NTNU
Norwegian University of
Science and Technology

Development and Testing of a Ship Controller Interface - An Affective Engineering and Wayfaring Approach

Erik Andreas Karlsson

Master of Science in Mechanical Engineering
Submission date: June 2016
Supervisor: Martin Steinert, IPM

Norwegian University of Science and Technology
Department of Engineering Design and Materials

NTNU - NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

MASTER'S THESIS SPRING 2016
FOR
STUD.TECHN. Erik Andreas Karlsson

Next Generation ship bridge wing – Future Interaction

Neste generasjons skipsbro vinge – Fremtidens interaksjon

How might interaction during docking of a ship be improved for the captain and his crew?

The ship captain and his crew are working under high stress situations during docking. They take advantage of the ship's bridge-wing to improve their field of view and increase control of the ship close to the dock. Today, the ship bridge wing workstation is composed of a large console with numerous buttons, devices and screens, although they only use a few of them to control the ship.

A Pre-master project, executed during the fall of 2015, lays the background for this master's thesis. The pre-master showed that a great deal of positive changes can be made, but regulations hold the evolution back. A lot of these regulations are ignored during this master's thesis, in order to be innovative and forward thinking. The master's thesis will concentrate on human-machine interactions, implementing aspects from affective engineering, human machine interface and stress measuring in developing new interaction-devices for the ship bridge wing.

Focus areas in master's thesis:
- Devices
    - Main functions
    - Device operation
    - Multi-function vs. dedicated devices
- Information
    - System feedback
    - Visual information
- Device measuring
- Cognitive load measuring
- Experimental setup

The aim is to develop high resolution prototypes that help to model and judge prospective interactions. If possible the work shall constitute the foundation or parts of an academic publication.

Formal requirements:
Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (https://www.ntnu.no/web/ipm/masteroppgave-ved-ipm). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.
The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.
The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

The contact person at Kongsberg Maritime Espen Strange, and at NTNU Prof. Martin Steinert.

Torgeir Welo
Head of Division

Martin Steinert
Professor/Supervisor

NTNU
Norwegian University of Science and Technology
Department of Engineering, Design and Materials

Acknowledgements

This master's thesis is the result of an initial challenge from Kongsberg Maritime to look into the next generation ship bridge. Thanks to the research community at TrollLabs NTNU and my two industry contacts in Kongsberg Maritime – Espen Strange & Pål Gunnar Eie – my time working with this thesis (and the pre master thesis), introduced me to a new way of working with development and experimental research. I would like to send a special thank you to Martin Steinert, the head of TrollLabs for inspiring collaboration and guidance. I must also thank Stephanie Balters for guiding me in the jungle of human related experiments. Lastly, the guys in the third-floor hallway at Perleporten has been helpful and always up for good discussions, thanks to you all!

This page is intentionally left blank.

Abstract

The ship bridge environment is complex and the task of navigating large vessels is a highly demanding task. This leads to a large responsibility resting on the officers' shoulders, thus developers should aim to ease the crew members' everyday working environment. In this thesis, Affective Engineering is combined with a Wayfaring approach to help develop a new controller interface and test aspects of inflicting nature on the captain's attention and mental resources. This is done through a pilot experiment setup measuring cognitive load of the user while interacting with a novel controller design. The new design proposed is a multifunction interface with dedicated input devices, substantially smaller than existing versions. Further statistical analysis of the recorded experimental data is performed, comparing the new design to one of old characteristics. The main intention with the work presented is to serve as a pilot for further introduction of Affective Engineering in maritime industry development. The experiment showed some tendencies towards possible solutions for measuring aspects of cognitive load, control device interaction and partially positive concept evaluation of a novel controller interface.

This page is intentionally left blank.

Sammendrag

Miljøet om bord på en skipsbro er svært komplekst og oppgaven med å navigere større fartøy er en svært krevende oppgave. Dette fører til et stort ansvar som hviler på offiserenes skuldre, og dermed bør produktutviklere og designere ta sikte på å lette mannskapets hverdag og arbeidsoppgaver. I denne oppgaven er Affective Engineering kombinert med Wayfaring for å utvikle et nytt kontrollergrensesnitt samt å teste aspekter ved kapteinens oppmerksomhet og mentale ressurser ved bruk av skipskontrollere. Dette er gjort gjennom et pilotforsøk, hvor kognitiv belastning hos brukeren er målt i samspill med en ny kontroller. Den nye utformingen foreslått i denne oppgaven er en multifunksjonell enhet med dedikerte brytere, vesentlig mindre enn eksisterende varianter. Statistisk analyse av de registrerte eksperimentelle data er utført, og resultatene er sammenlignet med et tradisjonelt design. Hovedintensjonen med arbeidet som presenteres er å teste muligheter for videre innføring av Affective Engineering i maritim utvikling. Forsøket viste noen tendenser til mulige løsninger for hvordan å måle deler av den kognitive belastningen, samt dels positive konseptevalueringsresultater i favør av det nye designet.

This page is intentionally left blank.

Table of Content

This page is intentionally left blank.

List of Figures

This page is intentionally left blank.

List of Tables

This page is intentionally left blank.

1 Introduction

The maritime industry plays a critical role in the world economy, and spans across several areas such as passenger and goods transport, offshore installations and ship construction amongst others. Many of these sub industries work within developing, constructing and engineering ships for several of the above mentioned purposes. Diving even further, companies develop specific components to become parts of the ship bridge, the main control center of the ship and home to the captain and his navigating officers and crew. The ship bridge consists of several control areas: the center bridge, the bridge wing, and sometimes the aft bridge. For this thesis, the Ship Bridge Wing (SBW) and its controllers is of main interest and will be further introduced in the following sub sections. A definition of the SBW applied to this thesis is as follows:

"A ship bridge wing is an extension of the ship bridge, the "pilothouse" of a vessel, reaching out towards or slightly beyond both sides of the ship. It allows bridge personnel, such as captains and officers, to increase their overview of the shipside and environment while maneuvering in narrow waterways and/or docking" (Karlsson & Solvang, 2015)

In order to fully grasp the possibilities of the ship bridge wing, a previous study of the environment was performed during the fall of 2015 as a pre-master project thesis by Ferdinand Solvang and Erik Karlsson which is included in Appendix F, and will hereby be referred to as Karlsson and Solvang (2015). The pre-master serves as an exploratory foundation to the master's thesis presented in this report. It revealed a lot of potential for improvements within the SBW, and led to further investigation and development of the physical dimensions and specifications of the console chassis by Ferdinand Solvang, and the controller interface by this thesis' author.

The work presented in this thesis includes two main stages: controller interface development, and evaluation and measurement of the controller interface through an experiment. These descriptions are presented after an introduction to relevant theory and methods, and followed by statistical analysis, discussions and conclusions.

1.1 Ship Bridge Wing Environment

The ship bridge wing environment of today often consist of one fixed, large console cluttered with buttons, controllers and devices. This includes, but is not limited to, main propeller device, thruster devices, rudder device, interface control devices, Electronic Chart Display (ECDIS), radar, several communication devices, light switches, conning display and device-specific buttons. Previous studies, although fairly old, of the ship bridge proved inconsistency, non-ergonomic solutions and irrelevant information presented to the crew (May, 1999). As one might understand, the evolution of the control interface needs change, and this thesis ignores the strict regulations of the maritime industry to make radical suggestions towards a new ship controlling interface. Further, direct feedback from the controller is discussed, both as visual stimuli and haptic vibration feedback so that parts of the SBW environment can aid the captain in his task of safely navigating the ship. Possibly the most important criterion in this thesis is that the environment should support the captain and his crew's decision making, and that it should be adapted to the users rather than the users adapting to it. This involves understanding the interactions on a ship bridge wing, briefly introduced in the following section.

1.2 Interactions on a Ship

Onboard a ship bridge, numerous interactions occurs between humans, humans and machines, human and digital interfaces and between machines. The sheer number of interactions necessary to safely navigate the ship leads to a long chain of possible sources of error, thus it is an important task resting on the developers' shoulders. To help define what is meant by interactions in this thesis, some examples of the different categories is defined in table 1-1.

Table 1-1: Interaction examples

Category	**Interaction**
Human – Human	• Direct discussions/orders • Radio communication
Human – Machine	• Controller changes • Computer inputs
Machine – Machine	• Signal processing • Sensors

Further, this thesis focuses on the Human Machine Interface (HMI), in particular related to the controller. Such interaction interfaces serve as critical components of the complex system that is a ship bridge. In addition, one might argue that the most critical situations are navigating in close relation to something or someone, i.e. during docking, and precise navigation is key. Also, as the increase of computerized and automated assistance is by now a fact, the development of these interfaces must gain increasing importance. The following sections present some of the previous work done within the field, and the next chapter introduces a theoretical background used in this thesis covering important aspects related to this development.

1.3 Previous and Similar Work

The ship bridge has through the years been subject of a lot of changes, all the way from manual rudders back in the days, to automated Dynamic Positioning (DP) vessels today. Aspects of mental workload and cognitive load of the users has been an increasingly important factor when developing new ship bridge systems. Bjørneseth, Renganayagalu, Dunlop, Homecker and Komandur (2012) did pre-studies analyzing the dynamic workload and visual patterns of DP operators using eye tracking and the NASA Task Load Index. They found that the operators' graphic interfaces might have greater influence on the performance then first anticipated, and that portions of the information displayed was not necessary.

Grootjen, Neerincx and Veltman (2006) and Grootjen, Bierman and Neerincx (2006) researched cognitive load related to interfaces in ship control centers and found that high levels of task switching and demanding information processing decreased performance, led to more errors, and stated that the interfaces should aid the user by applying the right support at the right time.

Nilsson, Gärling and Lützhöft (2009) analyzed differences between an old manual ship bridge and a new high-tech version in a full size ship simulator. The found that older more experienced officers had tendencies of greater performance with the old setup, but younger and less experienced officers had the opposite result. However, their statistical analysis showed no overall difference as to which degree of technology led to greater performance. This might indicate that younger officers might be more suitable for testing future solutions for a ship bridge because they are the ones that will eventually use the new products, but also because they have less traditional biases towards what they are familiar with after several years on the bridge. With these thoughts in mind, the following chapter introduces a theoretical background for the work done in this thesis.

This page is intentionally left blank.

2 Theoretical Background

2.1 Developing New Technological Products

To embrace the opportunities of a SBW, one should be able to zoom out and start with a blank sheet from time to time. In product development, this blank sheet is often referred to as the Fuzzy-Front End phase (FFE; Smith & Reinertsen, 1991), defined as the state between the discovery of a new opportunity and when it is taken in by the organization according to S. E. Reid and De Brentani (2004) and Kim and Wilemon (2002). The ambiguity that exists in such “blank-sheet-opportunities” in the FFE allows for great potential when developing new products (Reinertsen, 1999; Steinert & Leifer, 2012). On the other hand, ambiguity is for many a difficult state to deal with, especially organizational leaders, and might be daunting to development teams (Kim & Wilemon, 2002). Luckily, there exists methods and models for dealing with the FFE phase of product development, more precisely, the first states of Design Thinking (DT; Brown, 2008; Meinel & Leifer, 2010) and the concept of Wayfaring (Gerstenberg et al., 2015; Leifer & Steinert, 2014; Steinert & Leifer, 2012) amongst others.

Design Thinking is a philosophy and methodology with a human-centered point of view, which includes all activities of innovation, according to Brown (2008). A tweak of this mentality is discussed by Norman (2005) who argues that the activities performed by the human with the product of interest should be the center of attention, not the human itself. DT separates from traditional models such as the Stage-Gate model by Ulrich and Eppinger (2012) depicted in figure 2-1, by emphasizing iterations of states (Meinel & Leifer, 2010), see figure 2-2, rather than predefined linear steps. The advantages of the Stage-Gate model are often related to ease of control, follow-up and revision, while benefits of DT often relate to increased problem definition, product understanding and opportunity utilization.

Wayfaring, as proposed by Steinert and Leifer (2012), and further developed by Gerstenberg et al. (2015), illustrates the process through the “Hunter-Gatherer Model”. This model takes advantage of previous experiences in the team to anticipate the direction of a new product development process. However, as Steinert and Leifer states, the

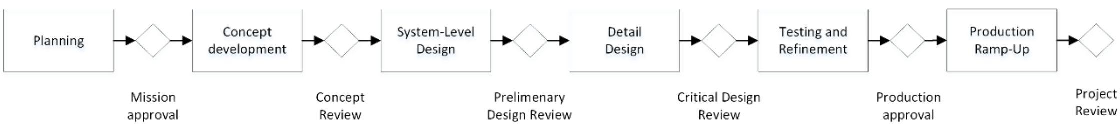


Figure 2-1: Stage gate model as proposed by (Ulrich & Eppinger, 2012, p. 22, Product Design and Development)

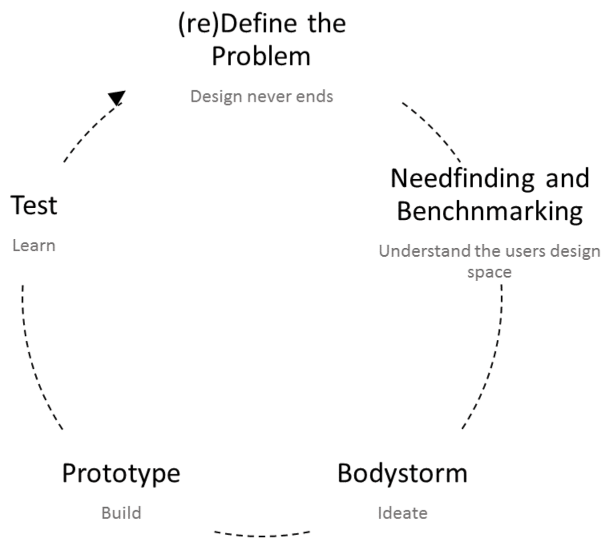


Figure 2-2: Design thinking model, remade from Meinel and Leifer (2010, p. xiv)

perspectives shift throughout the process and the directions change according to new learnings. The learnings are in term achieved through short iterations of prototypes and tests, as illustrated by the circles, or "probes" in figure 2-3. The probes are rounds of iterative work, starting with a phase of divergence, exploring and testing new ideas and concepts rapidly. It ends with a phase of convergence, where ideas are put into context. These cycles can then be repeated or done in parallel, both within each Probe, and as separate design Probes. A common tool to convey ideas and create learnings during probing is prototypes, which allows for fast learning through tests, customer interactions, and evaluation. Multiple runs and direction changes will again lead to an increased understanding and better definition of the concept, and eventually the product requirements. At the end of the Wayfaring process, a regular "Take it home" approach should be applied,

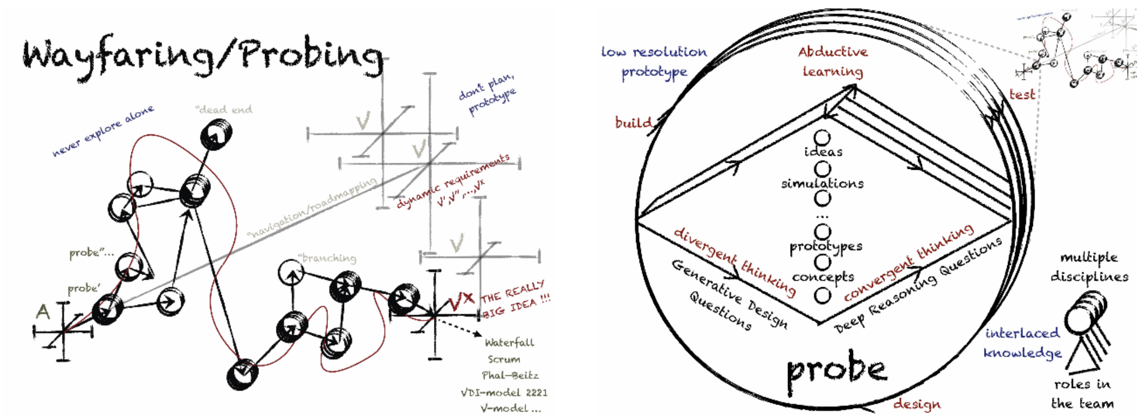


Figure 2-3: Wayfaring (left) and probing (right) as proposed by (Gerstenberg, Sjöman, Reime, Abrahamsson & Steinert, 2015, p. 4 & 5)

i.e. the stage gate model, for product optimization based on the new learnings and discovered opportunities of the "blank-sheet" start.

