would increase the feeling of control when operating the system. A comment often given by participants was that it would be very good to get feedback from the system when the task was completed, and a nice way to confirm that the gesture responded as expected. An example could be that a vibration was given for every meter the vessel moved to make the move more distinct. A problem that was brought forward was the possibility that the operator would trust the tactile feedback too much and not pay enough attention to the interface. The operator might get sloppy at actually looking at the display to ensure that the amount of meters felt from the vibration were the intended amount of meters needed to the move the vessel.

6.6 Experiment Conclusion

Looking at the different factors that had an influence on this user test, it is interesting to note that half of the participants were sceptical towards using direct gesture interaction when operating a DP system. This stands in contrast with the statistical results concerning time taken and also to the answers on which technique they found most intuitive. The majority of the participants found the direct gesture interaction more intuitive than the traditional button and menu interaction. When comparing the observational and numerical results, it is clear that using direct gesture interaction is both faster and, according to participants' comments, more intuitive than the traditional button/menu interaction. The intuitiveness has not been scientifically proven, but has been suggested by the participants. This is supported in the observational results concerning intuitiveness and future usage of the method. There is a general optimism towards direct gesture interaction, provided that the technology is improved and made as optimal as possible. In this particular study the participants felt that the multi-touch display sensed the gestures made on the display too easily, so that the gesture caused the vessel to move too abruptly. This occurred even with an implemented "tremble"-buffer that gave a 10% buffer to handle inaccuracy when performing a gesture. Inaccuracy is a concern at this stage and will be investigated further in chapter 7 by utilising a different multi-touch display.

The results from this study have shown in particular that direct gesture interaction was faster for simple positioning movements. These are the most frequent moves made when operating DP systems. The three tasks found to be slower with multi-touch concerned zooming and tilting upwards. Zooming and tilting was slower due to the nature of the gesture: pinch and hold until the desired size was achieved for zooming, and for tilting the same: curved gesture and hold until the desired tilt angle was reached. This provided better dynamic control of the zoom/tilt than the button provided when using touch button and menu interaction, which one has to press several times to achieve the same result. The dynamic nature of the zoom/tilt does however come at a price of time taken, which shows in this user test.

With this, it is possible to conclude that direct gesture interaction can be used to operate a DP system in a more efficient way than using traditional touch button and menu interaction. Hypothesis H1 is therefore supported and tasks were carried out in less time when using direct gesture interaction.

The above statement is supported by previous research done by Buxton and Myers (1986), Balakrishnan and Hinckley (1999), Forlines, Wigdor, Shen and Balakrishnan (2007), Kabbash, Buxton and Sellen (1994), Owen, Kurtenbach, Fitzmaurice, Baudel and Buxton (2005) and Yee (2004), who all have found aspects with using direct gesture interaction that has favourable features. However, concerns bearing in mind the needs and dispositions of the older generation of seamen and DP operators were present (Paul and Stegbauer, 2005). It is likely that they initially and at first glance would disapprove with the new interaction techniques, due to the unfamiliar way of interacting with the system.

The post-task discussion gave positive feedback about the overall impression of using direct gesture interaction. Scepticism is mostly related to issues around the current multi-touch display, which can be remedied with better technology as mentioned above. The discussion considering efficiency, safety and feeling of control when using direct gesture interaction supports optimism about the direct gesture interaction technique. This experiment has not taken into account the opinions of maritime classification societies[12], due to the stage of this research and that it has to be tested more thoroughly before it can be fitted on a vessel in normal operation.

6.7 Chapter Summary

This chapter has reported the results of the second study of this research where the aim was to investigate if gesture interaction gave faster task performance than traditional touch button and menu interaction. The experiment was carried out using the first generation software based prototype that utilised two displays for interaction, one for multi-touch interaction while the other for touch button and menu interaction. The DP's GUI was fed live data produced by a controller so that the system could operate as it normally does when being offshore. Eleven participants from the Aalesund University College's nautical studies were included who had knowledge of DP systems, but not extended experience. This was due to the desire to find a trend using novice users who did not have predisposed habits or opinions from extended use and experience from DP systems. The test participants carried out nine tasks in two different conditions, ending the session with a post-task discussion where the facilitator asked for answers to nine different questions concerning the participants' experience of the two interaction techniques. The results emerging from this experiment were in favour of gesture interaction where task performance was significantly faster, however not uniform. Hypothesis H1 was supported and gesture interaction was found to reduce task performance time. The post-task discussion gave an insight into the participants' opinions where the answers were also generally in favour of gesture interaction. Some participants were, however, concerned about

[12] A maritime classification society is a non-governmental organization in the maritime industry that establishes and maintains standards for ships and offshore installations. The classification societies also supervise new-builds and carry out regular surveys.

gesture accuracy and that tactile feedback would possibly enhance the feeling of control.

The results gained from this experiment will be used as a basis for further studies that will be described in the next chapter, chapter 7.

7 Realistic Prototype Testing: Investigating the Differences using a Ship Motion Simulator

7.1 Introduction

This chapter contains the main study of this research and concerns the investigation of two user studies. Twenty-seven participants in total were involved across both studies with an overall test time in a simulated environment of approximately ten hours including in-between and post-task discussions. There was one pilot study with eight participants, and one main study with nineteen participants. The experiments were carried out in a high speed craft simulator, i.e. a ship motion simulator (SMS), at Aalesund University College where the participants were tested while situated on a moving platform. The aim was to address issues discovered in the previous studies (chapter 6) regarding sensitivity of touch on the display and to continue testing the general performance of the gestures found (chapter 3). The discoveries made during the observation study (chapter 4) contributed to a task set that aimed at investigating the operator's cognitive load in terms of measuring reaction time. In addition it was desirable to investigate the impact of a moving versus a static environment to see if movement had any impact on performance or supported the work of the theories and research summarised by Wertheim (1998), when using the different interaction techniques, direct gesture interaction and touch button and menu interaction. The chapter opens by giving a short theoretical background overview concerning related research and connected topics and proceeding with discussing the results of the pilot study and the main study with associated questionnaires and post-task discussions. The chapter closes with a chapter summary that sums up the main features and findings. Relevant material (questionnaires, consent form etc.) can be found in Appendix E and published material in Appendix C.

7.2 Background and Related Research

After doing two previous user studies involving testing in a static environment, it was desirable to supplement the research by testing in a moving environment more realistic and similar to the environment that the DP system is used in on a daily basis.

Investigating the usage of direct gesture interaction in a moving environment is built on the theories behind how working in a moving environment (Wertheim, 1998) can affect performance and also which factors play a noticeable role in the degradation of performance both physically and mentally (Dobie, 2000) This will later on be accompanied with the theory behind selected statistical methods, critique and defence of using questionnaires and the reason behind using distraction tasks to keep the test-subjects alert and on watch at all times during the study.

7.2.1 Addressing Interaction in a Moving Environment

Interacting with a system in a moving environment can be a challenge not only on board a boat that is susceptible to movement in all six degrees of freedom, but also in cars aeroplanes, watching wide screen television, in simulators and other moving installations. It is argued by Wertheim (1998) that performance decrements can be expected to occur as a result of general effects or as a result of specific effects of particular human skills. Wertheim (1998) differs between the general effects and the specific effects. Motion sickness includes many different effects, apart from actually being sick. General effects occur when environmental motion, simulated or real, reduces motivation, increases fatigue or creates balance problems, while specific effects on task performance may only be expected though biomechanical influences on particular skills such as perception or motor skills. In other words, being exposed to conditions that causes motion sickness can degrade the level of performance significantly.

Overall both general and specific effects contribute to a reduced level of performance where the general effects can cause such strong physical impact that the mariner has difficulties maintaining his/her tasks, but in terms of system interaction the specific effects are more interesting in this context.

7.2.1.1 Specific Effects affecting Performance

When investigating the performance of interacting with a system in a moving environment, such as in this research, there are several different aspects one can take into account. There is how well the test participants carry out the tasks, how accurate they do it and how fast they react and respond to distractions. The tasks in a real life, and in this case the bridge, setting can be complex and not always easy to recreate in a simulated environment. Normally the setting is intensified to save time and the tasks carried out are real, but the frequency of carrying out the tasks has increased. Research done in a Ship Motion Simulator (SMS) by Helsdingen (1997) and Wertheim and Kistemaker (1997) involved complex tasks that included activating a range of different psychological skills. In one particular study, they instructed users to memorize information (from a radar image) that had to be sampled and transferred by clicking on targeted icons. Their studies consisted of an interplay of cognitive skills, perceptual skills and fine-motor coordination skills where the traditional analysis of one-dimensional parameters (investigating reaction times and error rates) were not sufficient. They discovered that with a moving SMS there was a small, but significant reduction of the information transferred. Here they used a general system analytical parameter that reflected the amount of information that was transferred from the task to the human operator. The effect from this analysis could however not be explained as a motioninduced interference with any one particular human skill. To solve this, the complex tasks were divided into three different classes based on their underlying skill components (Wertheim, 1998):

1) Cognitive tasks (to pay attention, remember, learn. In this case remember gestures and button/menu combinations);
2) Motor tasks (do physical tasks with your hands. In this case carry out tasks by using gestures or traditional touch button and menu interaction); and
3) Perceptual tasks (to see or hear. In this case: to look and listen for crossing vessels).

There have been several different studies done by analysing these three classes and the conclusions were all similar. For cognitive tasks the overall conclusion signals that the participants' cognitive skills are not directly affected by ship movements. They can however be affected if the participant is experiencing seasickness or where the tasks require high effort (Gaillard and Wientjes, 1994) (Hockey, 1997). For motor tasks there is a slight indication that ship movements interfere with fine motor control. It is however not consistent and there are reason to believe that when it occurs it is caused or affected by biomechanical factors such as the general effects mentioned above. For perceptual tasks, neither, was there any large impact of ship motion on performance. It can however be argued that biomechanical factors play a role and some motion-induced performance decrements can occur if the visual perception is interfered with (e.g. reading small text, display vibrating or similar)(Wertheim, 1998).

Fine motor control can be defined by Kimmel (2007) as:
"the coordination of muscular, bone (skeletal), and neurological functions to produce small, precise movements. The opposite of fine motor control is gross (large, general) motor control. An example of fine motor control is picking up a small item with index finger and thumb. An example of gross motor control would be waving an arm in greeting."

In context of this research, direct gesture interaction can be categorised as using fine motor control to operate the system. Interestingly findings from the research done by Wertheim and Kistemaker (1997), Wertheim (1998), Gaillard and Wientjes (1994), Hockey (1997) and Kimmel (2007) can be connected to the findings from the study discussed in this chapter. This will be outlined in the following sections after discussing the statistical methods used. In addition, critiques of utilising questionnaires to register test-participant's opinions and the reason behind distraction tasks will be discussed.

7.2.2 Selected Statistical Methods

Selecting the correct and most appropriate statistical test can be difficult and in this case the statistical methods selected for the pilot study and the main study was a combination between doing some tests using repeated- measure analysis of variance (ANOVA) and simple two-tailed t-tests. The tools used for statistical analysis was SPSS and Microsoft Excel.

7.2.2.1 Repeated-measure ANOVA

Doing a repeated-measure ANOVA was well suited for the data collected from the main study where all participants carried out all four conditions, hence in a static versus a moving environment using gestures versus touch button and menu interaction, just in terms with the description given by Field (2009). Having three dependent variables (DV) (see section 7.5.1), two of them were analysed using repeated –measures ANOVA, while the third was analysed using a two-tailed t-test. Two separate repeated measures ANOVAs were carried out, one for each of the DV's selected. In SPSS there were four columns for each of the DV's (timing of tasks in all conditions and error rate for all tasks in all conditions). Each DV was defined with a repeated measures factor which each had two levels. The confidence interval adjustment was done by using Bonferroni with a confidence interval of the classical 0.05. The statistical output from SPSS gave a good insight in the descriptive statistics, specifying the means and standard deviations. The Mauchly's test of sphericity was convenient to use in case the sphericity was violated demanding further testing. According to Field (2009) sphericity is a less restrictive form of compound symmetry and refers to the equality of variances of the differences between treatment levels. You need minimum three conditions for sphericity to be an issue. Violations of sphericity can be spotted by studying the significance after doing Mauchly's test.

The withinsubjects effects analysis gave insight in the F-value for each of the main effects and the interaction between them while the pair-wise comparisons gave a more detailed image of the analysis and told where the differences were between conditions. The last but very useful output was a plot with errorbars. This gave a better insight into what was going on and whether there was an interaction between the conditions. Detailed statistical results will be given in section 7.5.9.

7.2.2.2 Paired T-Test

The last DV concerned reaction time to distraction tasks given. The test selected for this was a paired t-test due to its simplicity and that for this purpose it gave sufficiently good answers. According to Field (2009) a paired (dependent) t-test can be utilised when there are two experimental conditions, in this case motion and interaction/input technique, where all participants take part in both conditions of the experiment. Detailed statistical results for reaction time will be given in section 7.5.10.

7.2.3 Pros and Cons of using Questionnaires

Questionnaires have always been an easy way of gathering information about people's opinions and they have been widely used for scholarly research. Their benefit is that the participants can chose to stay anonymous which gives an advantage especially when it comes to researching social issues where some questions can feel difficult to answer. It is also less intrusive than carrying out telephone or face-to-face interviews. However, for usability studies, questionnaires can be a double edged sword. For testing systems e.g. old versus new system, it is apparent to the participant that the facilitators want a positive answer towards the new system and followed by the participants' "kindness" the answers might be biased. It is therefore important to emphasise to the user that it is important that the answers are their honest opinion. However, the answers can and still will in some cases be biased. According to Jahoda et al. (1962) written questionnaires may reduce the interviewer bias you get with a face to face interview because there is a uniform question presentation. However this can also become problematic if the facilitator/owner of the questionnaire is not available for immediate response to coming questions from the participants regarding the questionnaire. Therefore the general layout of the questionnaire must be clear and concise with good instructions on how to answer. In addition the questionnaires should use simple and direct language (Norton, 1930). The order of the questions together with the length of the questionnaire are also important issues; this is however out of the scope of this thesis and further supplementary information can be found in the paper "Everything you wanted to know about questionnaires but were afraid to ask" by D.S. Walonick (Walonick, 1993).

The NASA-TLX questionnaire is a questionnaire that gives the possibility of looking at how difficult the participants find it to use each method (Blandford, Cairns and Cox, 2008) and can be defined as a subjective workload assessment tool. According to the NASA-TLX research team (Hart and Staveland, 1988) the NASA-TLX allows users to perform subjective workload assessments on operator(s) working with various human-machine systems and is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales include Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration. It can be used to assess workload in various human-machine environments such as aircraft cockpits, command, control, and communication (C3) workstations, supervisory and process control environments, simulations, and laboratory tests. The NASA-TLX has however received some critique due to being a purely subjective questionnaire that only reflects a participant's opinion. It is therefore vulnerable to biased answers and analysis of the questionnaires must be carefully interpreted.

For the two studies discussed in this chapter, questionnaires were given pre-, during- and post- task. During the pilot-study the NASA-TLX questionnaire was utilised, while for the main study three questionnaires were used. Two identical questionnaires with questions using 5 point Likert scales and additional comment fields were handed out in-between and post-task, while the third, also handed out post-task was purely based on answering three questions in comment fields. The questionnaires followed the guidelines given by Walonick (1993) and Dix et al. (1997). To counteract biased answers, the participants had to fill out, as mentioned above, multiple questionnaires at different stages through the experiment. In addition, the facilitator was available for questions and also emphasised the importance of giving an honest opinion. Although precautions have been made, the possibilities of biased answers are still present and analysis must be interpreted thereafter.

7.2.4 Simulating Situation Awareness using Cognitive Distractions

Experiments and studies are either carried out in the field or in a laboratory environment, where studying in the field and the user's natural habitat is often preferred because of the increased amount of data it is possible to collect and the situational validity of the study. In many cases studying in the field is not always possible. Examples of this are for instance when carrying out experiments with very expensive equipment that can be exposed to damage or doing field studies in a safety critical environment, such as in a car or in this particular case a boat, where there is both expensive equipment involved and dangers of death or injuries to participants and/or surrounding environment. Operators of vessels must at all times be on watch to keep updated on the surrounding waters and research has defined that situation awareness can be interpreted to involve identifying relevant environmental stimuli or cues, where that that information is integrated into the operator's knowledge base to form a mental model or representation of the situation. This knowledge is then used to project the occurrence of events in the near future, hence a crossing vessel or nearby on or offshore installations (Kass, Cole and Stanny, 2006).

To create instances of situation awareness in a laboratory environment, cognitive distractions can be generated around the participants. These tasks are directly related to the experiment and tasks given during the study, and can for car related research be an incoming mobile telephone call (Kass, Cole and Stanny, 2006) or for maritime research, vessels or helicopters approaching the boat. The reason for adding cognitive distraction tasks to the experiment described below is connected to the discoveries made during the observation study mention in chapter 4. Here it was observed that the operator spent most of his/her time looking out of the windows during operation to ensure safety on deck and around the vessel. For the pilot study it was decided to simulate the sea environment so the operator had to maintain an appropriate level of observational awareness. Similar work has been done by Lumsden, Langton and Kondratova (2008) that tested recognition accuracy to speech input in a maritime environment using distraction tasks.

7.3 Ship Motion Simulator Pilot Study

A pilot study with eight participating test subjects was carried out to prepare and gain experience for a larger study. The pilot study was carried out in the same environment where the main study was to take place, in a High Speed Craft (HSC) simulator, from here on called a ship motion simulator (SMS) at Aalesund University College. However due to that the ship software was still under development, photographs were used to assess the validity of using the SMS. The aim of the study was as mentioned to gain experience in operating the SMS and how to plan the main study, but also to investigate the differences between manipulating a computer displayed object using gestures or buttons in a static environment versus in a moving environment, using a tablet computer and a movement-platform to simulate sea movement. From this it was possible to collect samples to investigate if there was a comparable trend between the conditions. Before the pilot could commence, training was given by staff at the university college in how to operate the simulator.

The eight participating students and staff had various backgrounds. They utilised the second HW/SW prototype tablet computer from Dell with multi-touch functionality to carry out the experiment. In addition they were seated on a moving platform which moved according to settings which simulated different sea conditions, in this case rough sea. The motion platform pilot gave insight in how to perform a larger study using the DP system and also gave an indicator towards the impact of movement and which technique was more efficient. The test-participants felt more comfortable operating the interface using gesture interaction. In addition it gave insight into practical considerations such as the screen being slightly unstable, indicating that for the main study support for the device in the shape of a lectern or similar is needed. The purpose of using direct gesture interaction to manipulate a photo was to relate it to using similar gestures to manipulate a vessel in the 3D scene of a dynamic positioning system. This allowed us to investigate the pros and cons of using gestures in a moving environment.

7.3.1 Design of Pilot Experiment

The participants were presented a collection of photographs displayed in a standard photo viewer (Windows Picture and Fax viewer). They interacted with the displayed photos in four different conditions (interaction x environment). The tasks were identical, but the settings while interacting to achieve the task goal were different. The tasks were conducted in a non-moving and in a moving environment. In each environmental condition, the participants carried out the tasks using two different interaction methods, multi-touch interaction or the buttons and menus manipulating a picture in the photo viewer. The test subjects would use their hands to perform different gestures that will change the photos' appearance. Between the sets of tasks and post-task discussion the test participants filled out NASA TLX questionnaires.

NASA-TLX is a subjective workload assessment tool that allows users to perform subjective workload assessments on operator(s) working with various human-machine systems (Blandford, Cairns and Cox, 2008). The questionnaire consists of six different questions that concerns mental demand, physical demand, temporal demand, performance, effort and frustration marked on a standard NASA-TLX gradtiation scale ranging from very low to very high for all questions apart from performance that had a scale from perfect to failure.

7.3.2 Experimental parameters

For the pilot study there are two hypotheses supported by two independent variables (IV) and one dependent variable (DV). The purpose was to test the principles of using a motion platform and what should be taken into account when preparing for the main study. Six students and two lecturers participated. For this study error rate and distraction tasks were not taken into account.

The independent variables are

IV1: Interaction style

Conditions: multi-touch gesture (GE) and buttons (BUT)

IV2: Motion

Conditions: static (ST) and moving (MO) simulated medium rough sea

The dependant variables are

DV1: Average time spent on each task

The pilot study hypotheses are

H1: Tasks will be conducted in less time using direct gesture interaction

H2: Interaction time will be less affected by motion for gestures than buttons

7.3.3 Experimental Setup

Each participant entered the room and received a short briefing of what was happening by reading the introduction sheet where the details were described, followed by reading and signing the consent form where name, gender, education/background and email address were registered (see appendix E). It was emphasized that the personal details would only be used for administrative purposes and to categorize the participants. In addition they indicated their preference concerning publication of results, footage and videos being used and published for research purposes. Each participant took place in the left hand captain's chair on the SMS bridge. The multi-touch display/ tablet computer was situated on the participant's lap during the whole duration of the study apart from when the participant filled out NASA TLX questionnaires. After the participant was given training in the different gestures, i.e. zooming, panning and flicking, and using the traditional touch buttons normally clicked on by using the mouse, the tasks were carried out in the following sequences:

1) ST/BUT ST/GE MOV/GE MOV/BUT
2) MOV/BUT MOV/GE ST/GE ST/BUT
3) ST/GE ST/BUT MOV/BUT MOV/GE
4) MOV/GE MOV/BUT ST/BUT ST/GE

The different sessions started in a moving environment with the moving platform turned on and half way through the condition was changed to static. The following session started in a static environment and changed to a moving environment half way through the session. Each session was divided into two parts. During the first part the condition was either static or moving, where the participant carried out the first two tasks and filled out a NASA TLX questionnaire. For the second part the condition changed and the participant finished by doing the last two tasks and filling out another identical NASA TLX questionnaire. The last part was finished by asking a general question regarding their performance during the different conditions. The question concerned if the movement from the SMS affected the participants' performance.

Schedule

- Participant enters the room
- Participant reads introduction sheet
- Participant signs consent form
- Participant takes place in left hand captain's chair

- Participant gets training
- Condition selected (MOV/ST)
- First part of testing commences and tasks are given
- Finishes the first set of tasks
- Participant fills in NASA TLX questionnaire
- Condition changes
- Second part of testing commences and tasks are given
- Finishes second set of tasks
- Participant fills in NASA TLX questionnaire
- Post-Task question asked by facilitator
- Participant leaves the room

Tasks

The tasks given were concerned with looking for specific photographs in a collection of about 40 different images and to find information in a picture. By giving these types of tasks it was possible to make them interact with the system using interaction techniques almost identical to the ones being used for operating a DP system. The first set of tasks were given separately, so that the participants would not get confused or remember the photo they were instructed to find in the next and second set of tasks. This was because they could flick through the photos faster if they could approximately remember its position in the collection. The interaction techniques used were gesture interaction and touch button and menu interaction. There were two variations of the task sheet depending on the order of tasks. The collection of photographs used is reproduced from Yann (2010). They were used because they are a relatively unknown large set of photographs.

An example of the tasks is as followed:

1: Information in a picture.

With the image on screen answer the following:

* What is the registration plate of the white car?

* What do the sign to the right of the main building advertise?

2: Find a picture

Find the following picture using flicks:

3: Information in a picture

With the image on screen answer the following:

* How long can the red car park for legally?

* What do the sign to the left of the main building advertise?

4: Find a picture

Find the following picture using the on-screen buttons:

7.3.3.1 In General

The test lasted for duration of approximately 2 hours where each participant had about 15 minutes each. 13 minutes was used to perform both sets of tasks and the last 2 minutes was spent on a post –task question. The two main conditions were counter balanced, where half of the participants started mving half static.sets were for each participant counter-balanced where there were four tests starting in a moving environment and four tests starting in a static environment. A camera was used to record the movements on the surface of the touch-display in addition to freeze screen software that recorded all moves initialized in the computer.

7.3.4 Findings

Described below are the findings for all four tasks from the pilot study. This is followed by a discussion of the results found in the participant's NASA-TLX questionnaires.

7.3.4.1 Analysis of Task Timing

The mean values for all four conditions for all four tasks have been compared and reports as followed:

Descriptive Statistics

The total length of time spent (table 7.1) on the tasks (n = 5) when using direct gesture interaction averaged in a static condition on 65.51s (SD = 19,29s) and on 30.25s (SD = 18.15) in a moving condition. For touch button and menu interaction the average for total time spent on the tasks was 54.96 s (SD = 56.04) in a static condition and 74.08s (SD = 40.59) in a moving condition. This indicates that the tasks were carried out quicker in a moving environment while using gesture interaction.

Descriptive Statistics

	Mean	Std. Deviation	N
StaticGesture	65.5144	19.28672	5
StaticButton	54.9612	56.04687	5
MovingGestures	30.2512	18.15177	5
MovingButtons	74.0828	40.58789	5

Table 7.1: Descriptive statistics for time spent on tasks 1 to 4

Tests of Within-Subjects Effects

There was no effect on time spent on the tasks of motion, $F(1,1) = 0.475$, $p>0.05$ or for input type of motion, $F(1,1) = 1.319$, $p>0.05$. Nor was there any interaction between motion and input, $F(1,1) = 1.433$, $p>0.05$. Since there were no effects overall, no further tests were necessary.

7.3.4.2 Summary Task Timing

The graph (figure 7.1) below illustrates the results where as indicated in the initial descriptive statistics, the results show that there is no main effect of motion or input and no interaction between motion and input. From the plot it can be seen that there is however an indicative trend where using gesture interaction in a moving environment is slightly faster than using touch button and menu interaction. It is important to emphasise that this is a small pilot where the selection of participants was small.

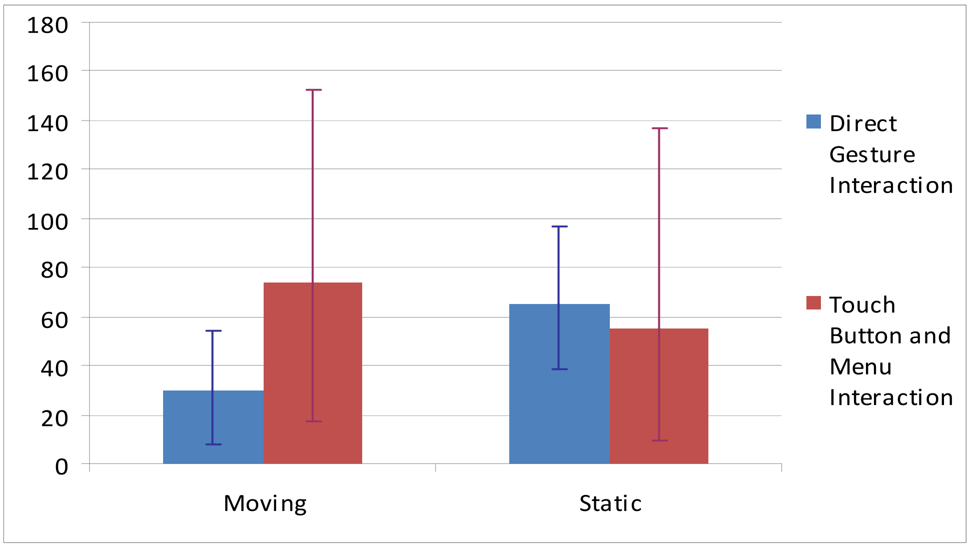


Figure 7.1: Illustrating motion x input for timing of pilot study tasks. The y-axis illustrates time spent on tasks. The error bars show the fastest and the slowest individual for the time spent on each task.

7.3.4.3 Analysis of answers from NASA-TLX Questionnaires

The analysis of the questionnaires is based on the calculation of the mean of the answers from each of the six demands of the NASA-TLX questionnaire. The figures that illustrate the questions, in example figure 7.2, show the scale and the 95% confidence interval of the line. The NASA-TLX was filled out in the middle of the session after task 1 and 2 had been completed. The condition then changed to a moving or a static environment depending on which condition they started with. After task 3 and 4 was completed, a new NASA-TLX was filled out.

NASA-TLX for Task 1 and 2:

Question 1:

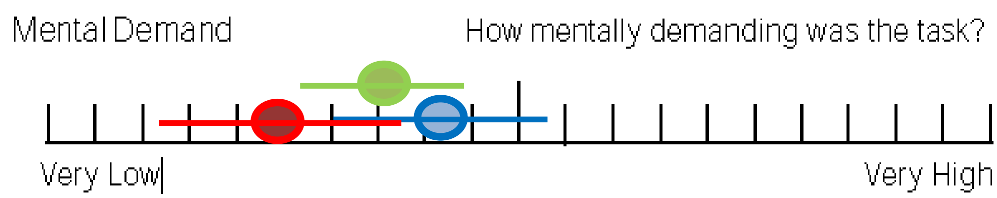


Figure 7.2: Mean with confidence interval for mental demand

The mean of overall mental demand (figure 7.2, green dot) was 7.43 (SD = 4.5) with a confidence interval (CI) of 3.33, of mental demand in a static condition (blue dot) was 8.75 (SD = 4.57 and CI = 4.48) and of mental demand in a moving condition (red dot) was 5.67 (SD = 4.62 and CI = 5.23). This indicates that the participants felt an overall low mental demand when performing the tasks, but felt the lowest mental demand in a moving environment. All participants did all tasks in all conditions, with gestures and touch button and menu interaction while in a static and in a moving environment.

Question 2:

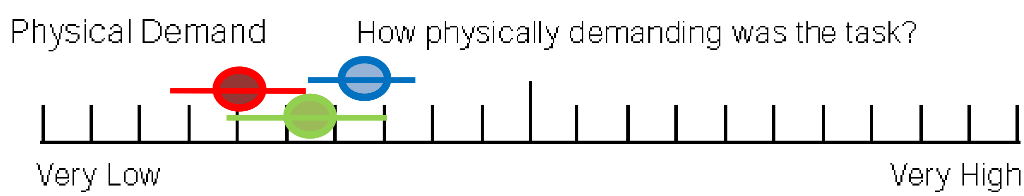


Figure 7.3: Mean with confidence interval for physical demand

The overall mean of physical demand (figure 7.3, green) was 6 (SD = 2.67) with a confidence interval of 2.93, of physical demand in a static environment (blue) was 7.25 (SD = 2.06 and CI = 2.02) and of physical demand in a moving environment (red) was 4.75 (SD = 2.87 and CI = 2.81). This indicates that the participants felt a low physical demand when performing the tasks, but felt lowest physical demand in a moving condition.

Question 3:

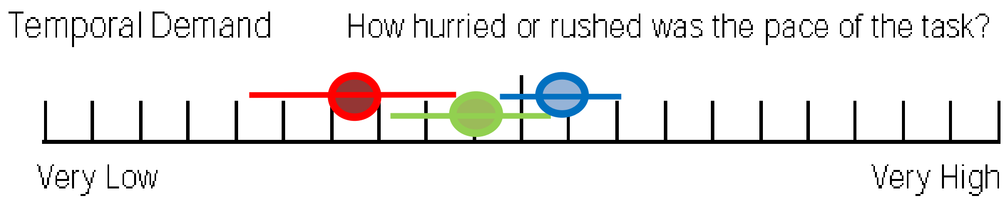


Figure 7.4: Mean with confidence interval for temporal demand

The overall mean of temporal demand (figure 7.4, green) was 9.37 (SD = 4.24) with a confidence interval of 2.93, of temporal demand in a static environment (blue) was 11.75 (SD = 2.87, CI = 2.94) and of temporal demand in a moving environment (red) was 7 (SD = 4.32, CI = 4.23). This indicates that the participants felt close to an average time pressure when performing the tasks, but felt lowest time pressure in a moving condition.

Question 4:

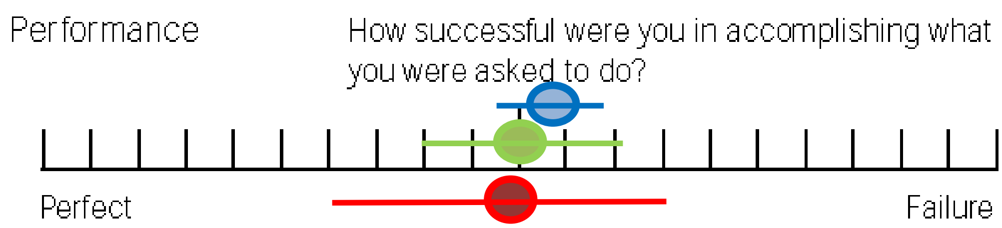


Figure 7.5: Mean with confidence interval for performance

The overall mean of performance (figure 7.5, green) was 10.5 (SD = 4.92) with a confidence interval of 3.41, of performance in a static environment (blue) was 10.75 (SD = 2.22, CI = 2.17) and of performance in a moving environment (red) was 10.25 (SD = 7.18, CI = 7.04).This indicates that the participants felt they performed averagely when doing the tasks, regardless of environmental condition.

Question 5:

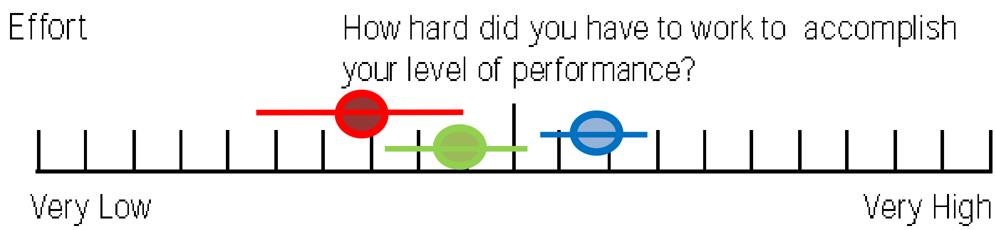


Figure 7.6: Mean with confidence interval for effort

The mean of effort (figure 7.6, green) was 9.25 (SD = 3.80) with a confidence interval of 2.63, of effort in a static environment (blue) was 11.25 (SD = 2.22, CI = 2.18) and of effort in a moving environment (red) was 7.25 (SD = 4.27, CI = 4.19). This indicates that the participants felt they had to perform on an average level to accomplish the tasks**,** but felt they had to make less effort when performing in a moving environment.