The earlier mentioned prototypes and especially the act of prototyping can be defined as iterative rounds of communicating a desired idea or concept related to any or multiple features and/or qualities, serving as support in testing, evaluation and learning (Dow, Heddleston & Klemmer, 2009; Houde & Hill, 1997; Lim, Stolterman & Tenenberg, 2008). Further, Dow et al. argues that the iterative way of dealing with prototypes increases the likelihood of a good result, which corresponds well with the mindset of Wayfaring and Probing.

However, prototypes are not straight forward building and testing. The prototype and its characteristics, may it be level of detail, material properties, purpose or function, is important factors to consider when using this tool. Such considerations is often referred to as *"manifestation dimensions"* (Lim et al., 2008, p. 3) or *"prototype resolution"* (Edelman & Currano, 2011, p. 62), where the latter will be referred to in this thesis. The different resolutions may also lead to biases related to a model's affordance, as a higher resolution prototype may seem more finished than a lower one, which is not always the case. It all depends on whom and what the prototype is intended for. For instance, graphical models on a computer is considered to have rather high resolution, but conveys lower affordance relating to alteration possibilities from a stakeholder (Edelman & Currano, 2011).

2.2 Interaction Design and Ergonomics

Sharp, Rogers and Preece (2007) speaks of interaction design (ID) as the development of products, in particular interactive products, that is easily understandable, easily usable and effective to use. Cooper, Reimann, Cronin and Noessel (2014) reviews interaction design as designing systems and products with interactive characteristics. This spans across a variety of disciplines and product categories, and in today's market, its impact is forever expanding. Interaction design could very well be performed using the methods described above (Wayfaring and Design Thinking), as designing products relating to human interactions calls for a user-centered approach (Sharp et al., 2007), which is also the basis of DT, see Brown (2008). In order to create new, effective interfaces, the integration of the user as part of the process has positive effects (Blair-Early & Zender, 2008), and should serve as a guide towards the end product. The synthesis of the user and the designer/engineer will eventually also aid the ergonomics of a product.

Ergonomics cover everything from the form and shape of a single feature, to the feedback from a system and all the way to the user's motions and the usability (International Ergonomics Association, 2016). It even relates to the cognitive attributes of a product (Bridger, 1995; Hollnagel, 1997). (Cognitive load is discussed further in subsection 2.4.) Such cognitive attributes may be related to the products affordance and subjective understanding of certain aspects, i.e. a button, an interface, a scale etc. Following up on this, the relation between these attributes and the human should be further investigated and included in engineering design as suggested by the affective engineering approach presented next.

2.3 Affective Engineering

Affective engineering, also known as *Kansei engineering* (KE), was founded by a Japanese professor, Mitsuo Nagamachi, in the 1970s as a means to include and formalize the customer's emotions into product design and engineering. Kansei is a Japanese word for physiological feelings or needs, (Dahlgaard & Nagamachi, 2008), and KE is defined in short as:

"Translating technology of a consumer's feelings (Kansei) and image for a product into design elements" Nagamachi (1995, p. 4).

Nagamachi categorizes KE into three styles, Type I, II and III, where Type I can be referred to as a quantifying or classification tool to aid decision making and product specification. Type II and III involves computer systems and relies on algorithms to transform the customer's holistic image and feel for a product into product specifications. This traditional form of KE relies on subjective humans or computerized mathematical models and algorithms to interpret customers' emotions, and transform them into product design. Although ship bridge components may not fall under the definition of a consumer market as Nagamachi's original KE was intended for, the founding principles and philosophy it builds upon allows for application to the ship bridge environment as well.

However, Balters and Steinert (2014) argues that the engineers' decisions are, as well as the users', affected by their emotions, and suggests an hypothesis that:

"Engineering decisions are per se non-rational and/or unconscious."(Balters & Steinert, 2014, p. 14)

By applying this radical thought to engineering design, Balters and Steinert calls for more research on and a change of view regarding decision-making in engineering design, both with respect to the customer and the engineer. Further work of Balters and Steinert (2015) shows the complexity of the human, and states that the irrational and unpredictable behavior causes difficulties when making engineering decisions that affects the end user. Such decisions are often based on experiences from previous trials and errors, but in the maritime sector, wrong decisions often have fatal and/or highly expensive outcomes, thus the affective engineering approach may aid the development and understanding of how future interactions affects the ship bridge environment.

For this thesis, the main focus is the cognitive load of the user, as it is known to be a critical factor in complex systems (Moray, 1988; O'Donnell & Eggemeier, 1986), and is for this reason an important aspect of the early design phase (Xie & Salvendy, 2000) of a human machine interface. Aspects of cognitive load are discussed further in the following section.

2.4 Cognitive Load

Maritime accidents is often caused by humans (Bryant, 1991; U.K. P&I Club, 1992), and Kum, Furusho and Fuchi (2008) links the effect of mental workload to the initial human error. Thus, a product’s impact on the user is vital in a high responsibility task such as that of controlling a ship full of people, precious cargo or high-risk offshore tasks. According to Di Nocera, Camilli and Terenzi (2007), high states of mental workload increase the probability of human errors by decreasing the humans ability to react to information, and F. G. Paas and Van Merriënboer (1994) says that the human’s limited cognitive processing capacity is a restricting factor when doing problem solving in complex domains. Breaking this down could indicate that components used during the captain’s primary task of safely navigating the ship should therefore build up his chances to perform at his best. One aspect of increasing performance, could be to reduce the mental workload of the captain, especially related to interaction with the ship’s systems during operation. As the systems on existing ship bridges is highly complex, they are responsible for increased likelihood of human errors, as discussed in previous work by Karlsson and Solvang (2015). It is also known that increasing complexity is directly related to higher mental workload and cognitive load, thus decreasing the captain’s ability to perform his task without errors.

A generally accepted definition of cognitive load is:

“The mental effort or load that a particular task imposes on an individual’s working memory”(F. Paas, Tuovinen, Tabbers & Van Gerven, 2003; F. G. Paas & Van Merriënboer, 1994; van Gog & Paas, 2012)

A similar, redefined definition of mental effort, supporting the above mentioned is:

“Mental effort is the aspect of cognitive load that refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task; thus, it can be considered to reflect the actual cognitive load” (F. Paas, Tuovinen, et al., 2003)

Further, Sweller (1994) and Sweller, Van Merrienboer and Paas (1998) defines three types of cognitive load: *intrinsic*, *extraneous* and *germane*. Intrinsic cognitive load is the effort of processing what is essential for a specific task, extraneous cognitive load is the processing of how tasks or objectives are presented, and germane cognitive load refers to storing information in the long term memory and relating it to previous knowledge (DeLeeuw & Mayer, 2008). In this thesis, the intrinsic and extraneous cognitive load is the main focus within the cognitive load construct.

While cognitive load is a known subject and factor in the performance of a task and acquiring knowledge, it is one of the directions that needs to be investigated, especially as part of human-machine interfaces (Rubio, Díaz, Martín & Puente, 2004). It also applies to the development of new products which include humans in general according to the affective engineering proposal by Balters and Steinert (2014), thus ways of measuring and quantifying human product relations is key.

Several ways to measure the cognitive load construct exists, such as the *NASA-Task Load Index* (TLX) (Hart, 2006; Hart & Staveland, 1988), the *Subjective Workload Assessment Technique* (SWAT) (G. B. Reid & Nygren, 1988), and the Workload Profile (Tsang & Velazquez, 1996). As DeLeeuw and Mayer (2008) points out, different measures and methods highlight distinct areas of cognitive load, and all of the above mentioned methods assess the user’s subjective rating of cognitive load and/or mental effort, as discussed in the following section. Therefore, objective measures such as a secondary tasks, see Kerr (1973), is also presented.

2.4.1 Cognitive Load Measurements

As the above section mentions, there exists several ways of measuring cognitive load subjectively and objectively. These methods can often be classified into three categories according to Meshkati, Hancock, Rahimi and Dawes (1995). These categories are: subjective-, physiological- and performance measures, relating to self-perceived effort, physiological activation and increased task demand respectively.

In the early days of measuring cognitive load, computational models and indirect measures was used to grasp the construct of cognitive load and mental effort (see Sweller, 1988; Sweller, Ayres & Kalyuga, 2011). Through the development of cognitive load theory (CLT; Chandler & Sweller, 1991; F. Paas, Renkl & Sweller, 2003; Sweller, 1988, 1994), concerning the relation between learning ability and cognitive load, and due to the advance in technology the past 20-25 years, more direct measures of the aspects of cognitive load arises. Subjects' abilities to rate and discuss the mental effort involved in a particular task as an "intensity of effort" measure, is defined by F. G. Paas (1992, p. 429) and could be treated as a measure, or "index", of cognitive load. Another traditional approach to assess mental effort and working memory load is through the use of a dual-task methodology, see Britton and Tesser (1982). An even earlier use of the secondary task approach is done by Kerr (1973). Kerr also argues that the secondary task should not inflict the performance of a primary task, but performances should be similar to a control group not performing two tasks in order to avoid conflicting measures. The different types of cognitive load measures, subjective and objective, are discussed in the following sections.

2.4.1.1 Subjective cognitive load measurement

When discussing subjective measures of cognitive load, the gold standard since its birth in 1988, is, according to many (Cao, Chintamani, Pandya & Ellis, 2009; Noyes & Bruneau, 2007; Xie & Salvendy, 2000), the NASA TLX (Hart & Staveland, 1988). The TLX is a questionnaire consisting of six scales to assess several dimensions of mental effort and cognitive load, to get a score of the overall workload of a specific task. It has been used in over 550 studies (Hart, 2006), applied across many disciplines and translated to several languages and cultures. The TLX's six scales are divided into three categories: task-related-, behavior-related- and subject-related scales, all with 5 point intervals ranging from 0-100 in score, resulting in a 21-point scale resolution. These are presented in Table 2-1, along

Table 2-1: Categories, scales and description of the NASA TLX

Category	Title	Scale	Description
Task related			
	Physical Demand (PD)	Low – High	Physical activity required
	Mental Demand (MD)	Low – High	Mental and perceptual activity required
	Temporal Demand (TD)	Low – High	Perceived time pressure during task
Behavior related			
	Own Performance (OP)	Perfect - Failure	Self-evaluation of performance according to the task
	Mental Effort (ME)	Low – High	Effort invested in the task
Subject related			
	Frustration (F)	Low – High	Level of insecurity, discourage, irritation, stress

with the scale endpoints, and the TLX scale is presented in its original form in Appendix A.

The original TLX includes pairwise weighing of the different scales to accommodate subjects' individual ranking of the scales relevance to the task and answers. This was initially to increase the sensitivity of the scale, but as it leads to a more time consuming and complicated process, later studies and applications often eliminate this process (see Byers, Bittner & Hill, 1989), and is often referred to as RAW TLX, or One-step TLX (RTLX; Hart, 2006) . Multiple studies comparing RTLX to the original yields no preferred method when it comes to the results (Byers et al., 1989; Hendy, Hamilton & Landry, 1993), but ease of use is in favor of the RTLX version, thus it has gained increasing popularity over the years. Because of this, the TLX's reputation and prior knowledge within the research team, the RTLX is the chosen method in the experiment described in chapter 0 and 6. However, some other alternatives are presented below.

Among the alternatives to the NASA TLX, or RTLX, is the mentioned SWAT and WP methods. SWAT, first described by G. B. Reid and Nygren (1988), utilizes a smaller scale and less questions than the TLX. It splits the workload into three dimensions (whereas TLX has six), called time load, mental effort load and psychological load, all rated in three levels, 1 – low, 2 – medium and 3 – high. Again, a ranking of the dimensions and levels are applied, but SWAT uses conjoint measurement procedures to develop ranked order intervals based on the subjects initial rating. Lastly, the score is converted to a 0-100 numeric value for each of the three dimensions. The Workload Profile method is derived by Tsang and Velazquez (1996) and is considered a hybrid cognitive load measure. It seeks to include assets from secondary task techniques in the subjective ratings of eight dimensions proposed by Christopher D Wickens (1987). The following section presents ways of measuring cognitive load objectively, including the secondary task technique implemented in the WP method.

2.4.1.2 Objective Cognitive Load Measurement

Objective measures of cognitive load spans from heart rate and blood pressure measurements (Fredericks, Choi, Hart, Butt & Mital, 2005), as well as pupillary responses and eye movement (Buettner, 2013), all the way to secondary task performance (Kerr, 1973). The origin of the relation between eye movement and pupillary response can be traced back to the work of Hess and Polt (1964) and Kahneman and Beatty (1966). They showed, together with Kahneman, Beatty and Pollack (1967), that a task's difficulty clearly relates to the subjects pupillary diameter, and that it corresponds with the cognitive load of the subject. In addition, eye movements, or more specified saccades (rapid eye movement), and blinking are correlated with cognitive load (Van Orden, Limbert, Makeig & Jung, 2001). This correlation is due to the fact that eye fixation is related to cognitive load, and the saccades are moments when the eye does not perceive information, a phenomenon called *saccadic suppression* (Matin, 1974). Thus, moments of increased fixations relate to higher cognitive load, while frequent saccades corresponds to low cognitive load (Van Orden et al., 2001). Such measurements of the eyes characteristics could be performed through eye-capture devices and computer algorithms for recognizing the motions.