Question 6:

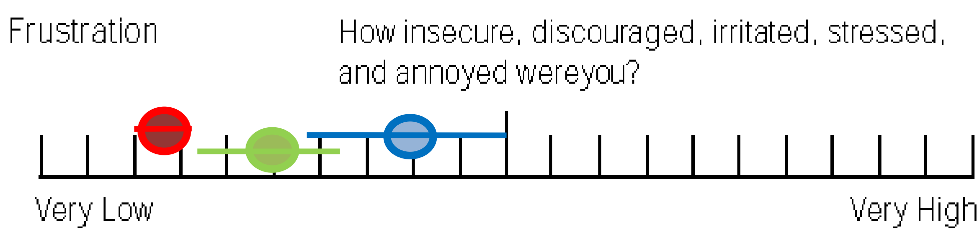


Figure 7.7: Mean with confidence interval for frustration

The overall mean of level of frustration (figure 7.7) was 5.38 (SD = 4.2) with a confidence interval of 2.92, of frustration in a static environment (blue) was 8.25 (SD = 4.19, CI = 4.11) and of frustration in a moving environment 2.5 (red) (SD = 1.29, CI = 1.27). This indicates that the participants did not feel especially frustrated when carrying out the tasks, but felt noticeable less frustrated when carrying out the tasks in a moving environment.

Summary of NASA-TLX for Task 1 and 2

The overall impression from the answers collected from the first set of NASA-TLX questionnaires were that the participants did not feel any particular discomfort when carrying out the tasks. All means were average or below average on the scale.

Interestingly the participants felt less discomfort in a moving environment than in a static environment. A possible explanation to this could be that all the participants that started in a moving environment utilised touch button and menu interaction for task 1. This is a familiar interface the participants are using more often than direct gesture interaction. Therefore when starting on task 2 utilising direct gesture interaction, they felt more comfortable due to that they had been familiarised with the environment (environmental setting, tablet computer and task set) through the first task.

NASA-TLX for Task 3 and 4:

Question 1:

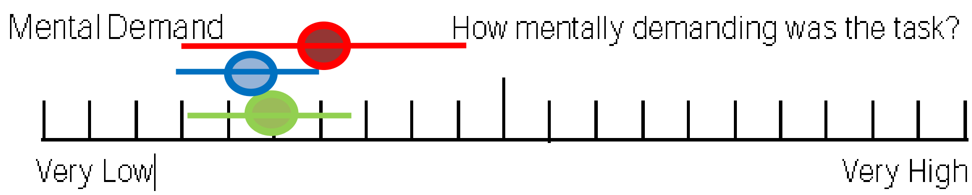


Figure 7.8: Mean with confidence interval for mental demand

The overall mean of mental demand (figure 7.8) was 5.87 (SD = 4.15) with a confidence interval of 2.88, of mental demand in a static environment (blue) was 5 (SD = 3.16, CI = 3.10) and of mental demand in a moving environment (red) was 6.75 (SD = 5.32, CI = 6.02). This indicates that the participants felt a low mental load when performing the tasks, but felt lowest in a static condition.

Question 2:

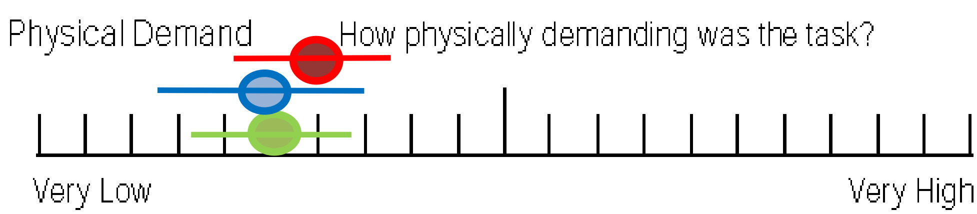


Figure 7.9: Mean with confidence interval for physical demand

The overall mean of physical demand (figure 7.9) was 5.87 (SD = 3.97) with a confidence interval of 2.75, of physical demand in a static environment (blue) was 5.5 (SD = 4.44, CI = 4.35) and of physical demand in a moving environment (red) was 6.25 (SD = 4.11, CI = 4.03). This indicates that the participants felt a low physical demand when performing the tasks, but lower in a static condition.

Question 3:

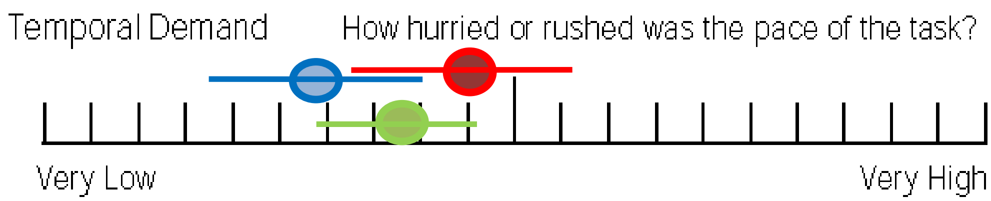


Figure 7.10: Mean with confidence interval for temporal demand

The overall mean of temporal demand (figure 7.10) was 8 (SD = 4.75) with a confidence interval of 3.29, of temporal demand in a static environment (blue) was 6.25 (SD = 4.65, CI = 4.55) and of temporal demand in a moving environment (red) was 9.75 (SD = 4.79, CI = 4.69).This indicates that the participants did not feel rushed when performing the tasks, but felt more rushed in a moving environment.

Question 4:

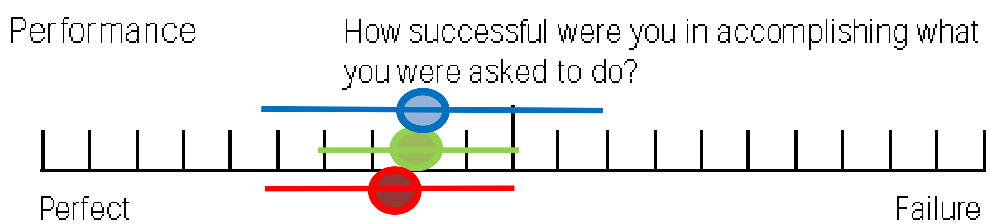


Figure 7.11: Mean with confidence interval for performance

The overall mean of performance (figure 7.11) was 8.25 (SD = 6.13) with a confidence interval of 4.25, of performance in a static environment (blue) was 8.5 (SD = 7.68, CI = 7.53) and of performance in a moving environment (red) was 8 (SD = 5.35, CI = 5.25). This indicates that the participants felt they performed well when doing the tasks, but better in a moving environment.

Question 5:

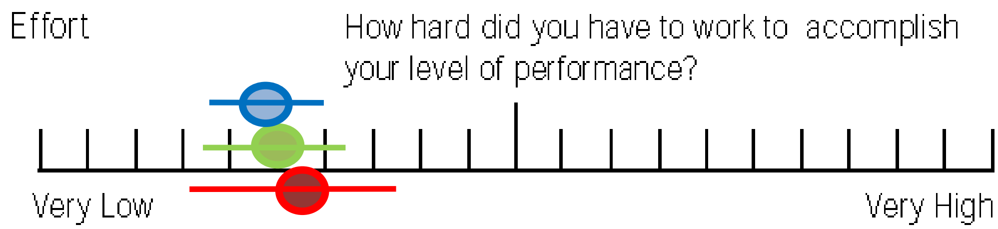


Figure 7.12: Mean with confidence interval for effort

The overall mean of effort (figure 7.12, green) was 5.88 (SD = 3.31) with a confidence interval of 2.29, of effort in a static environment (blue) was 5.25 (SD = 2.22, CI = 2.17) and of effort in a moving environment (red) was 6.5 (SD = 4.44, CI = 4.35).This indicates that the participants did not have to work hard to accomplish the tasks, but worked harder in a moving environment.

Question 6:

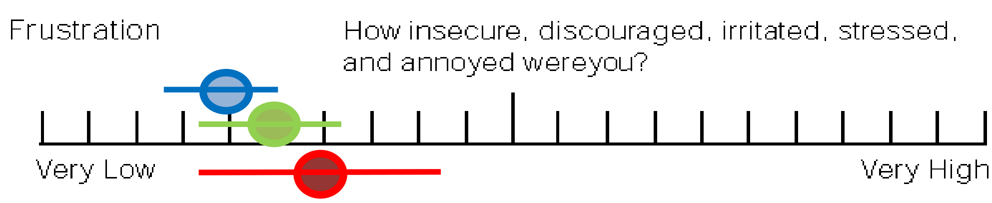


Figure 7.13: Mean with confidence interval for frustration

The overall mean of frustration (figure 7.13, green) was 5.38 (SD = 3.96) with a confidence interval of 2.74, of frustration in a static environment (blue) was 4.5 (SD = 2.52, CI = 2.47) and of frustration in a moving environment (red) was 6.25 (SD = 5.31, CI = 5.21). This indicates that they felt a general low level of frustration when carrying out the tasks, but felt less frustrated in a static environment.

After completing the last questionnaire, the participants answered a general question that concerned whether movement affected their performance. Four participants opted to not give a reply, while the remaining four replied that movement affected them little to not at all.

Summary of Analysis of NASA-TLX for Task 3 and 4

The overall impression of the second iteration of NASA-TLX questionnaires for task 3 and 4, was that the participants gave lower scores and felt more comfortable than when doing the first two tasks. This implies that with some exercises they felt a lower task load. In addition, in this case the participants gave below average scores and felt an overall low taskload when performing the tasks. However, for these tasks they felt more uncomfortable in a moving environment than in a static environment, this could due to the same reasons as for task 1 and 2 where the participants in this case started with direct gesture interaction in a moving environment. The difference weren't as noticeable as for the first two tasks. This could be because they were more used to the interaction from the experienced gained from task 1 and 2. The post-task question implied that the moving environment had little to no effect on the participants' performance.

7.4 SMS Pilot Study Conclusion

The results from the pilot study imply that there are no main effects of either input or motion on the participants' performance when timing the tasks done in the different conditions. In addition there are no interactions between motion and input. There is however an indicative trend that using gesture interaction in a moving environment can be slightly faster than using touch button and menu interaction. This trend is not significant. The results from the NASA-TLX questionnaires show overall no discomfort when performing the experiment tasks. For both iterations of questionnaires (task 1 and 2, task 3 and 4) the participants gave average or below average scores, however for task 3 and 4 they gave scores slightly lower than for task 1 and 2. This implies that the participants performed better with some training. Together with the results mentioned above and the post-task questionnaire it indicates that carrying out the tasks on a moving environment had little to no effect on performance: this is supported by the participants in the post-task question and previous research studies summarized in the paper by Wertheim (Wertheim, 1998).

To answer the hypotheses set for the pilot study:

H1: Tasks will be conducted in less time using gestural interaction

The tasks were not conducted using significantly less time with direct gesture interaction, which proves that hypothesis H1 is not supported.

H2: Interaction time will be less affected by motion for gestures than buttons
The interaction time was not significantly less affected by motion for gestures than for buttons, which proves that hypothesis H2 is not supported.

7.5 Using Direct Gesture Interaction and Touch Button and Menu Interaction to Operate a DP System in a Static versus Moving Environment

The fourth and last iteration of user studies was carried out using the second HW/SW prototype. The aim of this experiment was to investigate the differences between using direct gesture interaction versus the conventional touch button and menu interaction in a static environment versus a moving environment. This iteration used the authentic DP system, the SMS and a live visualisation where vessels were crossing at specified time intervals. Four hypotheses were investigated in connection with this study and independent and dependant variables were taken into account. These will be described below in section 7.5.1. A panel of 19 test participants carried out the experiment. An overview of the participants' age, DP experience and if they were righr or left handed can be found in Appendix E. They were seated in the operator's chair in the SMS. The movements were set according to settings simulating rough sea. A timestamp for each operation was recorded using a video camera. This gave useful information when analysing the results using the statistical method of ANOVA for the timestamps and calculating the mean and standard deviation for the average results of the data obtained from the questionnaires.

7.5.1 Experimental Parameters

This user study investigated four different hypotheses that were selected on the basis of the experiences obtained from the previous iterations of user studies, including the pilot study. It was desirable to collect as much information as possible around using gestures in a moving environment. The experiment was carried out in a controlled environment beacause testing in a real environment would be costly (approximately

£6000 per hour for offshore vessel hire) and possibly dangerous due to it being a safety-critical application. To make the experiment more authentic the SMS (utilising the moving platform) was supplemented with a realistic visualisation of the vessel's surrounding environment. Crossing vessels were programmed into the visualisation after specific time intervals. This reflected the mariner's responsibility of being on continuous look-out for changes in the vessel's surrounding environment. Similar comparisons have been done by Lumsden, Langton and Kondratova (2008). The aim was to test the efficiency and accuracy of using gestures against using conventional touch to navigate in menus and press soft buttons in the system's GUI. In addition it was interesting to investigate the conditions' effect on reaction time to distraction tasks and how the motion affected the two different interaction techniques tested. These conditions were outlined in a set of four hypotheses.

Hypotheses

H1: Tasks will be conducted in less time using gestural interaction

H2: Tasks will be more accurate with gestural interaction

H3: Interaction time will be less affected by motion for gestures than buttons

H4: Reaction time to environmental activities will be faster for gestural interaction

To be able to test the hypotheses, a set of dependent and independent variables was used. The experiment had three dependent variables that were measured and two independent variables that were manipulated, where each of the independent variables had two levels of values.

Independent Variables

IV1: Interaction style

- Direct Gesture Interaction versus touch button and menu interaction

IV2: Motion

- Static and moving simulated medium rough sea

In addition a cognitive distraction task was given, which was balanced to prevent habituation/learning, with vessels crossing either after 1,3, 4 or 1,3, 5 minutes in each study condition.

Dependent Variables

DV1: Average time spent on each task

DV2: Average error rate on each task

DV3: Reaction time to distraction task

7.5.2 Experimental Setup

The second HW/SW prototype ran the Rolls-Royce DP system on the Dell Latitude XT2 multi-touch tablet. Unlike the experiment using the NextWindow multi-touch display, the device utilised to feed the DP system's GUI with data was not the Rolls-Royce Marine Controller, but a software framework based on the script language Python. This software was running on the tablet computer and eliminated the need for an additional device. The Python framework supplied the system with data, to make it possible for the GUI to come alive and be operated authentically as done on an offshore vessel. As all software applications were running on the tablet computer, it made the scene of the experiment less cluttered with equipment and cables. This made it easier to carry out the experiment when both the test participant and the facilitator only had to deal with one device used to carry out the actual tests.

The test was conducted in a combined 2D and 3D software environment. The DP system's GUI was divided into two different sections where the menus were presented in 2D and the visualisation of the manipulations of the vessel was conducted in the 3D scene. This made it possible to test four of six available degrees of freedom (DOF); surge, sway, heave and yaw. The degrees of freedom that represented pitching and rolling the vessel were left out of the test due to the discovery made during the observation study on board the platform supply vessel, i.e. Havila Foresight. Pitching and rolling the vessel in the 3D scene is rarely carried out and therefore not relevant to this particular study.

This study was a 2x2 study design where the participants interacted with the vessel in four different interface conditions varying interaction style and motion. The tasks were identical for all conditions. The conditions were tested in a within-group balanced study where all the test participants underwent all four conditions, with the conditions in counterbalanced order to counteract learning effects. Instructions were given verbally in Norwegian read from a manuscript, so that it was the same for all participants. The tasks were conducted in two states that concerned the environment. The first was a static state where the moving platform of the SMS was static and the second a moving state where the moving platform was moving according to settings that simulated medium rough sea. The participants carried out the experiment using two different interaction techniques. One technique was aimed at manipulating the DP system using conventional touch to operate the menus in order to achieve the goal of the tasks given. The second method was aimed at the participant using gestural interaction directly in the GUI's 3D scene to achieve the goal. All tasks were identical and tested in all conditions. The participants were given training at the beginning of their session where the facilitator outlined how to operate the system. Each session lasted for about 20 to 25 minutes depending on how much time the participant spent on doing the tasks. During the study the test participants also had to keep an eye out of the window for crossing vessels or rescue helicopters. The conditions were consistently tested with visualisation in the simulator, which means that the test participants saw a landscape when looking out of the bridge windows. The landscape is an authentic visualisation of a well-known strait outside Aalesund, called Breisundet. Every time a crossing craft was visible in the landscape, the test participant had to verbally inform the facilitator by shouting: "Boat!" or "Helicopter!". There were six vessel crossings for each session. In addition to the crossing crafts (vessels and helicopters), seagulls and other sights found naturally in a marine environment were present in the visualisation. It was emphasised by the staff that programmed the visualisation and were in charge of the SMS, that such frequent crossings were not realistic. However, it was desirable to maintain frequent vessel crossings to test the participants' alertness during the whole duration of the experiment. This mirrors the authentic behaviour when being on bridge watch, where the officers must maintain a constant observational awareness of the environment around the vessel.

Experimental States

The experimental states can be described as:

MO/ST: Moving/Static

GE/BUT: Gestures/Buttons

For a within-subject design all users, as mentioned above, have to do the four combinations of MO/ST and GE/BUT. To balance the design there are four categories of users who will perform tasks in the following order:
Category 1: *MO/GE MO/BUT   ST/BUT ST/GE
Category 2: *MO/BUT MOV/GE   ST/GE ST/BUT
Category 3: *ST/GE ST/BUT   MO/BUT MO/GE
Category 4: *ST/BUT ST/GE MO/GE MO/BUT
* = training on interface about to use
Not all sequences were covered. This was due to the SMS was slow to start and stop, so the condition changed only once per subject. However, a balanced study with all conditions experienced was carried out.

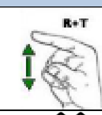
The participants filled out in total 3 forms during the experiment. The first form was a consent form, while the second and third forms were identical questionnaires. The consent form was filled out before the participant entered the room of the experiment and ensured that the test participants' ethical considerations were taken into account. It also informed them about their rights concerning their participation in the experiment. In addition they answered questions concerning the usage of digital video footage and images recorded during the study. Most of the participants agreed to the questions asked in the consent form while one used the right to keep footage private and only for internal use. In the consent form they also noted down their names, age and education in addition to their experience with DP systems and if they were left or right handed. The questionnaires will be described in more detail below in section 7.5.11.

7.5.3 Equipment Setup

One camera recording in HD format was used to document the experiment. It was mounted on a tripod behind the operator chairs on top of a cabinet where it was directed downwards to catch the events happening on the tablet's surface. During the motion platform pilot study indications towards the users wanting a table for the tablet were discovered. This was taken into account and the tablet was placed on a ring-binder to give the appropriate angel for interaction. The lectern shape functioned well due to the test participants getting a tilt on the display that made it easier to see the graphics and also to carry out the tasks without having to worry about the tablet's position. The participants had the ring-binder with tablet computer on their lap while doing the tasks. Ideally the tablet would be fixed to a table that could be folded in and out in front of the operator. This was not possible to achieve for the current study. The facilitator observed the sessions and was seated in the operator chair to the right of the test participant. This enabled the facilitator to have full overview of the sessions and assist if any incidents such as equipment failure should occur. In addition concurrent field notes were written, so that events worth noticing were easier to re-locate when watching the recordings post-experiment.

7.5.4 Interaction Techniques Used

When interacting with the DP system two different interaction techniques were used. For direct interaction with the 3D scene the participants used their hands to perform several pre-determined gestured to move the vessel (see table 7.2). Two fingers held slightly apart in parallel were used to move the vessel in the surge and sway direction, for the heave direction sliding two fingers together initialised zooming out while sliding them apart initialised zooming in (the pinch gesture). When changing the vessel's heading, in yaw direction, the thumb was kept static on the display while index or the middle finger was flicked in a curved movement either to port or starboard depending on the task. For all tasks the move had to be applied with a double tap using two fingers. All menus had been removed and only the 3D scene was visible (see figure 7.15) for interaction.

Task No	Task	Touch Gesture
1	Zoom out (heave) from the vessel in the 3D scene.	
2	Move the vessel 15 meters forward (surge) and apply movement.	

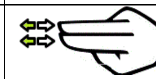
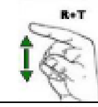
3	Move the vessel 15 meters aft/backward (surge) and apply movement.	
4	Move the vessel 15 meters starboard/right (sway) and apply movement.	
5	Move the vessel 15 meters port/left (sway) and apply movement.	
6	Rotate (yaw) the vessel 7 degrees starboard/right.	
7	Rotate (yaw) the vessel 7 degrees port/left.	
8	Zoom in (heave) on the vessel in the 3D scene.	
	Apply movement after every gesture	

Table 7.2: Illustrations of gestures used for the specific tasks

For operating the DP system using the traditional touch button and menus, the participants navigated by tapping menu selections and soft keys in the DP's GUI (see figure 7.14) in the same manner as touch screen interfaces traditionally are manipulated. The menus were enabled and visible to the left in the DP's GUI. To move the vessel in either direction, a selection in the menus was done followed by further selections in the menus structure. The number of metres for movement in surge and sway direction and number of degrees for yaw direction was entered using a soft key numeric keypad. All moves were applied by pressing the Apply- button. For zooming in the heave direction two buttons to the right in the GUI were used (figure 7.14). Minimum click count (table 7.3) to touch button and menu interaction, gives perspective over the effort the operator has to engage in to carry out the tasks. Clicking apply was left out due to direct gesture interaction having a similar apply-action done by double tapping the display using two fingers.

Task number	Task	Minimal click count
1	Zoom out from the vessel in the 3D scene.	1 (press and hold button)
2	Move the vessel 15 meters forward.	1 double click 2 single clicks to enter 15 meters = 4 clicks in total
3	Move the vessel 15 meters backward.	1 double click to open the menu 3 single clicks to activate field (bwd) and enter 15 meters = 5 clicks in total
4	Move the vessel 15 meters port/left.	1 double click to open the menu 4 single clicks to activate the field (port) and enter 15 meters = 6 clicks in total
5	Move the vessel 15 meters starboard/right.	1 double click to open menu 3 single clicks to enter 15 meters = 5 clicks in total
6	Rotate the vessel 7 degrees starboard/right.	1 double click to open menu 1 single click to enter 7 degrees = 3 clicks in total
7	Rotate the vessel 7 degrees port/left.	1 double click to open the menu 2 single clicks to activate field (port) and enter 7 = 4 clicks in total
8	Zoom in on the vessel in the 3D scene.	1 (press and hold)

Table 7.3: Experiment tasks main study with minimum click count for touch button and menu interaction

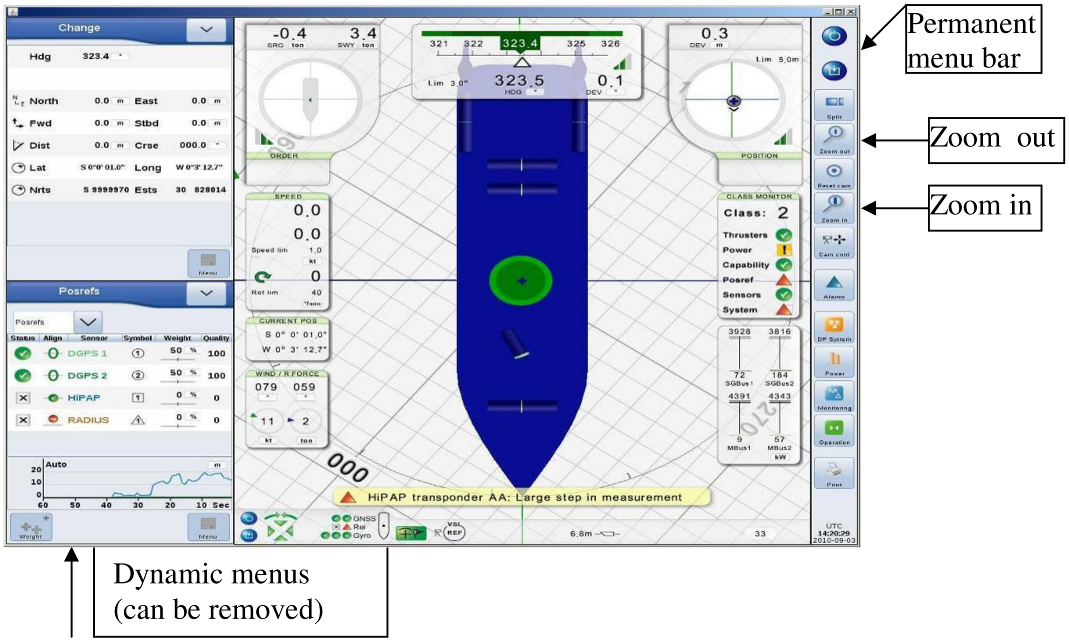


Figure 7.14: DP GUI with menus enabled and no extra details in setpoint (green circle). Zoom buttons are located to the right visualised by the icon of a magnifying glass. Large vessel in the magnifying glass equals o zooming in and the small vessel equals to zooming out.

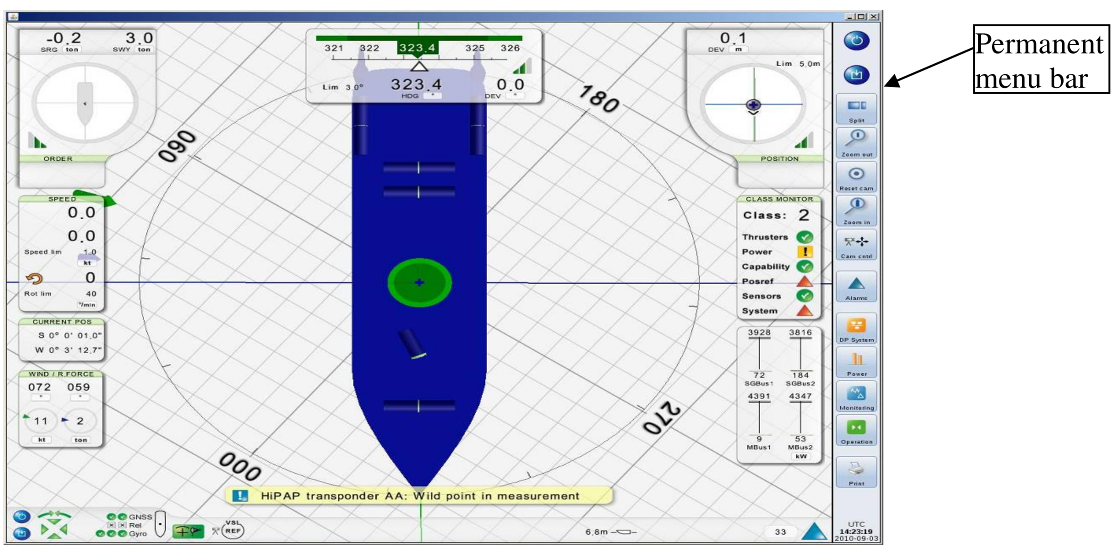


Figure 7.15: DP GUI with menus disabled (no extra details in setpoint).

7.5.5 Statistical Methods Used

To analyse the data collected from the study where there were four different conditions, SPSS was used to do a repeated measured analysis of variance (ANOVA) to analyse the error rate and the timing of the different tasks. This enabled the possibility of testing within-subjects effects and contrasts and to do pair-wise comparisons of the different conditions, hence input (interaction technique used) and motion (platform being in a moving or static condition). In addition it was possible to register if there was any interaction between the conditions. Significant effects were verified using pairwise comparisons with Bonferroni correction, and re-tested excluding extreme data points (i.e. the two fastest and two slowest). Excluding extreme data points will ensure that the statistical results are not biased and only the core data is being analysed. For analysing the reaction time to the distraction tasks a simple t-test was utilised using Excel. This test was chosen due to no knowledge about variance.

7.5.6 Respondents and Participants

The participants were a combination of first and third year students from the Nautical Institute at Aalesund University College where they were studying towards a degree within navigation and manoeuvring large vessels. In total 19 students participated where 11 represented third year students and 8 represented first year students. Only two of the test participants were female. This is natural due to maritime professions being strongly male dominated. They had booked timeslots in advance to be sure they found the timeslot best suited to participate. The participants' knowledge of DP systems was indicated in the consent form where they circled the answer corresponding to their particular level of knowledge to the question: "How well do you know Dynamic Positioning Systems and operating DP systems?" They could choose between the alternatives:

Little Knowledge/Experience - Average Knowledge/Experience - Good Knowledge/Experience.

Little knowledge/experience indicated that the participant had little knowledge of the system and had never operated or experienced a DP operation. Average knowledge/experience indicated some knowledge of DP systems and had experienced a DP operation. Good knowledge/experience indicated that the participant had extended knowledge of DP systems and that they had operated a vessel in DP. None of the participants circled this alternative. The participants had in the majority of cases little knowledge of DP systems. Fifteen participants circled this alternative, where seven were third year students and eight were first year students. The four participants that circled average knowledge/experience were third year students who had been offshore as a part of their work experience scheme or as cadets during summer jobs. The participants' age distribution was between 20 and 32, with an average age of 23.05. Eleven of the participants were between 20 and 23, while the remaining participants were distributed with one participant for each age distributed between the 24, 26, 28, 30 and 32. The question that investigated if the participants were right or left handed discovered that only one participant was left handed. This can therefore not be taken into account when analysing the results. The information about the participants' details was only used for organising purposes and was not taken into account in the analysis.

The reason for selecting students to participate in the study was because they had little experience with operating DP systems. While they understood DP operations, they had limited experience with commercial DP systems. This was desirable as it would reduce the bias towards the traditional interaction style. This was due to that if experienced users were selected for the study, they could be influenced by their use of other brands of DP systems or have extended experience of operating Rolls-Royce DP systems. This could distort the experiment and give confounding results.

7.5.7 General Observations of Interaction

Initially after observing the user study and before looking into the statistical data, it seemed like the participants had varying experiences of which method they preferred. Pros and cons of both methods appeared during the user tests, but generally the interaction went well in all conditions, with some minor software problems. The tablet froze twice during the experiment and had to be restarted. The reason for this is unknown, but it seems likely that a memory leakage in the software caused CPU overload. This did not have any impact on the execution of the experiment, because the participant was instructed to redo the task he/she was doing before the incident, so the timing would be correct. Below a general discussion of observations made during the experiment will be outlined. Before settling on a final determination using statistical results, the condition concerning the moving platform did seem to have some impact on direct gesture interaction in a moving environment. This will be further discussed at a later stage in section 7.5.9, together with the statistical figures.

When the participants interacted with the DP system carrying out the tasks using gesture interaction, they easily understood how to use the gestures to do the tasks. Without mentioning a fixed result on measurement of learnability, the participants seemed to need very little training to reach their task goal. Training was given once before the session started, which was sufficient for gestures. Double tap to accept the actual move of the vessel, was a procedure that was common after all gesture interaction tasks. Adjusting the vessel to hit the exact position outlined in the task sheet i.e., 15 metres, was the largest challenge and most frequently occurring issue. Some participants got it straight away, while others found it difficult to hit the exact 15m position. The other issue that arose concerned the final double tap to accept the movement and to send the message to the system that the vessel could start moving. The participants wanted to tap only once and followed the procedure; move – lift off – single tap to apply, instead of applying the double tap at the end. In addition to the general issues mentioned above, one issue that appeared a few times concerned the actual gesture of using two fingers to move the vessel in either surge or sway direction. This appeared to be troublesome in some cases where the participants held their fingers too close. The system was not enabled to detect two touch points meaning that the system did not detect the gesture or send the message that the vessel was moving. Other task-specific issues will be discussed in the next section under the relevant task.

When interacting with the system using traditional touch interaction to operate the system by pressing touch buttons and menus, some of the participants seemed more insecure the first time they did tasks using this technique. They were observed to hesitate before pressing the buttons or talking to themselves saying i.e. “Hmm.. oh yes.. there it is.” The training did however seem sufficient, but some participants needed assurance that they were selecting the correct choices in the menus. The most frequently occurring issue was the participants struggling with the double tap needed to open the selection made by the participant in the menu. They often followed the procedure wherein they pressed once on the menu selection and then pressed again to realise that still nothing happened. Only after the second time nothing happened did they realise that it needed a double tap. The other procedure frequently used was tapping once on the menu to mark the selected menu item, and then did a double tap to open the menu item. In some cases the participants also opened the wrong menu item, this did however not occur so frequently. As these issues can possibly be traced back to poor system design, this was not changed due to as it was a part of the standard DP system. Another issue was entering numbers on the keypad to make the vessel move. The keypad has two fields for input of numbers that each can take input for movement in four different directions, forward/backward and port/starboard (surge and sway). The top field was marked as default, so they had to tap the field wanted in order for the numbers applied to appear in the correct field. The minimal click count is reported in table 7.3 where it is illustrated that i.e. moving backward has one more click than forward. This is due to that the default marking of the field in the keypad is set to forward, hence to move backward need one additional click to activate the backward field. This was sometimes forgotten and by pressing the apply button the vessel moved in the wrong direction. The pressing of the apply button also introduced some challenges. After entering the specific amount of metres outlined in the task sheet, also in this case 15 metres, they were to press apply to confirm that the vessel was ready to move. The one second delay before the apply button turned green was difficult for some participants to take into consideration and they instantly wanted to press apply after entering the numbers. This resulted in them either pressing the apply button many times until it “worked” and registered the input or thinking that the apply button was pressed and proceeding on to the next task. Also with this interaction technique, task-specific issues will be discussed in the section below under the relevant task.

During the session the participants looked out for crossing vessels. This distraction task was continuous and went on in parallel with the direct interaction with the DP system. Interesting observations made during the session were the differences that appeared in the combination between the actual look-out and the interaction with the system. For gesture interaction the majority of the participants continued their gesture while at the same time looking out of the window. When interacting with the system using touch menu and button interaction, the participant paused the interaction to look-out and resumed by looking down to ensure not pressing the wrong button. A technique the participants adopted was looking out for crossing vessels while waiting for the apply button to turn green and be receptive to touch. This happened after they got more used to using the traditional touch technique and knew how the system reacted to this type of interaction.

7.5.8 Experiment Tasks

Eight tasks were presented to the participants that were a combination of giving commands that moved the vessel and commands that gave the participant the possibility to orientate in the 3D scene by zooming in and out. Zooming involves manipulating the camera function in the 3D scene. This function is important due to the DP system giving a greater level of detail the further in that you zoom. A good example is position reference indicators that inform the operator of the status and the location of the position reference sensors in the GUI (see figure 7.16). The tasks were, as mentioned, read from the task sheet by the facilitator. On a vessel's bridge in normal operation, the lights are always dimmed down as light pollution decreases the visibility of GUIs on the equipment's display units. During night sailing the bridge is blacked out apart from lights from displays, equipment and one lamp over the chart table, where charts and logbooks are situated. Around this table there is a dark curtain used to further reduce the light. Reflections in the bridge windows at night cause reduced visibility which can be hazardous.

Figure 7.16: Illustration of level of detail in the DP GUI's visualisation of position reference sensors (circled in red).

Each task that concerned moving the vessel's position had to be accepted by pressing the apply- button when using menus/buttons and a double –tap with two fingers when operating the system using gestures. Moving the vessel is a safety-critical operation that is placed under strict rules from classification authorities. This is due to the need to prevent a movement of the vessel or other safety critical actions happening by accident. It must be emphasized that the interaction technique concerning using gestures to manipulate the vessel has not taken classification rules into account. The experiment was carried out strictly to investigate the impact of using a novel technique in maritime circumstances versus traditional input techniques. The tasks were outlined as followed (table 7.3) and will be discussed in detail below including statistical results calculated for all 19 participants (timing + erroneous attempts) and for 15 (timing) participants where the two fastest and the two slowest values for each condition were removed to give a more balanced result.

7.5.9 Findings

Below the findings (time spent and error rate) from each task will be outlined with the corresponding statistical analysis and figures. Following the results from measuring timing, error rate and the reaction time to the cognitive distraction task will be discussed.

7.5.9.1 Task 1 and 8: Zoom in/out on the vessel in the 3D scene (simulation of heave)

For zooming in and out using direct gesture interaction, the gesture we know as “the pinch” was utilised where two fingers moved together to zoom out or apart to zoom in. When operating the system using touch button and menu interaction, two zoom buttons were located on a static menu (not removable) to the right in the GUI (see figure 7.14). The buttons were pressed and held down until the desired zoom effect was obtained.

Table 7.4 and figure 7.17 show the times for task 1. The mean separated by input type alone gave for direct gesture interaction (N = 12) an average of 9.72s (sd = 7.80), while for touch button and menu interaction (N = 12) an average of 9.91s (sd = 4.09). There was no effect of motion on time spent on task 1 ($F(1,11) = 0.186$, $p>0.05$) nor was there any interaction between motion and input ($F(1,11) = 0.080$, $p>0.05$). However, there was a main effect of input type ($F(1,11) = 13{,}36$, $p<0.01$). Pairwise comparisons (with a Bonferroni correction), confirmed the observation that participants took longer to complete the task using direct gesture interaction than with using touch button and menu interaction. Similar results were found when omitting the two slowest and fastest users from analysis, except that results now also showed a possible interaction between motion and input ($F(1,5) = 0.045$, $p<0.10$ ($p=0.053$)).

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	9.8875	6.01788	12
MotionButton	4.4533	6.41741	12
NoMotionGesture	9.5558	5.02109	12
NoMotionButton	3.3642	1.81974	12

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	8.3992	7.89945	13
MotionButton	3.1554	1.78579	13
NoMotionGesture	8.8077	6.14700	13
NoMotionButton	2.6146	.99683	13

Table 7.4: Left: Descriptive statistics for time spent on Task 1 all values included, N= participants

Table 7.5: Right: Descriptive statistics for time spent on Task 8 all values included, N = participants

Again for task 8 (table 7.5 and figure 7.18) the mean separated by input type alone gave for direct gesture interaction (N = 13) an average of 8.60s (sd = 6.38), while for touch button and menu interaction (N = 13) an average of 2.89s (sd = 1.30). There was a main effect of input type ($F(1,12) = 14.61$, $p<0.01$) showing that participants took longer to complete the task using direct gesture interaction than when using touch button and menu interaction. There was, again, no effect on time spent by motion ($F(1,12) = 0.002$, $p>0.05$) nor any interaction between motion and input ($F(1,12) = 0.114$, $p>0.05$). Similar results were found when omitting the two slowest and fastest users.

The tables (table 7.4 and 7.5) show a difference between the N-values. The N-values indicates the number of participants. Ideally N should be equal 19, due to there were 19 participants. However due that there were some missing data for some of the tasks, all the measures from that particular participant was excluded for comparisons. This affected task 1 more than task 8.

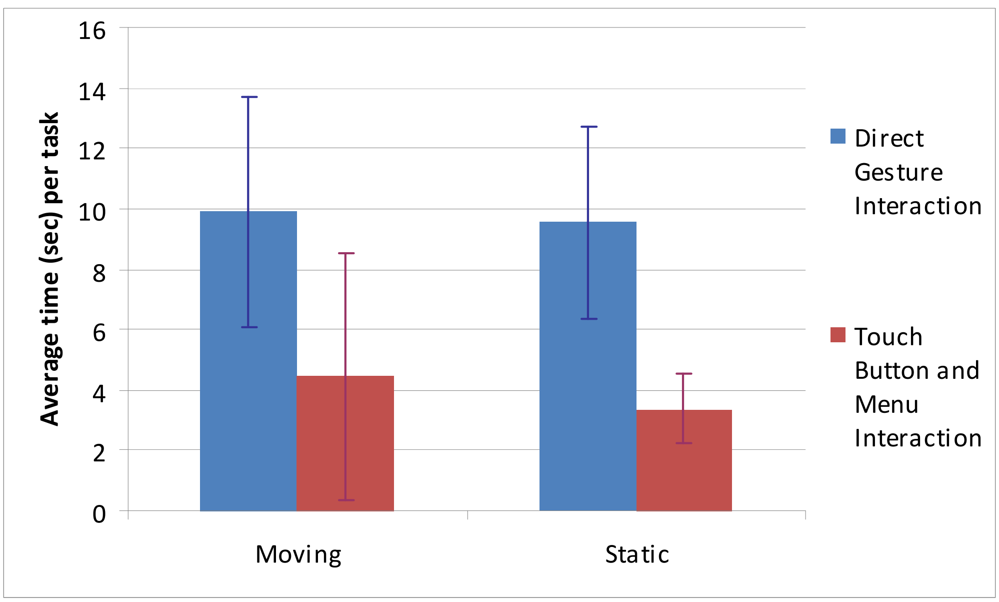


Figure 7.17: Illustrating motion x input for timing task 1 all values included.

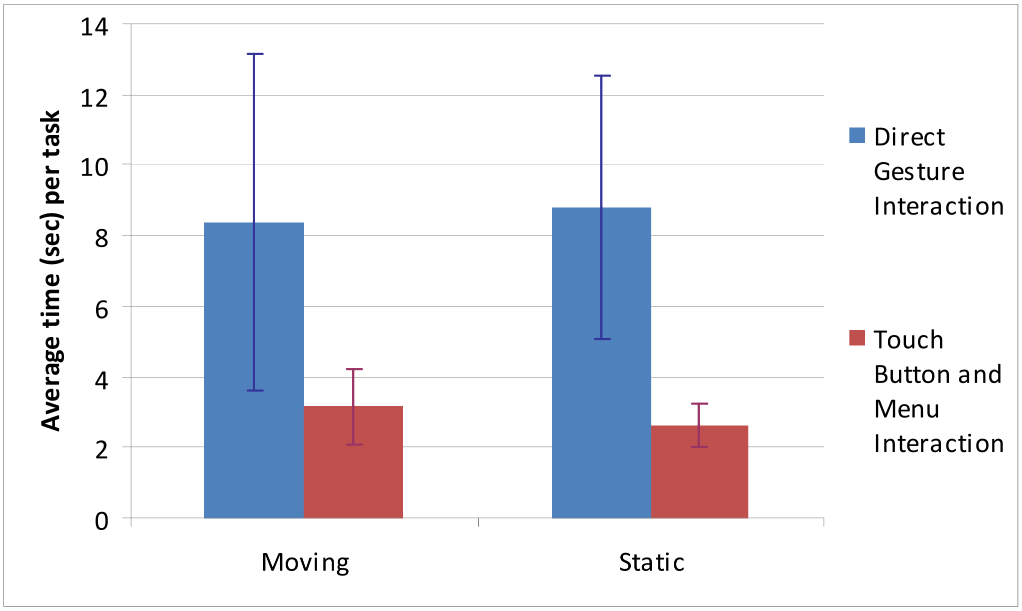


Figure 7.18: Illustrating motion x input for timing task 8 all values included.

When it comes to error rates, errors were measured as incorrect gestures or button presses, even if corrected. The gesture for zooming in and out, also called the "pinch" gesture, is the best known gesture as used on the iPhone and Windows 7 for zooming images and maps. It was believed that this gesture would be easy to carry out. However many users initially zoomed the wrong way confusing zoom in and zoom out gestures in 44% of attempts on task 1 (table 7.6 and figure 7.19) (16 out of 36), which was the first zooming attempt (compared to 6% with the button interface, where they tapped the wrong icon and zoomed the wrong way). The overall values for all attempts when using the pinch gesture showed that 33% failed when trying to zoom compared to 9% for touch button and menu interaction. This difference was significant ($F(1,11) = 4.714$, $p<0.05$, pairwise comparison with a Bonferroni correction). There was, however, no main effect of motion on errors ($F(1,11) = 0.00$, $p>0.05$) nor any interaction between motion and input ($F(1,11) = 0.000$, $p>0.05$). On task 8, there were no errors in the button conditions and a reduced number for gesture (23%).

Descriptive Statistics

	Mean	Std. Deviation	N
failedAB	.3333	.49237	12
failedAB1	.0833	.28868	12
failedA1B	.3333	.49237	12
failedA1B1	.0833	.28868	12

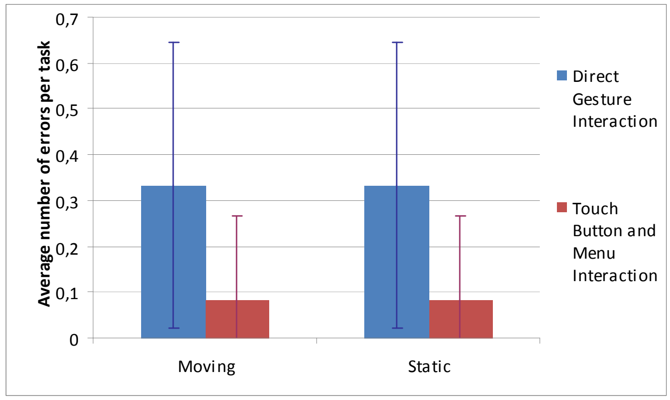


Table 7.6: Left: Descriptive statistics of erroneous attempts of task 1 (A/A1 = motion/static, B/B1 = gestures/buttons).

Figure 7.19: Right: Illustrating motion x input for erroneous attempts task 1.

7.5.9.2 Task 2 and 3: Move the vessel 15 meters forward/backward (surge direction).

For moving the vessel in surge direction using direct gesture interaction, two fingers were utilised. The fingers were situated slightly apart (see table 7.2) and slid in a vertical direction across the screen to move the vessel. A double tap in the 3D scene was used to apply the movement of the vessel. When using touch button and menu interaction, the menus on the left side of the display were utilised (see figure 7.14). These were removed when operating the system using direct gesture interaction. Here the participants selected the appropriate menu selection by tapping and double tapping. The desired amount of meters was entered using a popup keypad (GUI, not physical). The participant then applied the gesture by tapping the apply-button to make the vessel move. This procedure was the same for tasks, 2 to 7, but with different menu selections.

Table 7.7 and figure 7.20 shows the times for task 2. The mean separated by input type alone gave for direct gesture interaction (N = 12) an average of 16.07s (sd = 6.19), while for touch button and menu interaction (N = 12) an average of 12.75s (sd = 7.27). There was no effect of motion on time spent on task 2 ($F(1,11) = 0.02$, $p > 0.05$). However, there was a main effect of input type ($F(1,11) = 5.20$, $p<0.05$) and an interaction between motion and input (F(1,11) = 10.92, p<0.01). This confirms that using direct gesture interaction performed better in a static environment than in a moving environment when moving the vessel forward. Pairwise comparisons(with a Bonferroni correction) confirmed the observation that participants took longer to complete the task using direct gesture interaction than with using touch button and menu interaction. Similar results were found when omitting the two slowest and fastest users from analysis, except that results showed no interaction between motion and input (F(1,4) = 4.772, p>0.05 (p = 0.094)). This indicates that large individual differences contributed to the significant interaction between motion and input previously found when including all values.

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	18.9167	7.49021	12
MotionButton	10.2442	4.37342	12
NoMotionGesture	13.2317	6.78537	12
NoMotionButton	15.2617	11.02905	12

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	20.0423	12.59914	13
MotionButton	10.3708	4.77051	13
NoMotionGesture	15.3877	7.36467	13
NoMotionButton	10.4592	4.74807	13

Table 7.7: Left : Descriptive statistics for time spent on task 2

Table 7.8: Right: Descriptive statistics for time spent on task 3

Again for task 3 (table 7.8 and figure 7.21) the mean separated by input type alone gave for direct gesture interaction (N = 13) an average of 17.72s (sd = 9.14), while for touch button and menu interaction (N = 13) an average of 10.42s (sd = 4.29). There was a main effect of input type (F(1,12) = 7.502, p<0.05) showing that participants took longer to complete the task using gesture interaction than when using touch buttons and menus. There was, again, no effect of motion on time spent (F(1,12) = 1.432, p>0.05) nor any interaction between motion and input (F(1, 12) = 1.535, p> 0.05). Similar results were found when omitting the two slowest and fastest users, except that results now showed no effect of input type on time taken (F(1,2) = 8.529, p>0.05 (p = 0.622)). This result is not applicable due to a high degree of discarded data.

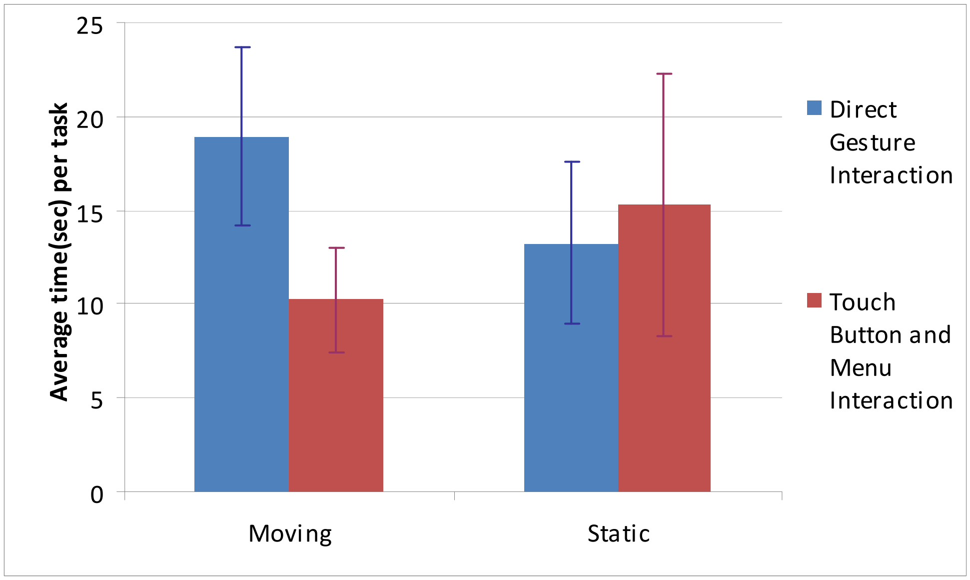


Figure 7.20: Illustrating motion x input for timing task 2 all values included.

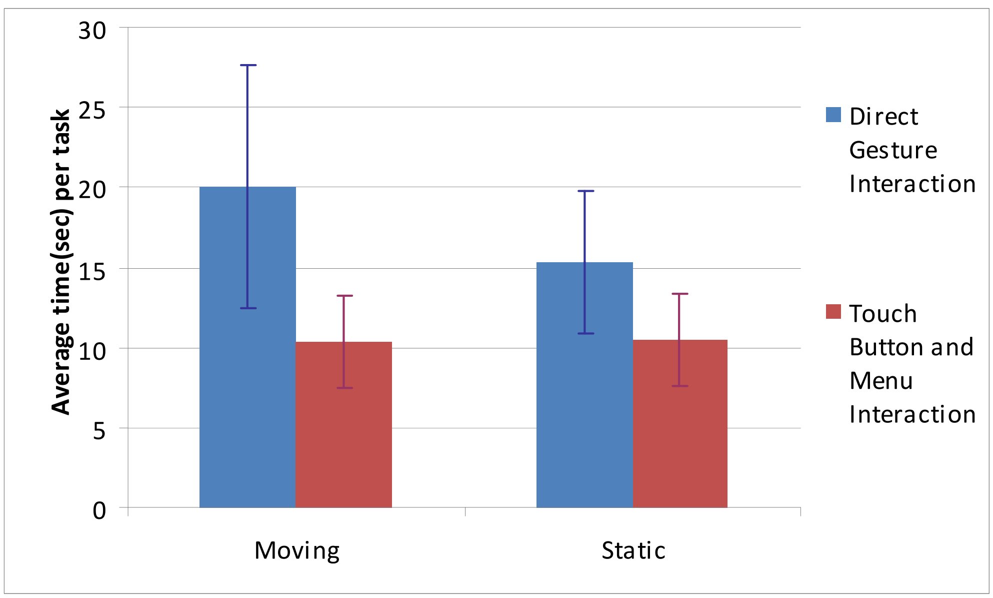


Figure 7.21: Illustrating motion x input for timing task 2 all values included.

The gesture for moving in the surge direction (forward and backward), had to be performed with two fingers slightly apart, which caused some trouble for the users. The most frequently occurring error using direct gesture interaction was to make the vessel stop exactly at the correct position, on the 15 meter indication. For touch button and menu interaction, the most frequently occurring error was hitting the apply-button before it had been activated. In addition it seemed like one mistake triggered a series of errors due to confusion and feeling uncertain as to how to correct the mistake. There were no statistical differences of erroneous attempts, however there was an indicative trend when moving forward indicating that the error rate for both input types were affected by motion. For touch button and menu interaction, there was an indicative trend of being more erroneous (figure 7.22) in a static condition. When moving backward, there was an indicative trend of interaction between motion and input, where direct gesture interaction was more affected by motion and also more erroneous. The results of erroneous attempts for task 2 (table 7.9) was not significant for either conditions. There was no effect of: motion ($F(1,12) = 0.17$, $p>0.05$, pairwise comparison with a Bonferroni correction), input ($F(1.12) = 1.43$, $p>0.05$) or any interaction between motion and input ($F(1,12) = 1.430$, $p>0.05$). Similar results were found for task 3.

Descriptive Statistics

	Mean	Std. Deviation	N
failedAB	.5385	.66023	13
failedAB1	.5385	.66023	13
failedA1B	.3846	.50637	13
failedA1B1	.8462	.80064	13

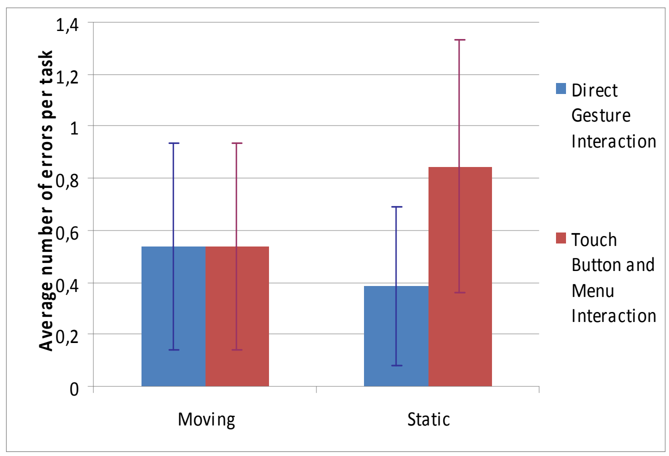


Table 7.9: Left: Descriptive statistics of erroneous attempts for Task 2 (A/A1 = motion/no motion, B/B1 = gestures/buttons)

Figure 7.22: Right: Illustrating motion x input for timing task 2 erroneous attempts.

7.5.9.3 Task 4 and 5: Move the vessel 15 meters port/starboard (sway direction).

When moving the vessel in the sway direction the same procedure as described above in section 7.5.9.2 was utilised for touch button and menu interaction. When using direct gesture interaction a horizontal slide using two fingers across the screen made the vessel move. A double tap in the 3D scene was used to apply the movement to the vessel.

Table 7.10 and figure 7.23 shows the times for task 4. The mean separated by input type alone gave for direct gesture interaction (N = 13) an average of 15.79s (sd = 7.79), while for touch button and menu interaction (N = 13) an average of 15.998s (sd = 10.74). There was no effect of motion on time spent on task 4 ($F(1,12) = 1.508$, $p>0.05$) and there was no main effect of input type ($F(1,12) = 0.009$, $p>0.05$). Nor was there any interaction between motion and input for time taken ($F(1,12) = 0.028$, $p>0.05$). This confirms that regardless of interaction technique used in any condition (moving or static), the performance on task completion for timing was equally good. Similar results were found when omitting the two slowest and fastest users from analysis.

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	17.6838	7.21634	13
MotionButton	18.2900	12.90308	13
NoMotionGesture	13.8862	8.31559	13
NoMotionButton	13.7062	7.99938	13

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	16.3381	7.72785	16
MotionButton	8.2700	2.17951	16
NoMotionGesture	15.1388	7.71413	16
NoMotionButton	7.6506	1.71042	16

Table 7.10: Left : Descriptive statistics for time spent on Task 4

Table 7.11: Right : Descriptive statistics for time spent on Task 5

Again for task 5 (table 7.11 and figure 7.24) the mean separated by input type alone have for direct gesture interaction (N = 16) an average of 15.74s (sd = 7.61s), while for touch button and menu interaction (N = 16) an average of 7.96s (sd = 1.96s). There was no main effect of motion ($F(1,15) = 0.679$, $p>0.05$). There was however a strong main effect of input type on time taken ($F(1,15) = 28.921$, $p<0.01$ ($p = 0$, pairwise comparisons with a Bonferroni correction for multiple comparisons)), showing that participants took longer to complete the task using gesture interaction than when using touch button and menu interaction. There was, again, no interaction between motion and input ($F(1,15) = 0.061$, $p>0.05$). Similar results were found when omitting the two slowest and fastest users.

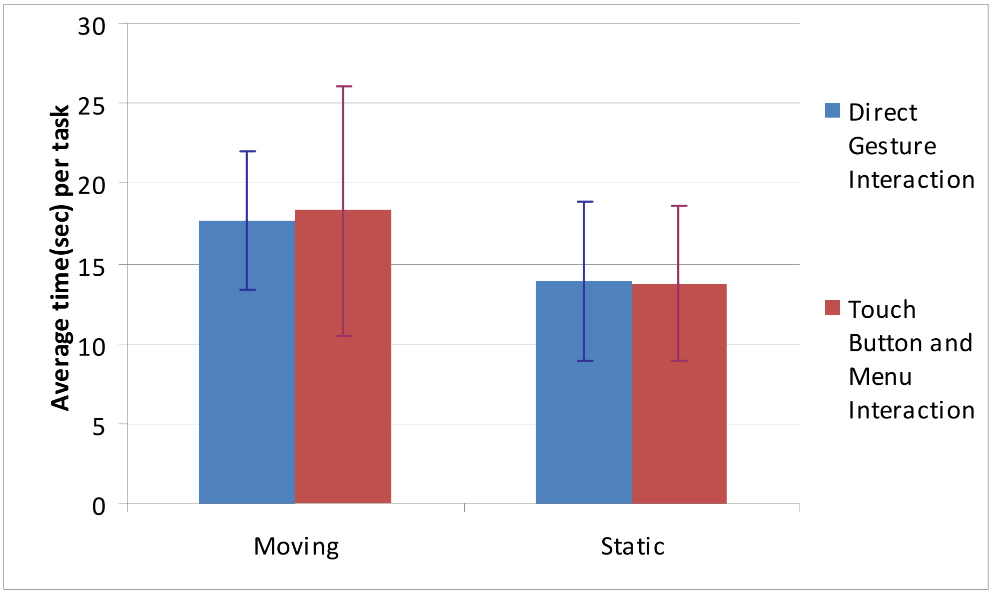


Figure 7.23: Illustrating motion x input for timing task 4 all values included.

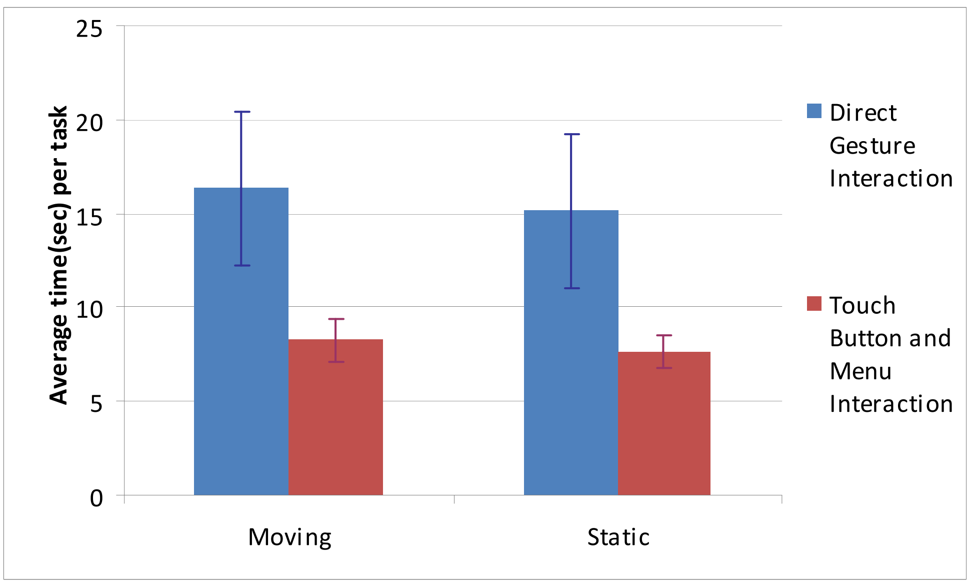
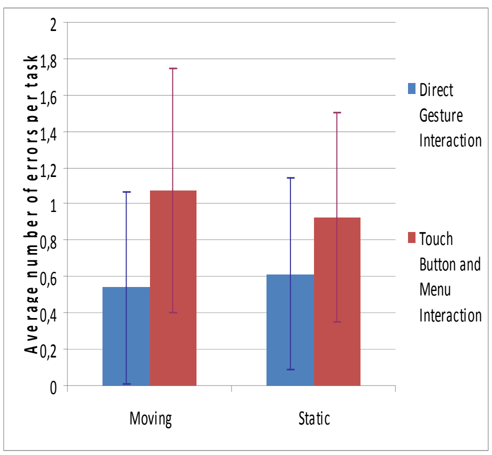


Figure 7.24: Illustrating motion x input for timing task 5 all values included.

The gesture for moving in the sway direction (port and starboard), was performed using the same gesture as for the two previous tasks (tasks 2 and 3) with two fingers slightly apart. While in the surge direction this gesture caused few problems, it was different for the sway direction. Task 4 showed no main effect of motion on error $F(1,12) = 0.020$, $p>0.05$) nor was there any interaction between motion and input on error ($F(1,12) = 0.133$, $p>0.05$). Similar results were found on task 5. For port direction (task 4, figure 7.25), there was a strong indicative effect of input type (F(1.12) = 4.347, p<0.10 (p = 0.059)) where using direct gesture interaction was less erroneous than using touch button and menu interaction. When moving the vessel starboard (task 5, figure 7.26), it showed a strong indicative tendency for input effect (F(1,15) = 4.233, p<0.10, p = 0.057 (pairwise comparison with a Bonferroni correction)), where using touch button and menu interaction generated less error than using direct gesture interaction. This indicates that there is a possible problem with the position of the hand when performing the gesture in the starboard direction. In this study there were 18 right handed participants and only 1 left handed participant. The handedness issue was also present for the left handed participant when moving in port direction. It was however the difference was not as clear as for the right handed participants. To find a trend for left handed participants, more left handed participants had to be measured. Unfortunately for this experiment, further measurement readings were not possible due to time constraints.



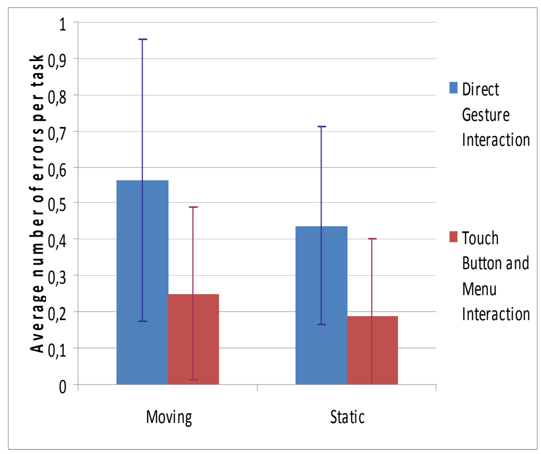


Figure 7.25: Left: Illustrating motion x input for erroneous attempts task 4.

Figure 7.26: Right: Illustrating motion x input for erroneous attempts task 5.

7.5.9.4 Task 6 and 7: Rotate the vessel 7 degrees port/starboard (yaw direction).

Rotating the vessel 7 degrees in the port/starboard direction is known as changing the vessel's heading. For touch button and menu interaction this entails entering a menu using the same procedure as when doing the previous tasks, but using another menu selection. The overall procedure was however the same. For gesture interaction, the gesture was shaped so the participant held their thumb in a static position on the screen while they flicked their index finger (or any other suited finger) towards the port or starboard. A double tap in the 3D scene applied the movement to the vessel.

Table 7.12 and figure 7.27 shows the times for task 6. The mean separated by input type alone have for direct gesture interaction (N = 14) an average of 21.86s (sd = 12.28s), while for touch button and menu interaction (N = 14) an average of 9.29s (sd = 5.52s). There was no effect of motion on time spent on task 6 ($F(1,13) = 0.178$, $p>0.05$) nor was there any interaction between motion and input ($F(1,13) = 0.266$, $p>0.05$). However, there was a main effect of input type ($F(1,13) = 14.814$, $p<0.01$, pairwise comparisons, with a Bonferroni correction): results confirmed our observation that participants took longer to complete the task using direct gesture interaction than with using touch button and menu interaction. Similar results were found when omitting the two slowest and fastest users from analysis ($F(1,5) = 7.238$, $p<0.05$, $p = 0.043$).

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	21.9593	13.23966	14
MotionButton	8.3836	4.11544	14
NoMotionGesture	21.7657	13.01064	14
NoMotionButton	10.2000	7.26613	14

Descriptive Statistics

	Mean	Std. Deviation	N
MotionGesture	32.8992	12.77514	12
MotionButton	6.3492	3.88695	12
NoMotionGesture	20.8817	7.33867	12
NoMotionButton	8.8150	7.55728	12

Table 7.12: Left: Descriptive statistics for time spent on Task 6

Table 7.13: Right: Descriptive statistics for time spent on Task 7

For task 7 (table 7.13 and figure 7.28) the mean separated by input type alone have for direct gesture interaction (N = 12) an average of 26.89s (sd = 9.02s), while for touch button and menu interaction (N = 12) an average of 7.58s (sd = 5.20s). There was a main effect of motion ($F(1,11) = 5.053$, $p < 0.05$) and a main effect of input type on time taken ($(1,11) = 90.014$, $p<0.01$, $p = 0.000$, pairwise comparisons with a Bonferroni correction). Results showed that participants took significantly longer to complete the task using gesture interaction than when using touch button and menu interaction. There was an interaction between motion and input (where $F(1,11) = 9.885$, $p<0.01$) which confirmed that the moving environment contributed to a much higher task completion time when using direct gesture interaction. When omitting the two slowest and fastest users, the results changed and showed no main effect of motion (, $F(1,3) = 0.925$, $p>0.05$) nor any significant interaction between motion and input type ($F(1,3) = 3.526$, $p>0.05$). However, there was still a main effect of input type ($F(1,3) = 179.187$, $p<0.01$, $p = 0.001$), which indicates that rotating the vessel in port direction takes longer using direct gesture interaction.

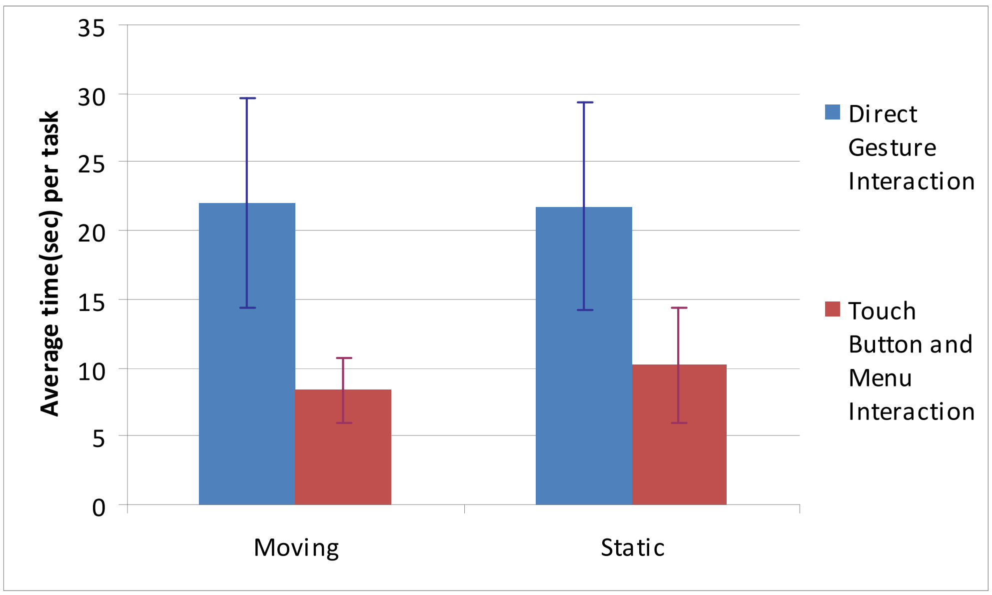


Figure 7.27: Illustrating motion x input for timing task 6 all values included.