Other studies performed by Kakizaki (1984) and Kohlisch and Schaefer (1996) showed a relation between heart rate (HR) and mental workload, specifically the attentional aspects. Previous studies by Ettema and Zielhuis (1971) concluded that both blood pressure and HR increased by 10-15% when a subject is affected by higher mental load, and Becker et al. (1996) also found similar results in their experiments. This, increased HR, could serve as a measure of cognitive load, but measuring it is somewhat intrusive on the subject since measurement tools needs to be fixed on the person (i.e. ECG electrodes, HR finger monitor). A less invasive method might be to use a secondary task as presented below, as it does not result in intrusiveness regarding the subject.

The secondary task approach, or dual-task methodology, is widely used within psychology (F. Paas, Renkl, et al., 2003; Sweller, 1994; C. D Wickens, 1984), and in learning activity research (Brunken, Plass & Leutner, 2003; Brünken, Steinbacher, Plass & Leutner, 2002; Chandler & Sweller, 1996). One underlying assumption is basis for the dual-task methodology. That is, the working memory's processing ability is limited, but it could alternate between different tasks (Miyake & Shah, 1999). Brünken et al. (2002) applies the secondary task to a primary learning activity. Here, the subjects are instructed to react to a letterbox changing color from black to red, by pushing a button at random intervals through the primary activity. The reaction times between the color change and the push of the button was related to the cognitive load of the primary task. A high demand led to longer reaction times and vice versa. This method has proven its reliability and noninvasiveness through many experiments, spanning from learning to aviation control (Camp, Paas, Rikers & van Merrienboer, 2001).

2.5 Application of theoretical models and knowledge

The models, theories and knowledge discussed in this chapter has been applied differently to different situations throughout this project. The project, as discussed in the introduction, can be split into two main parts: part one, development of a new interface and part two, measurement of the interface through an experimental setup. Wayfaring and interaction design principles was used in the development of the new controller interface described in chapter 3. It should be noted that since the controller, which this thesis aims to test in-situ, is still at an early stage in the development, the purely ergonomic and physical design aspects comes somewhat second to the functional facets. However, some ergonomic features have been tested and are presented later on during in the development chapter.

While developing the experimental setup (see chapter 0), including choosing variables and measurement methods, the principles from Wayfaring was again applied in addition to the theoretical groundwork on cognitive load and affective engineering. In both the experimental setup trials and development of the controller, own interpretations of the models and theory has been applied. A bias towards action, as Steinert and Leifer (2012) highlights in the Wayfaring model, has heavily influenced the work described in this thesis, and several aspects has been subject to prototyping and testing throughout. As Leikanger (2016) suggests, Wayfaring approach works well within experimental setup trials, although it might be outside the original intent of the model (product development). It also proved effective for this experiment as the author's experience of performing research experiments with humans is limited, and trials and errors made it all possible.

This page is intentionally left blank.

3 Controller Development

As part of the fuzzy front end phase of developing and testing new solutions for the ship bridge wing, the controller described in this chapter is a concept still undergoing development. It will later on be used in testing, where several aspects of the interaction between user and product is evaluated. This experimental testing, described in chapter 0, was designed as a study to test and evaluate the controller in action, in addition to introducing affective engineering to maritime product development. The challenge of developing this product is presented in this chapter, and given a broader context. Also, this development has not reached (and was not intended to reach) the “take-it-home” part of the wayfaring model (Steinert & Leifer, 2012), which is reserved for later stages. The work presented is instead one of many possible directions/concepts within the design of a new ship bridge wing environment still to be considered. Hopefully, the results and evaluations presented at the end of this thesis will indicate where to go next, both within conceptual development of SBW environment, and affective engineering in maritime development.

3.1 The Development Challenge

On the SBW, there are numerous devices the captain communicates and interacts with, both actively and passively. A traditional SBW console, exemplified in figure 3-1, presents a cluttered interface, little to no flexibility and a space-demanding design, forcing captains to adapt to the console, rather than opting for an ergonomically adaptable environment. In this chapter, a new concept to the steering interface is proposed, as a smaller and space-friendly control interface. The idea is to merge the main control devices into one unit, but still keep the devices dedicated, as well as contrast and challenge the old layout. In addition, the proposed concept with its components and technical features serves as a base for further rapid functional prototyping to help judge prospective ship-controlling interactions. With a smaller control interface, I refer to the physical size of the controller, meaning that it should be substantially smaller than the existing one.

The need for separate control of other functions, such as device lights, sensitivity, activation/deactivation and so forth is not directly included in the development described here. It is however suggested to be placed within close proximity of the captain, on a separate console during previous work (Karlsson & Solvang, 2015).

Figure 3-1: Traditional ship bridge wing. Courtesy of Kongsberg Maritime. Retrieved from https://www.km.kongsberg.com, 23.05.2016

3.2 Starting point

When controlling a large vessel or ship, previous work shows there is constant needs for interactions between the captain and the user interface of the ship. Through multiple devices, such as thruster controllers, rudder wheels and numerous buttons, communication devices and several information screens, the captain communicates his/hers demands to the computer, the crew, and all the way to the engines, ultimately changing the ship's current state. Dangers lure along this informational path, so it is highly beneficial to reduce the chance of mistakes and misinterpretations all the way from start to finish. Above 89 % of all collisions in the maritime industry is caused by human errors (Bryant, 1991; U.K. P&I Club, 1992), and it is likely that a substantial part of these are related to interface misinterpretations. Therefore, a natural place to start reducing the risk of errors is in the top level interfaces between the captain and the ship. This includes inputs from the user as well as feedback from the system, which constitutes to a complexed looped system. Although feedback to the user from the "man-made" consoles and systems is a central part of the environment on the ship bridge, the single most important factor is to see, observe and register the situation and environment outside, thus also to react to the necessary conditions. Therefore, as visits and interviews shows, see Karlsson and Solvang (2015), a new console and interface must not take attention away from the outside environment, but rather encourage a less disturbed working environment, and increase the captain's flexibility on the bridge wing.

Today, the captain controls the ship through several devices, whereas some of the most common are briefly presented in the following subsections in addition to a short introduction to the ships motions. Each of these controllers are quite intuitive and easy to use by them self, but when one adds them all together, as figure 3-1 exemplifies, the combination occupies a large surface area, accumulates higher degrees of complexity, thus increasing the demand on the user (Moray, 1988). Following the mentioned introductory sections is a presentation of the development of the new controller.

3.3 Development Scope

As of today, there are a lot of possible propulsion-thruster-rudder layouts and configurations out there (briefly presented in the following section). Thus, the number of options of available control device- and interface combinations adds up to a vast number of more or less feasible solutions. To ensure a viable foundation for development and testing, some boundaries are set as a starting point. The ship configuration chosen for this project is depicted in figure 3-2 and includes the following:

- Bow tunnel thrusters with simultaneous control.
- Stern tunnel thruster
- Single fixed-shaft propeller
- Single rudder

This traditional configuration suits a large variety of ships, within many different services, thus serving as a good foundation for further research and development. It should be noted that the number of thrusters at the bow and stern may vary without inflicting the interface. Further, the controller's intended use case is during docking and other navigational activities controlled from the SBW.

This includes, but are not limited to, lightering, close quarter navigation and offshore loading/unloading. In addition, this thesis builds upon the same assumption as the pre master thesis (Appendix F), namely that the bridge wing is occupied by two officers: the captain controlling the ship, and a first mate for communications and or other tasks. Note

Figure 3-2: Ship hull configuration scope

that this ordering is not any specific standard, but the one chosen amongst others, to ease the descriptions and discussions.

3.4 The ships motions

This section briefly presents the ships motions, in particular the ones controlled by the setup described in the scope above. The ship can move and rotate in all three axes, but when controlling it, it is (usually) limited to adjusting the following three motions illustrated in figure 3-3:

- Linear longitudinal (forwards and backwards and vice versa)
- Linear lateral (port to starboard and vice versa)
- Horizontal rotation (rotation about the vertical axis)

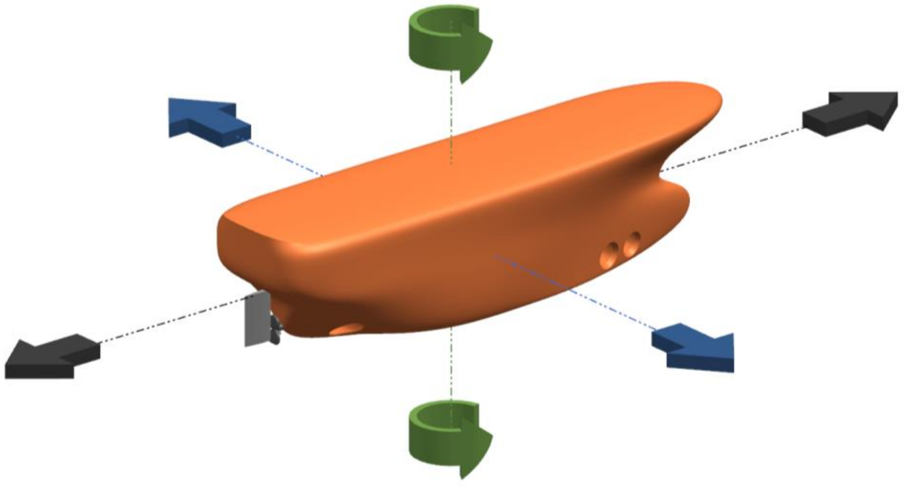


Figure 3-3: Ship motions. Black arrows indicate linear longitudinal, blue arrows shows linear lateral and the green arrows highlight the horizontal rotation about the vertical axis.

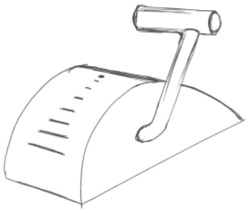
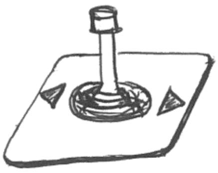
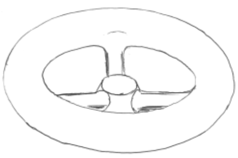
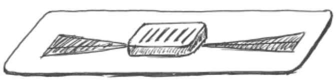
Systems do exist for controlling the linear vertical motion (heave) and rotation about the longitudinal axis (roll), often as stabilizer fins to reduce the effect of waves, or to adjust hydrodynamics. These attributes however do not serve as part of this thesis' scope, and is therefore not further discussed. Another important factor when operating from the ship bridge wing is that the speed is often fairly low, and it usually involves bringing the ship to or from a halt. This again means that things happen slowly and the changes in a controller's pitch is small. By controller pitch it is here referred to the controller's physical position in relation to zero.

3.5 Existing controllable systems

Several marine component manufacturers deliver various models of hydro propulsion arrangements, controlled through distinct devices. In order to understand how to efficiently and safely operate them, the need to understand how they work is undoubtedly a key factor. As the control device manufacturers operate with many different names on similar class arrangements, the following paragraphs use common tongue maritime terms for the different setups, divided into three categories: thruster-, propulsion- and rudder arrangements. Some existing control devices used to control such arrangements are also discussed.

One of multiple thruster(s) in the bow and/or stern of a ship is the most common way of controlling linear lateral motion, i.e. sideways movement towards port or starboard. Since they are offset in relation to the vertical center axis of the ship, they may also aid close quarter turning. A very common thruster is the *tunnel thruster*, see the bow of the hull depicted in figure 3-2. It works by creating a water stream towards either port or starboard, hence pushing/pulling the ship towards the opposite direction. The controllers for such thrusters are typically mimicking this lateral translation behavior. By moving a lever towards port or starboard, see table 3-1, one communicates to the ship that you want to move in the direction of the lever. The same principle is used to control fixed propulsion devices, such as the traditional fixed shaft propeller in figure 3-2, and waterjets, where you move the lever forwards or backwards. It should however be noted that there exist thruster systems which use the opposite interaction pattern, i.e. moving the controller to port results in moving the ship to starboard, thus mimicking the force exerted by the propeller/thruster, not the resulting movement of the ship. This relation is set in the control system by the bridge console supplier in collaboration with the wharf, owner and current crew.

Table 3-1: Selected control devices with pros and cons. The marking shows possible applications.
▲ = Main propeller, ● = Rudder and ■ = Thrusters.

Device	Pros	Cons
 **Vertical handle**	- Direct position feedback - Distinctive - Could have two "arms" controlling two units individually ▲ ■	- Fairly large
 **Horizontal handle**	- Direct position feedback (▲) ● ■	- Space demanding
 **Joystick**	- Could be accurate - Could be small ▲ (●) ■	- Not distinctive - No direct position feedback
 **Wheel**	- Distinctive - Could be small ●	- Less direct position feedback
 **Buttons**	- Small - Could be accurate ▲ ■	- Not distinctive - No direct position feedback
 **Slider**	- Direct position feedback - Fairly small ▲ (●) ■	

However, on ships that demand high degrees of freedom when navigating, different types of *pod* designs, such as Azipod, Azipull or Azimuth thrusters, is available (herby referred to as azimuth). These represent a propeller-shaft arrangement (pod) available to rotate around its vertical center axis, resulting in horizontal omnidirectional propulsion, and thus eliminating the need for reversing the rotation of the propeller or the blade pitch. They might be used as main propulsion or as bow and stern thrusters. Such pod arrangements can work through pull-, or push-forces based on design and desired characteristics, and may be positioned at the stern and/or at the bow of the ship. These also exist as retractable pods

to increase hydrodynamics and flexibility. When controlling these azimuth thrusters, it is common to use a dual-axis control device, where horizontal rotation of the base changes direction and pushing the lever adjusts thrust (power output of the controlled unit). These arrangements will not be discussed further as they do not fall within the scope of this thesis, see section 3.3.

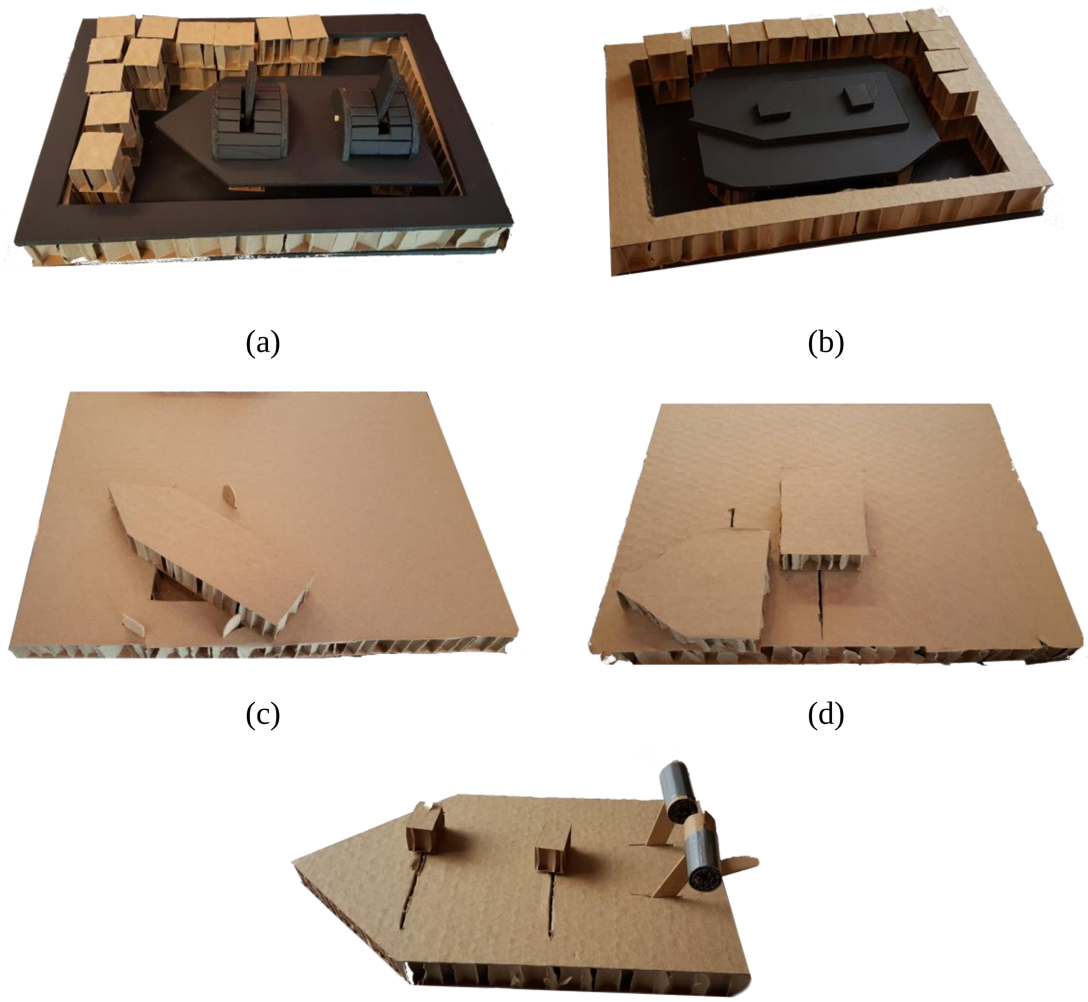
The third control device category is the rudder, the element that changes heading. It rotates around a vertical axis changing the flow of water around it resulting in directional change in the horizontal plane. A traditional rudder controller is often a small steering wheel, knob or horizontal lever. At a SBW, these are usually oriented horizontally on the console surface, see example “Horizontal lever” in table 3-1. These are operated through rotating the input device, but the resulting rudder change depends on the following reference systems (author’s notation):

- Direct rudder reference
- Ship direction reference

The direct rudder reference means that the rudder rotates according to the input device, while ship direction reference means a direct relation to the ships course.

3.6 Unified controller

Previous research (Karlsson & Solvang, 2015) showed potential in reducing the physical impact and increase the flexibility of a SBW console, as well as increasing the intuitiveness/usability of the control panel. Because of this, a great effort is put into developing a compact solution for controlling the ship. In addition, the complex environment of the ship bridge sets limitations and demands as to how to interpret intuitiveness in a ship console and controller, thus some knowledge of the ships systems



(a) (b) (c) (d) (e)

Figure 3-4: Early phase prototypes of ship-like controller layouts

discussed earlier in this chapter is regarded as a prerequisite. This applies especially to knowledge of the thrusters and rudders effects on navigation.

Early rapid prototypes of a ship-like controller showed potential and appeared multiple times at several workshops (see figure 3-4). The idea is to include multiple devices into one unified layout, but still keep the devices dedicated to their individual task. To accomplish this, the unified interface must distinguish between the different motions achieved with each device, as well as separating them through their physical design. As several of the controllers indicate in figure 3-4, especially 3-4 e, this distinction is tried and tested in many variants. These tests led in terms to discussions on the benefits of being able to control the whole ship with one hand, which again led to evolved prototypes and further testing. The next steps and further development of the separate parts of the interaction layout is elaborated in the following sections.

3.6.1 Thruster control device

As table 3-1 on page 40 shows, several different input devices are possible to use for thruster control. The table shows only a selected few of the available options, which is what the exploratory work of the project thesis showed most common. However, most of today's control devices fall within one of the mentioned categories.

As explained earlier, the thrusters are used to induce lateral linear motion, thus the *slider* imitates this motion directly, by moving linearly from side to side. This impose a direct visual feedback to the user, as the position of the slider shows the direction the ship is heading as well as a vague indication of the power output from the thruster. This visual feedback is in addition one of the primary sources of information on a ship bridge (Bjørneseth et al., 2012). The horisontal lever accomplishes some of the same characteristics, but it's rotational movement is not as directly linked to the resulting motion of the thruster. However, it presents an advantage when it comes to placing and wiring, because its base is "stationary" around a fixed rotational axis.

Further, vertical lever devices (see table 3-1) are often used as thruster control device as well (an example is the thruster handles in figure 3-1), but with directions across the

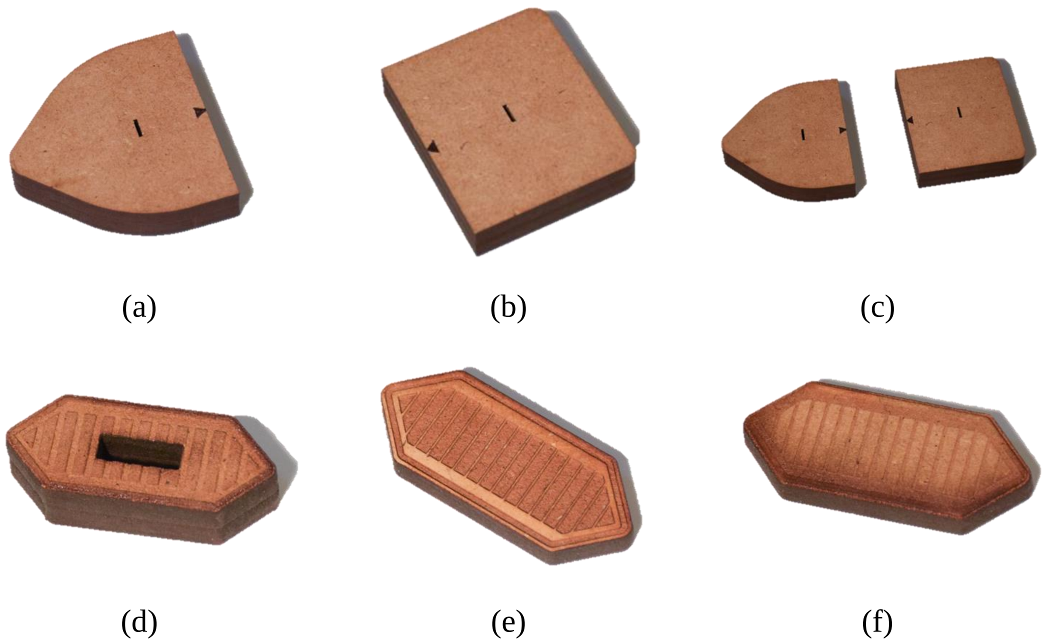


Figure 3-5: Different thruster control device handles. A, B and C shows early versions, whereas D, E and F show later versions with different tactile enhancements

longitudinal axis. The physical size however, tend to be smaller than the main propulsion device to distinguish between them. Buttons and traditional joysticks on the other hand, lack the possibility to be used as a follow-up device such as the above mentioned devices, which was confirmed preferrable in early tests. They are however often used in thruster controllers for smaller recreatonal boats, and in dynamic positioning consoles.

After rounds of early testing, the slider device was chosen for implementation in a functional prototype connected to a ship simulator computer game, “Ship Simulator 2008” (VSTEP, 2008). See illustrations in the following sections, in particular the implementation chapter 3.7.

3.6.2 Main Propeller Control Device

A lot of the same principles as for the thruster device applies to the propeller device as well. The intention is again to familiarize the ship’s movement through the device. To distinguish the main propeller from the thrusters, it should be distinctively different in design, as well as moving along the longitudinal axis of the ship. A common device for this purpose, as the lower right corner of the console in figure 3-1 illustrates, is a large vertical handle (illustration in table 3-1) with evident scales. This gives the captain clear visual and physical feedback directly and is easy to distinguish in states of emergency.

However, the slider again showed potential, as it reduced the physical demand of the device, and could serve as a base for other controllers as the drawings in figure 3-6 illustrates. Also, the slider handle could have a variety of shapes, and as a starting point, which early and late tests proved to be interesting, was the projection of a ship. This results in the possibility of placing the rudder sliders according to their respective positions on the ship itself, i.e. the bow thruster(s) in the front and the stern thruster(s) in the back (see figure 3-6 b, c and d). Through this layout, a combination of main propulsion and thrusters is possible to integrate into one interface as mentioned earlier and exemplified physically in figure 3-4, and in the later models in figure 3-8 and figure 3-7. For these reasons, the slider input device was chosen for the main propulsion as well.

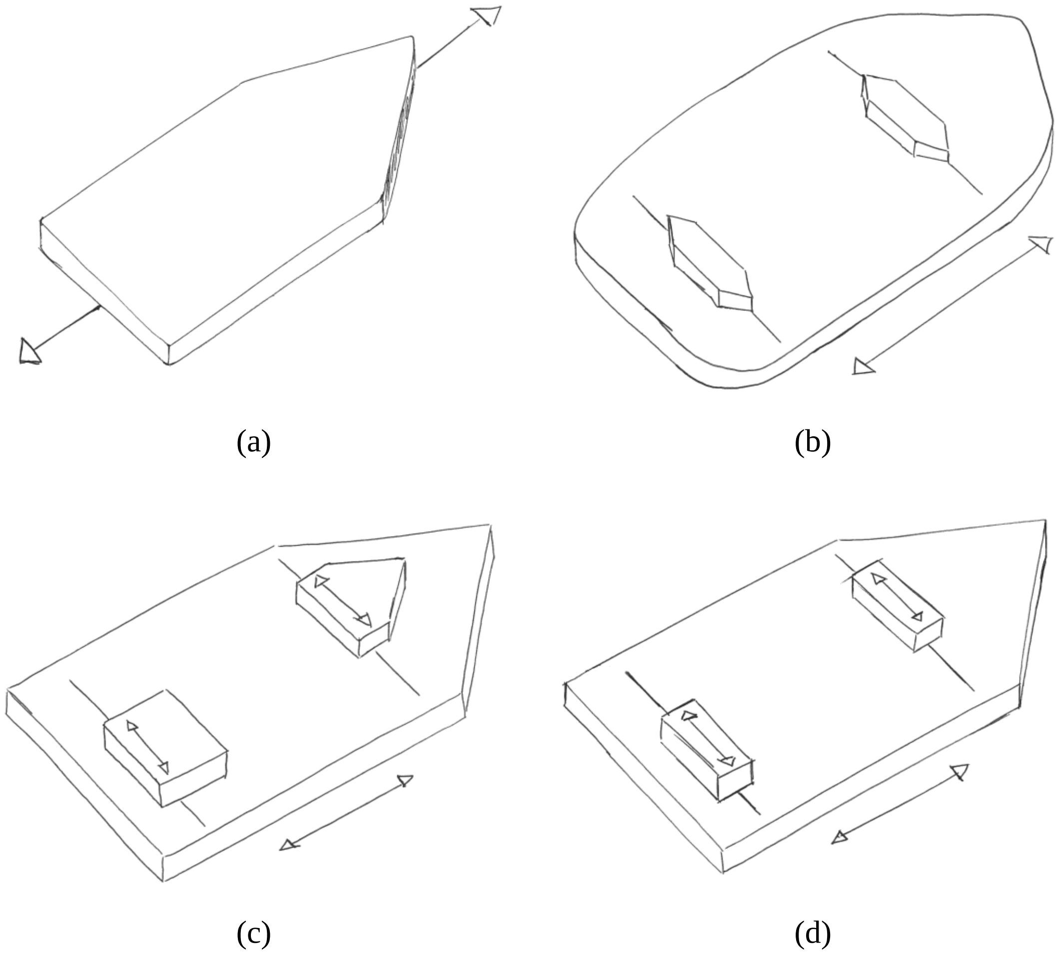
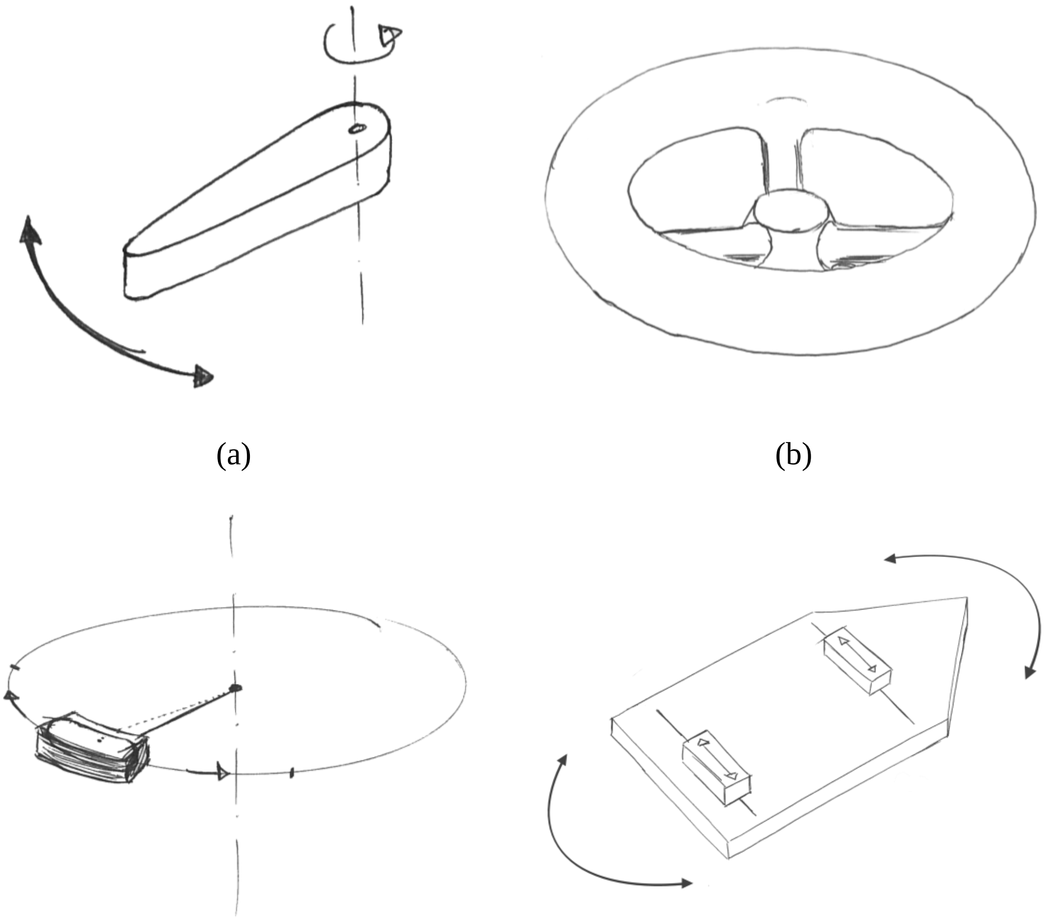


Figure 3-6: Main propulsion device layout.