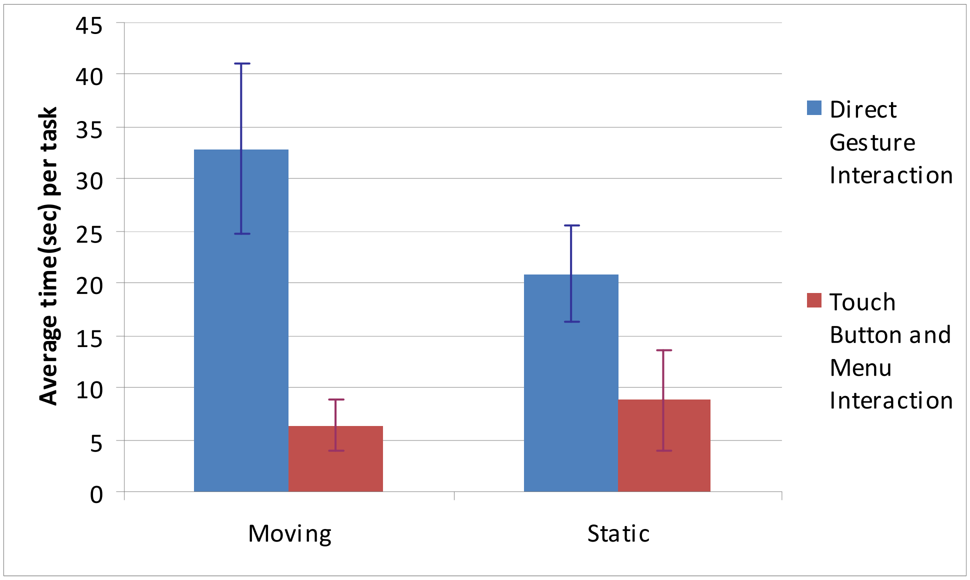


Figure 7.28: Illustrating motion x input for timing task 7 all values included.

The gesture for changing the vessel's heading (rotation) in the yaw direction (port and starboard), was a gesture about which the participants had mixed feelings. Some participants managed to perform well, while others struggled, especially when rotating in the port direction (task 7). The most frequent error occurring for touch button and menu interaction, as with other tasks, was forgetting to double tap on the menu selection to be able to enter it and they also selected the wrong menu item. For gesture interaction the most frequent error was problems with the gesture itself. The participants tried to flick several times with their index finger towards either side without getting the system to respond to their interaction. This indicates that to be able to interact with the system properly when using the rotating gesture, it demands practice. This implies that the gesture utilised is not optimal. Task 6 showed no main effect of motion ($F(1,13) = 0.044$, $p>0.05$), no effect of input type ($F(1,14) = 0.295$, $p>0.05$) nor any interaction between motion and input ($F(1,14) = 0.055$, $p>0.05$) . This confirms that there were no significant differences between conditions in terms of erroneous attempts when rotating the vessel starboard. Yet for task 7, there was a main effect of both motion and input type on errors ($F(1,11) = 6.769$, $p<0.05$, for both measured variables. Pairwise comparisons confirm that rotating port generated far more errors using direct gesture interaction in a moving environment. This shows an interaction between motion and input type ($F(1,11) = 5.077$, $p<0.05$). Whereas in a static environment there are fewer errors made for both input types (see table 7.14 and figure 7.29).

Descriptive Statistics

	Mean	Std. Deviation	N
failedAB	1.2500	.62158	12
failedAB1	.4167	.51493	12
failedA1B	.4167	.66856	12
failedA1B1	.5833	.66856	12

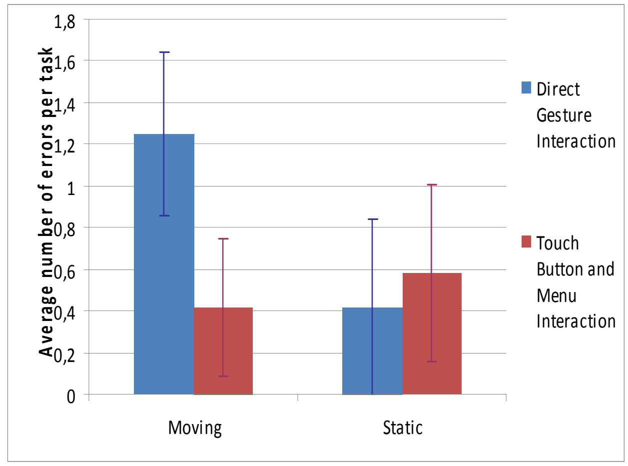


Table 7.14: Left: Descriptive statistics of erroneous attempts for task 7 (A/A1 = motion/no motion, B/B1 = gestures/buttons)

Figure 7.29: Right: Illustrating motion x input for erroneous attempts task 7.

7.5.10 Reaction Time to Distraction Tasks

During the sessions the participants were introduced to distraction tasks while carrying out the interaction tasks given. Six vessels were crossing for each session, where four vessels were boats of different types (high speed crafts and coast guard patrol vessels), while two were helicopters. The session was divided into two parts where each part was carried out in different conditions; hence the movement platform was in a moving condition or a in static condition. The vessels crossed at different time intervals, as mentioned earlier, at 1-3 and 4 minutes into the first part of the session and at 1- 3 and 5 minutes into the second part of the session. The reason for introducing different time intervals was to prevent predictability. The visualisation in the SMS was equipped with both sound and a live scenario from the archipelago, so the vessels could be heard before they appeared visually in the scene. The participants were however instructed to shout “Boat!” or “Helicopter” only when they could confirm visibility. This made it possible to maintain activity on watch and thereafter measure the reaction time from the time when the sound could be heard to the time when the participant noticed the vessel.

The overall impression of how the participants reacted to being on watch while interacting with the system was that during touch button and menu interaction the participants paused while looking up to watch for vessels, whereas while using gesture interaction the participants had a more dynamic interaction, continuing to interact while looking out at the same time. This did however generate more errors. Before doing the statistical analysis the reaction time did not seem to differ noticeably between the interaction techniques.

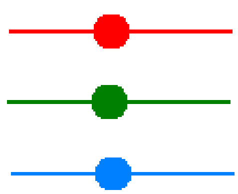
A paired-samples t-test was conducted to compare the effect of the reaction time to distraction tasks when using gesture interaction versus using touch button and menu interaction. There was no significant difference in the scores for using touch button and menu interaction ($M = 37.81$, $SD = 21.41$) and gesture interaction ($M = 42.27$, $SD = 21.66$); $t(24) = 0.45$, $p = 0.05$. These results suggest that the reaction time to distraction tasks was not shorter for gesture interaction.

7.5.11 Questionnaires

The participants (see participant overview in Appendix E) filled out three questionnaires in total for each session where the first two were identical questionnaires that consisted of four questions and two comment fields that concerned rating the two different interaction techniques. The third and last questionnaire consisted of three comment fields. Here the participants answered questions regarding the impact motion and visualisation with crossing vessels had on their performance.

7.5.11.1 Questionnaires 1 and 2: Rating of Interaction Techniques

The initial two identical questionnaires were filled out between the changing of conditions; half way through the session and after the session ended, post-task. The reason for using two identical questionnaires was to investigate whether their opinions changed after a change of conditions and also after getting more used to the system. The data collected was quantitatively measured using 7-point Likert-scaled questions. For the questionnaires a separate mean and confidence interval was calculated for each question. For example, the replies from question 1 from the first questionnaire answered mid-way through the session were treated separately, followed by a separate treatment of question 1 from the second questionnaire filled out post- task. One session equals all tasks done in a moving and a static environment using direct gesture interaction and touch button and menu interaction. The questionnaire was filled out half-way through the session, i.e. when the participant had finished the tasks one time using direct gesture interaction and one time using touch button and menu interaction in a moving environment. The next half of the session then started in a static condition where the participants again did the tasks using the two different interaction techniques. They were then combined and treated as one to find the average trend for question 1 for both questionnaires. Below the results are outlined with their belonging figures. The dot (figure 7.30) illustrates the average, while the line illustrates the confidence interval. The colour red is related to the total mean and confidence interval (including both iterations of questions, hence 38 entries in total), while green indicates the first iteration (mid-session) and blue the second iteration (post-task) of questions from the questionnaires.



Total mean and confidence level for both questions

Mean and confidence level for first iteration

Mean and confidence level for second iteration

Figure 7.30: Illustrating colours for total mean, first and second iteration.

The tables below illustrate the average mean and confidence intervals for each question in the questionnaire. The x-axis has the values representing the 7-point Likert-scale with 0.5 intervals. These are further divided into squares indicating intervals representing 0.25 to illustrate a more nuanced picture of the means and confidence intervals.

In which system was it easier to do a rotate?

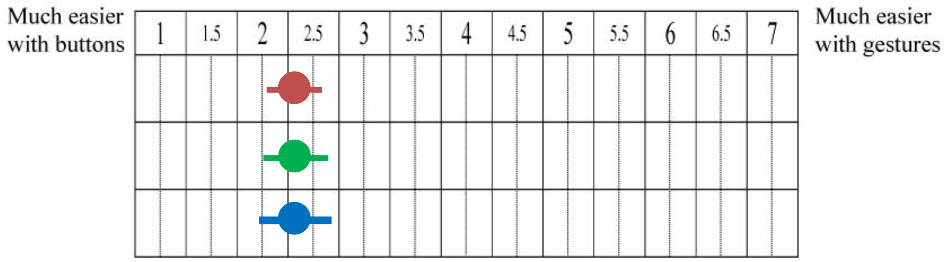


Table 7.15:Arithmetic means with confidence intervals of question 1 (Total, 1st and 2nd iteration).

This question gave a good indication of the overall opinion of which method was preferred when carrying out a heading change (rotation) of the vessel. This is illustrated in figure 7.31 that shows a strong positive skew. The total arithmetic mean (table 7.15) of both iterations of question 1 was 2.21 with a confidence interval of 0.49 that indicates that most participants selected numbers on the Likert-scale that were between 1 and 3, hence on the side of the scale counting towards preferring the use of touch buttons and menus to rotate the vessel. Sixteen out of nineteen participants answered towards the button- side of the scale for both iterations of the question. One participant changed his mind toward preferring direct gesture interaction, while two answered number 6 on the scale indicating that they would prefer gestures instead of buttons.

For both the first and second iterations of question 1 the mean was 2.21 with a confidence interval of 0.68 and 0.71 respectively. The difference between the confidence intervals is because some participants decided to either select a higher or lower value on the Likert-scale from the first to the second iteration of answering.

The overall opinion from the participants preferring using touch buttons and menus for changing the vessel's heading correspond with the facilitator's observations and also the comments made in the comment fields (will be discussed below). The participants had problems with getting the gesture right apart from two who got it right straight away and rotated with ease in both directions, both port and starboard.

These two preferred using gestures for rotating. The background leading to two participant's instant success on rotation the vessel using gestures is unknown and will be further discussed in conjunction with the other results.

How easy was it to move forward/backward?

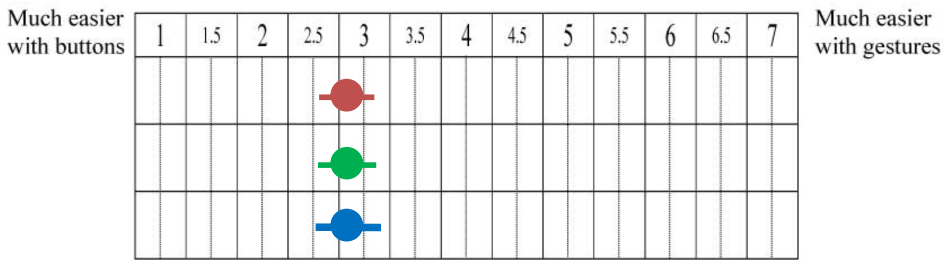


Table 7.16: Arithmetic means with confidence intervals of question 2 (Total, 1st and 2nd iteration).

The mean of question 2, moving the vessel forward and backward, still shows a clear indication towards participants preferring to use touch buttons and menus instead of gestures (table 7.16). The arithmetic mean moves slightly to the right in comparison with question 1 and had the value 2.79 with a confidence interval of 0.46. Figure 7.32 illustrates the distribution of answers to the different points on the Likert-scale. The histogram has a main peak like a normal distribution, but with a slight positive skew that indicates that more participants felt more positive towards using gestures when moving the vessel in the surge direction (forward and backward).

For both the first and second iteration of question 2 the arithmetic mean was 2.79 with a confidence interval of 0.68 and 0.62 respectively. The difference between the confidence intervals are because some participants decided to either select a higher or lower value on the Likert-scale from the first to the second iteration of answering. Four participants increased their value from first to second iteration, while four decreased their value.

The overall opinion of the participants' performance of moving the vessel in the surge direction was a slight improvement from the first question, concerning rotation.

This corresponds with observations made during the sessions, where also in this case some of the participants performed noticeably better than the others. This concerned a group of three students, who commented that they would prefer to use gestures instead of touch buttons and menus.

How easy was it to move port/starboard?

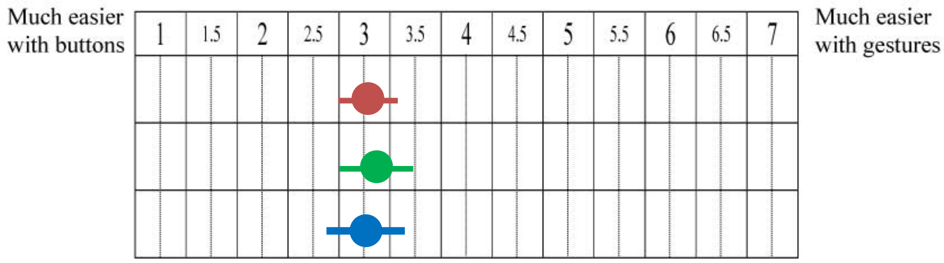


Table 7.17: Arithmetic means with confidence intervals of question 3 (Total, 1st and 2nd iteration).

Moving the vessel in the sway direction (port/starboard) gave a total arithmetic mean of 2.95 with a confidence interval of 0.46 (table 7.17). This indicates that the participants move further towards the right and using gestures, but still prefers using touch buttons and menus also for these tasks. Figure 7.33 shows a more symmetrical distribution with a main peak and a slight positive skew.

Seven out of nineteen participants selected points towards preferring to use gestures (selected values from 4 and above), while twelve selected lower ranged values from 3 and below.

The second iteration had a lower arithmetic mean than the first iteration. The arithmetic mean was calculated to 2.84 with a confidence interval of 0.67. This was due to five participants selecting a lower score for this question after filling out the second questionnaire, while only two selected a higher score. Comparing this with the comments made later in the questionnaire, the gestures were not accurate enough and some struggled with this when completing the tasks.

The overall opinion outlined from the participants' answers for question 3, was that the main distribution of scores was concentrated around the points 2 to 4. The participants still prefer using touch buttons and menus, but are moving towards finding it easier to do the tasks using gestures. This could be due to better mastering of the tasks with some training and also the gesture being less complicated than in example, the rotation gesture, where the largest part of the participants had selected score number 1.

How easy was it to zoom in and out?

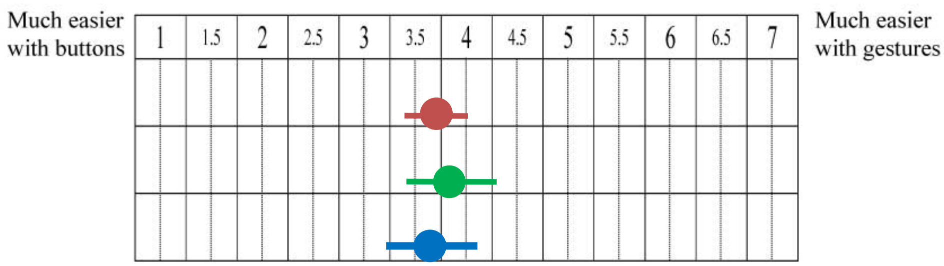


Table 7.18: Arithmetic means with confidence intervals of question 4 (Total, 1st and 2nd iteration).

Zooming in and out (heave direction) of the 3D scene was the tasks that scored highest on the total arithmetic mean with a value of 3.61 and a confidence interval of 0.62 (table 7.18). This indicates that the participants had a neutral attitude or preference towards which interaction technique to use. The arithmetic mean points slightly towards using gestures, but the distribution is even. Figure 7.34 illustrates the distribution of scores. A peak is seen on score number one, while the rest are close to evenly distributed.

The first iteration for question 4 had an arithmetic mean of 3.63 with a confidence interval of 0.88. The distribution of scores showed that nine of the nineteen participants indicated scores from 4 to 7 on the Likert-scale while ten indicated score from 1 to 3. The second iteration had an arithmetic mean of 3.58 with a confidence interval of 0.90. This is quite close to the mean found in the first iteration, but the distribution of scores is reversed Here, the first ten out of nineteen participants indicated scores ranking from 4 to 7 on the scale whereas the other nine selected scores from 1 to 3.

The above indicates that the general opinion towards which interaction method to use for zooming is split and about half prefer using gestures and half prefer using touch buttons and menus. The gesture used for zooming is the best known gesture from commercial products. This could have an effect on the participants if they were used to using gestures on their mobile phones or mp3-players.

Which method would you use and why?

The comments given in the first iteration of this question were in accordance with the answers given under the previous four questions. The majority of the participants, hence twelve of nineteen preferred using buttons instead of gestures. The main reason for this was that the gestures did not follow a one to one scale, so that the vessel in the 3D scene would therefore not instantly move wherever the finger moved. The participants felt it being difficult and frustrating to get the accurate number of meters outlined in the tasks. They therefore felt that using touch buttons and menus was more effective to reach the task goal. It is however natural to believe that using touch buttons and menus had an advantage, due to the participants being used to such systems from everyday life, such as operating petrol pumps, cash machines, mobile phones and other similar devices. Touch button and menu interaction is a more established interaction technique than the newer direct gesture interaction that has become more common only the past couple of years. The errors made when using touch buttons and menus were more easily forgotten compared to the feeling of not being able to adjust the values using gestures. This underlines the importance of fine tuned and well designed gestures. Three participants were unsure which method they would prefer. The comments made were mainly if they could practise more and have a more sensitive display (one to one scale), they would prefer using gestures to interact with the system. Four participants preferred gestures as their interaction technique. One of the participants disliked the gesture for rotation and suggested that gestures would be used for all interaction apart from changing the vessel's heading (rotating), where touch buttons and menus would be used. Three of the participants preferring gestures gave high scores on the Likert-scale, which indicates that they felt the performance was much better when using gestures instead of touch menus and buttons. Their comments were mainly that using gestures felt easy and faster to use. They could instantly interact with the system without having to navigate in different menus. The last participant preferring gestures indicated that with a more sensitive touch display gestures would be preferred. This participant gave low scores indicating a preference to using touch buttons and menus, but had a without doubt opinion that interacting with the system using gestures would be the best alternative.

In the second iteration of this question which was asked after they had finished the session, the picture had changed slightly and nine out of nineteen participants (previously twelve out of nineteen) stated that they would prefer to use touch button and menu interaction. Two participants preferred using direct gesture interaction (previously four out of nineteen), while the number of participants who partly had changed their mind and were unsure of which method they preferred had grown. They suggested that if the gesture based system was optimized, they would prefer using direct gesture interaction. This group had increased from four to eight participants. The comments were largely the same for preferring to use buttons and gestures, but the participants who had changed their opinion during the session felt that their interaction using gestures would improve with a better and more responsive system and more training. Some participants suggest that using gesture makes them lose focus on the outside environment. This is however incompatible with the observations where the participants continued to carry out the action using gestures while looking out of the window at the same time.

The overall impression of the outcome of this question about which method the participants preferred is that most would prefer using touch buttons and menus, but there was a division between the participants who were sure that buttons were of their preference and the participants who wanted to use gesture interaction but felt that the system could have been more responsive to the gestures or wanted more training. This indicates that if the gesture interaction had been improved and better suited to the experience gained from this experiment, it is possible that the participants preferring to use touch buttons and menus due to a better feeling of control and quicker response time would consider using gestures as their preferred technique.

Do you have any other comments?

Under this question the participants were encouraged to comment about whatever they had one their mind. For comment fields, the response rate is experienced to be low and from the first iteration of this questionnaire ten out of nineteen participants made no further comments half way through the experiment. The second iteration had a lower response rate where twelve of the nineteen participants choose to not add any further comments.

From the first iteration, mid-session, the participants' comments concerned three areas. The rotation gesture was the gesture most participants struggled with. This was emphasized in the comment field where two participants mentioned their problems with the rotation gesture. Four participants suggested that if the sensitivity had been better on the display, the gesture interaction would have been experienced in a more satisfactory way. Two participants suggested that their gesture interaction could have improved if they got more training, while the last participant, who experienced some software problems, felt that his performance level had decreased because of that. However, his timing was not affected due to that he repeated the task affected by the software issues.

The second iteration had a lower response rate with twelve participants choosing not to give any feedback. Three participants were concerned with the sensitivity of the display (wanted increased gesture responsiveness) and thought their performance would have improved if the gesture interaction had replied better to their interaction. One of them stated that touch/gesture interaction is the interaction technique of the future where interacting with maritime equipment is concerned, while another sought a settings menu option where he could fine tune the sensitivity of the touch display to his own preference. Also in this iteration the difficulty of rotating the vessel using gestures was mentioned by one of the participants in addition to one of the participants also mentioning software problems. This was however the same participant as in the first iteration. The comments that differed from the previous iteration were one comment made where the participant implied that the movement of the moving platform did not have any impact on performance. The other comment concerned the delay when the apply button was pressed when interacting with the system using touch buttons and menus. This had a delay of about 1 second before it had received a signal from the control system and turned green. The participant felt this was frustrating and suggested that this time interval be shortened.

The overall impression from the comments made was that the participants were positive towards gestures, but wanted a more fine tuned system and felt they wanted more training. The rotation gesture seemed to be a problem and, as observed during the experiment, the participants performed better when rotating to the right than when rotating to the left. This is also mirrored in the statistical results from the timing of the different tasks.

7.5.11.2 Questionnaire 3: Impact of External Conditions

The last questionnaire was filled out once after the session finished, post-task. The question sought to investigate the participants' opinions regarding the environmental factors that influenced the participants during the experiment i.e. the movement of the platform and the visualisation with crossing vessels. Also in this questionnaire the last question was a comment field where the participants were encouraged to comment on whatever they had on their minds.

How did the movement of the platform impact you?

The aim of using the movement platform was to increase the participants' cognitive load and make it more realistic, and using that as a basis to investigate whether the movement had any impact of performance when operating the system using touch buttons and menus versus gesture interaction. The movement of the platform was switched on either in the beginning of the session and switched off half way through or switched on mid-session. Offshore vessels are large vessels compared to fishing vessels and high speed craft and the movements will therefore not be as abrupt as in small boats. Twelve out of nineteen participants felt that the moving platform had no impact at all on their performance. One of the twelve suggested that if the platform had moved more vigorously it could possibly have had an impact. This is however not realistic in an offshore setting with a larger vessel. Four out of nineteen participants felt that the platform had some, but very little impact on their performance. This was because they felt a bit more stressed and that it was more difficult to keep a good look-out. The last three participants had split opinions, where their comments concerned the movement making the session more interesting and real, while the last participant criticised the placement of the display (angular position on participant's lap) made it difficult to see the graphics properly. He suggested a fixed display that could be released and carried around if desired.

The overall impression from the participants' opinions was that the movement had little to no impact on their performance. This corresponded with the impression gained after observing the experiment and did also correspond with the results from the pilot study. The statistical results did however show a tendency of motion having an impact on performance.

How did the visualisation and the fact that you had to keep an eye out for crossing boats in your waters impact you?

The aim of using visualisation and crossing vessels as a distraction task was to make the situation as realistic as possible. The vessels did cross more frequently than they would in real life, but the frequency was increased to keep the participants active at all times, as a normal DP operator would while being in operation.

The participants had a spectrum of different comments, but felt generally comfortable about doing two things at the same time. They also felt that the level of stress increased more with visualisation and distraction tasks than the moving platform, as they had to concentrate more and were forced to look out of the windows to spot the crossing craft. Some felt that they spotted the craft and vessels too late, which corresponded with the observed information where one participant spotted the vessels and craft very late, while two others forgot about mentioning them at all due to concentrating on carrying out the tasks. It was also emphasized by one of the participants that the view out of the windows was the most important and that the interface, especially the gesture interaction technique, should be so well tuned that it took as little visual attention as possible. Two participants suggested that a better ergonomic solution of the placement of the tablet, possibly at a better height, would make the look-out easier and more comfortable regardless of which interaction technique was used. Three participants felt that keeping a good look-out was difficult because they didn't get the anticipated result from the tablet. One participant specified that annoying gestures took his concentration away from the visualisation, while the rest did not specify which interaction technique was being used when finding it difficult to operate as well as being on look-out. In addition one participant felt that the task completion time increased when doing two things at the same time. The comments made towards using touch buttons and menus were that the buttons were small and when both looking out the windows and trying to press buttons it was easier to press the wrong one. However one participant felt it was easier to keep a good lookout using the buttons because he was more familiar with that kind of interaction technique. Four participants felt that the visualisation had little to no impact on them, where one of the four felt that everything went really well and he had both a good look-out and felt relaxed. This particular participant performed very well when carrying out the tasks using both techniques, but did especially well using gestures. Gesture was also his preferred interaction technique.

The overall impression gained from the participants' opinions was that the visualisation and distraction task had more impact on their performance than the movement of the platform. They felt a slight increase in stress levels and the negative issues concerning the two different interaction techniques were more prominent i.e., small buttons and the tablet not providing the participants with the anticipated result immediately. However, the participants who performed best using gestures felt that the visualisation and distraction task had little to no impact on their performance. This implies that with training and better response from the system, gesture based interaction can be beneficial.

Do you have any other comments?

The last comment field returned, as with the previous ones, a low response rate. Twelve out of nineteen participants chose not to fill in any additional comments. The comments made were diverse, but one comment was particularly interesting. One participant stated that the interaction with the tablet demanded that one had to keep an eye on the tablet to make sure that the correct actions were carried out. This is an issue you do not have to consider when operating the system using physical devices such as joysticks and push buttons. This comment implies that haptic feedback would be beneficial. When using gestures one participant suggested a pop-up window with an apply button, so instead of using a double tap to apply the movement to the system, the pop-up apply-button would be better. The criticisms that were brought forward by two participants were the difficulty of moving the vessel an accurate amount of meters and that the system did not give the immediate response anticipated after doing a gesture. Two participants also gave positive feedback where they thought that doing the experiment was interesting and fun and had great belief in using gestures as a future interaction technique. The impact the motion platform had on one of the participants, was that he felt he had sea-legs after stepping out of the simulator. This is considered normal after spending time in a moving environment.

7.5.12 Experiment Conclusion

After conducting the experiment by utilising the ship motion simulator and cognitive distraction tasks, the differences between the two interaction techniques became clearer and also the specific requirements demanded by each technique was more prominent.

The key results from the study were as follows:

1. Touch button and menu interaction is overall faster than direct gesture interaction. This is illustrated in table 7.19 and figure 7.31 (on the next page).

Descriptive Statistics

	Mean	Std. Deviation	N
AllTimeGesturesMoving	18.1801	11.70206	105
AllTimeButtonMoving	8.7225	7.19070	105
AllTimeGestureStatic	14.9146	8.97044	105
AllTimeButtonStatic	8.9775	7.29214	105

Table 7.19: Descriptive statistics for all times in each condition.

Table 7.19 shows the average time over all tasks. There was a main effect of motion on time spent on all tasks ($F(1,104) = 4.25$, $p < 0.05$, $p = 0.04$) , a main effect of input type ($F(1,104) = 72.62$, $p < 0.01$, $p = 0.00$) and an interaction between motion and input ($F(1,104) = 7.05$, $p < 0.01$) (pairwise comparisons, with a Bonferroni correction). Participants took longer to complete the task using direct gesture interaction than when using touch button and menu interaction. In addition, motion had an influence on direct gesture interaction, and performance was degraded even though the participants did not notice the degradation. The interaction between motion and input highlighted that the tasks were carried out faster when using direct gesture interaction in a static environment, whereas motion did not affect touch button and menu interaction much.

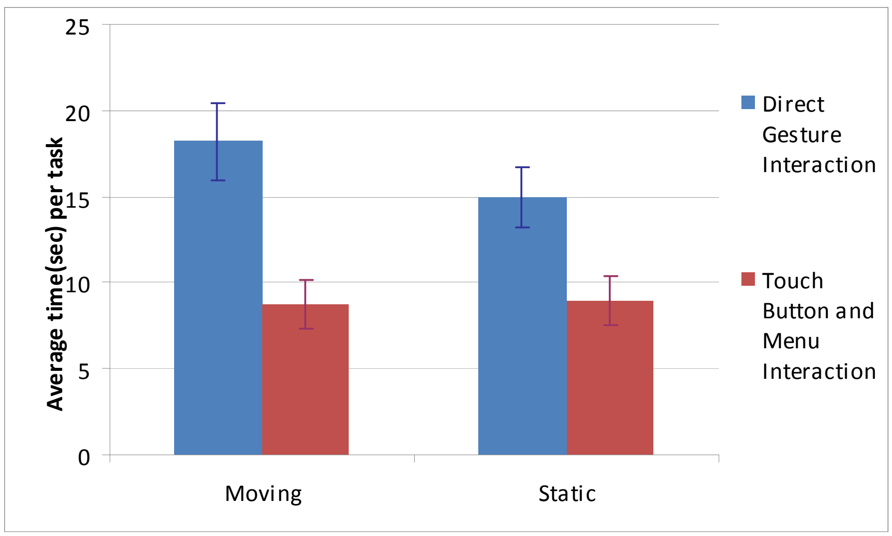


Figure 7.31: Illustrating overall interaction between motion and input type on timing.

2. Touch button and menu interaction was not affected by motion, but direct gesture interaction was. This indicates, as supported by Helsdingen (1996) and Wertheim and Kistemaker (1997), that there are some influences of motion on performance when using fine motor control. However, this is not noticeable by the participants themselves.

3. There are issues with performing the gestures where it is noticeably more difficult to move in a starboard direction than in the port direction. This strongly indicates that there is an effect that is due to which hand the gestures were done with. It implies that it might be easier to do the movements in one

direction than the other. This is reinforced by the amount of right-handed participants in the study, where all participants were right-handed except for one (18 out of 19 were right handed).

4. An interesting feature with direct gesture interaction was that the participants paid attention to other issues (cognitive distraction tasks), while at the same time carrying on with the operation without lifting their hands from the display. This was achieved without having any effect on the error rate. For touch button and menu interaction, the participants suspended the interaction, by lifting their hands when paying attention to other issues. When the attention returned to the task, the participant either started over or carried on by looking down to make sure no buttons were pressed unintentionally. This can imply that direct gesture interaction has an advantage by presenting a more dynamic way of interacting concurrently with the interface while at the same time do other tasks.

5. When comparing the error rate it shows that (table 7.20 and figure 7.32) there is no significant difference in error rate between the two interaction techniques.

Descriptive Statistics

	Mean	Std. Deviation	N
AllErrorsGesturesMoving	.5755	.67539	106
AllErrorsButtonsMoving	.4434	.70482	106
AllErrorsGesturesStatic	.4434	.61845	106
AllErrorsButtonsStatic	.4811	.75884	106

Table 7.20: Descriptive statistics for summarising all errors

Table 7.20 shows the average error rate over all tasks. There was no main effect of motion on error rate on all tasks ($F(1,105) = 0.62$, $p > 0.05$), no main effect of input type on error rate ($F(1,105) = 0.52$, $p > 0.05$), and nor was there any interaction between motion and input on error rate ($F(1,105) = 1.55$, $p > 0.05$) (pairwise comparisons, with a Bonferroni correction). This confirms that there was no difference in error rate between the two interaction techniques. However, motion had an indicative influence on both interaction techniques, but direct gesture interaction was more indicatively affected than touch button and menu interaction.

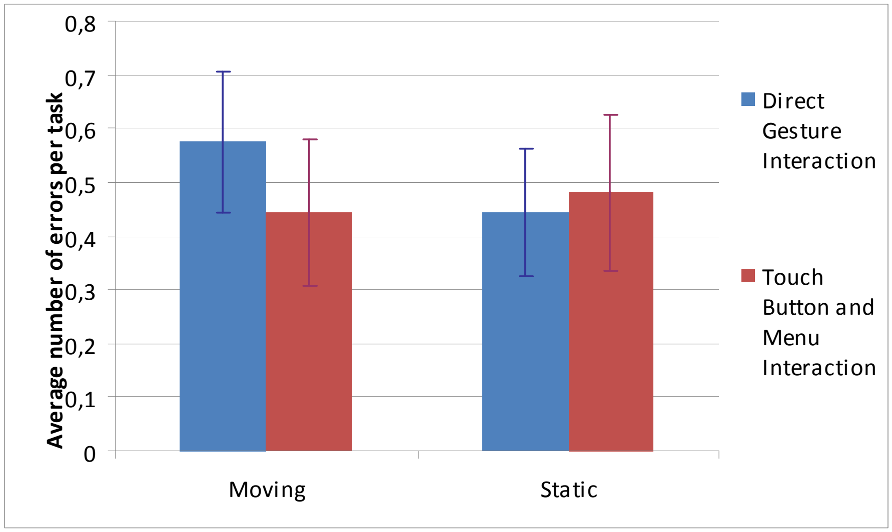


Figure 7.32: Illustrating overall interaction between motion and input type on error rate.

Details from analysing the task time where all values where included and the two slowest and two fastest were excluded the results were as following:

Heave Direction (zooming in and out): using touch button and menu interaction was overall faster.

Surge Direction (forwards and backwards): using touch button and menu interaction was overall faster in the forwards direction, however when moving the vessel backwards there were no differences between the interaction techniques.