3.6.3 Rudder Control Device

One feature separating the rudder from the rest of the controllers is that it no longer refers to translation behavior, but rotation. Because of this, a number of options was considered with one limitation, integrating it into the surface of the main propulsion. Some of these options is shown in figure 3-7, all relating to the rotational behavior of the rudder. First trials were made with a version of the horizontal lever in figure 3-7 a, and the first round of implementation in a functional prototype is shown in figure 3-8 in chapter 3.7. Such a lever gives instant feedback of the rudders position to the user if the “direct rudder reference” from section 3.5 is used. In addition, this type of control device has direct relations to the design of the rudder, increasing the understanding of how it works. If one uses the wheel depicted in figure 3-7b, it creates ambiguity relating to the reference system as it could be used with both “direct rudder”- and “ship direction”. Because of this, the wheel is not considered a viable solution in this controller.



(a) (b)

(c) (d)

Figure 3-7: Rudder control device

Looking at the other options presented in figure 3-7 c and d, they represent novel application and use of existing methods. The “rotational slider” in figure c, is just a combination of the slider and the horizontal lever. This do however cause difficulties when working with implementation of the mechanism behind it, and as the experimental tests sat time restrictions, this one was not further tested. In figure 3-7 d however, the idea is that the whole device of the main propulsion and thrusters will rotate to mimic the resulting motion of the ship. Some early tests of the mechanics and use of such a solution was conducted, resulting in both benefits and disadvantages. Some of the benefits were that the whole interface is easily controllable through one hand, and it could be made fairly compact. Two significant disadvantages are the complexity of the underlying mechanics, and that the rotation of the “ship” device (rudder change) might conflict with the rotation imposed by thrusters (rotation around the ships center axis). Time however, because of the execution of the experiment, sat unfortunate restrictions to the extent of the work done with the rudder control device. The non-conflicting rudder handle in figure 3-7 a was therefore chosen.

3.7 Implementation and functionality

When implementing the different control devices into one functional cohesive and unified controller prototype, the components for digitalizing the inputs was established and included in the model. Figure 3-8 shows exterior design of the first iteration of an implemented functional prototype, and the internal components is shown in figure 3-9. The layout of the different devices resembles that of a ship: with the thrusters at the bow and near the stern, and the rudder at the stern. The whole base of the thrusters is also movable (back and forth) to adjust the main propellers according to the scale on each side. The thrusters share the same moving pattern and therefore also the same scale in the middle.

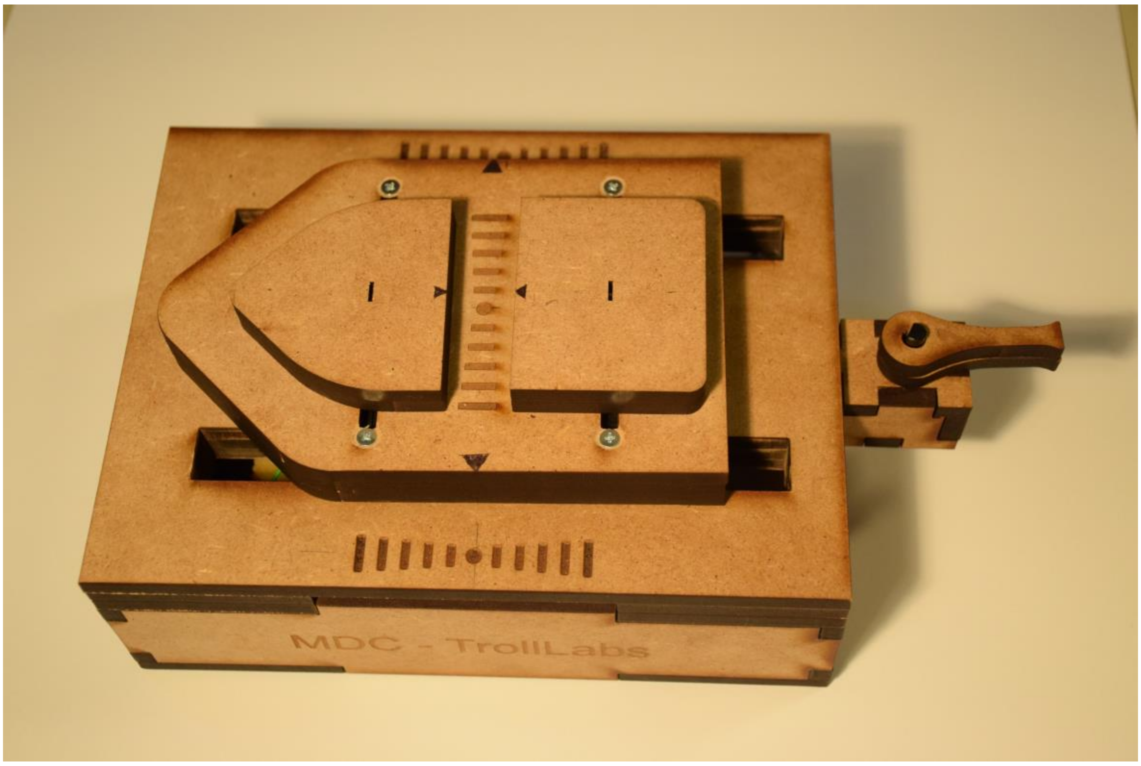


Figure 3-8: First round of implementation prototype

Since both thrusters and the main propeller is controlled through slider devices, a good component to register these inputs are linear slide potentiometers. They are simple, passive components with linear variable resistance and can be tailored to a specific size and travel distance. Standard off-the-shelf versions with 60mm travel distance and 10kOhm resistance is used in this particular prototype. The equivalent rotary potentiometer is used to record the rudder position. All of these components are in turn connected to an Arduino Leonardo which has a built in Human Input Device (HID) USB interface, meaning it could be connected to the computer as a keyboard, mouse or joystick with small alterations. This property was applied to the ship simulator computer game for pre experiment testing.

After several rounds of simulator testing, the need for a better implementation of the rudder, and the clarity of the thrusters' affordance became apparent. This led to a new iteration, this time including increased tactile surface and a vibration motor for haptic feedback options within the thruster devices, as well as an undivided base surface. The haptic feedback pattern used in the experiment was dependent of the device pitch, and was present at each 20% interval. This yields 5-point resolution with increasing vibration strengths towards the outer extremities of both starboard and port. Although this feature was not thoroughly tested, the main feedback from the experiment participants was positive.

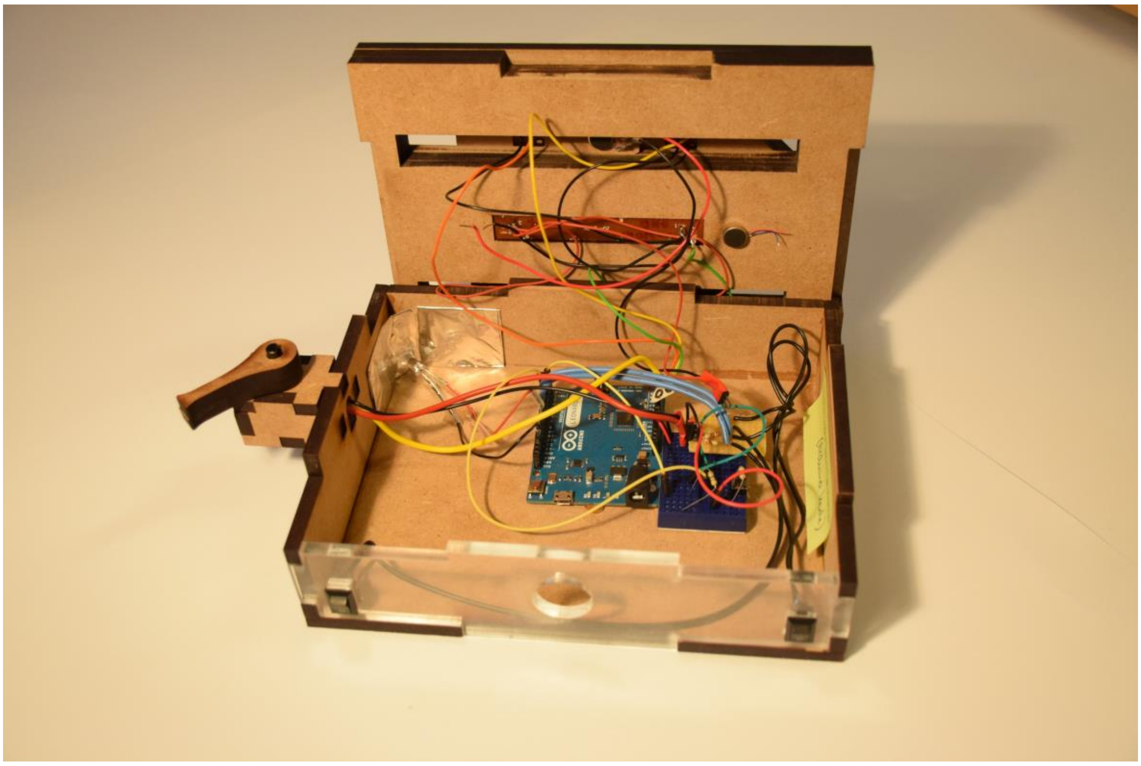


Figure 3-9: Interior components of the first implementation iteration.

Further updates in the second version includes a new set of scales, along with new and improved pitch indicators on the thrusters and main propeller handles. This second iteration also served one additional noteworthy purpose - the ability to communicate with two

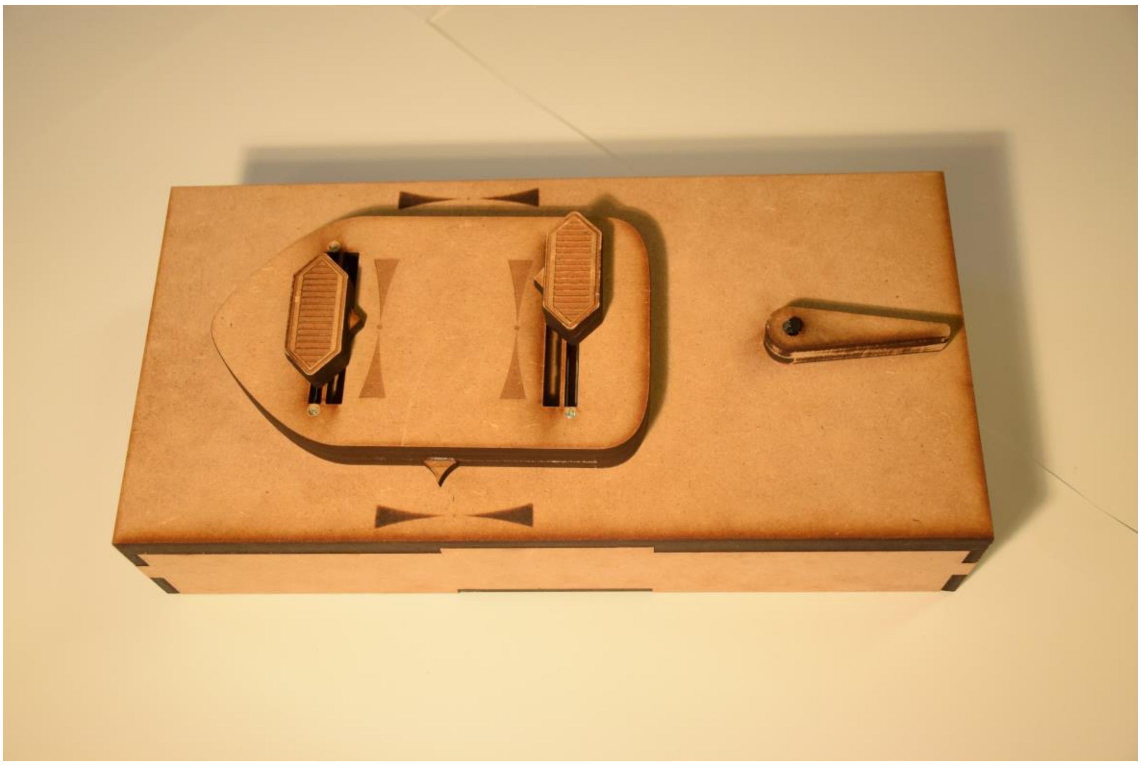


Figure 3-10: Second round of implementation prototype

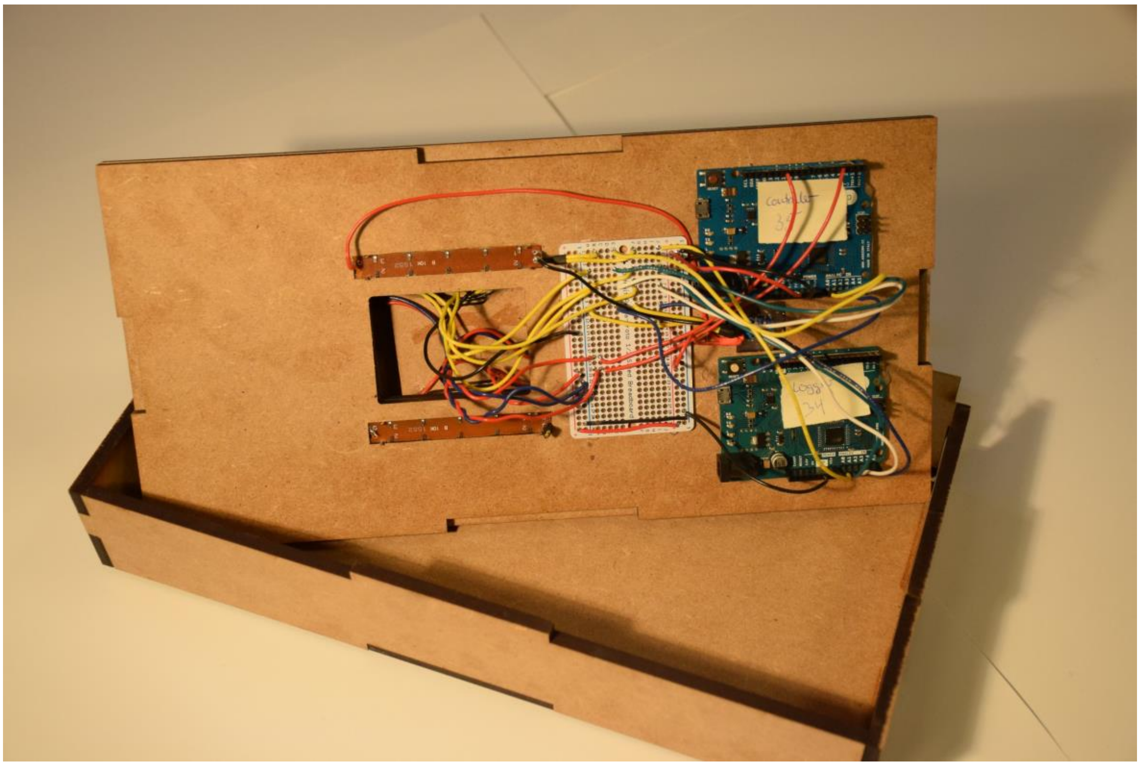


Figure 3-11: Interior layout of the second iteration. Notice the two Arduinos.

computers simultaneously. This was accomplished by using two Arduinos, see Appendix B for details, with the same input for the sole purpose of sending information from one Arduino to the game, and from the other to a recording computer during the experiment. See chapter 0 for details about this setup. The fact that this prototype uses only electronic stock parts and can be connected to a simple computer game makes it viable for further rapid iterations regarding increased functionality and design without the need for expensive and complicated high-end simulators and components. However, the digital interface of this controller would also be fairly easy to integrate in an already existing high-end ship simulator towards the later stages of development. But, as mentioned, this thesis takes advantage of what is readily available, increasing the rapidness of the iterations and allowing for quick tests of "good enough" scenarios during the early phases. Note that the controller presented in this chapter is hereby referred to as the Unified controller. The experiment described later also leverages the ability for fast iterations, as well as comparing the new controller up against a baseline model described briefly in the following chapter.