Sway Direction (port and starboard): there were no differences between the interaction techniques when moving port. Using touch button and menu interaction was the faster interaction technique when moving starboard.

Yaw Direction (rotation): using touch button and menu interaction was overall faster when rotating the vessel. When rotating in the port direction the task took longer in a moving environment when using direct gesture interaction due to difficulties of getting the gesture right.

From analysing the error rate the results were as followed:

Heave Direction: Using touch button and menu interaction had a lower error rate.
Surge Direction: There were no differences between the interaction techniques. There was however a indication that direct gesture interaction was more affected by motion than touch button and menu interaction.
Sway Direction: Moving starboard was less erroneous when using direct gesture interaction with a strong indicative result ($p = 0.059$), while moving port was less erroneous using touch button and menu interaction with a strong indicative result ($p = 0.057$).
Yaw Direction: When rotating in the starboard direction neither technique was more erroneous. When moving in the port direction touch button and menu interaction was less erroneous in a moving environment. In a static environment (port direction), they performed equally well.

To answer the experiment's hypotheses:

H1: Tasks will be conducted in less time using gestural interaction

The above results give a conclusion that does not support the hypothesis H1: tasks were not conducted in less time using gestural interaction. On the contrary, they needed significantly more time and the hypothesis had been contradicted.

H2: Tasks will be more accurate with gesture interaction

The above results give a conclusion that is mixed in terms of supporting or not supporting hypothesis H2. Direct gesture interaction leads to fewer errors in some cases due to the elimination of several stages during the interaction that is to say that the only action to be remembered is the gesture itself while when using touch buttons and menu interaction navigating through the menus cause a higher mental load. When using touch buttons and menu interaction a series of errors often appeared when the participants initially made a mistake and found it difficult to correct it. However, when using gesture interaction the errors appeared when the participant could not hit the exact number of meters set or found it difficult to get the gesture correct.

When summarising the average of all errors over all tasks, the result shows that there are no significant difference between the interaction techniques on error rate.

Hypothesis H2 is therefore partly supported because in some cases the tasks were more accurate using direct gesture interaction, however in the cases where the gesture itself failed, using touch button and menu interaction was more accurate.

H3: Interaction time will be less affected by motion for gestures than buttons

Hypothesis H3, is supported for some tasks, but the overall summary of all times confirms that interaction time was affected by motion more when using direct gesture interaction. Hence, H3 is not supported.

H4: Reaction time to environmental activities will be faster for gestural interaction

When analysing the reaction time, there were no significant differences between the interaction techniques, so hypothesis H4 cannot be supported. Reaction time to environmental activities was not faster with either direct gesture interaction or with touch button and menu interaction.

When analysing the questionnaires it became clear what the participants' opinions and frustrations were. In addition some suggestions of improvements were also added.

The participants' overall opinions gathered in the first two Likert-scaled questionnaires carried out in-between the change of conditions and post-tasks, was that the majority of participants felt it was easier to perform the tasks using touch buttons and gestures than using direct gesture interaction. However as the tasks proceeded, the values on the scale increased and went towards feeling more comfortable using gestures. This indicates that with more training and a more responsive system, the participants would feel more encouraged about gesture interaction. The participants that preferred using direct gesture interaction were the participants who performed well and did the tasks quickly. The comments made in the comment field concentrated on the fact that they felt more comfortable using touch buttons and menu interaction, while there were also some suggestions about wanting more training and that the display should have had a higher sensitivity or a settings menu where this could have been tuned to the participant's own wishes. This is an interesting comment, as personalization of workspaces is not allowed on boats for safety purposes.

The last post-task questionnaires concerned the participants' overall experience of the ship's motion platform and the visualisation. The majority of the participants did not feel that motion had any impact at all on their performance, which corresponds to some extent with the statistical results found. However there was a tendency that movement had an impact on direct gesture interaction, as supported by previous research mentioned in section 7.2.1. The participants' opinions regarding the visualisation were in general that it made it more realistic and some participants felt a higher level of mental load and stress. The criticism given regarding both interaction techniques was that the buttons felt small and some gestures were difficult, especially when the system did not give the immediate response they expected.

When it comes to the questionnaires, it is however important to keep in mind that the results could have been biased as explained in section 7.2.3.

7.6 Chapter Summary

This chapter has reported two different studies, one pilot study with eight participants where the aim was to investigate whether movement had any impact on performance in a SMS, and one main study with 19 participants where the aim was to investigate whether gesture interaction was faster, more accurate, gave shorter reaction time to distraction tasks and was less affected by motion than touch buttons and menu interaction. The lessons learned from the studies were that the result from the pilot study mirrored the results from previous studies referred to by Wertheim (1998) where motion had little to no effect on task performance. This conclusion could also be made for the main study, but differed for direct gesture interaction where performance degraded when summarising the data across tasks. The results from the main study could therefore conclude that touch button and menu interaction was quicker and less erroneous than direct gesture interaction with the currently utilised system. It was however emphasised by the participants that if the system had been more responsive/accurate to gesture detection and/or they were given more training, direct gesture interaction would possibly be preferred due the instant interaction with the system where there was no need for menu navigation. With menu navigation one error could trigger a series of unfortunate events where the participant got confused and made new errors. In the next and last chapter of this thesis, chapter 8, the results from the above studies will be discussed in comparison with the results from the study reported in chapter 6. Chapter 8 will give a main conclusion of the outcome of this research.

8 Conclusions and Future Work

8.1 Introduction

The final chapter of this thesis gathers the threads and gives a conclusion of this doctoral research where the overall aim was to test three main hypotheses concerning the enhancement of accuracy and safety during dynamic positioning operations. These were targeted by bringing the interface physically closer to the user and by implementing and testing a new interaction technique novel to the maritime domain, direct gesture interaction. This enabled interaction directly with the display surface and was compared with one of the traditional interaction techniques the DP operators use today, touch button and menu interaction. For this particular research it was desirable to compare the available on-screen interaction techniques, hence comparing the usage of direct gesture interaction with the usage of physical input devices (joystick and heading wheel placed on the armrest of the operator's chair) will be discussed in the future work section (section 8.4). In total five studies were conducted where four concerned prototype planning and user testing, and one was an observational study. The latter study was conducted on board a platform supply vessel where the aim was to get insight in the DP operator's work environment (on the bridge) and how the platform supply vessel's DP operators work. The remaining four studies concerned using several stages of prototypes in user studies. In total two working hardware and software based prototypes were built (where the software was developed by the researcher) and one paper/cardboard prototype were utilised. For the initial prototype, lo-fi material (cardboard) was used to investigate which gestures would feel natural to use to operate a DP system. The results from this study founded the base for the next iterations of prototypes, which were software and hardware based. The first hardware and software based prototype used optical touch technology for testing the differences between using gesture interaction versus touch button and menu interaction in a static laboratory environment (chapter 6). The second used capacitive touch technology for testing in a realistic, simulated environment, using a ship motion simulator. This study (chapter 7) was this research's main study and included a pilot study and a main user study. Issues that were criticized in the previous study (chapter 6) were addressed and more variables were added to the experiment design. The test participants were tested in four different conditions in a moving environment versus a static environment using touch button and menu interaction versus direct gesture interaction. Interaction error rates and reaction time to cognitive distractions tasks were recorded.

This chapter will start with giving the contributions to the field by outlining the overall experiment results, review the original hypotheses given in section 1.2, outline the implications for designing maritime systems and give a future work section. This chapter and thesis ends with a final thesis conclusion.

8.2 Contributions and Outline of Overall Experiment Results

There is no currently research done on utilising the interaction technique, direct gesture interaction in safety critical industry or in safety critical applications. The technique is best known from the consumer market, hence tablets and mobile phones, and its mission in this new context was to make it possible to carry out standard DP operation tasks faster (enhance efficiency) than with traditional touch button and menu interaction. The process to achieve this was to give the operator the possibility of directly interacting with the DP GUI's 3D scene and move the vessel in the desired direction at the touch of the fingertips, without navigating through menu structures. It was anticipated that this method could then reduce interaction time and lower the error rates during interaction which could lead to the operator feeling more in control of the operation. There was however a clear difference between the anticipated result and the outcome of the studies carried out. The results indicated that using direct gesture interaction in safety critical operations was not as optimal as anticipated for the tested scenarios.

When interacting with the equipment using direct gesture interaction the position of the equipment is important. Normally the touch screen displays are vertically placed on the armrest of the operator's chairs. In a gesture and multi-touch interaction situation this position would cause strain on the operator's hands and shoulders due to the lack of possibility to rest the arms during interaction. The display was therefore moved to a desk like position in front of the operator, while still fitting into the layout of the work station and not interfering with the clear demands of maintaining good visibility of the aft deck.

To approach the problems outlined above and arrive at a suitable set of research questions (hypotheses), it was necessary to collect more knowledge of previous research done in the field of the safety critical industry, human error, multi-touch and bi-manual interaction, human factors in the maritime domain and how the human being performs in a moving environment, such as is experienced at sea. As outlined in Chapter 2, previous research showed that in the maritime industry, to make the vessels as cost efficient as possible, time consuming user studies and consultations with the crew using the equipment are not prioritised. The human factor of the equipment is often not considered until late in the vessels' lifecycle, which in most cases were too late. Equipment already installed cannot be replaced and only in cases where the equipment proposed a danger to the crew on board, were expensive retro fittings carried out (Sillitoe, Walker and Earthy, 2009). Poorly fitted equipment and bad user interfaces will lead to a higher cognitive load on the crew/operator. This will leave less mental capacity available for safety-critical situations (Redmill and Rajan, 1997). Redesigning the whole bridge environment is out of the scope of this thesis and with this in mind, it was decided to focus on investigating an interaction technique that could lower the cognitive load during operation. Han presented his research on multi-touch interaction (2005), where the ease of interaction with the display surface seemed promising. Buxton and Myers (1986) together with several other early studies by amongst others, Kabbash, Buxton and Sellen (1994) and Chatty (1994), confirmed that using multi-touch or bi-manual interaction could enhance performance, however only if the design was good. Putting this in context with the maritime environment, the Rolls-Royce DP system was suited for further research on this novel interaction technique due to its appropriate graphical user interface and the 3D scene where the vessel was visualised.

The process to address the issues mentioned above included two qualitative studies (chapter 3 and 4) that gave the knowledge necessary to proceed to testing and collecting quantitative data, comparing the differences between using traditional touch and button interaction versus direct gesture interaction (chapter 6 and 7). The studies were supported by related literature and previous research done in related areas. It is worth emphasising that the commercialisation of multi-touch technology was at the beginning of this research, only on the starting line and there were little resources available on the hardware and software side. In the last three years the development has increased rapidly and today there is more technology available in addition to the noticeable growth of the multi-touch research community. This indicates that gesture interaction and multi-touch is a technology and interaction technique that is here to stay.

The outcome from the review of the field (chapter 2) gave a set of three main hypotheses, as outlined in section 1.2:

H1: Direct gesture interaction will enhance safety in DP- operations.
This will be tested by measuring error rate per task and reaction time to distraction tasks in an initial study in a usability lab setting and latterly in a ship motion simulator setting. These studies were based on the results from an observation study.

H2: Direct gesture interaction will enhance efficiency when using the DP system.
This will be tested by measuring task completion time in three separate user studies where one was carried out in a ship motion simulator setting.

H3: Direct gesture interaction will enhance the user's feeling of control when operating the DP system.
This will be tested by analysing qualitative data collected from an observation study and from questionnaires and post-experiment discussions during user studies.

These hypotheses form the basis of the rest of this research. Hypotheses H1 and H2 are directly connected to measurable statistical results (efficiency and accuracy), while H3 covers the overall quantitative knowledge gained from observations and questionnaires. Below, each hypothesis will be discussed in connection with the results from the studies done.

8.2.1 Direct Gesture Interaction will Enhance Safety in DP Operations

The first hypothesis of this doctoral research concerned investigating if interacting directly with the DP GUI's interface to carry out the most standard DP tasks could make the operation itself safer. Safety is highly prioritised in an industrial setting such as the maritime environment, but traditionally the focus has been directed more towards the physical devices and equipment, and not towards the equipment's interface where the actual interaction occurs. In the context of this research project, increased safety is taken to be the operator making fewer mistakes during the interaction with the interface. Hence not to measure safety directly, but by using indicators (error rate and reaction time) that contributes to a safer dynamic positioning operation. This was quantitatively measured by calculating the error rate and measuring the reaction time to the cognitive distraction tasks given. The mistakes can be defined as misunderstandings, getting lost under menu navigation, entering the wrong values, failing to observe vital actions on deck due to high cognitive load or similar cases (Reason, 1990).

The review of related literature (maritime, human machine interaction and multi-touch) in chapter 2 gave a clearer insight into the current problem and how to link the different areas. The DP operator interacts solely with the interface of the system and depends 100% on the interface reflecting the correct reality (Redmill and Rajan, 1997). It became clear that in the commercial world of consumer products, products with a lifecycle of approximately 1 or 2 years from entering the market to being outdated are developed to fully fit the user's needs and make interaction as simple as possible. In industry, such as the maritime industry, where the equipment is developed with a possible lifecycle of 10 to 15 years and above before being outdated, the users' needs are often downgraded (Sillitoe, Walker and Earthy, 2009). Whether this is intentional, due to lack of knowledge or due to costs, remains an open question.

To test hypothesis H1, a set of gestures was determined as a result of the initial qualitative study outlined in chapter 3. The lessons learned from this were for the need of a small set of plain gestures considered easy to remember in a safety critical and stressful situation. This could also be reflected back to previous research done by Nishino et al. (1997) and Wu and Balakrishnan (2003). Although the test-participants suggested a variety of combinations for each gesture, a gesture that included the main features of each suggestion was created and, after comparing the data from all the suggestions given, four different gestures stood out, where one of them was going to give a controversial result- the gesture for zooming. The four gestures were the basis for the next iterations of user studies using hardware- and software- based prototypes (Chapters 6 and 7), where error rates and reaction times were measured to support further testing of hypothesis H1.

When registering the error rate the key results from the main study of chapter 7 came out mixed. For moving in heave direction (zooming) touch button and menu interaction had a lower error rate. The interesting results are that the majority of errors for zooming when using gesture interaction were the result of the user zooming in the wrong direction. When the user was asked to zoom in, he/she zoomed out and vice versa. This was also the case for the study described in chapter 6, however the error rate was not registered. The participants had dynamic feedback from the system and all actions happened in real time. It can therefore be debated whether the pinching gesture for zooming is the best suited gesture for this task, especially in a safety-critical application. Even though the gesture is well known from consumer products such as the iPhone and Windows 7, and users can therefore more easily relate to the gesture, in 44 % (section 7.5.9.1, chapter 7) of the cases the user failed getting the gesture right on the first attempt compared to 6% for touch button and menu interaction.

In the surge direction there was no difference between the techniques, but when it comes to the sway direction the error rate reflected that moving starboard was performed less erroneously using gesture interaction than using touch button and menu interaction with an indicative result. The participants found it difficult to move port wards using gesture interaction due to the position of the hand. When changing the vessel's heading (yaw) there was no difference between the techniques when rotating starboard, while rotating port using touch buttons and menus was less erroneous in a moving environment. Only two participants decided to use their left hand and bypassed the problem. However in a static environment the techniques performed equally well.

When comparing the overall error rates of the two interaction techniques, it became clear that there were no significant differences between them in either condition. This confirms that there was a problem with the touch button and menu interface, which was due to if one error was made using touch button and menu interaction, it often triggered a series of unfortunate events where more errors were made due to the operator's uncertainty. When an error was made using direct gesture interaction, the user immediately understood what to do next and was back in control. In addition, when looking at the minimal click count (table 7.3) for touch button and menu interaction, the click count for, for example moving in the port direction, had one more click than when moving in the starboard direction because starboard was set as default. However, the system is operated by experts daily, which implies that all the erroneous actions observed, might not occur every day. This confirms that since the error rate is not significantly lower for either of the interaction techniques, they impose equal stress on the novice operator.

The analysis of reaction time to cognitive distraction tasks showed no difference between the different interaction techniques and conditions. One can therefore conclude that reaction time to environmental activities were not shorter using direct gesture interaction, nor was it shorter when using touch button and menu interaction.

8.2.1.1 To Conclude H1

Direct gesture interaction gave an error count approximately the same as touch button and menu interaction, in addition the reaction time to cognitive distraction tasks was not higher for gestures. It is therefore possible to imply that if the issues with zooming and rotating had been addressed, the error rate could be lower for gesture interaction. This suggests that for the novel interaction technique to have full success, the technique must be even more finely tuned to suit the system and its environment.

In summary when studying error rates and reaction times, this indicates that no gestures are natural for the human being to use when directly interacting with a display interface. This statement is supported by Cassell (1998), who states that gestures are no more intuitive to people than DOS commands. The issues that appeared when using “the pinch” for zooming are interesting. This is especially questionable due to the well known fact that it is supposed to feel natural. However when such a large percentage of the test participants constantly zoomed the wrong way, is it really natural? This indicates that there are no natural gestures and they have to be learned. Even though the learning curve is short and gestures feel intuitive, they are not natural. This statement supports the work done by Norman (2010) and Norman and Nielsen (2010).

Hypothesis H1 can therefore not be fully supported. Direct gesture interaction does not enhance safety in DP operations, but does in many of the studied cases perform equally well as the traditional touch button and menu interaction technique.

Even though it was discovered through these particular studies that the error rate was not significantly lowered, lowering the error rate will give ripple effects throughout the interaction between the operator and the system by making the interaction more streamline and efficient. This leads on to the next objective in this research which concerns the efficiency of interaction with the system.

8.2.2 Direct Gesture Interaction will Enhance Efficiency when Using the DP System

The second hypothesis of this research is built on the proposed ripple effects of enhancing the safety in DP operations by lowering the error rate. If error rates are lowered, the efficiency will increase (if the interface is kept unchanged) relative to the traditional interaction technique. This is due to eliminating several steps throughout task completion, such as navigating through menu selections to move the vessel or orientate in the graphical user interface 3D scene. An efficient system can be described as a system that is both fast and easy to interact with and error free, hence the optimal system. This is difficult to achieve and there are, in most cases, compromises made between safety and interaction speed. The quantitative measurement for efficiency is in this context the time the participants spent on completing the tasks given.

Chapters 6 and 7 investigated the differences in efficiency between the two tested techniques: the chapters were separated based on two different touch screen technologies (optical and capacitive). When using optical technology (Chapter 6) in a laboratory environment it was discovered that, even though half of the participants were sceptical towards using direct gesture interaction, using gesture interaction proved overall significantly faster than using touch button and menu interaction. According to comments made by the participants during the post-task discussion, using direct gesture interaction felt more intuitive although the intuitiveness has not been scientifically proven. The result was however not uniform and zooming and tilting the vessel was performed faster using the traditional touch button and menu interaction technique. This was due to the nature of the gesture. It was emphasised by the test participants that accuracy was an issue and the technology (optical) was too sensitive for touch if the vessel moved too abruptly. This sparked the concern that the display could be touched by accident causing unwanted actions. With the experiences from this study in mind, the next two studies were designed where more variables were added to make the scenario more realistic.

The last two studies (pilot and main study) in this research (Chapter 7), were carried out in a ship motion simulator (SMS) corresponding to a more realistic environment. The main task of the touch technology selected (capacitive) was to deal with the accuracy issues mentioned by the test participants in the previous study. A common result for both studies was discovered when evaluating the effect of motion on performance where motion had little to no effect. There was however a strong indication of interaction between motion and input type, where motion seemed to have a more severe effect on direct gesture interaction than on touch button and menu interaction. This was supported by previous research summarized by Wertheim (1998), where it was confirmed that movement had an effect on fine motor control. The participants did not seem to notice this, which was reflected by the answers given in the questionnaires. This proves that the efficiency of task completion was not significantly slowed down or disrupted by movement, but showed a tendency of degrading performance using direct gesture interaction in a moving environment, when looking at how motion affects all tasks regardless of input condition.

The key results of task completion time for this study, hence the efficiency of the two interaction techniques, returned a different picture than in the first hardware and software based study (Chapter 6). The pilot study (Chapter 7) indicated that that direct gesture interaction performed indicatively faster, hence direct gesture interaction being more efficient. When using a larger population, like in the main study (chapter 7), the results of task efficiency changed. Two sets of ANOVA's were carried out where one statistical calculation included all data while one excluded the two fastest and two slowest times. The results came out very similar. For moving the vessel aft and port there was no difference between the techniques. Changing the vessel's heading in port direction was the only task that showed difference between a moving and a static environment and the task took significantly longer to complete using direct gesture interaction. This was due to difficulties of getting the gesture right and the movement added additional stress to the situation. The initial use problems with gestures and the handedness asymmetries indicate that even though the majority of the participants (18 out of 19) were right handed, it was easier to move in the port direction than in the starboard direction. On the positive side, users were able to suspend the direct gesture interaction, while maintaining awareness of their environment.

8.2.2.1 To Conclude H2

In summary, the user study reported in chapter 6 gave an overall significant result towards direct gesture interaction being faster, hence more efficient than traditional touch button and menu interaction. In chapter 7 this picture changed to the opposite and touch button and menu interaction was now significantly more efficient. This was due to the change of technologies and making the system less sensitive for touch input. However, according to the users, the sensitivity was now too low and the vessel did not respond to direct gesture interaction as quickly as they wanted. The moving environment accentuated the differences and added stress to the situation where the user already was frustrated or confused over a system that did not react as anticipated. This shows from the experience gained, that to make a system successful using direct gesture interaction it must be flawless and perfectly tuned for the user to adopt and feel comfortable with it.

In reference to the hypothesis H2 it can be concluded that the hypothesis is not supported, but rejected under the tested circumstances and it has been proven that direct gesture interaction does not enhance efficiency when using the DP system. The tasks were not conducted in less time using direct gesture interaction and movement did have an overall effect where the performance experienced degradation when using direct gesture interaction in a moving environment.

This leads to the last hypothesis that concerns the qualitative part of this research, the feeling of control when operating the system using an interaction technique novel to the maritime domain.

8.2.3 Direct gesture interaction will enhance the user's feeling of control when operating the DP system.

The third objective/hypothesis of this research is based on the qualitative research done, hence the two qualitative studies (chapters 3 and 4) and the information gathered from the questionnaires and post-task discussions (chapters 3, 4, 6 and 7). To measure the user's feeling of control is closely related to the wholeness of interaction with the system, hence that the above hypotheses are fulfilled concerning safety and efficiency. In this context the above hypotheses cannot be fully supported, however this hypothesis can be tested by summarising the general opinion from the test-participants supported by the observations made. The possibility of collecting biased results from the participants is this hypothesis' risk.

They key results from the post-task discussions imply that there is a general positive attitude towards using direct gesture interaction, but there is still a way to go when it comes to technology. The general feedback from the questionnaires was that the participants felt the technique was both intuitive and easy to understand/learn. Learning is key and this is supported by the statistical results from analysing the Likert-scaled and NASA-TLX questionnaires (chapter 7), where the participants felt better and less stressed when using direct gesture interaction during the second half of the experiment session after they had gained some experience and more practise.

The concerns that arose in chapter 3 concerning how the interaction technique would be affected by sea movement, were partially confirmed by the results found in chapter 7 where motion had an overall effect of degrading performance when using direct gesture interaction (Wertheim, 1998). The interface itself had a larger impact on the participants' feeling of control and whenever the system did not react or give the feedback anticipated, frustration and confusion were common. This did especially appear during the main user study (chapter 7) where capacitive touch technology was selected to tone down the abrupt and quick movements of the vessel (chapter 6) and give a better touch surface than when using optical touch technology. In addition, the observation study (chapter 4) revealed a much slower pace of system interaction/use than anticipated; however this would increase in an emergency situation or when using the equipment for other types of operations (planning routes for tracking or similar).

It was discovered that the physical input devices on the armrests can be operated more dynamically (chapter 4) than button and menu interaction. The operator can close in on the installation gradually meter by meter and not feel obligated to decide on a specific distance before having full overview if the selected value is correct. Direct gesture interaction acts similarly and adopts the characteristics of the physical input devices and enables the user to both interact with the display and have the advantage of a gradually closing in on the installation. Using direct gesture interaction for DP operation was considered a possibility by the operators, but they saw it as a supplement and not a replacement for the physical input devices due to the physical devices' strong traditions and removing them would cause a radical change in the interaction pattern. This could possibly change due to the novelty of the interaction technique in a maritime setting and that the operators are well used to and feel comfortable with the traditional devices.

8.2.3.1 To Conclude H3:

To conclude, the qualitative information gathered indicates that using direct gesture interaction does not currently enhance users' feeling of control when operating the DP system. The interaction technique does have a potential, but the technology and software must interact seamlessly to give an optimal result. Hypothesis H3 is not supported.

8.3 Implications of Design of Maritime Systems using Direct Gesture Interaction

When comparing direct gesture interaction with touch button and menu interaction, the vessel can be operated without having to navigate through menus that reduce the possibility of selecting the wrong menu item or getting lost during task completion. Another advantage is the area available for interaction increases due to freeing space in the graphical user interface previously reserved for menus. This gives an open visual expression that invites the user to interact with the system. The interaction technique has shown to be a possible supplement to using traditional input devices and touch button and menu interaction and what has been discovered is the possibility of directly interacting with the system's interface more easily and dynamically. However, the main challenge which was reflected in the hypotheses described in the sections above is to get a successful integration between hardware, display (touch technology) and software technology. The interaction technique fail the moment it does not react instantly to the user's commands and sparks frustration and/or confusion. This is not an exceptional requirement only for this particular interaction technique, but is a general issue for interaction with any kind of system using any kind of technique. With the experiences gained from the five studies carried out, a set of recommendations for development of maritime applications using direct gesture interaction can be outlined; including placement of display, application specific adaptations, GUI presentation and gestures.

- **Placement**

  The first amendment when working with interfaces where the aim is to make the user directly interact with a system using gestures is to bring the work interface close to the user so it can easily be touched without causing any additional strain or discomfort. In this research both a standing display (chapter 6, vertical) and a display lying down (chapter 7, horizontal) were studied. It became clear that a horizontally placed display right in front of the user where the display was slightly tilted with an angle of approximately 30 degrees would be preferred. The optimal solution is to have a retractable arm or similar, so it can quickly be pushed away if the operator needs to attend to important matters elsewhere on the bridge, where the angle can individually be adjusted according to each user's preference. Personalisation of workplaces on board vessels are not allowed, however individual ergonomic adaptations are allowed to maintain a good health and safety environment. Good visibility will also be maintained with a horizontally mounted display, due to that the display will not be placed further ahead than the operator's knees.

  Challenge:

  For implementations of physical equipment such as displays, each case must be evaluated in terms of equipping the operator station by obeying the rules and regulations given by maritime classification societies. In addition, usability and ergonomic principles should be utilised to evaluate if the chosen equipment setup is the optimal setup for the particular station in connection with the vessel type.

- **Application Specific Adaptations**

  To make a maritime application suitable for gesture interaction it is important that it is not implemented directly as an additional feature to an old application. The application must either be an application developed especially with gesture interaction in mind or be an application modified and thoroughly tested to suit the usage of the interaction technique. The GUI must be adapted to using touch interaction with good touch sensitivity and preferably a one to one touch algorithm, meaning that the object targeted for movement by the user will follow the user's finger instantly. It was discovered during studies (chapter 7) that this was an important point of failure causing the user to feel frustrated and adding inaccuracy to the movement of the object.

Challenge:

To get a seamless integration between hardware, display/touch technology and software. It is vital to not overload the system with values due to the concurrent update of values during a move, which demands well programmed software and hardware that handles the network traffic.

- **GUI Presentation**

The user is dependent on well presented information in the GUI during an operation. The GUI must not be cluttered with too much information. Light colours in day mode and suitable darker colours during night sailing (night mode) in combination with a well designed GUI, will give an interface that welcomes the operator to directly interact with the interface. In addition it is important to present the user with constant updates of changing values, e.g. when moving the vessel it is vital to present a box or similar that gives information of how many meters the vessel has changed its position. The optimal solution for touch interaction would be to have tactile feedback as a supplement. This will be discussed in the future work section.

Challenge:

To include the correct level of detail in the GUI to avoid a cluttered visual expression is a well known challenge. Experienced users often demand a great level of detail, which makes the GUI difficult to interpret when the cognitive load is high during a safety-critical situation. The aim is to have instant understanding of the GUI at all times regardless of mental load. A solution to increase the level of detail is to zoom into the scene or tap specific parts of the object to get more detailed information.

- **Gestures**

  When designing a system suited and prepared for gesture interaction, the set of gestures itself is important. In this case (as in GUI design in general) more is less and a small set of straightforward gestures that are easy to remember by the operator can decide between success and failure. For gesture interaction to compete with traditional interaction techniques the user must have an instant reaction to the gestural commands and the system must provide the correct feedback. As proven during this research and assuming there are no natural gestures, one must appeal to the user's previous knowledge (Mills, 1998) and that the gestures must be easy to remember under stress. This suggests that building interfaces that are easy to learn and interfaces that support learning and using gestures are important (Norman, 2010).

  Challenge:

  Depending on which system and what tasks the gestures are designed for it can be difficult to maintain the "less is more" principle and feel tempting to add a whole spectre of different gestures. This is not recommended.

Gesture interaction is a suited technique not only for moving objects in a scene (hence DP), but also for orientation. To take the concept one step further, a common task in the majority of maritime applications is logging and trending of values. The user is often presented with long lists and detailed graphs. Here, using gesture interaction can give an advantage when investigating logs and trends by being able to more directly and easily orientate in the GUI by zooming in on trends to get a greater level of detail and understanding of the displayed values, or by following trend lines to investigate the connection between logged values.

8.4 Future Work

In the previous sections the main contributions to the field and recommendations for using gesture interaction in maritime applications have been outlined. As the research proceeded several different areas were identified as qualifying for further investigation. Below some of the main opportunities for future work connected to each of the objectives/hypotheses will be discussed.

8.4.1 In the Future: Direct Gesture Interaction will Enhance Safety in DP Operations

This thesis has given insight in how it is possible to increase the level of safety when using direct gesture interaction to operate a DP system. However, the work has been limited to using two different types of touch technology of different sensitivity and software that was not optimally tuned for gesture interaction. This indicates that more work is required to improve the error rate of the proposed interaction technique. In addition, it would be interesting to do an extended study and compare the safety of using the physical input devices versus using direct gesture interaction. This could possibly give a better insight to whether future physical input devices can be replaced by the alternative technique, which can give a wider possibility of interaction and also having economical benefits for both customer and provider.

8.4.2 In the Future: Direct Gesture Interaction will Enhance Efficiency when Using the DP System

Enhancing efficiency by reducing task completion time when operating the DP system using direct gesture interaction relies on a perfectly tuned system. There is no doubt that the interaction technique has potential but it is today suffering from being a novel technique using novel technology. It will however harvest advantages as it develops over time when the multi-touch market has expanded and become an even larger part of people's everyday life. The development has throughout this research, gone from using a prototype display from NextWindow with optical technology with very little software available, to having a commercially available multi-touch tablets.

It would therefore be interesting to carry out more user studies using an optimal gesture interaction technology to investigate the difference between the tests carried out in this research and tests carried out using a finely tuned and optimal solution. In addition, limitations were proposed in terms of training time. The test participants had little time to practice and get acquainted with the gesture based interaction technique. Further, it would have been rewarding to implement a haptic technology in the display to give tactile feedback (Hoggan, Brewster and Johnston, 2007) when the user interacted with it. The test-participants indicated that tactile feedback would be useful and contribute to enhance the feeling of control by reducing the urge to look down on the display during interaction. An example of use would be to have different types of vibrations or audio feedback (Lumsden et al., 2008) implemented similar to what some hand hold devices have today (mobile phones and portable gaming consoles), hence one type of vibration or audio feedback for every meter moved or degree changed in yaw direction and possibly a more powerful vibration for a larger interval (10 meters or similar) (Hall, Hoggan and Brewster, 2008). It is plausible to believe that this would add to reducing task completion times (Akamatsu, MacKenzie and Hasbrouc, 1995).

8.4.3 In the Future: Direct Gesture Interaction will Enhance the User's Feeling of Control when Operating the DP system.

The objective of enhancing the user's feeling of control when operating the DP system is closely related to the two previous hypotheses. If direct gesture interaction had been 100% successful in reducing error rates to make interaction safer and reducing task completion time, it is natural to believe it would contribute to increased feelings of control when interacting with the system. It would be desirable to conduct more studies in connection with the studies mentioned in the future work sections above, where a more diverse group of test participants would be included. Testing more left-handed participants, experienced seafarers versus novices and participants with varying experience with touch screen based systems could possibly give a more nuanced picture. Other interesting results could be gained from testing how long it would take to learn to use both interfaces to a similar degree (until the test participants only make a small number of errors) and whether their performance in one of the interfaces would crash under stress.

In the long run direct gesture interaction is here to stay both in a commercial setting where we have got so acquainted with tapping the screen and flicking from page to page, but also in an industrial setting. However, as indicated by Norman (2010), it all comes with a price. The circle of testing and standardising must be repeated just as it was with other earlier innovations, such as the computer mouse and using a joystick and not a large wooden wheel to manoeuvre a ship. For direct gesture interaction to become successful and safe, more investigation must be done in the field of standardising the gestures and the framework around them.

For the maritime domain to adopt new and innovative technologies in a safe way, the classification societies could benefit from being one step ahead and taking the novel interaction techniques into account now to create guidelines that must be obeyed by suppliers of software and equipment to get their products approved for maritime usage. Somewhere up the line, direct gesture interaction will also be adopted by the conservative maritime environment, and ready-made guidelines could prevent a larger tidy-up at a later stage when everyone creates their own standards that they think are the best suited. In general, a lack of standardisation of gestures will cause a higher risk of accidents, due to possibly one gesture meaning one thing on board one vessel and something different on board another.

In the world of human machine interaction, it is important that direct gesture interaction is also investigated thoroughly in terms of the ergonomic aspects (Moore, 2010). As of today, gesture interfaces are being fitted on traditional displays without consideration to the fact that the position of interaction causes strain on the users' hands, shoulders and neck. Gesticulating in the air without support for the wrists is a science that has been widely researched when the computer mouse was introduced into offices, creating a large industry profiting on making support equipment for strained wrists during interaction with the computer mouse. Will product development yet again step into this pitfall?

The questions around why we prefer at this stage to utilise the joystick instead of direct gesture interaction to manoeuvre the ship were probably asked when the wooden wheel was replaced with the joystick. Changes are seldom very welcome, but today we cherish our power-assisted steering wheels and that we no longer have to be two people to turn the wheel in slow speed. Removing the steering wheel altogether would propose a radical change and yet again challenge our habits.

8.5 Thesis Conclusion

The research reported in this thesis had an overall aim of assessing the effect of direct gesture interaction for DP operation. The technique presented is novel in the maritime and safety critical domain and through five studies the outcomes of the three main hypotheses tested have come forward. The studies confirm that direct gesture interaction:

- Does not fully enhance safety in DP operations due to the error rate being higher in some cases for direct gesture interaction than for touch button and menu interaction. However, when comparing the overall error rate there were no significant differences between the interaction techniques, hence the hypothesis can be supported in some cases and in others not. The work casted doubt on the naturalness of gestures, suggesting that they can only be learned. This supports statements made by Nielsen and Norman (2010), Norman (2010) and is supported by Cassell (1998).
- Does not enhance efficiency of DP operations due to touch button and menu interaction giving significantly lower task completion times than direct gesture interaction. In addition, there was an interaction between motion and input type when comparing the overall results, where direct gesture interaction experienced a degradation of performance when being used in a moving environment. This was supported by the research summarised by Wertheim (1998). Problems with the use of gestures and handedness asymmetries strongly suggest an effect of which hand the gestures were done with.
- Does not enhance the user's feeling of control when operating the DP system because of the system not giving the response anticipated by the users. There was, however, a positive attitude towards using direct gesture interaction but the system must be finer tuned to suit the users' needs to achieve success.

The above results led to a set of guidelines/recommendations for development of maritime applications using direct gesture interaction interfaces. This included the placement of display, application specific adaptations, graphical user interface presentation and gestures.

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Appendix A

Study of DP's System Design

Introductory Sheet

The background of this small study is to investigate if Rolls – Royce Marine's dynamic positioning system (DP) has a system design that is intuitive to the user when it comes to operating the vessel in its graphical user interface (GUI).

The test will be conducted in a 2D environment, in contrast to the 3D environment, which is available in the real- life system. This leads to a test of 3 of the 6 available degrees of freedom (DOF); yaw, surge and sway.

You are presented to a sheet of paper in A3 format which illustrates the DP's GUI and a cardboard boat that illustrates the vessel visible on the screen.

There will be 9 tasks given where you will move the cardboard vessel using your hand(s). The experiment will take approximately 15 minutes altogether, where 10 minutes are reserved for the 9 tasks and 5 for a post- test discussion. The session will be video recorded and information that arises during the experiment can be published. The information will be depersonalized and is purely used to improve and research system design.

Please proceed to the next page after filling out the details below.

Age: ____________ **Sex:** ____________

Official title/education: ___________________________

How well do you know Dynamic Positioning and operating DP systems?
(Please circle the appropriate alternative below.)
Little knowledge - Average knowledge - Good knowledge

Consent

- I am aware that I can leave the experiment at any point without feeling obligated to sit throughout the estimated time.

- I agree to the session being digitally recorded, both sound and picture.

- I agree to the information obtained in this experiment can be published in suitable research forums and conferences.

- I am aware that the data obtained during this experiment, is solely used for researching system design.

- I am aware that the information given by myself to this experiment is depersonalized.

Date: __________ Place: _____________

Signature: ______________________________

Dynamic Positioning Systems– Usability and Interaction Styles

Frøy Birte Bjørneseth
University of Strathclyde
Rolls-Royce Marine AS
Froy.Bjorneseth@cis.strath.ac.uk

Mark D. Dunlop
University of Strathclyde
Mark.Dunlop@cis.strath.ac.uk

Jann Peter Strand
Rolls-Royce Marine AS
Jann.Strand@rolls-royce.com

ABSTRACT

This paper describes the first steps of a research project directed towards human computer interaction (HCI) within the maritime environment and on maritime equipment. The focus is at this stage mainly on interaction with Dynamic Positioning Systems (DP) and how new interaction styles can be introduced to make the interaction more efficient and less faulty in both standard operations and in safety-critical situations. The initial experiment looks into how a DP operator can operate a DP system by using bi-manual interaction/multi-touch combined with hand-gestures to create a new type of user-experience. The aim for this research is to investigate which gestures feel natural to the DP operator and how/if they can be implemented into a real-life DP system.

Categories and Subject Descriptors

H.5.2 [Information interfaces and presentation]: User Interfaces – Interaction Styles, Human Factors, Input devices and strategies.

General Terms

Design, Experimentation, Security, Human Factors

Keywords

Dynamic Positioning, Maritime Environment, Bi-manual Interaction, Multi-Touch, Gestures, Graphical User Interface, Safety Critical situations

1. INTRODUCTION

In the late 1960's and early 1970's the demand for petroleum related products increased and the petroleum industry started offshore- drilling in search of larger deposits of oil. With this, a new generation of vessels emerged, which was fitted with equipment adapted to the offshore industry, and also had the ability to provide oil platforms with needed supplies. New requirements appeared with new operations and anchor handling-, supply-, seismic- and cable lying - vessels, amongst others, were designed to support the offshore petroleum industry.

When drilling commenced in deep-sea areas, the usage of traditional anchors to maintain position was no longer possible. Vessels were in the beginning, held in the right position manually by manipulating the propulsion system, which included different types of thrusters and propellers. This was a risky operation and vulnerable to human errors. This has lead onto the invention of the first Dynamic Positioning Systems.

NordiCHI 2008: Using Bridges, 18-22 October, Lund, Sweden
Copyright 2008 ACM ISBN 978-1-59593-704-9. $5.00

2. BACKGROUND AND RELATED WORK

2.1 Dynamic Positioning (DP)

To keep the vessel in a fixed position, a system was developed which automatically compensated to natural forces such as waves, wind and current. This is called a Dynamic Positioning system (DP) and its technology has developed from the first simple systems in the 1960's to today's advanced systems covering single, double and triple redundancy according to the operation's safety critical level.

A Dynamic Positioning system (DP) can be defined as:

-A computer controlled system to automatically maintain a ship's position and heading by using her own propellers and thrusters.

A DP system [4] can be seen as a complete system that includes operator stations, position reference sensors, gyro compasses (detects true north by using an electrically powered fast spinning wheel and friction forces, in order to exploit the rotation of the earth), and a range of different sensors that give feedback to the operator about the ship's position and the forces that influence the its direction.

A vessel has 6 degrees of freedom (DOF) (see figure 1), which enables it to move around three axis, x-, y-, and z-axis. The DP system is only concerned with manipulating three degrees of freedom, surge, sway and yaw. In non- maritime terms these DOFs can be translated to forward/backward- , left/right- and a rotation movement where the vessel can rotate both clockwise and counter clockwise around its own axis. In addition there are the movements that correspond to up/down, rolling from side to side and pitching that happen, for example, when the vessel meets a wave.

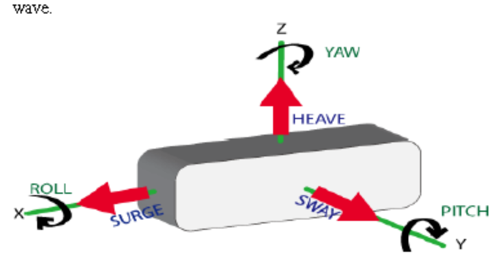

Figure 1: A vessel's 6 Degrees of Freedom (DOF)

The three DOF's available in the DP system enables the operator to manipulate the ship so the DP system can carry out its main task, to maintain position and heading. The DP operator assists the system by inputting setpoint values, which are measured to obtain feedback values from the system. By obtaining the feedback values from the sensors available, the vessel can be manipulated in an accurate manner. The vessel's position is determined by information received from the position reference system and/or the navigation system. The heading is determined with information gained from one or more gyrocompasses situated in the lower levels of the vessel's hull.

Together with the complex information from the DP system, the DP operator plays an important role in the system. The DP system must be monitored and the operator must at all times be alert to any irregularities or changes that can be a hazard to vessel or crew. DP- operations are often carried out close to oil rigs and expensive equipment, where there is no room for errors or unexpected sudden events. To be able to carry out the operations as safe and efficient as possible, it is important that the operator has a comfortable work environment supported with a good graphical user interface (GUI) to visualize the ongoing processes in the DP-system. The GUI (see figure 2) should supply the operator with the information needed and give little doubt on which buttons to press, levers to turn, alarms to acknowledge or displays to look at. On many types of maritime equipment, consistency and intuitivism is not always the real-life situation.

2.2 Human Computer Interaction on Maritime Equipment

HCI on maritime equipment has not always been, and is still not always a priority in the maritime realm. The economic aspects play an important role even though the majority of accidents onboard vessels are attributed largely to human errors. The errors are often due to misunderstandings during stressful situations, and not system failure [23]. Poor design is often blamed, and there has been a trade-off between the usability of the maritime equipment and issues such as the safety-critical aspect, and also the robustness. There will however, always to some extent be a compromise between the design, technical issues and maritime directives. Modern technology does become cheaper and there has been made legislations that push safety onboard vessels forward [26]. The maritime industry is conservative about novel technologies due to safety issues, but with time, the industry will most likely adopt new innovations supported by research that enhance safety.

There is not much known published material on research directed towards human computer interaction on maritime equipment. The reason is unknown, and the focus seems to be directed towards human factors in general, and not the interaction between the operator and the graphical user interface. Stella Mills [21-26], as one of the researchers within maritime sector, has published papers mainly concerning smaller vessels and fishing vessels. Her theories can also, in some cases, be connected to larger vessels, such as offshore vessels.

2.2.1 Operator vs. System

A vessel can be seen as a joint system where all equipment plays different, but equally important roles. The operator depends on the GUI, which depends on the control system that trusts the sensors, propulsion system and the ship itself. With this vision of teamwork between man/crew and vessel, both bridge design and ergonomics are crucial in addition to a usable GUI. By using this mindset, it is possible to understand the interaction between all parts of a vessel, and also to see the importance of a good user interface, both graphically and physically.

Operators of an automated control system, such as a DP-operator, are set to carry out tasks to achieve a goal or several goals [23]. The goal(s) do not necessarily have anything to do with the system itself, but the system is, together with the GUI, used as a tool to achieve the goal(s). According to Mills [23], this means that the combination between system and tool is a product, which assists the users in meeting their goals. If the product is not suited to the user's needs, the possibility of errors occurring increases. This introduces interesting issues around how to develop well-designed equipment for the maritime environment.

Faulkner [10] emphasizes that *'knowing the user'* is of paramount importance of good design, which supports the different methods used to obtain knowledge about the situation where the product is to be used. These methods can often be poor substitutes to real life experience [23]. The best designers of maritime equipment are most likely the mariners themselves, who have experience and know what requirements the equipment must be capable of handling. A contradiction is when new equipment for maritime environment is to be designed. The user knows what goal(s) to reach, but not how to get there or which tools to use. To depend solely on the user's information, can in many cases be inefficient and time-consuming.

2.2.2 Operator vs. Interface

The operator's only possibility of interaction and manipulation of the system, is through its interface. The interface can be categorized as both the physical appearance of the equipment (visual display units (VDU), joysticks, buttons, levers or similar) and the visualization of the system, the GUI.

The bridge is the vessel's control centre, where most of the interaction between humans and graphical user interfaces occur. Stella Mills [26] discusses how bridge design has undergone many changes in the last few decades, which have resulted in increased awareness of safety- critical issues on board. This will be discussed at a later stage. Simultaneously there has been pressure from ship- owners to keep the personnel at a minimum. This increases the workload on remaining crew, which supports the need for good ergonomics and following certain legal principles when out at sea.

Mill's [26] summary of legal and ergonomic principles concerns mainly smaller fishing vessels, but can also, as mentioned above, be applied to larger vessels with a slight change. The legal principles mainly concern the visibility of equipment on the bridge, where the importance of a 360° view from the wheelhouse and non- occluding equipment are emphasized. For offshore vessels this is equally important, but the bridge's size will also increase, and the visibility will be reduced. Therefore on larger vessels there are at minimum two members of crew on the bridge at all times. The placing of equipment is important due to the cognitive load on the operator. If the operator constantly has to move or turn to control important information, this will strain the operator and he/she will sense fatigue earlier [37].To ensure safety onboard, it is vital that the operators of the vessel are comfortable and not put under any extra strain.

The ergonomic principles [26] deal with, once again visibility, but also computer related tasks. On larger vessels, such as offshore vessels, it is highly important to the operator, that he/she is presented with only the information needed. Excessive information increases workload, which can lead to the operator making the wrong decisions and again unsafe operation of the vessel. It is therefore important that the information presented to the operator on the different VDU's, is grouped. Related information should be placed together and information with similar appearance that handles different tasks should be placed apart, to avoid misreading of the information. This principle applies to all equipment to minimize faulty decisions and misunderstandings. Lazet and Schuffel [18] emphasize that with too much visual information, critical information may be lost because of inattention, or simply because the operator is not looking in the right direction. This means that when decisions are to be made by interpretation of displayed information, the presentation of data is highly important. However the most important task when discussing bridge/wheelhouse design is consistency, both concerning software and hardware. Consistency is the keyword that enables humans to recognize patterns and situations that are similar. By recognizing resemblance, the operator can act by using the knowledge the brain already holds.

2.2.2.1 Presenting Information in GUI's

A GUI consists of different components. In a DP system, there will typically be a main overview where a graphical illustration of the vessel is visible. In addition, other relevant information is placed in menus or similar, on each side and top/bottom of the display. The component's composition is crucial to the overall operator vs. interface experience.

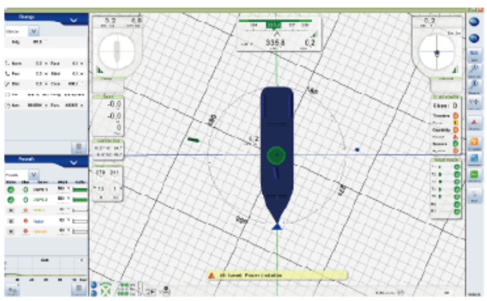

Figure 2. Rolls- Royce (RR) DP GUI

The symbols should be crystal clear with only one purpose and meaning [24] that is not possible to misunderstand. Colors should be consistent, and the same should the composition of the components be. It is considered an advantage if the operator can be presented to a 3D visualization [25], where the designer has assurance that the objects are easy to learn, recognizable and realistic [24].

Colors are often misused. Powerful colors, which is naturally connected with danger or i.e. STOP, such as red, should not be used for other purposes than actions related to the ones mentioned above. In a DP system, it is crucial that the colors support division between different states on vital parts of the system. The colors red and green also correspond to the lanterns on the vessel, which symbolizes port or starboard, and are often used in maritime GUIs to illustrate left or right. Red and green can therefore be difficult to use due to the dual meaning, and shades of similar colors are often used instead. This is important to take into account when designing GUI's for maritime equipment, in addition to taking advantage of the operator's previous knowledge [25] when designing the GUI. This can improve the design and ease the cognitive load on the operator.

A problem the operator can encounter while using modern maritime equipment, is loss of control of the system [24]. This work against the GUI's purpose and according to Dix, Finlay, Abowd and Beale [8], who mention an example from the Apple Guidelines which refers to user control:

The user, not the computer, initiates and controls all actions.

If the user has lost his/her feeling of control, the operator will experience stress and insecurity, which dangers the operation. Leaving the user in control can be a design challenge. A solution can be to follow Norman's Stages of Action as Design Aids [29] that suggests a checklist, where visibility, a good conceptual model, good mappings and feedback to the user are assuring steps of design, leading in the right direction.

There are, in addition, other issues concerning bridge design, which is outside the scope of this paper, such as information integration [24, 25] and centralization of equipment.

2.2.3 Interface vs. Safety Critical Situations

Safety at sea is of utter importance when operating large vessels close to oilrigs and other offshore installations. Accidents considered small-scaled can cause abortion of operations and cost large sums of money. When accidents become large-scale, life of crew and vessel is at danger. In many cases "human error" is concluded as the fatal cause of the accident, or a factor in a series of unfortunate events. To minimize the frequency of human errors, usable equipment is, as mentioned above, the key issue. Most of the time it is not the user's fault, poor design is often the sinner [29]. Wendy MacKay [38] emphasizes that the design of safety-critical systems differs from that of other interactive systems: while improving productivity is important, safety remains the overriding concern. Increasing the former at the expense of the latter is simply not acceptable.

Every year numerous false alarms [21] sound at rescue centers based in maritime nations, which calls for a lot of resources. In order to find a solution to false alarms, i.e. slips caused by misunderstandings and stress-related issues, the composition of the different types of equipment, where it's placed on the bridge according to the operator(s) and if the GUI is suitable for its purpose must be investigated.

In a safety critical situation a button press- combination can be hard to remember [23]. The human mind gets clouded by fear of an impending accident. Depending on how critical the situation is, our mind starts re- organizing our senses, some are sharpened and others are paralyzed and put on hold. Irrational behavior occurs when something unexpected happens[1]. On board a vessel, the

[1] http://www.betterhealth.vic.gov.au/bhcv2/bhcarticles.nsf/pages/Trauma_how_our_body_reacts?Open Accessed: 12.08.2008

consequences of such behavior are at a much higher level than on shore. This is why a clear menu structure [27], grouping of equipment related to the same functions and correct usage of colors, amongst others, is of such importance. Under extreme stress, an experienced user mirrors the behavior of a novice or less experienced user. A clear and concise system will bring the operator back in his/her position as an experienced user [31].

2.2.4 *Visual Display Units (VDU) and Input- devices*

Maritime equipment installed on a vessel's bridge has today numerous different displays and input- devices available. Some are operated by using touch-panels, where the operator can directly on the display and press to select different choices in the menu (or similar). Usage of joysticks, trackballs, buttons, keyboards or computer mice are also widespread, and seen more frequently than touch- panels. The size of the VDUs varies from system to system, and the number of operator stations varies with redundancy requirements. A typical DP system can include two operator stations on aft bridge and one on each wing. This is also dependant on the supplier of the DP system. In this case a Rolls-Royce DP–system (see figure 2) is used as the base of experiments and further investigation. The two operator stations on aft bridge can typically include one 19" and two 10.4" touch-panels. The smallest displays are placed on the armrest of the operator's chair (see figure 3) while the 19" is placed to the left on a consol desk.

The wing stations include a 10.4" touch-panel supported with a joystick and a position device. The input devices will depend on the system's design and usage, which also applies to the displays. Normally the largest displays are around 20" (+/-) and the smallest are 7". The sizes of the displays are determined by the distance from the operator to the display.

The usage of touch–panels simplifies the development process of novel user interfaces and GUIs. It opens a whole new specter of possibilities, when it comes to upgrading the system (i.e. soft-buttons vs. fixed buttons). This introduces new possibilities both in terms of operator control/ user closeness and new interaction styles.

2.3 Multi-Touch and Bi- Manual Interaction

In 2007 a simple form of multi-touch was popularized by Apple through IPhone and IPod Touch. Although Apple was first to popularize it, multi- touch and bi-manual interaction have been a topic since Jeff Han spread interest with his first public presentation of multi-touch interaction on the TED conference in February 2006[2]. This demonstrated his principle of Frustrated Total Internal Reflection (FTIR) [13], which is low-cost multi-touch sensing. The interaction with both GUI and software seemed surprisingly easy and natural, with flowing movements and easy gestures. The demonstration was presented by using a large rear-projected display in front of the user, like a workbench. This inspired the thought of implementing multi-touch/bi-manual interaction into maritime equipment, hence a DP system, due to the direct control of the interaction techniques. This can enhance the DP operator's feeling of control when using a DP system, which is described below.

[2] http://www.ted.com/index.php/talks/view/id/65 Accessed: 01.04.2008

Figure 3. RR DP chair

The majority of DP systems available on the market do not have advanced 3D graphics, including manipulation of the camera, implemented. The Rolls-Royce DP system is however based on a 3D engine, which makes new types of user- interaction possible, together with a correct scaling of all visualization. With use of 3D, multi-touch and gestures, the original three degrees of freedom can be extended to six. This means that the user will be able to control the camera in the 3D scene by using gestures in three additional DOFs [15], which are referred to as pitch, roll and heave. This can lead to the user feeling closer to the system and more in control. The aim for this research is to enhance user control, interface interaction and closeness to the system.

Multi-touch is a human computer interaction technique together with the hardware that implements it. This allows the user to interact with the computer without using the conventional input devices. Multi-touch consists of a touch-display that can recognize more than one point of entry and there is a range of different technologies that implements it. Most technologies are however still not commercially available in an extended format to be used on a normal sized display, such as a 19" display.

Multi-touch, gestures and bi-manual interaction is not research that suddenly appeared with Apple and J. Han. It has been researched for over 25 years and the story started with keyboards. From the early 1980's, University of Toronto was a pioneer in researching multi- touch technologies [5, 19]. At the same time the topic grew in two different directions: multi-touch technology and multi-touch interaction. Some found interest in the technology itself, while others used the scarce technology available to research the human aspect around using more than one point of input. From then and towards today, there is still very little commercially available equipment on the multi-touch market.

2.3.1 *Manipulation of a 3D object*

Using two-hands can in theory make it possible to perform the same tasks using half the number of steps, and also perform different tasks simultaneously [36]. When selecting an object through direct manipulation with a single touch, the object has initially three degrees of freedom (DOF) if the point of contact is in the centre of the object. Hancock et al. [15] introduced a project where an algorithm provided 2 DOF's for each touch-point. With three touches, six DOFs could be implemented, and it proved that with a higher number of touches, both performance and user preference increased. If gestures in addition to more than one point of direct interaction were introduced to DP systems, this will provide the operator with an extra three DOFs. The operator can directly manipulate the vessel through the GUI around six axes (x- y and z- axis), where three enables him/her to physically move the vessel and three is virtual DOFs, which today can be achieved by manipulating a camera in the 3D scene.

2.3.2 *Gestures*

A gesture is a form of non-verbal communication. In the terms of multi-touch, a gesture is non-verbal communication, as described above, but supported with action on a display. The human mind can not remember an unlimited amount of taught movements without training. To be able to take advantage of the knowledge the mind already possesses, signalizing how a certain object is to behave when moving it, should feel easy and natural. The purpose is to ease the user's workload and to enhance the feeling of control. By using 3D graphics and multi-touch gestures, testing the efficiency and accuracy when using the DP system is possible.

2.3.2.1 Efficiency and Accuracy using Multi – touch vs. Single touch

One of the initial studies of two-handed input was presented by Buxton and Myers [6], where two experiments were carried out. The first experiment concerned positioning and scaling, while the second concerned navigation and selection. They concluded that the users were capable of simultaneously provide continuous data from two hands, without a significant overhead. The experiment also showed that the speed of the tasks performed was strongly correlated to the degree of parallelism employed. The second experiment involved the performance of a compound navigation/selection task. It compared a one-handed versus two-handed method for finding words in a document. The two-handed method outperformed the one-handed technique, which was most commonly used in 1986 when the experiment was conducted, and also is today. This early research supports the results of numerous other research projects [1-3,6,7,9,11,12,14,16,17,23,30,35], which all have come to the conclusion that bi- manual interaction, either using both hands or multiple fingers, is more efficient than using only one hand or a single-touch technique. What appears interesting, is the fact that poor design can make interaction with two hands worse than with one [16]. It is unclear if occlusion and reaching over the tabletop can counteract the benefits of such interaction [11]. This will increase the need of well- designed GUI's especially in a maritime environment where safety is of utter importance.

Precision and accuracy when operating a large vessel close to an offshore installation, is crucial. If a DP system is to be operated using multi-touch and bimanual interaction, the gestures must be accurate. What should be taken into account is how the vessel is influenced by external forces such as wind, waves and current. These forces can move the vessel vigorously and systems must have a GUI that supports the possibility of the operator being "tossed" around. In DP systems, all actions that move the vessel physically, must be acknowledged by the operator by either pressing a button (not always a physical button) or similar.

2.3.2.2 Gesture styles

The common features with gesture related research, is firstly the usage of the index- finger [3, 9, 12, 33] and secondly the thumb. Wu and Balakrishnan [34] developed the *Roomplanner*, where a set of 10 different gestures were introduced. Four combinations included the index finger and six included a combination of one or both hands, taking advantage of the palm and the side of the hand. Similar techniques are used in *SmartSkin* [32], where also the index finger on the dominant hand is in focus. In *SmartSkin* the "pinching-gesture", well- known from IPhone and IPod Touch, was introduced. In contradiction to how we know "the pinch" today, as a zooming gesture, *SmartSkin* uses "the pinch" for picking up an object. Two fingers move towards the center of an object and the object is picked up and moved to another location. To drop the object, the opposite movement is used, fingers sliding away from the object's center. In 2004, Malik and Laszlo [20] presented their *Visual TouchPad* where "the pinch" is presented as we know it today, zooming in and out. Fingers (thumb and index finger) slide apart, represents zooming in and the opposite zooming out. Nishino et al. designed an interactive two-handed gesture interface [28], where a range of various gestures were tested. The shapes defined by the gestures were geometrical, in combination with an illustration of sign language and user defined gestures. There was found proof of increased efficiency when using two hands, but in some cases the rate of recognition was found too low and the test objects was also confused by the variety of gestures available.

This returns the initial issue mentioned earlier, which concerns the amount a human mind can remember without mixing it together or filter out what may seem unimportant or irrelevant. If multi-touch and bi-manual interaction were to be implemented on for instance a DP system on an offshore vessel, the gestures must be designed natural and intuitive. In a safety- critical moment with significant strain on the operator, the gestures should be remembered and carried out correctly. With this in mind the first experiment concerning multi-touch and bi-manual interaction on a DP system, was carried out.

Topics concerning symmetric and asymmetrical behavior while operating multi-touch equipment will not be emphasized in this paper.

3. User Study: Mapping hand movements/gestures that feel natural to use when operating a touch- screen DP system

The purpose of this experiment was to map which gestures a panel of eight experienced users would use when operating a touch-screen DP system. A cardboard prototype was used, where the participants moved a cardboard vessel on a paper surface, illustrating the graphical user interface of the DP system. Normally the main DP operator-display is placed vertically to the left side of the operator. In this case, the prototype display will be placed in a desk-like position in front of the operator, adjusted to suit usage of both hands. The cardboard model was in A3 format and simulated the vessel normally visible in the GUI. The test was conducted in a 2D environment, in contrast to the 3D environment, available in the real- life system. This leads to testing the three main degrees of freedom (DOF); yaw, surge and sway. In addition there was a task concerning the last three DOFs which mapped which gestures were preferred, by manipulating the camera in the 3D scene.

The participants did not hold DP certificates, but had extended knowledge of DP from developing DP systems and maneuvering vessels during Sea Acceptance Trials, where the DP system undergoes fine tuning to be adapted to the vessel's characteristics. The test lasted for duration of approximately 90 minutes where each participant had about 15 minutes each. The participants was kept separate and carried out the experiment without discussing it with each other. A camera was used to record the movements on the surface of the prototype. Initially the participants informed how well they knew Dynamic Positioning and operating DP systems. This was indicated on a scale from:

Little knowledge – Average knowledge – Good knowledge.

The participants' age, sex and official title/education was also registered.

DP knowledge	Age	Gender	Title/education
6 Average	**2** users 50+	7 male	**6** DP software developers with MSc, BSc
2 Good	**6** users 24-44	**1** female	**2** Technical Product Managers (MSc, 50 +)

Table 1: Overview of participants

The test objects were given the same nine tasks, but in a randomized order. After completion of each task, the vessel was moved back to its initial position, shown in grey color. Before the tasks were carried out, the participants were encouraged to move the vessel in any way they found natural, regardless using one or two hands or touching the prototype display with more than one point. The participants got the opportunity to read through the tasks in advance, but not the opportunity to practice. The tasks given were:

1) Move the vessel a ship's length forward (surge).

2) Move the vessel a ship's length aft (surge).

3) Move the vessel a ship's length starboard (sway).

4) Move the vessel a ship's length port (sway).

5) Change the vessel's heading (rotate) to 90° starboard (yaw).

6) Change the vessel's heading (rotate) to 180° starboard (yaw).

7) Change the vessel's heading (rotate) to 90° port (yaw).

8) Change the vessel's heading (rotate) to 180° port (yaw).

9) Which movements would you use for the 3 remaining camera angles: heave (zoom), roll, and pitch?

The participants took approximately 10 minutes on the tasks and five minutes were spent on a post-task walkthrough together with a general discussion regarding which gestures would be preferred.

3.1 Discussion of Findings

The tasks carried out showed an extended use of the index finger on the right hand. All the participants were right-handed and the majority used their right hand index finger (RI) and the thumb on the same hand to perform most of the tasks. The tables and illustrations above/below, show the division between which fingers used and how the vessel was moved. If there is no indication in the table concerning which direction the vessel is moved, the same method (fingers) was used in both directions.

3.1.1 Surge: Task 1 and 2

The results from task 1 and 2 (see figure 4) illustrated that with few variations the same fingers were used to move the vessel both forward and backward. From the table (see Table 2) only one user (user 6) used left index and two users (user 3 and 8) changed their method between the tasks. This indicates that right index finger is in most cases the dominant finger, while the thumb is used as a support. It is worth noting that the texture of the cardboard prototype, could initially influence the users' choice of method if they anticipated that the cardboard vessel would be difficult to move.

3.1.2 Sway: Task 3 and 4

Task 3 and 4 (see figure 5) gave as expected, similar results as the first two tasks. This was due to the similar type of motion required to move the vessel. The difference is however that none of the users changed their method between the tasks. There is an almost equal division between the users who only use the index finger and the users who in addition use their thumb (see Table 3).

3.1.3 Yaw: Task 5 - 8

The result showed more variety when it came to the yaw-direction (see figure 1), where rotation techniques of the vessel had some correspondence, but with different variations. Four of eight participants changed their method between the tasks. This was due to the problems of rotating 180° where the hand gets in an awkward position. The participants could rotate the 90° tasks by using only one hand (see figure 7), while the 180° tasks where either done in two separate operations using one hand (90° + 90°, see figure 8) or by using two hands and both index fingers to rotate 180° in one movement (see figure 6). From the rotation tasks it seems like the most natural gesture would be to use both hands' index fingers to rotate the vessel in one continuous movement (see Table 4).

3.1.4 Heave: Task 9

The three remaining degrees of freedom, pitch, roll and heave, were more of a challenge. Heave equals movement along the z-axis (see figure 1) and can not be implemented to physically move a vessel. It is however possible, as mentioned, to simulate heave by manipulating the camera using gestures to zoom in/out.

	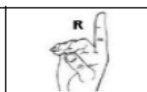	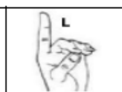	
User 1	**X**		
User 2	**X**		
User 3	**X (aft)**		**X (fore)**
User 4	**X**		
User 5	**X**		
User 6		**X**	
User 7			**X**
User 8	**X(aft)**		**X(fore)**

Table 2: Summary of fingers used to move the vessel surge

	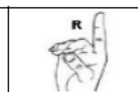	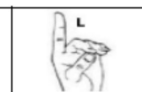	
User 1			**X**
User 2	**X**		
User 3			**X**
User 4	**X**		
User 5	**X**		
User 6		**X**	
User 7			**X**
User 8	**X**		

Table 3: Summary of fingers used to move the vessel sway

	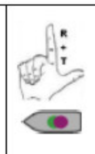	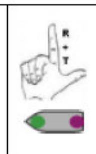	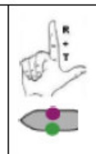	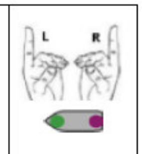
User 1	X			X
User 2				X
User 3	X	X		
User 4		X		X
User 5		X		X
User 6				X
User 7			X	
User 8			X	

Table 4: Summary of fingers used to move the vessel yaw

	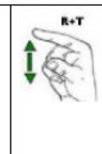	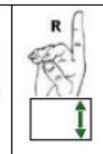	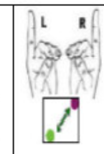	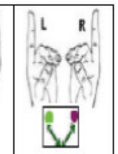
User 1				X
User 2		X		
User 3	X	X		
User 4			X	
User 5	X			
User 6			X	
User 7	Suggested a magnetic finger. Move finger away from the display, zoom out, towards display, zoom in.			
User 8	X			

Table 5. Summary of fingers used to zoom in and out.

Some of the participants tried different gestures for zooming. The pinching gesture was popular (see figure 9), which is interesting with the new iPhone and iPod Touch out on the market. The gestures that arose from the zooming (see Table 5), implies a close relation between the pinching and the diagonal slide (see figure 10), which is the same gesture apart from using one hand when pinching. Five out of eight participants preferred the pinch or the corresponding diagonal slide, while the remaining three suggested different movements. The v-shaped gesture is illustrated in Figure 9.

3.1.5 Pitch: Task 9

The last two degrees of freedom roll and pitch, experienced more variation and creativeness.

Pitch is a DOF where movement happens along the y- axis (see Figure 1). It can in correspondence to heave, virtually be implemented into the system, by manipulating the camera's angle in the 3D scene.

To illustrate movement along the y-axis, half of the participants, found it natural to use a vertical curved gesture using their right index finger (see figure 11). An interesting issue that arose from the experiment was the fact that, some of the same gestures suggested for zooming, were also suggested for pitching the vessel, which can become an issue if the users mix up the different gestures. User 7 had the most original suggestion where pressing either end of the vessel to make it "tip over" in the direction the user wished for. This shows however that the vertical curve along the y-axis seems to be the most natural choice of gesture for most of the users (see table 6).

3.1.6 Roll: Task 9

When the participants tried to roll the vessel, similar gestures as the ones mentioned for pitching the vessel appeared. Rolling happens along the x- axis (see Figure 1) and can be simulated by manipulating the camera's angle in the 3D scene.