4 Baseline controller

This chapter describes the features implemented in a baseline example of an existing ship control interface. The intention is to use it as ground for comparison against the Unified controller elaborated in the previous chapter. This model is not subject to any form of development and/or optimization, but has taken inspiration from an existing console design onboard M/S "Color Magic" (2006). The layout can be seen in figure 4-1 and its features and limitations is presented in the following. As the intent of this model is solely to work as a baseline when testing in the experiment, it somewhat represents a typical layout of a ship bridge wing control panel, and features only the main control devices: main propeller, port and starboard rudder, bow thruster, and stern thruster. Similar to the Unified controller, this model also includes two Arduinos, one for the game computer, and one for the recording computer. It utilizes 10kOhm rotary potentiometers in all components (see Appendix B for details). Further, the thrusters have horizontal levers, the main propeller is a vertical lever, and the rudders are small wheels. As the figure below shows, it contains two rudder wheels, this is simply because "Color Magic" has two rudders, but in this model, only one is active. This is due to limitations in the simulator game, which could only handle

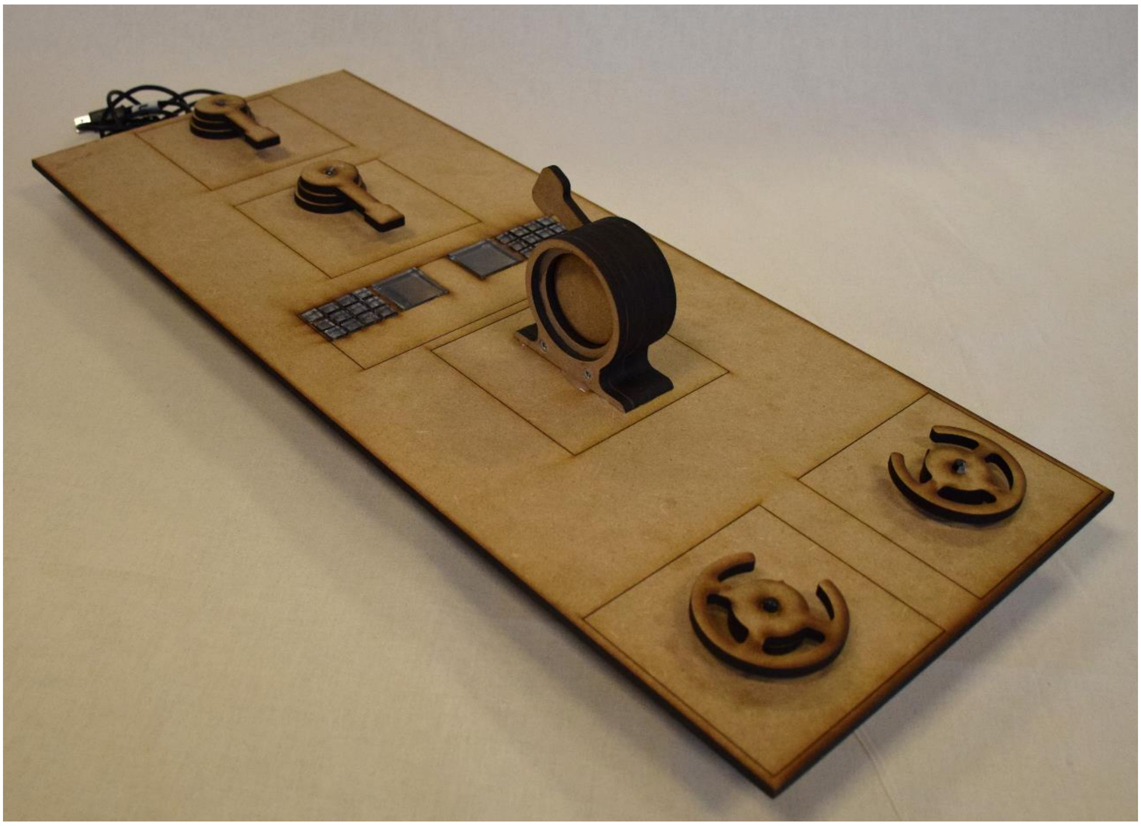


Figure 4-1: Baseline model, inspired by M/S "Color Magic"

one rudder input. The description of the experiment and how the two controllers were tested is presented in the following chapter.

5 Experimental Setup of Ship Controller Test

As the proposed Unified controller's intention is to be used in a complex environment, specifically the ship bridge wing, it should undergo rigorous testing before being applied. This experiment serves as a pilot for such tests, combining further research within maritime environment design and affective engineering in addition to evaluating certain aspects of the Unified controller's performance. As brought up earlier, the new controller is tested up against a traditional control interface. However, because the call for increased affective engineering dimensions in engineering design is fairly new (Balters & Steinert, 2014), some of the measurements are somewhat experimental. During the work with setting up this experiment, a number of variables relating to the use of the controller has been considered: interactions between human and controller, the cognitive load imposed by the controller, general concept evaluation through user testing, stress and arousal associated with use, and analysis of controller usage. It is worth noting that this experiment serves as a trial of how to measure and analyze the wanted data in eventually real situations and not "white-box", clinical experimentation rooms. An effort is therefore made to keep the scenarios somewhat realistic. This chapter present and discuss the hypotheses, the chosen methods for data measurement, the experimental setup and the methods for results evaluation.

5.1 Hypotheses

With basis in the above mentioned intention of the experiment and problem at hand, a number of hypotheses are presented below. The intent is to find out whether the measurements chosen could quantify and distinguish certain facets and attributes of the controller, and link them to the effect on the human user. All four hypotheses (H1 – H4) are presented with corresponding null hypotheses, and relates to cognitive load, interactions and concept evaluation. Further, the hypotheses are formulated to separate the two controllers through objective and subjective measurements. The effects of the measurements will be discussed later on.

5.1.1 In-situ Cognitive Load Hypothesis

This hypothesis directly relates to the affective engineering approach intended to test the cognitive load impact of the new controller in relation to the traditional layout:

H1: "The Unified ship controller reduces the in-situ cognitive load of the user."

The corresponding null hypothesis is:

"The Unified ship controller does not reduce the in-situ cognitive load of the user."

To test this hypothesis, two indicators of cognitive load is measured: objective-, and subjective cognitive load. The subjective cognitive load is tested using the RTLX developed by Hart and Staveland (1988) (see section 2.4 on cognitive load.) This is a tried, tested and reliable way of measuring a subjects' perceived mental effort and cognitive load of a task. Further, dual-task methodology is adopted to measure the cognitive load objectively, in particular through a secondary task where the subject is to respond to a change, in this case an alarm.

5.1.2 Interaction Hypotheses

Both the second and third hypotheses relate to the controller and the Human Computer Interaction (HCI), but are spilt up to distinguish between the number of interactions and the extent of the interactions. These hypotheses' main intention is to test for ways of evaluating the interactions with the controller. The first interaction hypothesis is:

H2: "The Unified ship controller reduces the in-situ number of interactions with the ship controller."

This has the corresponding null hypothesis:

"The Unified ship controller does not reduce the in-situ number of interactions with the ship controller"

The third hypothesis relates to the way the user interacts with the controller and is as follows:

H3: "The Unified ship controller reduces the extent of the interactions with the ship controller."

With the corresponding null hypothesis:

"The Unified ship controller does not reduce the extent of the interactions with the ship controller."

Hypothesis H2 and H3 are both tested with data from real-time logging of the positions of and interactions with the four different UIDs. The data is then analyzed quantitatively and qualitatively through either the number or extent of the interactions for H2 and H3 respectively.

5.1.3 Concept Evaluation Hypothesis

The last hypothesis in this experiment relates to the subjective ratings of the controller's usability and design and is stated as follows:

H4: "The Unified ship controller scores higher in user concept evaluation."

With the corresponding null hypothesis:

"The Unified ship controller does not score higher in user concept evaluation."

This hypothesis is challenged through concept evaluation ratings of the controllers performed by each participant and compared through statistical analysis. The intent is to evaluate the novel design on five separate key factors and compare it to the Baseline model.

5.2 Independent Variables

The main independent variable is the control surface used to control the ship during maneuvering. It could be one out of two control interfaces, see figure 5-1, described in earlier chapters:

- A baseline interface imitating the old setup of a ship (Baseline controller)
- A Unified interface merging the devices into one controller (Unified controller)

A detailed description of the newly proposed design, the Unified controller, is presented in chapter 3, and characteristics of the baseline controller in chapter 4, along with a brief presentation in the following sub sections. The controllers will be present one at a time to the participants, in both orders and with an even number of participants, 12 in total. This is so learning effects of the controller and comparisons between them could be minimized when analyzing the total results. The following sections briefly describe the controllers.

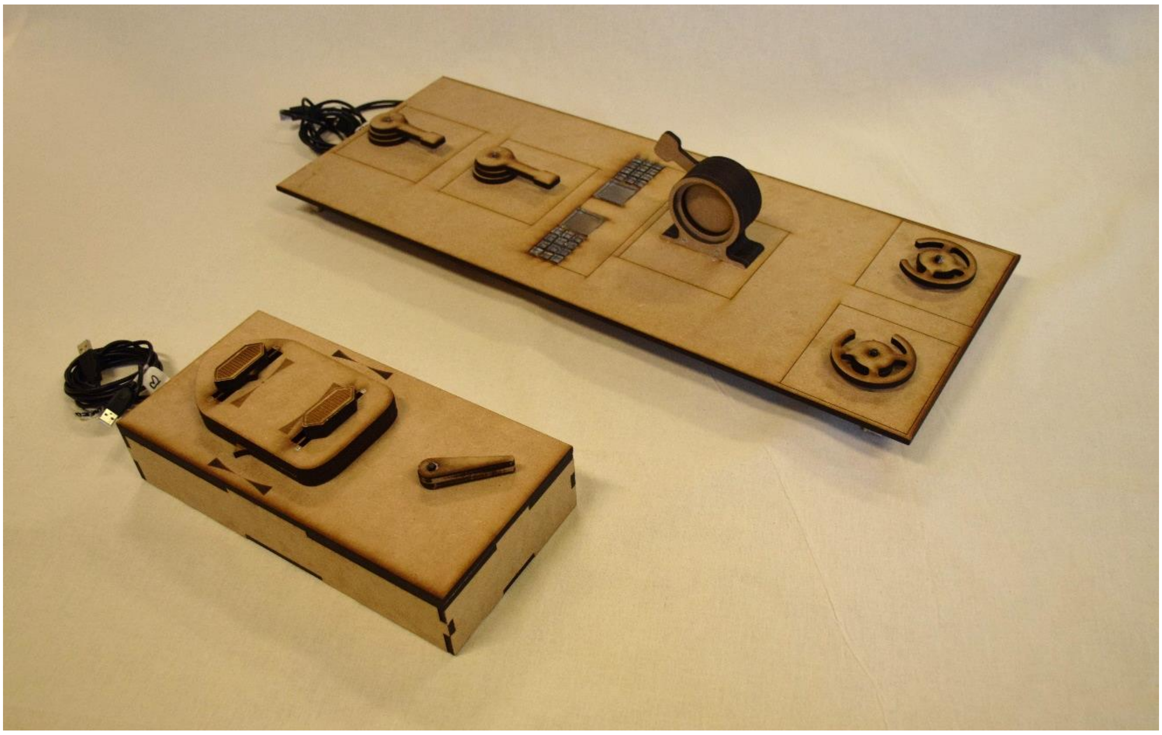


Figure 5-1: Unified (lower left) and baseline (upper right) controllers

5.2.1 Baseline Controller

The baseline controller, made to resemble the control surface of an existing ship, is familiar to those that have seen and/or operated an actual SBW console, see figure 5-2. It is however, made at a somewhat similar resolution as the Unified controller to avoid resolution biases (see section 2.1), and includes the following five user input devices (UID):

- Main propeller
- Rudder, port
- Rudder, starboard (Not active)
- Stern thruster
- Bow thruster

A more elaborative description of the Baseline controller is presented in chapter 4. However, because of limitations regarding input devices in “Ship Simulator 2008”, the rudders are controlled from the port (left) rudder input device.

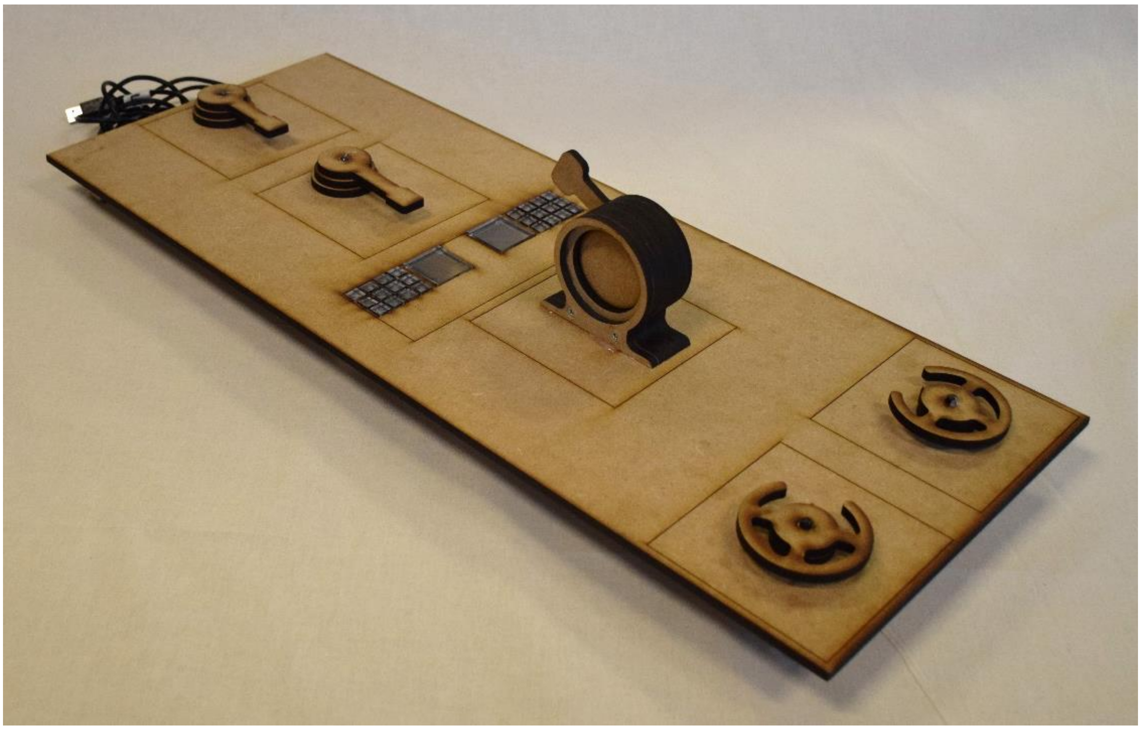


Figure 5-2: Baseline controller used in experiment

5.2.2 Unified Controller

As described in chapter 3, the Unified controller combines the input devices in a ship-like interface with the intention to increase intuitiveness and operational control. As seen in figure 5-3, the devices are positioned at the same location as on the ship itself. In total, the Unified controller includes 4 UIDs:

- Main propeller
- Main rudder
- Stern thruster
- Bow thruster

This number of input devices works well with “Ship Simulator 2008” and all UID’s are active. The haptic feedback described in section 3.7 is also activated.