The gestures suggested, indicated a connection between pitch and roll, and it is natural to believe that using the horizontal curve around the x-axis (see figure 12) is a corresponding gesture to the pitch gesture (vertical curve around the y-axis). Three of seven (user 8 had no suggestions for roll gesture) participants (see table 7) indicated that the horizontal curve around the x-axis were the best alternative and two suggested a vertical curve around the y-axis. This can cause misunderstandings if mixed together.

3.1.7 Post-task Discussion

The post-task discussion gave insight in what concerns the participants have, when using mainly gestures to operate the DP system. Overall the participants' opinions were positive, especially when using dual or multiple input points.

A concern arose around the display placed in front of the operator in opposite to the left or right hand side where it is placed today, where the operator's attention would be too focused downwards and not towards the aft of the vessel where the real life operations are happening. Solutions to this were suggested to be, transparent displays or window projection, where the GUI was projected onto the window of the vessel. This can however disconnect the user

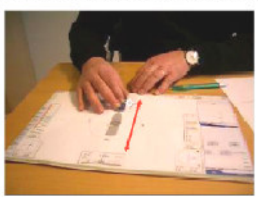

Figure 4. Surge using RI + thumb

Figure 5. Sway using RI+ thumb direction (sideways left and right).

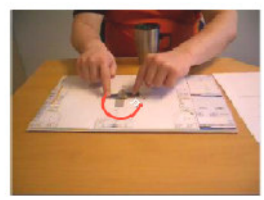

Figure 6. Yaw using RI+ LI

	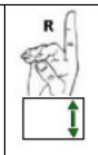	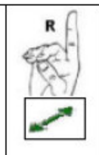	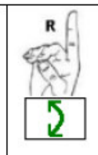	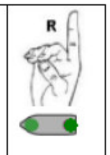
User 1	**X**			
User 2		**X**		
User 3		**X**		
User 4			**X**	
User 5			**X**	
User 6			**X(RI+ thumb)**	
User 7				**X**
User 8			**X**	

Table 6. Summary of fingers used to pitch the vessel.

	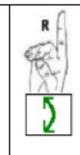		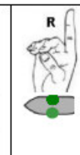	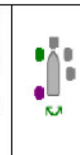	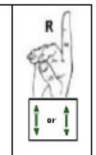
User 1	**X**				
User 2	**X (LI)**				
User 3				**X**	**X**
User 4		**X**			
User 5		**X**			
User 6		**X (RI + thumb)**			
User 7			**X**		
User 8	**No suggestions**				

Table 7. Summary of fingers used to roll the vessel.

from feeling close to the system and in control. Another important issue was heat that arises from a device on the operator's lap, response time to get out of the seat in case of an emergency situation onboard and a place to rest the arms while operating the DP system. Further limitations can be the lack of tactile resistance and haptic perception, which will be further investigated as the research proceed.

3.1.8 Conclusion of Experiment

After investigating how the eight participants preferred to move the vessel, four typical gestures stood out as a result of the tests.

The right index finger was used for all degrees of freedom, apart from the rotation tasks and zooming where mainly two fingers where used. It is therefore possible to imply that a straight vertical or horizontal gesture is used to move the object in the horizontal plane. A curved gesture seems natural for movement in the vertical plane and a rotating gesture around the center of the object, using thumb + index finger or both index fingers to change the object's heading. The pinch gesture stood out as the more natural alternative to zooming in and out.

Two of the participants were above 50 years old, but the experiment showed no noticeable difference between the participants above 50 years of age and the remaining six below. The only difference was a clear sign of extended experience within the maritime area for the 50 + participants.

There are also other suggestions and solutions to illustrate the movements, but in this case, these are the ones that seem to feel natural to the participants. An issue for further investigation is to test how the participants remember the gestures and if they mix the different gestures together.

This experiment will be repeated onboard a vessel in realistic conditions different from the comfort of a lab, to investigate if the participants' behaviors change from being on shore to being on a ship. This is to get more relevant input from the real users of the system and also to increase the statistical weight of the experiment.

3.1.9 Prototype

A prototype implementing gestures using single touch was created and added to the DP system. This made it possible to manipulate the vessel in four of six available degrees of freedom, surge, sway, pitch and roll. The DOFs that needed more than one point/finger touching the screen, such as zoom/heave (see figure 8, 9) and rotate/yaw (see figure 6-8) could not be implemented due to lack of a proper multi-touch display.

By using Java and jME (Java MonkeyEngine, a 3D gaming engine) and a standard touch-display, the touch-point could be tracked and the coordinates inserted into a datastructure. This introduced vectors which were processed and used to calculate the curvature (κ). It was now possible to determine what type of gesture the user was executing (curve or straight line).

$$\kappa = \frac{|y''|}{(1 + y'^2)^{3/2}}$$

In parallel with the calculation of curvature, the angle (Θ) between the vectors' axes and the speed vector was calculated.

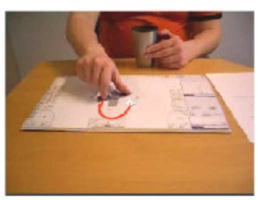

Figure 7. Yaw using RI + thumb

Figure 8. Yaw using RI + thumb

Figure 9. Zoom in diagonally v-shaped

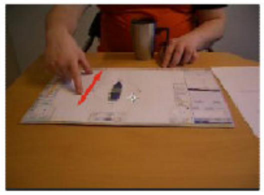

Figure 10. Zoom in using "the pinch"

Figure 11. Pitch: curvature around y-axis

Figure 12. Roll: curvature around x-axis

$$\theta = \arccos\left(\frac{\mathbf{a}\cdot\mathbf{b}}{|\mathbf{a}||\mathbf{b}|}\right)$$

This made it possible to determine the touch-point's direction of movement.

The prototype will be extended to include the last two DOFs, by using a NextWindow Display. The display is currently not fully developed to handle multi-touch interaction. It can however be solved by connecting the signals from the two IR-cameras and the C++ DLL, convert it in to a header- file by using JNI (Java Native Interface) and make it readable for a general java interface.

4. Conclusion and Future Work

The aim for this initial research was to set focus on HCI on maritime equipment, mainly on dynamic positioning systems and also to raise awareness around the often lack of usable systems onboard vessels.

In this paper, popular topics of today, multi-touch and bi-manual interaction are connected with the maritime realm and DP, to find new and innovative ways of interacting with the safety critical DP systems and GUIs. Multi-touch and bi-manual interaction can be a promising solution to improve HCI on maritime equipment, and to enhance safety by bringing the interface closer to the user. When the user has the possibility of direct manipulation of the GUI by using his/her hand(s), the feeling of being in control can increase and lead to less insecurity and a safer operation.

As a first step in our research, the experiment mapped the different gestures the test objects intuitively found natural to use while manipulating the vessel in the DP's GUI. The gestures that stood out as a result of the tasks carried out were: a straight line for movement in the horizontal plane, a curved gesture for movement in the vertical plane, a circular gesture for rotating using either index finger and thumb or both index fingers to change the objects heading, and a pinch gesture to zoom in and out on the object.

This research will be extended and is the base of a more thorough investigation of how the operators/users at sea interact with the GUI's on maritime equipment, and if new interaction techniques can be implemented in harsh environments, like vessels offshore experience at a regular basis. A field trip to an offshore vessel will be carried out, to observe a DP operator using a DP system to execute real- life operations. The knowledge achieved will enhance understanding of offshore operations and usage of DP systems, which will be favorable when investigating HCI on maritime equipment. The prototype will be extended to include multi-touch interaction, and used to carry out an extended user study to test a selection of DP operators doing the same tasks as mentioned above. This is to investigate if there are any differences from carrying out the tasks on a cardboard prototype of the system, to a simulated real life system where they can use direct manipulation to move the vessel. It is also desirable to time the different actions performed on a multi-touch system vs. a single-touch, to investigate if one system is more efficient than the other, and do a test to see if left handed operators perform differently than right handed.

When changing the current methods used for DP operation, i.e. by moving the display from a left and upright position to a centered and horizontal position, issues like occlusion must be investigated. This concerns if the display occludes any important views when placing it in this position. In addition concerns arise around the gestures' accuracy in rough weather, when the operator's hands are not steady. All these different questions add up to one common topic, which is safety. It is in a safety-critical situation, the GUI, interaction techniques, the system and the operator's mind must function optimally. The safety-critical aspect must be investigated closely and if possible, tests will be carried out in a ship simulator environment. The system will be tested by usage in standard offshore operations vs. usage in operations where safety-critical situations appear.

People's interpretation of HCI is in general focused around HCI on consumer goods, such as PC's, mobile phones and similar equipment, which we encounter everyday. The equipment is expected to be easy to use without training or extended knowledge of the product's design and/or construction. If the product is hard to use it is quickly considered useless and replaced with another product in the same category. In industry, equipment with bad usability is not as easily replaceable and the operators' complains are often ignored due to the economical consequences of bad investments. The development has moved towards touch operated panels controlling the machines, which can replace physical buttons with soft buttons, and can therefore be more cost- efficient and enhance usability. Redesign of the software's GUI is easier if the operator's preferences are taken into account during the development process. Touch operated displays (both single and multi-touch) can suffer from limitations such as bad design, dirt on the display, lack of tactile resistance and haptic perception. These are factors that must be considered carefully and will be investigated further at a later stage in this research.

After this initial research three hypotheses stand out, in addition to the questions above, that inspires to further investigation:

H1: Multi-Touch will enhance safety in DP- operations.

H2: Multi-Touch will enhance efficiency when using the DP system.

H3: Multi-Touch will enhance the user's feeling of control when operating the DP system.

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Appendix B

Frøy Birte Bjørneseth: Proposal to Ethics Committee

The author proposes an ethnography study of DP operators and bridge crew on board the PSV vessel, Havila Foresight. The aim of the study is to observe how the crew on board interact on the bridge, if there are any specific movement patterns between the different operator stations on the bridge and also to observe the DP (Dynamic Position) operators during a real DP operation at the Troll oilfield on the Norwegian continental shelf. The study will take place over 2-3 days in the last week of January 2010. The author is covered by Roll-Royce's insurance agreements. In addition the below four issues will be taken into account:

- The researcher(s) are aware that their presence and actions on board the vessel can cause the crew to act differently than normal (hence video recording and asking questions). This will be taken into consideration when the qualitative data is analysed.
- The researcher(s) will interfere as little as possible with the crew and their tasks to obtain as natural data as possible.
- The researcher(s) will be objective and give fair considerations to both sides of opinions that arise during the study.

How will the participants be obtained?

The participants are the bridgecrew on board Havila Foresight. They will be obtained with the assistance of the captain or second officer, who informs the crew in advance and have given permission for the study to be conducted. The researcher(s) will be present on the vessel's bridge for the whole duration of the study.

What will they be told?

The participants will be informed in advance by the officers about the upcoming observational study. In addition when the researcher(s) arrive at the site, they will inform the crew that the data collected will be kept anonymous. The researcher(s) will be available for questions during the study. The subjects will be anonymous and they will have the opportunity of opting out of part of the observation or to ask the observer to leave/stop recording/observing at their request.

What will they be expected to do?

The participants will be asked to act naturally and carry out the tasks and routines they normally do on board the vessel and during the DP operation.

How data will be obtained and stored?

All data will be stored in accordance with the *University of Strathclyde's Code of Practice on Investigations involving Human Beings*. The study will consist of three observational sessions and one interview. For two of the observational studies (to and from the oilfield and the interview) will be participant observation where the author/researcher use a field not diary and a map over the bridge area to note down where/how people move and the communication between them. The last observational study (the DP operation) will be supported by two video cameras directed towards the operator stations to catch communication between the operators, interaction between the operators, communication between the operators and the other crew members and interaction with the DP system. A laptop will also be used if needed. The data collected using the video cameras will be transferred to a securely encrypted and password protected portable harddrive. The data (written and electronic) will be stored in a locked cabinet in the researcher's office and back-ups will be stored on a secure Rolls-Royce server.

How data will be processed
The author will analyse and log the data using an appropriate data analysis package, most likely the qualitative data analysis package NVivo(TBC). Analysis of the data will be password protected and stored on an encrypted harddrive. The data will only be accessible the the author.

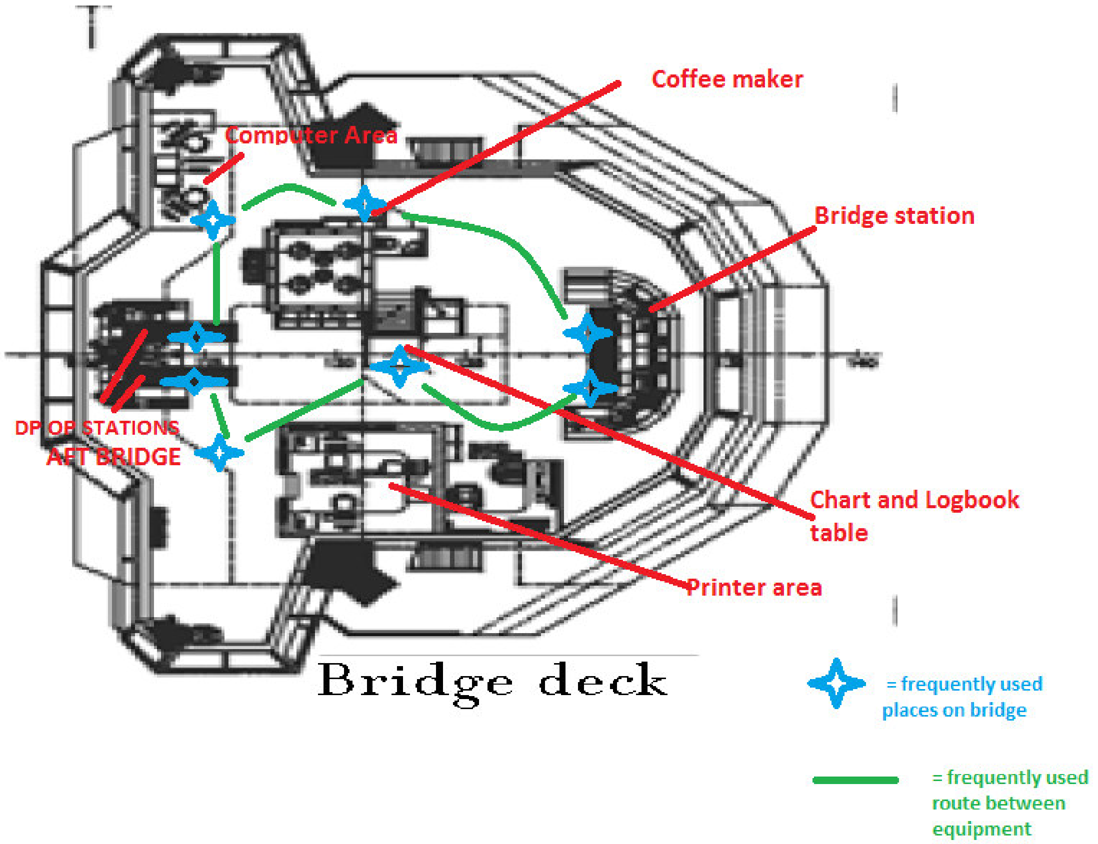
How data will be disposed of and when
The author will dispose of the data one year after publication or after five years from study date whichever is soonest. Following consultation with the CIS Systems Support team it is the intention to use a software data destruction package such as Jetico's BC Wipe, which permanently deletes files and ensures that they cannot be recovered.

The author will conduct observations, collect, analyse and store data in accordance with the University of Strathclyde's Code of Practice on Investigations on Human Beings; The Data Protection Act (1995); and the CILIP Code of Professional Practice.

Questions DP op.

1. Age	
2. Experience?	
3. Experience as a DP operator?	
4. Experience with Rolls-Royce DP system?	
5. Rate the Rolls-Royce DP system compared to DP systems from other suppliers?	På en skala fra 0-7 hvor 7 er bra og null er dårlig 0 1 2 3 4 5 6 7
6. Comments	

Map of movement pattern on Bridge on board Havila Foresight



DP CHECKLIST

☐ **Swing up thrusters - only to be lowered at a speed below 5 kts**
☐ **HPR valve confirmed open, green light**
☐ **HPR transducer - only to be lowered at a speed below 2 kts**

1. GENERAL		**2. COLLISION REGULATIONS**		
Vessel name		Navigation lights and NUC on	☐ Yes	☐ No
Date :		Day-marks displayed	☐ Yes	☐ No
Time:		AIS shows correct information	☐ Yes	☐ No
Location :		Prepared security radio messages	☐ Yes	☐ No
Project :		S-Band Radar on	☐ Yes	☐ No
Client :		X-band Radar on	☐ Yes	☐ No

DP class operation	☐ 1	☐ 2	MSB settings in accordance to DP Class 2	☐ Yes	☐ No
"*Transducer out*" warning sign posted on both fore and aft main engine manoeuvring handles.				☐ Yes	☐ No

3. COMMUNICATION				
Bridge to:	UHF Ch.	VHF Ch.	Clear comms	Internal phone
Deck / Crane				
Survey				
ROV				
Installation				NA
Other				
Other				

4. GENERAL SETTINGS			**5. Alarms**		
Operator station in command	☐ 1	☐ 2	Any active alarms	☐ Yes	☐ No
DP Heading			1.		
Rotation point			2.		
Follow Sub reaction radius			3.		
Gain mode	.		Comments :		
Allocation mode					
Bios					

6. DP WARNING / ALARM / SPEED SETTINGS / ACCELERATION						
Position warning / alarm set to			mtr	Heading Strategies set to	☐ Operator	☐ System
Heading warning / alarm set to			° Deg	Rotation speed set to		°/min
Cross warning / alarm set to			mtr	DP speed set-point		m/s
DP acceleration speed	Surge		%			
DP acceleration speed	Sway		%			
DP acceleration speed	Hdg		%			

7. GENERATOR STATUS	**8. THRUSTER STATUS**

Generator	Running	Available	Unavailable	Thruster	Online	Available	Unavailable
DG1	☐	☐	☐	Bow tunnel 1	☐	☐	☐
DG2	☐	☐	☐	Bow tunnel 2	☐	☐	☐
DG3	☐	☐	☐	Azimuth Fwd	☐	☐	☐
DG4	☐	☐	☐	Stb main prop	☐	☐	☐
DG5	☐	☐	☐	Port main prop	☐	☐	☐

9. Signal intensity & performance level		
REF	**Check**	**Restrictions / Remarks**
GPS Satellites, elevation and numbers	☐ Ok	
Differential ref. signals intensity and performance	☐ Ok	
FanBeam	☐ Ok	
Radius	☐ Ok	
Hipap	☐ Ok	

10. HPR transponders								
Location:	No.	Type of TP	Location:	No.	Type of TP	Location:	No.	Type of TP
Vessels own			ROV 1					
Vessels own			ROV 2					

11. ROV (if in follow sub)					
ROV 1 offsets	X: m	Y: m	ROV 2 Offsets	X: m	Y: m

12. Reference systems							
Systems in use	☐ D-GPS 1	☐ D-GPS 2	☐ FanBeam	☐ Radius	☐ HiPAP	☐ HPR	☐ LTW1
Systems available	☐ D-GPS 1	☐ D-GPS 2	☐ FanBeam	☐ Radius	☐ HiPAP	☐ HPR	☐ LTW1

13. ENVIRONMENTAL SENSORS					
Reference gyro:	° Deg.				
Gyro no 1	☐ Preference	☐ Enabled	Wind Sensor no 2	☐ Preference	☐ Enabled
Gyro no 2	☐ Preference	☐ Enabled	VRS (MRU) no 1	☐ Preference	☐ Enabled
Gyro no 3	☐ Preference	☐ Enabled	VRS (MRU) no 2	☐ Preference	☐ Enabled
Wind Sensor no 1	☐ Preference	☐ Enabled	VRS (MRU) no 3	☐ Preference	☐ Enabled

14. TRACK SETTINGS / ALARMS (If applicable)					
Speed mode:	Low speed ☐	High Speed ☐	Waypoint table ☐	Operator ☐ kts	
Track setup:	Leg offset mtr	Next waypoint no.	Across speed setpoint m/s		
Track course:	Forward ☐	Reverse ☐	Track Course ° Deg.	System ☐	Operator ☐

15. Engine room checklist		
Completed:	☐ OK	Remarks :

REMARKS :

17. SIGNATURES	
DPO 1	DPO 2

Appendix C

Assessing the Effectiveness of Multi-Touch Interfaces for DP Operation

Frøy Birte Bjørneseth[1,2], *Mark D. Dunlop*[2] and Eva Hornecker[2]

[1] Rolls-Royce Marine AS, Common Control Platform, Parkgata 3, 6003 Aalesund, Norway
[2] Computer and Information Sciences, University of Strathclyde, Glasgow G1 1XH, Scotland, UK

froy.bjorneseth@rolls-royce.com mark.dunlop@cis.strath.ac.uk eva.hornecker@cis.strath.ac.uk

ABSTRACT

Navigating a vessel using dynamic positioning (DP) systems close to offshore installations is a challenge. The operator's only possibility of manipulating the system is through its interface, which can be categorized as the physical appearance of the equipment and the visualization of the system. Are there possibilities of interaction between the operator and the system that can reduce strain and cognitive load during DP operations? Can parts of the system (e.g. displays) be physically brought closer to the user to enhance the feeling of control when operating the system? Can these changes make DP operations more efficient and safe? These questions inspired this research project, which investigates the use of multi-touch and hand gestures known from consumer products to directly manipulate the visualization of a vessel in the 3D scene of a DP system. Usability methodologies and evaluation techniques that are widely used in consumer market research were used to investigate how these interaction techniques, which are new to the maritime domain, could make interaction with the DP system more efficient and transparent both during standard and safety-critical operations. After investigating which gestures felt natural to use by running user tests with a paper prototype, the gestures were implemented into a Rolls-Royce DP system and tested in a static environment. The results showed that the test participants performed significantly faster using direct gesture manipulation compared to using traditional button/menu interaction. To support the results from these tests, further tests were carried out. The purpose is to investigate how gestures are performed in a moving environment, using a motion platform to simulate rough sea conditions. The key results and lessons learned from a collection of four user experiments, together with a discussion of the choice of evaluation techniques will be discussed in this paper.

Keywords: Usability Evaluation Techniques, HMI, Gestures, Multi-Touch, Safety Critical, Dynamic Positioning

1. INTRODUCTION

The maritime environment is deeply rooted in traditions and has the last years experienced an interesting and user-challenging technological development from suppliers of maritime equipment. The automation systems are continuously growing more advanced and the mariners have to keep up with technology. The demand of increased computer and technology related knowledge can for some feel overwhelming, while for others it feels natural and a part of everyday life. The division is often, but not exclusively, age related with the younger generation of mariners feeling more comfortable with technology than the older generation [Paul and Stegbauer, 2005]. The increasingly advanced automation systems controlling modern vessels lead to increasingly advanced and complex user interfaces. Furthermore, a typical operator must interact with many different systems, often with different interface styles, during an operation. On Dynamic Positioning (DP) vessels, which is the key focus of our work, the operator position can become stressful as (s)he must interact with at least three different systems – each with its own graphical user interface (GUI) and display. In addition, the operator must lead the radio communication, have an eye on the propulsion system and maintain "constant observational awareness" of the environment around the vessel. This can be a challenge both mentally and physically and the cognitive load can increase if presented with too much information [Lazet and Schuffel, 1977]. The physical strain also affects the operator if the equipment is poorly ergonomically placed [Galliers et al., 1999]. Depending on the ship owner, the ship yard and the suppliers of equipment, the composition of the equipment in the operator station can vary considerably and is often ergonomically sub-optimal.

Human Machine Interface (HMI) work has a long history in maritime settings, but is often given low priority due to perceived increased development time and economic pressures. The economic aspects play an important role in a vessel's lifecycle and issues concerning HMI and usability are in many cases not a part of the discussion until late in the cycle when it is often too late and expensive to make vital changes to obtain an optimal solution [Sillitoe et al., 2009]. Today's trend seems to move towards a more noticeable awareness around HMI issues, but is still not always properly accounted for.

An overall increased mental load when using a system is both tiring and leaves less mental capacity for handling safety-critical events. Such events are not prominent in every-day operation, but when they occur a high mental load can reduce the operator's experience to the level of a novice [Redmill and Rajan, 1997]. Poorly fitted equipment combined with low usability causes a long–term problem for the operators. Unlike personal consumer equipment which can often be easily replaced if the consumer is unhappy with the interface or usability, equipment installed on vessels typically lasts many years and will not be replaced before its operating time has ended. The overall aim of maritime-HMI research is to lower the operator's cognitive load and make the workflow more efficient by introducing interaction techniques known from other HMI domains, such as mobile technologies and personal computers, while also assessing them by using traditional usability methodologies. In safety-critical situations a lower cognitive load will require less attention on how to operate the system and enable more focus on the actual operation.

Within our work we are interested in multi-touch interaction – a form of interaction that was popularised by Apple on the iPhone range but which has existed in research labs since the early 1980s [Lee et al., 1985]. This interaction style seems to have a great potential for bringing the interface closer to the user. Our on-going research investigates multi-touch interaction on DP-systems. In particular we have investigated if it is possible to carry out the tasks faster and more safely when operating the Rolls-Royce Icon DP system using multi-touch interaction. Our hypothesis is that the user interface will be brought closer to the operator by enhancing the operator's possibilities for directly interacting with the interface of the maritime software application by using multi-touch gestures. This ties the advanced maritime interfaces together with its increasing resemblance to modern technological consumer products where multi-touch has introduced a new dimension of interaction techniques.

In this paper we discuss the methodologies used: an iteration of creating prototypes and assessing their usability through user studies. This is supported by an observational study to get insight in the DP operator's real-life situation. First we will give an overview of background and technologies used, then describe the topic concerning prototyping on different levels and last describe our studies. The studies consist of one observation study and four different iterations of user studies. The observation study was carried out to gain more knowledge on how DP operations are carried out in a real-life situation. This gave a good support for further studies. The initial study is based on the paper prototype where the aim is to investigate which gestures feel natural to use when operating a DP system. The second study is based on the results from the first, but where the aim is to investigate the efficiency of using multi-touch gestures vs. traditional buttons/menus when operating the DP system. The two last iterations concerns a pilot study where the aim is to investigate how motion affects task performance when doing tasks using multi-touch and a main study. The main study investigates operating the DP system in a moving/non-moving environment while comparing the usage of gestures vs. buttons/menus when operating. For each study the motivation for the methods chosen will be outlined together with the key results and lessons learned.

2. MARITIME SAFETY AND TECHNOLOGY

The advanced technology onboard vessels today leads to an increased amount of rules and regulations set by IMO and other large classification authorities such a Lloyd's Register that have to be complied with. Safety is the first priority and preventing accidents onboard has full focus. Accidents do however still occur and often they are connected to what is referred to as human error. The reasons behind a human error related accident can be widespread and are not always directly connected to personal fault as a result of inattention or unregulated behaviour.

2.1 HUMAN ERROR

Whenever maritime safety is discussed, it is not long before somebody produces a statistic showing that most accidents at sea are caused by human error. The statement is usually made in a tone of resignation, as though accidents are unavoidable, an impression that is reinforced by dictionary definitions. The Oxford English Dictionary defines an accident as "anything that happens without foresight or expectation; an unusual event, which proceeds from some unknown cause, or is an unusual effect of a known cause." [IMO, 1997]. Furthermore, accident reports show no improvement in the number of injuries and lives lost at sea since 1995 [Lloyd's Register, 2007]. Although shipping has increased implying a better safety record, there is still considerable room for improvement with sea safety improving considerably slower than, say, the airline and car industries over the same period. With this in mind we can ask; is it possible to improve safety by introducing technologies and interaction techniques better known from the consumer market into the maritime domain? Can taking advantage of the user's previous knowledge [Mills, 1998] of personal and mobile electronic equipment be an advantage?

Reason [Reason, 1990] discerns active failure (of front-end actors, e.g. operators) and latent failure. Latent failure originates from preceding actions, involves working conditions and load, competing demands, and is caused by designers, developers, decision-makers and managers. Latent failure is the type of failure that is frequently seen onboard vessels today. Active failure involves the human in the process and the operator can in some cases be blamed. There are two main approaches to handle the problem of human error [Song, 2009]. One approach would include increasing the number of well trained crew members. The second approach would be to look for ways to improve the working environment of the human onboard ships. The last is a more long –term solution which solves the actual problem.

2.2 HUMAN COMPUTER INTERACTION ON MARITIME EQUIPMENT

HMI on maritime equipment has not always been, and is still not always a priority in the maritime realm. The economic aspects play an important role even though the majority of accidents onboard vessels are attributed largely to human errors. The errors are often due to misunderstandings during stressful situations, and not system failure [Mills, 2005]. Poor design is often blamed, and there has been a trade-off between the usability of the maritime equipment and issues such as the safety-critical aspect, and also robustness. There will however, to some extent always be a compromise between the design, technical issues and maritime directives. Modern technology does become cheaper and there has been legislation that pushes safety onboard vessels forward [Mills, 2000]. The maritime industry is conservative about novel technologies due to safety issues, but with time, the industry will most likely adopt new innovations supported by research that will enhance safety onboard.

When developing equipment and graphical user interfaces for the maritime environment, *'knowing the user'* is of paramount importance in good design [Faulkner, 2000]. This underlies the different methods used to obtain knowledge about the situation where the product is to be used. These methods can however often be poor substitutes to real life experience [Mills, 2005]. The best designers of maritime equipment are most likely the mariners themselves, who have experience and know what requirements the equipment must be capable of handling. A contradiction is when new equipment for maritime environment is to be designed. The user knows what goal(s) to reach, but not how to get there or which tools to use. To depend solely on the user's information, can in many cases be inefficient and time-consuming due to predisposed opinions and habits. One of the products that underwent a rapid development the past few years is dynamic positioning systems. This is a product that demands performance on all areas from low-level control systems to top-end graphical user interfaces and input devices.

2.3 DYNAMIC POSITIONING SYSTEMS

To keep the vessel in a fixed position close to offshore installations without using anchors, a system was developed that automatically compensated natural forces such as waves, wind and current. This is called a Dynamic Positioning system (DP) and its technology has developed from the first simple systems in the 1960's to today's advanced systems covering single, double and triple redundancy according to the operation's safety critical level.

A Dynamic Positioning system (DP) can be defined as: *A computer controlled system to automatically maintain a ship's position and heading by using her own propellers and thrusters.*

A DP system [Bray, 2003] can be seen as a complete system that includes operator stations, position reference sensors, gyro compasses (detects true north by using an electrically powered fast spinning wheel and friction forces, in order to exploit the rotation of the earth), and a range of different sensors that give feedback to the operator about the ship's position and the forces that influence its direction.

2.4 MULTI-TOUCH INTERACTION

Multi-touch is a human computer interaction technique together with the hardware that implements it. It allows the user to interact with the computer without the conventional input devices (mouse, keyboard). Multi-touch consists of a touch-display that can recognize more than one point of touch and there is a range of different technologies that implements it. Two of these technologies, optical and capacitive sensing have been utilized in this research project.

Interacting directly with an application's interface has in the last few years been proposed as the new way of interacting with computers in the future. Multi-touch has been commercialised by Apple, and young user groups are already well acquainted with the world of gestures and directly touching the surface to reach their aim of interaction through the use of handheld gaming platforms such as Nintendo DS and mobile phones. Although Apple was first to popularize it, multi-touch and bi-manual interaction have been a topic since Jeff Han spread interest with his first public presentation of multi-touch interaction in 2006. This demonstrated the principle of Frustrated Total Internal Reflection [Han, 2005], a low-cost multi-touch sensing technique. The interaction with both GUI and software seemed easy and natural, with flowing movements and simple gestures. The demonstration utilized a large rear-projected display in front of the user, like a workbench. This inspired the idea of implementing multi-touch/bi-manual interaction into maritime equipment, hence a DP system, due to the direct control of the interaction techniques. This can possibly enhance the DP operator's feeling of control when using a DP system.

Multi-touch and bi-manual interaction has through several studies shown to be more efficient than traditional input techniques. One of the initial studies

Figure 1: PSV Havila Foresight

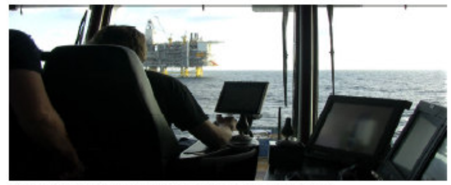


Figure 2: DP Operation onboard PSV

of two-handed input was presented by Buxton and Myers [Buxton and Myers, 1986]. They concluded that the two-handed method tested outperformed the one-handed technique, which was most commonly used in 1986 at the time (and still is today). What appears interesting is the fact that poor design can make interaction with two hands worse than with one [Kabbash et al., 1994]. It is unclear whether occlusion and reaching over the tabletop can counteract the benefits of such interaction [Forelines et al., 2007]. This will increase the need of well- designed GUI's especially in a maritime environment where safety is of utter importance.

The majority of DP systems available on the market do not have advanced 3D graphics, including manipulation of the camera in the 3D scene, implemented. The Rolls-Royce DP system is however based on a 3D engine, which makes new types of user- interaction possible, together with a correct scaling of all visualization. With use of 3D, multi-touch and gestures, the original three degrees of freedom can be extended to six. This means that the user will be able to control the camera in the 3D scene by using gestures in three additional DOFs [Hancock et al., 2007], which are referred to as pitch, roll and heave. This can lead to the user feeling closer to the system and more in control.

3. OBSERVATIONAL STUDIES

To observe and report are techniques widely used for both social research and usability related research. In social research the observation is often part of an ethnographic study where the researcher immerses him/herself in the environment observed for months or even years [Bryman, 2008]. For usability studies and gathering knowledge around processes connected to carrying out specific tasks, smaller studies combined with interviews of users are more beneficial and commonly used. As mentioned earlier, "knowing the user" is important, but it is often difficult for users to express their views and put these in the context of wider HMI work. The benefit of being an outsider observing the users is that the observer might question issues that the user may never have thought about. This gives a wider angle to finding the right solutions while still grounding it in the end users actual use of the systems and his/her environment.
In our work the observations were anchored in the guidelines given by Jordan and Henderson concerning interaction analysis of videodata [Jordan and Henderson, 1995] and Alan Bryman's work on social research methods [Bryman, 2008]. Our observational study was a non-participant observation, where the observer did not take part in any tasks or daily routines. This is one of the best-known methods of research in the social sciences and primarily associated with qualitative research. It entails a relatively prolonged immersion of the observer in a social setting in which he or she seeks to observe the behaviour of members of that setting [Bryman, 2008].