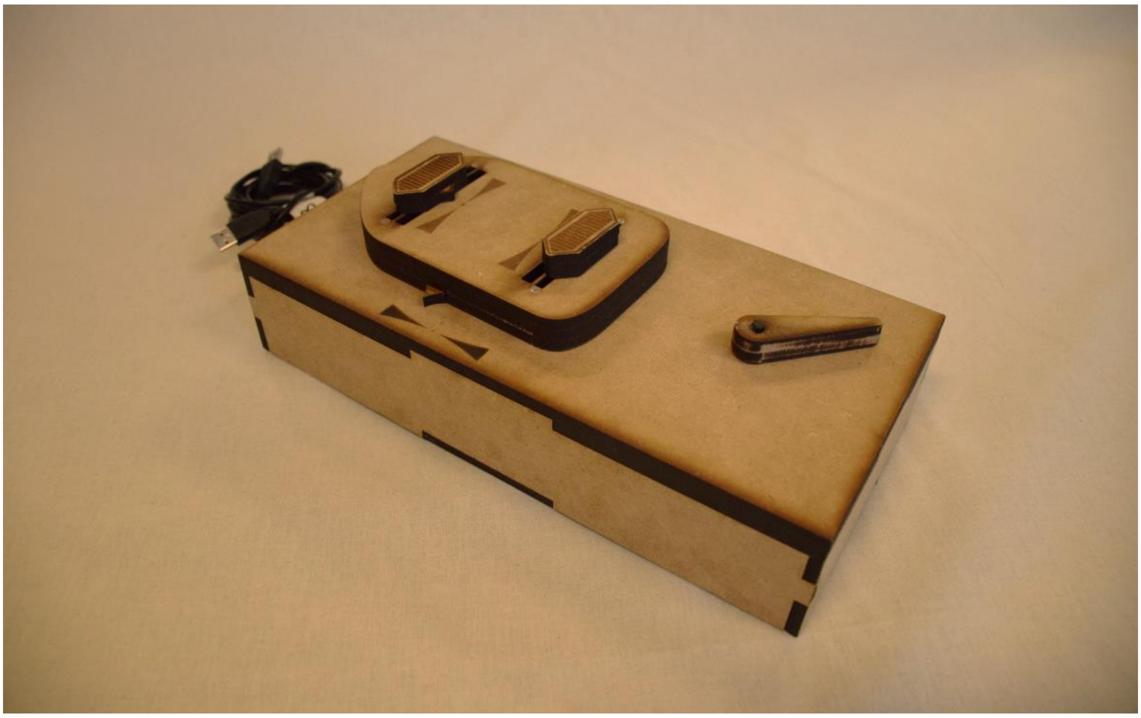


Figure 5-3: Unified controller as used in the experiment

5.3 Dependent Variables

The setup used in this study measures several different dependent variables. Some of which are objective variables, and some subjective. The goal is to compare the different data of the two controllers to use in user-concept evaluation and controller impacts. The variables and their characteristics are presented in table 5-1, and measurement methods and metrics are described in section 5.7.

Table 5-1: Variables measured and their characteristics.

Variable	Measurement	Subjective or objective
Cognitive load 1	Secondary task – Reaction time	Objective
Cognitive load 2	RTLX questionnaire – RTLX score	Subjective
Stress/arousal	ECG – Heart rate	Objective
Controller interactions	Logging of controller	Objective
Performance	Waypoints – No. of waypoints	Objective
Concept evaluation	Questionnaire – 5-point scale	Subjective

5.4 Physical setup

The experiment is set up as a small, closed, ship bridge environment, see figure 5-4, placed on a height adjustable table. It consists of three “walls” imitating bridge wings outer

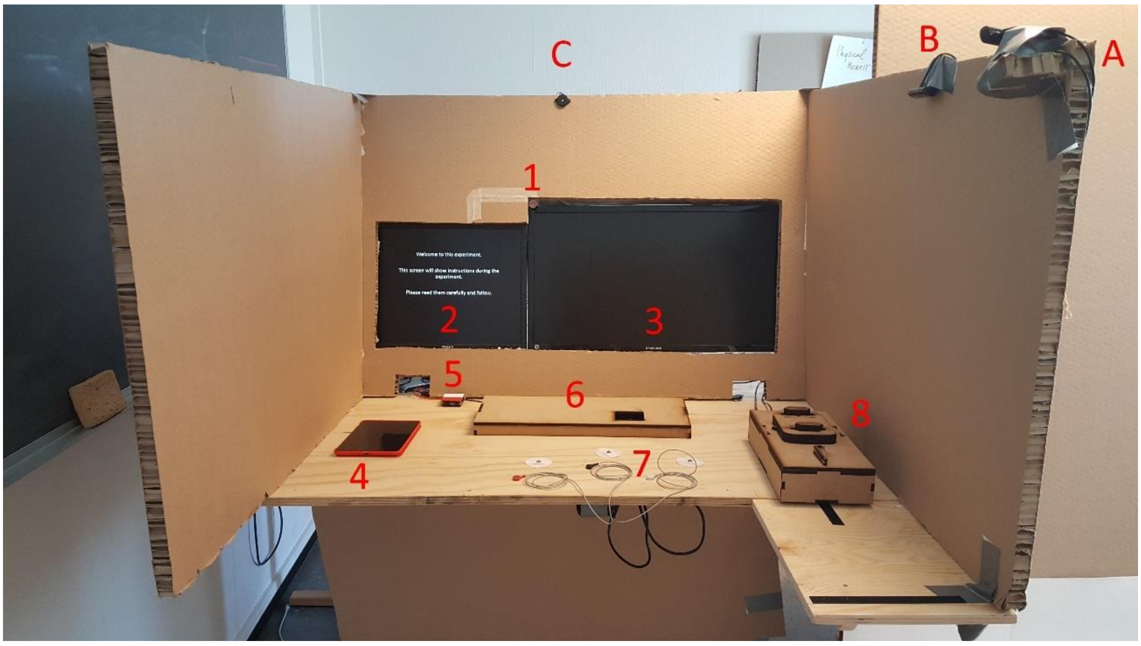


Figure 5-4: Physical setup of experiment with the Unified controller.

boundaries; two “walls” at the side, and one in the front. The front contains two computer screens connected to two separate computers, one game computer and one stimulus computer (see section 5.5). The larger screen [position 3 in figure 5-4] connected to the game computer runs the ship simulator game, and the smaller screen [2] displays information to the subject during the experiment. The ship simulator will be controlled trough one of the two controllers of interest.

The two controllers are positioned to the right [8] of the subject sequentially, see the two setups in figure 5-4 and figure 5-5. An alarm button [5], placed in the inner left corner of

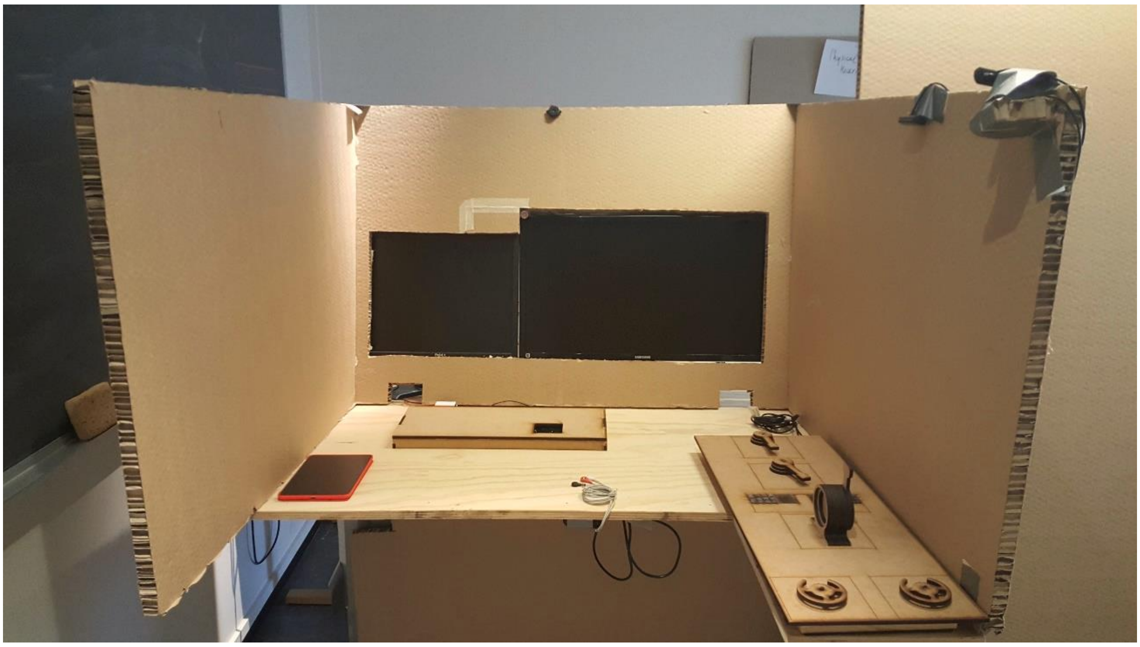


Figure 5-5: Physical setup of experiment with the Baseline controller

the table is connected to a red alarm light in the top left corner of the main screen [1], and a piezo buzzer placed above the game screen [C]. This imitates an alarm on a ship bridge and serves the purpose of a secondary task used to measure cognitive load, see (Brunken et al., 2003); Kerr (1973). In the right rear corner is a camera ([A], screen camera) recording the screens. Another camera ([B], controller camera) is placed directly above the controller to monitor the direct interactions. These cameras are connected to the same computer, and recorded simultaneously through “vMix 17.0.0.76” (vMix) video recording software by STUDIOCOAST PTY (2016).

5.5 Computer setup

In addition to the physical setup, the experiment required three computers to run, one for the game, one for information/stimuli to the subject and one for recording data. The setup and “nicknames” is shown in Table 5-2 (for computer specifications, see Appendix E). The computers are run manually, out of sight for the participant, and the game, controller, ECG and secondary task is monitored during the experiment.

Table 5-2: Computer setup overview.

N	Computer	Nickname	Screen	Purpose
1	Dell Precision T1700	Game computer	Game + monitor 1	Running game
2	Asus X550J	Recording computer	Monitor 2 + monitor 3	Recording data
3	Acer Aspire 4820TG	Stimuli computer	Stimuli + monitor 4	Show stimuli and info to subject

5.5.1 Digital Communication

In order for the controllers to communicate with the game computer and eventually the ship simulator as well as the recording computer, two individual Arduinos are connected to the user inputs and receives the same signals, see table 5-3.

One of the Arduinos records interactions and the other acts as a joystick controlling the game, with setup as described in table 5-6. The connections between the UIDs and the Arduinos are the same in both controllers and the base of the code uploaded is the same

Table 5-3: Overview of connected Arduinos in the different controllers.

Controller	Controlling game	Recording interactions
Unified	Arduino Leonardo	Arduino Leonardo
Baseline	Arduino Leonardo	Arduino Uno

(see Appendix B). Both the Baseline and Unified controller's recording Arduino reads a total of 4 input variables which is recorded by the recording computer through a self-made recording program based on Processing (Fry & Reas, 2015), see Appendix D. Each recorded variable is mapped into percentage of power, ranging from -100 to 100, and the signal processing and interpretation is shown in table 5-4.

*Table 5-4: Recording of signals from the UIDs. **Value from Arduino** is the analog read of the potentiometers, **mapped value** is the percentage of power, and **interpretation** is the resulting action of the input measured in percentage of power.*

Input	Value from Arduino	Mapped value	Interpretation
Main propeller	1023	100	100 % forwards
Bow Thruster	512	0	0 %
Stern thruster	205	-60	60 % to the left (port)
Rudder	870	70	70 % turn to the right (starboard)

The self-made recording software in Processing (see Appendix D) also permits adding multiple triggers such as waypoints crossed, crashes and tasks manually, which is done by the operator through the dual game screen display and video cameras. This is so in order to sync all the data to the different tasks and in-game events, and also se relations between the variables. The mapped values from the user and the triggers are separated by semicolons, timestamped and printed at a frequency of ~30 Hz, e.g. [34;-100;100;8;-8;1;3;0;1.70], see Table 5-5. The data is then written to a .txt file and saved with a unique name.

Table 5-5: Recorded values. Same example as in the text above; [34;-100;100;8;-8;1;3;0;1.70].

Time [ms]	Main prop	Bow thruster	Stern thruster	Rudder	Task	Waypoints crossed	Crashes	ECG value
34	-100	100	8	-8	1	3	0	1.70

At the same time, an Arduino Leonardo used as a USB HID (human input device) controls the game through acting as a joystick. The details of the signals are explained in Table 5-6.

Table 5-6: Signals to and from controlling Arduino to computer and to the game. Thrusters, here X- and Y-axis', are configured in the game to be bow- and stern thrusters respectively.

What	Values in Arduino	Variables to computer	Values to computer	Variable in game	Values to game [Percent]
Main propeller	0 – 1023	Throttle	0 – 255	Throttle	-100 – 100
Bow Thruster	0 – 1023	X – axis	-127 – 127	Bow thruster	-100 – 100
Stern Thruster	0 – 1023	Y – axis	-127 – 127	Aft thruster	-100 – 100
Main rudder	0 – 1023	Rudder	0 – 255	Rudder	-100 – 100

5.6 The simulator – "Ship Simulator 2008"

As mentioned earlier, the experiment uses a ship simulator computer game called "Ship Simulator 2008" (VSTEP, 2008) as foundations for testing. This simulator has the opportunity to build and control specific missions, control ships with a relative real-life response and to be connected with various controllers. As mentioned in the controller sections earlier it has some restrictions as to how many inputs it can handle. With this simulator, three scenarios (S0 – S2) were constructed and serves as foundation for the primary task of driving the ship. The scenarios and tasks is elaborated in the following section.