In this case the bridge crew of an offshore vessel is in focus and the main goal of the observation is to gather knowledge on how platform supply DP operations and related activities are carried out. This can also be called an overt "micro-ethnography" [Bryman, 2008], where being overt reflects the fact that the researcher is not "under-cover" pretending to be a part of the crew. It is often normal to have a key informant that initially gives the observer access to the group and also key information. In this case the key informant was the Chief Officer who invited and informed the observer throughout the observation. To gather as much information as possible regarding issues related to being a mariner and working offshore semi-structured interviews were carried out in addition to observations. This is an interview technique that encourages the natural flow of a conversation instead of a fixed setup with the interviewer asking questions and noting down or recording the answers [Bryman, 2008]. In this case the interview guide, which held the topics of the interviews, was memorized and incorporated into normal everyday conversation. Semi-structured interviews often give longer and more supplementary answers. Through the whole observation study, concurrent field notes were written. Field notes play an important role when the study is to be analysed and similar sections are coded/organized and given labels to component parts that seem to be of potential theoretical significance [Bryman, 2008]. In addition to the procedures around how to carry out the observation, the guidelines given by Jordan and Henderson [Jordan and Henderson, 1995] were utilized to plan what to look for, which questions to ask and how to structure the video recordings of the operations. A detailed observation study, selectively making use of video recording, was carried out to investigate how the DP operator operates the DP system in its authentic environment, and to find out which tasks are more frequent during the different operations. In addition, the situation around the operator's workplace onboard was analysed and it was also investigated if there were any specific movement patterns between the different equipment situated on the bridge. The study was conducted over a period of three days in early February 2010 onboard the Platform Supply Vessel (PSV) Havila Foresight. See Figure 1.

The participants of this observation study were the crew onboard Havila Foresight and two representative from Rolls-Royce Marine AS. The vessel's work tasks for the three day period, was to deliver drilling equipment, food and different liquids contained in the vessel's tanks below deck to four platforms in the Norwegian sector of The North Sea. On supply vessels the sailing schedule and tasks are determined just before loading the vessel with cargo, this meant that our schedule could not be finalised until arrival in harbour. After three days, four DP operations were observed and the crew was also observed when steaming to the oilfield, between the platforms and on return to shore. Due to similarity in operations only one DP operation was video recorded. See Figure 2. In total 7 observations were conducted (with one night-time DP operation unobserved). The participants observed were the captain, the first officer, two second officers and one midshipman. For the semi-structured interviews the captain and the first officer participated. This felt natural due to that they were the highest ranked officers onboard and also the spokesmen for the rest of the crew. Following a lightweight interview script, the semi-structured interviews were carried out in the shape of a normal conversation, where the captain and the first officer were asked questions while they were on duty on the bridge. The questions were asked during free periods between operations.

The observations were divided into four categories in addition to the semi-structured interviews. The first category concerned observing the crew on the bridge while steaming towards a goal (i.e. platform) and the second category concerned observing the operator during a DP operation. The third category concerned observing the crew on the bridge when steaming between oilrigs and the fourth category concerned observing the crew while returning from the oilfield to shore. Each category was supported with a set of questions in line with the guidelines given by Jordan and Henderson [Jordan and Henderson, 1995]. The questions concerned briefly: who was situated on the bridge, communication and movement patterns on the bridge, and also any usability issues with the equipment onboard. During the DP operation the official start and end to the operation was investigated, if there were any repetitive patterns, communication between the operators and also territorial issues. In addition the interaction between the operators and their abilities to work together was observed. The semi structured interviews consisted of questions revolving around the operator's daily routines when on watch, if any incidents had occurred and how they solved the issues.

Throughout the observations and analysis from the PSV Havila Foresight, a picture of a well-organised and formal vessel emerged. They carried out the tasks given with ease and followed procedures precisely, which is necessary on vessels working in safety-critical environments. However the personal relations between the crew members reflected an informal organisation that respected the ranking of an officer, but had an informal and cheerful tone between each other. They had an overall good working environment. The observations gave a good base of knowledge on how platform supply DP operations at sea were carried out in real life. For platform supply vessels the majority of time is spent on steaming to, from and between oil platforms and also waiting to get access within the 500 meter safety zone around the platforms. The discoveries made during this observation were that the pace onboard was much lower than anticipated. This can of course vary between different types of DP vessels, but what was anticipated in this case was a more hectic scenery on the bridge with lots of equipment interaction. The level of stress does increase if weather conditions are bad, but in general for platform supply DP vessels the pace is comfortable and slack time onboard is often used to browse the internet, check the weather reports and fishing. The most frequently used equipment on the bridge during steaming to or from a destination was the logbook, the coffee machine and the captain's chairs on the front bridge. There were always at least two officers on the bridge, with one always being on watch. They swapped from being on watch and doing other tasks, such as filling in entries into the logbook.

During a DP operation the DP operator stations were naturally the most frequently used equipment. During DP operation, the officer in command of the DP system maintained the view out the aft windows and aft deck the majority of the time. The operator's good overview of the aft deck and the actions happening on deck during operation give an advantage to ensure that safety on deck is maintained.

The observation provided detailed knowledge of the routines onboard and which tasks were more important than others. The interaction with the system had peak time when the operator closed in on the oilrig. The main interaction technique was using the input devices, such as the joystick and the heading wheel. They occasionally glanced on the belonging displays sometimes followed by quick interactions with them. A problem that was highlighted by the operators was a button that could be hit accidentally. This caused a change of state without the operator

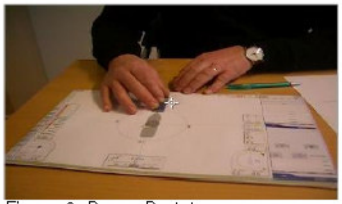


Figure 3: Paper Prototype


Figure 4: 1st Gen Prototype


Figure 5: 2nd Gen Prototype

being aware. This could possibly cause dangerous situations. In addition to the above, it was also interesting to observe and understand the communication patterns between lower and higher ranked officers, between the vessel and the oilrigs and also between the vessel and shore base.

The benefits of collecting observation data such as described above are that it provides a much more detailed understanding of the processes onboard a vessel. This will provide better knowledge when developing equipment and will save both time and money when the knowledge gained can prevent stepping into the most obvious pitfalls. The most beneficial time to do an observation study is in the early stages of the research or development process. An important preparation was to read the related literature mentioned above to gather information about what to look for and which questions to ask.

The limitations of this observation study are that only one vessel has been observed and that the observation was very time consuming. It did however give a valuable insight in what life at sea onboard offshore vessels is like and how the procedures concerning the different operations are carried out.

4. PAPER PROTOTYPING

Prototype development is a well- known technique for testing concepts and designs [Dix et al, 1997]. There are several different levels of prototyping varying from lo-fi (low fidelity) prototypes made in low-cost and easy accessible material to working prototypes made of hardware and software. The lo-fi prototype is often the first one created to test the basic functionality and to study which direction to follow before investing heavily in development.

A good initial study can save resources and prevent obvious errors during product development. The close to full functioning prototype is created in the last stages of the development and demands a larger amount of resources. Each prototype goes through an iteration of usability studies to discover errors and faulty design decisions. This is called iterative design where the design can be modified and redesigned to correct any false assumptions that were revealed in the testing. This initial prototype utilize the throw-away approach, due to that the results from the testing is used for next iterations, but the prototype itself is discarded and is not to be used as the final product [Dix et al, 1997].

The aim of our initial prototype study was to investigate which gestures would feel natural to use when operating a touch-screen DP-system [Bjørneseth, 2008]. To find out which gestures a selection of test participants were given a set of tasks to carry out using their hands directly on a lo-fi prototype. The participants were eight Rolls-Royce employees with experience from developing DP systems and tuning /installing DP systems onboard vessels. There was not given any guidance on how to proceed through the exercises or what gestures to use. This was due to the desire to investigate if it was possible to find common suggestions for movement/gesture for each task across participants.

The interface presented to the test participants, was a simple rectangle shaped piece of cardboard where a printout of the DP system's 3D interface was glued on. See Figure 3. The prototype display was placed in a desk-like position in front of the operator, adjusted to support usage of both hands. In the centre of the interface a grey boat was visible. This was displayed in a grey colour following the colour scheme the DP interface uses when the vessel is in a transitional between two positions. The vessel has a blue colour when it is in position and is not moving. To represent the blue vessel indicating the vessel in position, a small boat cut out from cardboard was used. On top of the small vessel a blue print-out from the authentic system was glued on top of it. The users moved this cardboard vessel when conducting the tasks given. A camera was used to record the movements on the surface of the prototype. The participants were given the same nine tasks, but in a randomized order. Before the tasks were carried out, the participants were encouraged to move the vessel in any way they found natural, regardless using one or two hands or touching the prototype display with more than one point. The tasks given were to move the vessel in all linear directions and to change the vessel's heading by rotation. Last the participants were asked to suggest method on how they would zoom in the 3D scene, pitch and roll the vessel. The last minutes were spent on a post-task walkthrough in addition to a general discussion regarding which gestures were preferred. In this experiment no quantitative data was collected and there were no hypotheses or experimental variables. This was due to it being a small experiment where the aim was not to compare different interfaces, but to investigate the possibilities within an interface.

The usability methods used to obtain the results needed from this study was to utilise the lo-fi prototype to do the simple tasks with a small collection of participants with knowledge about DP systems and maritime processes. Their knowledge was utilized to get a wider picture of why the hand gestures suggested could be usable in a DP system. To make the most out of the small experiment, the post-task walkthrough supported the results with the participants' thoughts on the different gestures selected. Video and audio recordings were useful tools to review the data and as a support details were noted down throughout the experiment. The combination of the above gave results worth building a new study on to investigate the impact of hand gesture interaction further. The outcome provided four hand gestures that the users felt were natural to use when operating the touch-screen DP system by directly manipulating the vessel in the system's 3D scene. These gestures created the basis for developing new and more advanced prototypes, with the gestures implemented. This made it possible to do user studies to investigate the pros and cons of using gestural interaction in maritime graphical user interfaces. The limitations of paper prototyping are because of their simplicity that paper prototypes do not support the evaluation of fine design detail. Due to the use of paper and a human operator, this form of prototype can not be reliably used to simulate system response times [Retting, 1994].

5. INITIAL SYSTEM PROTOTYPING

The purpose of system prototyping is to discover errors and design faults before the final product is released. As mentioned above, prototyping is a part of an iterative design process that can be described by the use of prototypes and artefacts that simulate or animate a selection of features of the intended system. There are three main approached to prototyping which are described by Dix et al. [Dix et al, 1997] as the throw-away approach, the incremental approach and the evolutionary approach. In our work three different prototypes were created that were built on the throw-away approach – discarding the prototype after collecting the data needed and using the knowledge gained to build the next product. The initial study above was conducted using a lo-fi paper prototype and was followed by two generations of software based prototypes tested on different hardware platforms.

The first generation prototype was built by using the Rolls-Royce Icon DP system, a NextWindow multi-touch display using optical technology (See Figure 4). The standard DP system's graphical user interface (GUI) was extended in Java, while the NextWindow drivers were programmed in C++ and C#. This first generation prototype enabled a second iteration of user tests where the aim was to uncover if operating the DP system using multi-touch and direct interaction with the GUI's 3D scene could be faster and more efficient than using single touch and button/menu interaction with the GUI. The experiences obtained from the initial lo-fi prototype were built into this software prototype to be able to test the gestures found in a working environment. A user study was carried out following standard user laboratory study procedures that are widely used in interface design [Dix et al, 1997], having been adapted from psychology experimentation methods.

To fully exploit the advantages of prototyping, the natural steps between each generation of prototypes are usability testing and usability studies. The experiences obtained and the results gained from this provide the base for the next generation of prototypes. What is covered under the term usability study is a study that demands a well planned setup. This includes planning the study, doing individual sessions with each test participant, thoughts about the observer's role, the outcome of the study and which tools to use to obtain data and analyse the results. The usability testing concerns the separate test where the aim is to measure performance, accuracy, recall and subjective response. Usability studies can give a good insight into the user's response to the system and gives the possibility to weed out serious faults before the final decisions towards the product are made. For maritime equipment and software, the costs of replacing equipment with bad usability are so high that it is only done if the product represents a safety hazard. The process of developing controlled experiments that can provide robust results has been by Blandford, Cox and Cairns [Cairns and Cox, 2008]. The focus for controlled experiments is on quantitative data and it is important to select the appropriate population for the experiments. The participants recruited must be familiar with the tasks and have knowledge about the experiment's surrounding scenario. In this project the appropriate population for all user studies was participants who had knowledge of DP systems, but not extended experience. Through observing the test participants the results from this test were hoped to demonstrate the potential efficiency of using multi-touch.

The participants selected for our user studies were a mix of people with DP experience, students studying to be officers and DP operators on vessels and for the pilot study students with various backgrounds. This was because the system is safety-critical and from previous research it has been proven that under excessive stress the knowledge of an experienced operator is lowered to the level of a novice [Redmill and Rajan, 1997]. Before the user studies were carried out the ethical considerations were taken into account. This is important to maintain the participants' trust. This was done by making all participants sign consent forms and make them aware that they could leave the experiments at any time. None of the participants were in this case were particularly vulnerable (i.e. children), but some maintained their right to not have video clips or photos published.

To carry out a user study, the experimenter usually has a hypothesis. In order to test the hypothesis a set of dependent variables (what the experimenter will control) and independent variables (what will be measured) must be identified, with the value of the dependant variables depending on the independent variable. For small and simple studies there is normally only one dependent variable, but for larger studies this number can increase. For the last study done in this project three dependant variables were studied: average time spent on each task, average error rate on each task and reaction time to environmental distractions. In formal experiments it is also important to minimise the number of confounding variables that are varied unintentionally between the conditions during the experiment. Partly to address this, the studies were designed using a within-subject design where all participants repeated the same, or a very similar procedure, several times with different variations of the independent variable (experimental conditions). This approach can lead to learning effects, so the experiments were balanced with an even split of which experimental condition users would first encounter. After the above setup was selected, a procedure describing the process of what the participants are supposed to do was fixed. This procedure ensures that all participants are treated the same and also makes it possible for others to replicate the experiments. To make the experiments more robust, pilot studies are recommended. For this particular project, three user studies and one pilot study supporting the last iteration of user studies were carried out. Post-experiment it can be desirable to collect some additional qualitative and quantitative data. This data is collected by conducting a post-task walkthrough and make the participants fill out questionnaires that can be quantitatively measured by using Likert-scaled questions combined with the participants' opinion on specific matters. Post-task walkthroughs and questionnaires were utilised for all the experiments in this project. To gather and safely keep the results of the experiments protocol analysis has several different methods. In this case paper and pencil in addition to video recording was used.

By using the first generation prototype for a second iteration of user tests, it was possible to discover issues that concerned not only the gesture interaction, but also issues concerning the display technology. This emphasizes the advantages of doing prototyping and user- studies as an iterative design process. The drawbacks of prototyping are however the time spent on it together with not being able to test aspects such as safety and reliability. These features are often the most important, but will in a prototype be non-functional [Sommerville, 1992]. The feedback from the test participants after finishing the user study and going through a post-task walkthrough led to the development of the second generation prototype which will be described in section 6.

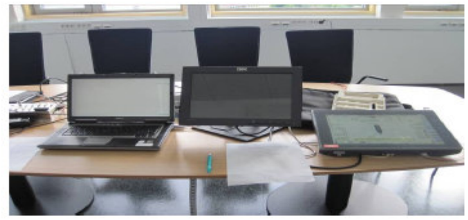


Figure 6: Static Lab Environment

5.1 TESTING GESTURES VS. BUTTONS/MENUS IN A STATIC ENVIRONMENT

The second iteration of user studies was built on the results from the initial study with the lo-fi paper/cardboard prototype. This study was carried out using the 1st generation prototype that implemented the four gestures into the Rolls-Royce DP system's software and the NextWindow display. This study employed the same tasks as the first user study in order to investigate the difference in interaction time between the use of gestures versus buttons and menus in a static lab environment. See Figure 6. The experiment included one independent and one dependent variable and one hypothesis was selected for testing.

Eleven first year nautical students from Aalesund University College participated. They had knowledge of DP systems in general, but no practical DP experience. This would make it easier to recognize a trend when operating the system using the different methods, because experienced/expert users can be predisposed from other DP systems, which could distort the result of the experiment. The reason for choosing test subjects with little to no experience is also based on earlier research [Redmill and Rajan, 1997], which implied that the experience of a skilled user is reduced to the level of a novice under strain and extreme stress. A system that is easily understood and operated by a novice will also support the skilled user in a safety-critical and stressful situation. During the experiment two touch screen systems were used, one with multi-touch functionality and one with standard single touch functionality. This was connected to an authentic DP application where a Rolls-Royce Marine Controller was used to supply the GUI with data. Four of six available degrees of freedom (DOF) were tested;

surge, sway, heave and pitch. The participants interacted with the vessel in two different conditions: button-based and using multi-touch. The tasks were identical for both conditions, but the methods used to interact were different. Initially the participants declared how well they knew Dynamic Positioning and operating DP systems. The experiment consisted of four parts: plenary session, introduction, series of tasks and a post task discussion. The students were briefed in plenary in a lecture room. All tasks were videotaped and the timestamp for each operation was recorded by the camera. All participants were given the same nine tasks to complete twice in each condition, in order to measure learning between first and second attempt. The tasks consisted of four tasks that changed the vessel's position and five tasks that oriented the camera in the 3D scene. After completing the tasks, the last minutes were spent on a post task discussion where questions concerning the understanding of the system, their overall impression of the interaction techniques presented and how they felt about operating a DP system using gestures were asked.

5.1(a) Findings and Methods used

To extract results from the experiment outlined above, the simple method used for the initial paper prototype study was extended and an experimental evaluation carried out to test the hypothesis. By using video recordings to time the different tasks, it was possible to measure the difference between the two presented methods and by using the timestamps for each task a statistical method was selected to analyse the data. Selecting the correct and most appropriate statistical test can be difficult. In this case a two-tailed paired t-test was selected due to the simple structure of the experiment with few variables and only one hypothesis. The outcome from the statistical tests gave an interesting and overall significant statistical result that supported the hypothesis. Due to the within groups design on the study the transfer of learning was likely to occur. This was therefore measured and between the first and second attempt the users improved in both interactions techniques. Overall, when comparing the observational and numerical results, it is clear that using direct gesture interaction is faster. Furthermore, according to participants' comments, it is more intuitive than the traditional button/menu interaction, though this has not been scientifically proven. The participants suggested a better display surface with more resistance and also a system that is less sensitive to touch and included a rotation gesture. The reason for more resistance on the surface was that the glass overlay caused problems for participants with moist hands. Their fingers kept sticking to the surface and made it difficult to carry out a continuous gesture movement. A system less sensitive to touch was suggested because even a small movement caused the system to register a gesture or a touch point. There is a general optimism towards direct gesture interaction, provided the technology is improved and made as optimal as possible. This together with the detailed statistical data is out of the scope of this paper and will be separately discussed in a future research paper.

Reading the post task discussion before doing the statistical analysis very often gives a good pointer towards which results will be unveiled from the statistical calculations. This was also the case for this experiment. The participants felt the system was overall a good regardless of which interaction techniques used. After a user study has been carried out and reported, critique is an issue that is either welcomed or despised. Possible critique for this particular study could be the lack of error rate analysis. If this had been added as an additional hypothesis and variable the structure would increasingly be more advanced and possibly another statistical test should have been chosen, such as the much often used ANOVA test. The experiences from this study were the foundation of a new and extended study described in the next section.

6. REALISTIC PROTOTYPE TESTING

The second generation prototype was built on the same software base as the previous, Rolls-Royce Icon DP. However a new generation tablet-PC replaced the NextWindow touch display (see Figure 5). The Dell Latitude XT2 tablet has a 12.1" mulitouch screen, runs Windows 7 (the first mainstream OS supporting multi-touch interaction) and uses touch drivers from NTrig. The tablet computer's display surface feels better to touch and is less sensitive than the NextWindow glass overlay, solving the issues raised by users of the previous prototype. The second generation prototype was used in two different iterations of user studies where the aim was to investigate if and how movement would impact operating the system using multi-touch interaction versus buttons and menus.

6.1 TESTING GESTURES VS BUTTONS/MENUS IN A STATIC VS MOVING ENVIRONMENT USING 2ND GENERATION PROTOTYPE

6.1(a) Motion Platform Pilot Study

The purpose of this experiment was to investigate the differences between manipulating a computer displayed object using gestures or buttons in a static environment versus in a moving environment, using a tablet computer and a movement-platform to simulate sea movement. Eight students with various backgrounds from Aalesund University College participated. They utilised the 2nd generation prototype tablet computer with multi-touch functionality to carry out the experiment. In addition they were seated on a moving platform which moved according to settings which simulated different conditions, in this case rough sea.

The participants were presented a collection of photographs displayed in a standard photo viewer (Windows Picture and Fax viewer). The participants interacted with the displayed photos in four different conditions (interaction x environment). The tasks were identical, but the setting while interacting to achieve the task goal was different. The tasks were conducted in a non-moving and in a moving environment. In each environmental condition, the participants carried out the tasks using two different interaction methods, multi-touch interaction or the buttons and menus manipulate a picture in the photo viewer. The purpose of using gestures to manipulate a photo was to relate it to using the same gestures to manipulate a vessel in the 3D scene of a dynamic positioning system. This allowed us to investigate the pros and cons of using gestures in a moving environment. Between the task sets and post-task the test participants filled out a NASA TLX questionnaires. NASA-TLX is a subjective workload assessment tool. NASA-TLX allows users to perform subjective workload assessments on operator(s) working with various human-machine systems. NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales [Cairns and Cox, 2008]. The motion platform pilot gave insight in how to perform a larger study using the DP system and also gave an indicator towards the impact of movement and which technique was more efficient. The test-participants felt more comfortable to operate the interface using gesture interaction. In addition it gave insight into practical considerations such as the screen being slightly unstable, indicating that for the main study support of a device in shape of a lectern or similar is needed.

Doing a pilot study has benefits such as that it is possible to pre-test conditions and gathers experience towards planning the main user study. A pilot is informal and does not need to be flawless. The equipment can be tested and the researcher can also get acquainted with the environment where the study is to be carried out. In this particular pilot study a HSC ship simulator was utilized that demanded some training to operate. The next iteration using the second generation prototype was the follow-up study.

6.1(b) Using Gestures to Operate a DP System in a Static vs. a Moving Environment

The fourth and last iteration of user studies was carried out also using the 2^{nd} generation prototype, but with the Rolls-Royce DP system running on the tablet computer. The aim of this experiment was to investigate the differences between using gestures or touch in a static environment versus a moving environment. This iteration used the authentic DP system, the HSC simulator with motion platform and a live visualisation where vessels were crossing at specified time intervals. See Figure 7. The study included 19 test participants with maritime


Figure 7: Moving environment using HSC simulator

background who encountered several conditions using gestures versus buttons and menus, and with and without movement of the motion platform. With buttons, in this case, the real context is using soft-keys on a display. A set of experimental parameters were prepared with independent and dependant variables and a set of four hypotheses.

Pre-experiment the participants filled out consent forms and gave information about themselves and their level of experience. The participants interacted with the vessel in four different conditions. Two Likert-scaled questionnaires were filled out, one between change of conditions and one after completing all conditions. The tasks were identical for all conditions, but the interaction style used to achieve the goal of the tasks was different. The instructions were given verbally in Norwegian read from a manuscript, so that it was the same for all participants. The tasks were conducted in a static and a moving condition where the participant carried out the tasks using multi-touch interaction manipulating the vessel in the 3D scene. The test participants used their hands to perform different gestures that changed the vessel's direction. The tasks were also performed in the traditional way using buttons and menus in a moving/non-moving environment. During the study the test participants also had to keep an eye out the window for crossing vessels. When they spotted a vessel in the visualisation, they notified the observer by saying: "Boat!". The reason for adding a distraction task to the experiment is connected to the discoveries made during the observation study. Here it was observed that the operator spent most of his/her time looking out the windows during operation to ensure safety on deck and around the vessel [Lumsden et al., 2008]. This study was thus a 2x2 study design resulting in the 4 conditions mentioned above. The conditions were tested in a within-group balanced study. The conditions are consistently tested with visualisation in the simulator, which means that the test subjects see a moving landscape when looking out of the bridge windows. For a within-subject design all users have to do four combinations of the conditions, with conditions in counterbalanced order to counteract learning effects.

6.2 Findings and Methods used

The experimental evaluation utilised the motion platform pilot study, hypotheses and experimental variables, within-group design, protocol analysis, questionnaires and a post-task walkthrough. To analyse the data the method used was adapted to suit the study design with more variables. The possible critique of the static environment experiments was addressed by investigating error rates and by selecting a more frequently used statistical test, repeated-measures ANOVA. The evaluation tested the hypotheses. For protocol analysis video recording was utilised to time the different tasks. While full analysis is still ongoing, initial results indicate that movement had little to no effect on the task performance. Under both conditions (gestures/buttons) the participants showed good awareness out the windows, but a difference between them appeared when performing tasks using gestures. During lookout using buttons, the participant lifted the fingers off the display, scanned the scenery and then shifted the attention down to the screen to finish the task. When using gestures, the participant kept moving the vessel while at the same time as scanning for crossing vessels. This gave a more flowing and dynamic interaction with the screen and supports that the interaction can be more efficient when using gestures in this type of scenario.

7. FUTURE METHODS

The study so far has focused on observing users and attempting to give a solid scientific foundation to attempt to prove the scientific hypotheses that multi-touch interaction with a DP system is more task appropriate than using the traditional interaction techniques mentioned. The results from the final tests do not appear to strongly support this, but detailed analysis still needs to be done to set any fixed conclusions. If Rolls-Royce Marine where to go forward with this, the next steps would be to build a fully operational system based on the results from the studies and to do think-aloud sessions with prospective users. The think-aloud technique involves participants thinking aloud as they are performing a set of specified tasks. Users are asked to say what they are looking at, thinking, doing, and feeling, as they go about their task [Lewis, 1982]. This provides a quick way of revealing problems people have with a working system and the possibility to correct them.

8. SUMMARY AND CONCLUSION

This paper has described the different steps of a research project where different methods were used to evaluate human computer interaction in a maritime environment, here a DP system. The project's aim was to investigate the possibilities of introducing multi-touch and direct manipulation of 3D objects in the DP system's GUI as an additional interaction technique. The methods used are well known from consumer-based research. Through several different iterations of prototyping followed by user studies it was possible to find answers to the presented hypotheses. The hypotheses were concerned with the differences between operating a DP system when using gestures versus traditional buttons and menus in a static versus moving environment. Three different prototypes were tested; where the initial was lo-fi and the first iteration of user tests produced the results needed to develop a second prototype where they could be implemented. The 1st generation prototype was software and hardware based and gave the possibility of investigating multi-touch interaction in a static environment through a second user study. This study resulted in interesting and significant results. The feedback from the test participants were taken into account and a 2nd generation prototype were developed using similar software adapted to fit new and better hardware. Two iterations of user studies were carried out using the 2nd generation prototype, one pilot study and one larger study. The larger study was the last study in this project that concerned operating a DP system using buttons/menus versus gestures in a static versus moving environment. In addition the participants were distracted in order to keep their focus on both the interface and the surrounding environment. Preliminary analysis of the data amongst others, seems to indicate that the movement had little to no impact on performance and that using gestures during look-out lead to a more flowing interaction.

After generating four different iterations of user studies and testing, it was possible to reveal issues that would have stayed hidden if decisions of selecting hardware and software were taken without utilising these methods of low-cost testing. In addition the results from extensive testing can be reused and used to create guidelines for similar types of problems to be addressed. The limitations of creating several prototypes are however that it is time consuming and often it is not possible to test all conditions to make it as authentic as possible. The other issues that limits the iterative design is that design decisions often made in the very beginning of the design process may be wrong. Dix et al. [Dix et al., 1997] state that when initial decisions are wrong, the design inertia can be so great as never to overcome an initial bad decision. In theory this means that an iterative design will discover changes that need to be made, but in practice there can be bad decisions within the basic design that are not unveiled and dealt with (finding a local minimum, but missing the global one). The other issue is that if a usability problem is diagnosed through testing, it is important to investigate the background of the problem and not only deal with the symptom. It is therefore important when working with an iterative design process to support the process with additional methods and thorough testing.

Overall for safety-critical environments such as the maritime sector, the process of investigating the product's surrounding environment and influencing factors is time consuming, thorough and expensive. However, this process is carried out once for each product area and by reusing the knowledge gained; user studies can more efficiently and often be carried out. That can save money and time by avoiding obvious pitfalls and faulty design decisions. In addition, it can give a more satisfactory product where the equipment is actually usability tested where the base for decisions made is grounded in reported research.

ACKNOWLEDGEMENTS

Many thanks to: Aalesund University College and the Nautical Institute, Mark and Eva for being ace supervisors, Rolls-Royce Marine AS for supporting my research and providing a great working environment, the Geek Ladies for good support and to the ones at home whom I could never be without.

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Appendix D

Study of DP's System Design - Introductory Sheet

The background of this study is to investigate which interface is the most intuitive interface for a Rolls– Royce Marine dynamic positioning system (DP). The aim is to examine if the system design is intuitive to the user when it comes to operating the vessel in its graphical user interface (GUI). The different methods of operating the vessel using multi-touch vs. single touch will be registered.

The test will be conducted in a 3D software environment, using a touch-display which is connected to the DP system (control system and application). This leads to a test of 4 of the 6 available degrees of freedom (DOF); surge, sway, pitch and heave.

You are presented to the DP's real-life graphical user interface used on vessels offshore. There will be 8 tasks given where you will move the vessel using either your hands or the menus presented to you in the interface. The experiment will take approximately 20 minutes altogether, where 15 minutes are reserved for the tasks and 5 for a post- test discussion. The session will be video recorded and information that arises during the experiment can possibly be published. The information will be depersonalized and is purely used to improve and research system design. If you feel uncomfortable and want to leave, please say so and you can leave at any time.

Please proceed to the next page after filling out the details below.

Age: ____________ **Sex:** ____________

Official title/education: ____________________________

How well do you know Dynamic Positioning and operating DP systems?

(Please circle the appropriate alternative below.)

Little experience - Average experience - Good experience

Consent

- I am aware that I can leave the experiment at any point without feeling obligated to sit throughout the estimated time.

- I agree to the session being digitally recorded, both sound and picture.

- I [give / do not give] * my consent for video and still images recorded during this session to be used in future academic publications and presentations by Frøy Birte Bjørneseth (* please mark which option that applies to you).

- I agree to the information obtained in this experiment can be published in suitable research forums and conferences.

- I am aware that the data obtained during this experiment, is solely used for researching system design.

- I am aware that the information given by myself to this experiment is depersonalized.

Date: __________ Place: _____________

Signature: _______________________________

Appendix E

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Rolls-Royce Marine AS, Dept. Common Control Platform

University of Strathclyde, Dept. Computer and Information Sciences

Consent Form: Testing gestures using a movement-platform to simulate sea movement

Voluntary Nature of the Study/Confidentiality:
Participation in this study is entirely voluntary. You may refuse to continue at any point or ask the researchers any questions. Your name will never be connected to the research results; a pseudonym will be used for identification purposes. Information that would make it possible to identify a participant will never be included in any sort of report, or disclosed outside the project, unless explicit permission has been given.

1. Participant's Name: ___________________________

2. Age: ___________________________

3. Education/position: ___________________________

4. Are you (circle the correct alternative): **Left Handed** **Right Handed**

5. **How well do you know Dynamic Positioning and operating DP systems?**
(Please circle the appropriate alternative below.)

Little knowledge/Experience - Average knowledge/Experience - Good knowledge/Experience

Please read all statements below indicate your preference by circling either yes or no.

a)	I have read and understood the accompanying information sheet. On this basis I consent to taking part in this study and to publication of the results of the project.	yes	no
b)	I consent to still images and video footage of me being *taken* and used by Frøy Birte Bjørneseth for research purposes.	yes	no

Video data and images may sometimes be required for academic presentations/publications to demonstrate features of the research. Participant's names are not released to anyone outside the project.

c)	I consent to video footage and digital images of me being used in academic conference presentations.	yes	no
d)	I consent to digital images of me being used in academic publications.	yes	no
e)	I consent to digital images of me being used in academic web pages of the project	yes	no

Signature: ____

Date and Place: _______________________________________

Email Address* and/or telephone*:_________________________________

Questionnaire 1 and 2:

In which system was it easier to do a rotate?

Much easier with buttons	1	2	3	4	5	6	7	Much easier with gestures

How easy was it to move forward/backward?

Much easier with buttons	1	2	3	4	5	6	7	Much easier with gestures

How easy was it to move left/right?

Much easier with buttons	1	2	3	4	5	6	7	Much easier with gestures

How easy was it to zoom in and out?

Much easier with buttons	1	2	3	4	5	6	7	Much easier with gestures

Which method would you use and why?

Do you have any other comments?

Questionnaire 3:

How did the movement of the platform impact you?

How did the visualisation and the fact that you had to keep an eye out for crossing boats in your waters impact your performance?

Do you have any other comments?

Overview of Participants for the main study reported in Chapter 7

Participant	**Age**	**Right/left handed**	**DP knowledge**
1	28	R	Average
2	23	R	Little
3	23	R	Little
4	23	R	Little
5	32	R	Little
6	22	R	Little
7	21	R	Average
8	21	L	Average
9	26	R	Little
10	24	R	Average
11	21	R	Little
12	20	R	Little
13	22	R	Little
14	20	R	Little
15	20	R	Little
16	22	R	Little
17	20	R	Little
18	20	R	Little
19	30	R	Little