5.7 Experiment Procedure and Measurements

This chapter aims to present the details about the procedure, tasks and measurement presented to the subjects. One run through the experiment took about 30 minutes in total, which included three stages and four in-between questionnaires, as well as setup time for a new participant of about 5 minutes. The experiment's three stages consist of three game scenarios to be executed with in total three different control interfaces. These scenarios are presented to the subjects in the same order – from 0 to 2 – and involves two tasks, one primary and one secondary.

5.7.1 Primary Task

The primary task performed by the subject is to navigate the ship in the given scenario with the presented controller. The controller order in scenario one and two varies from participant to participant, resulting in two participant groups: group 1, presented with the Baseline controller first, then the Unified; and group 2, presented with the Unified first, then the Baseline controller. This alteration is due to learning effects associated with the game and how it works, which should be minimized to ensure even evaluation of the results. The different scenarios are presented below.

5.7.1.1 Scenario 0 – Get to Know the Game

In this task, the subject is to familiarize him/her-self with the game through a free, open-sea scenario with the ship "Fairmount Sherpa" used through all the tasks, see figure 5-6. The game settings are calm, clear weather and no waves. Intentions are to give the subjects time to understand how interacting with the game works, primarily that there are significant

Figure 5-6: Scenario 0. Open sea environment. Screenshot from the game.

time delays between user input and game action, but also the interface of the game. This task is performed with the arrow keys on a regular computer keyboard to avoid learning one of the controllers to be used in scenario 1 and 2.

Figure 5-7: Layout of scenario 1. The red circle at the lower edge marks the player ship and the filled red circles marks the waypoints. (Screenshot from the mission editor)

5.7.1.2 Scenario 1

Scenario 1 (S1) involves an undocking, maneuvering and, if performing well, a docking procedure. As shown in the game image in figure 5-7, the course is set up to force the use of various input devices through navigating in narrow conditions. An expert user of the game will perform this task in about 5 minutes, and the subjects will have 4 minutes to get as far as possible whilst data are collected. Throughout the execution the waypoints, nine in total, and crashes are logged together with all other data through the synchronization software. While navigating the ship through the scenario, the participants are to perform the secondary task simultaneously, in total 13 instances.

5.7.1.3 Scenario 2

Scenario 2 (S2) is similar to S1, as the data collected should be comparable, but not the exact same so significant learning effect occurs. As in task 1, the goal is to undock, maneuver in tight spaces and, if performing great, dock again. The course is shown in figure 5-8. This task has the same characteristics, waypoints (9), and number of turns as S1, and takes an expert user about 5 minutes to finish. Again, the duration is time dependent for the sake of data comparison, and the subjects have 4 minutes to get as far as possible while data is collected. As in S1, the secondary task is active with a total of 13 instances.

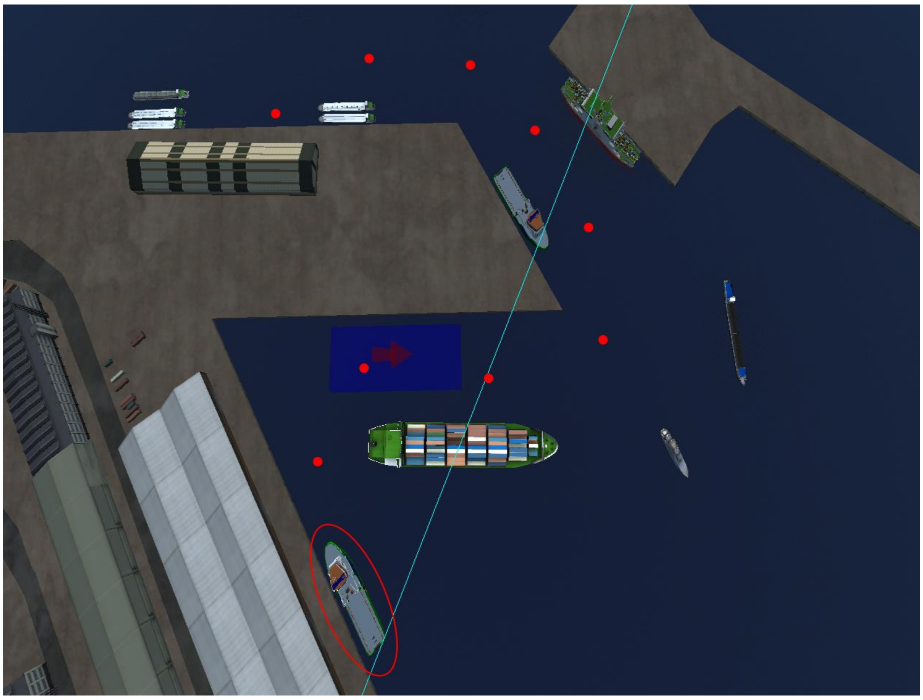


Figure 5-8: Layout of scenario 2. The red circle to the left marks the player ship, and the filled red circles marks the waypoints. (Screenshot from the mission editor)

5.7.2 Secondary task

Through the well-established dual-task methodology discussed in chapter 2.4.1.2, a basic responding task is added to evaluate the cognitive load objectively for testing the discussed hypotheses. This object is realized through an alarm, made apparent to the subject via sound and light simultaneously, and a button to stop the alarm. The button is to be pressed every time the alarm goes off, as fast as the participants are able to, resulting in the dependent variable of interest, namely the reaction times. In order to eliminate anticipation as to when to press the button, the alarm activates multiple times (13 in total) at random intervals of between 12 and 18 seconds (15s ± 3s). This interval is chosen because it ensures 13 measurements within the four-minute runtime. All of the components of the secondary task (button, light and alarm-buzzer) is connected and controlled from an Arduino UNO, which is in term connected to the recording computer. The Arduino code controlling the secondary task is presented in Appendix C, along with schematics. The total setup resembles the one used in learning activity experiments conducted by Brunken et al. (2003), except the one in this experiment is a standalone feature, not running of the computer, and includes a buzzer alarm. The reason for the alarm is to accomplish better resemblance to the ship bridge environment, which is cluttered with alarms (Karlsson & Solvang, 2015).

5.7.3 Heart Rate Measurements

As this experiment makes great effort to evaluate the cognitive load related to the different controllers, heart rate analysis is used to gain a deeper understanding. This is done through Electrocardiography (ECG) connected to an Arduino and eHealth shield combination (Libelium, 2013). The eHealth shield is an entry level physiological measurement tool made to work with the Arduino. Although it has the possibility to be used with several other sensors, this experiment only uses the ECG. The ECG raw data – the voltage differences related to the heart beats – is continuously measured during the scenarios as mentioned in the computer setup section earlier. The recorded data is transformed to fit the 10-bit resolution of the Arduino, resulting in output values between 0 and 1024. The data is further mapped onto a 0-5 voltage scale. In the analysis later on, the mean heart rate, i.e. the peaks of the ECG data, is the only concern, it has relations to the cognitive load.

5.7.4 NASA RTLX Questionnaire

For its proven reliability (Hart, 2006) and ease of use, in addition to prior knowledge of the RTLX within the research team, this method is chosen among others as the subjective measure of cognitive load. The six sub-scales of the RTLX: mental demand, physical demand, temporal demand, performance, effort and frustration, highlights multiple aspects of the cognitive load relating to the totality of the task (Hart & Staveland, 1988). The differentiation between the sub-scales means that certain characteristics of the controllers and their impacts on the user could be established, compared and evaluated, as well as a comparison of the total cognitive load.

To adapt the questionnaire to the survey program used in this experiment (QuestionPro), the paper and pen version of the TLX served as foundation (see Appendix A). Further, the different parts of the questionnaire were presented directly after each respective task, as this reduces invasiveness during the execution and has minimal effects on the in-task measurements.

5.7.5 User Concept Evaluation

The concept evaluation questionnaire asks the subjects to grade five characteristics of interest relating to each controller: understandability, usability, complexity, comfort and communication of purpose. In addition, after all the tasks, the participants were asked to choose their overall favorite controller. General feedback on concepts and experiment setup was also gathered after the experiment was finished.

The intention of having test persons rating the prototypes, is to include user feedback in the early phase of a products life cycle, increasing the output of the development process, an effective method according to Design Thinking (Brown, 2008), and the iterative prototyping mentality (Dow et al., 2009; Gerstenberg et al., 2015). This results in a number of prototype related ratings which can later be compared and evaluated, both in total and separately.

6 Results

To thoroughly test the hypothesis at hand, the experiment gathered data related to several factors which was then analyzed. This chapter presents the results of these recorded data, first as descriptive results and later as statistical evaluation of the hypotheses. The participants are split into two groups, group A and group B as mentioned in the previous chapter. However, because of the equal number of participants in each group and the alternate control ordering, order effects, or group effects, is minimized and herby excluded from the following results. The total number of participants was 12, (6 in each group) whom all conducted the experiment from May 10th through may 13th. Three of the participants was female, and 9 were males, and a total of 11 was between 21 – 25 years of age, and one between 26 – 30. All of the data is analyzed using a statistical analysis software, SPSS Statistics 23^{TM} (IBM, 2015).

6.1 Descriptive Results

This section presents descriptive results relating to the data collected in the described experiment. These are sectioned according to the dependent variables mentioned in section 5.3. Please note that throughout this section, two one-letter abbreviations occur multiple times – U for Unified controller, and B for Baseline Controller. Most of the data distributions are presented in box plots, with outliers marked consequently with the corresponding participant number. Furthermore, tables of means, standard deviation and number of participants indicates data necessary for the analysis later on, which is not shown in the boxplots

6.1.1 Cognitive Load – Subjective Measures

When using the RTLX, the subject is rating multiple dimensions of perceived cognitive load on a 21-point scale ranging from 0 – 100 (a score of 0 equals the lowest possible cognitive load, and 100 equals the opposing highest achievable cognitive load). A summary of the ratings of the different dimensions of the RTLX scales according to each controller is presented in table 6-1, with the total TLX score to the far right. The corresponding answer distributions are presented as box plots in figure 6-1.

Table 6-1: Subjective RTLX ratings of the controllers

		Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration	RTLX Score
Baseline	N	12	12	12	12	12	12	12
	Mean	54	37	41	52	58	40	47
	Median	63	30	38	48	68	25	48
	Std. Dev.	28,37	28,56	27,21	27,34	24,72	29,65	22,29
	Minimum	10	5	5	15	20	5	13
	Maximum	100	85	90	100	100	85	77
Unified	N	12	12	12	12	12	12	12
	Mean	50	31	35	47	57	42	44
	Median	50	30	30	45	55	40	44
	Std. Dev.	17,58	25,95	17,90	25,89	22,39	21,98	12,00
	Minimum	20	0	15	10	10	10	26
	Maximum	75	75	70	100	100	75	66

Note the distribution of the total TLX sum (far right in figure 6-1), which represents the total average of each participants' ratings.

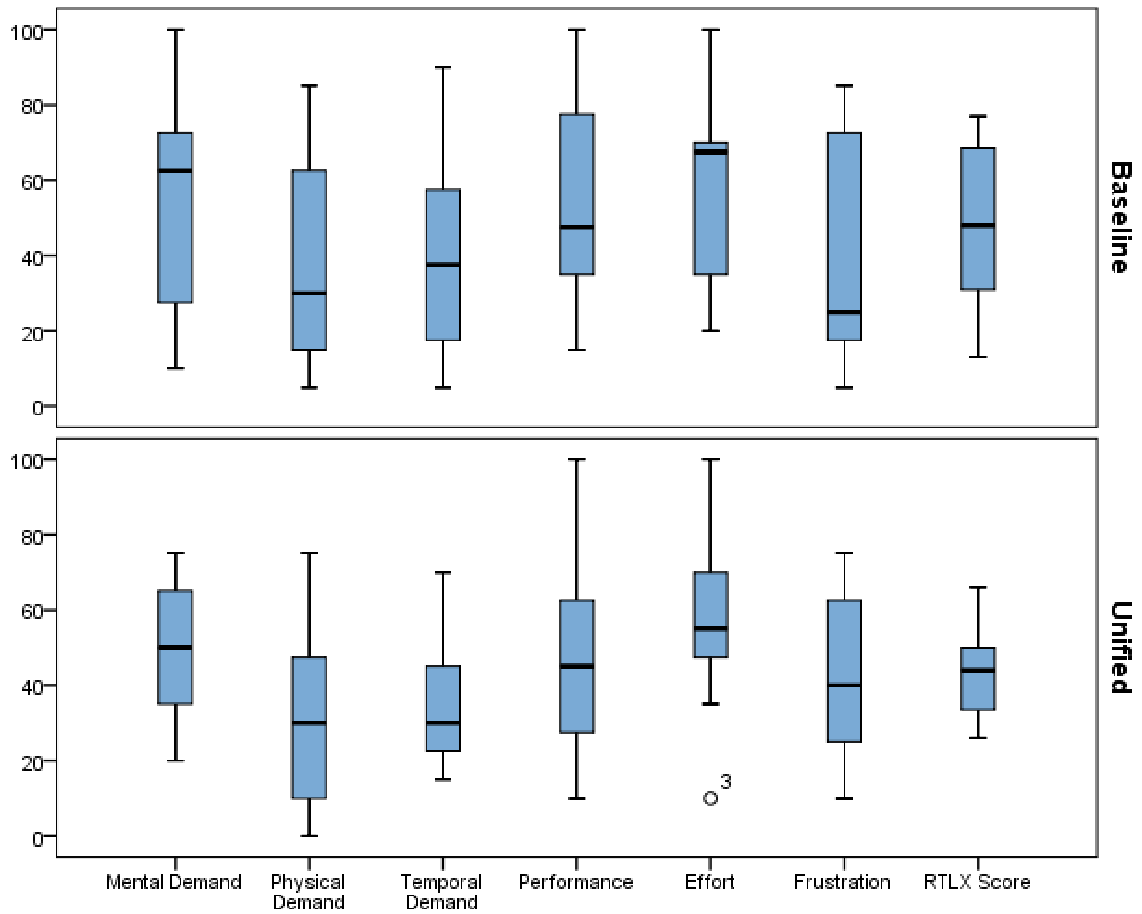


Figure 6-1: Box plot of TLX distributions from the RTLX ratings. Mild outliers are marked with circles.

6.1.2 Cognitive Load – Objective Measures

For thorough investigation of the cognitive load related to the controllers, two objective countermeasures to the subjective RTLX is presented below as reaction times from the secondary task, and mean heart rates during the scenarios.

6.1.2.1 Secondary Task – Reaction Times

This section presents the descriptive of the participants mean reaction times in table 6-2, and the corresponding distributions in figure 6-2.

Table 6-2: Mean reaction times of the two controllers

	Baseline	**Unified**
N	12	12
Mean	933	865
Median	930	847
Std. Deviation	318,57	238,77
Minimum	507	462
Maximum	1477	1186

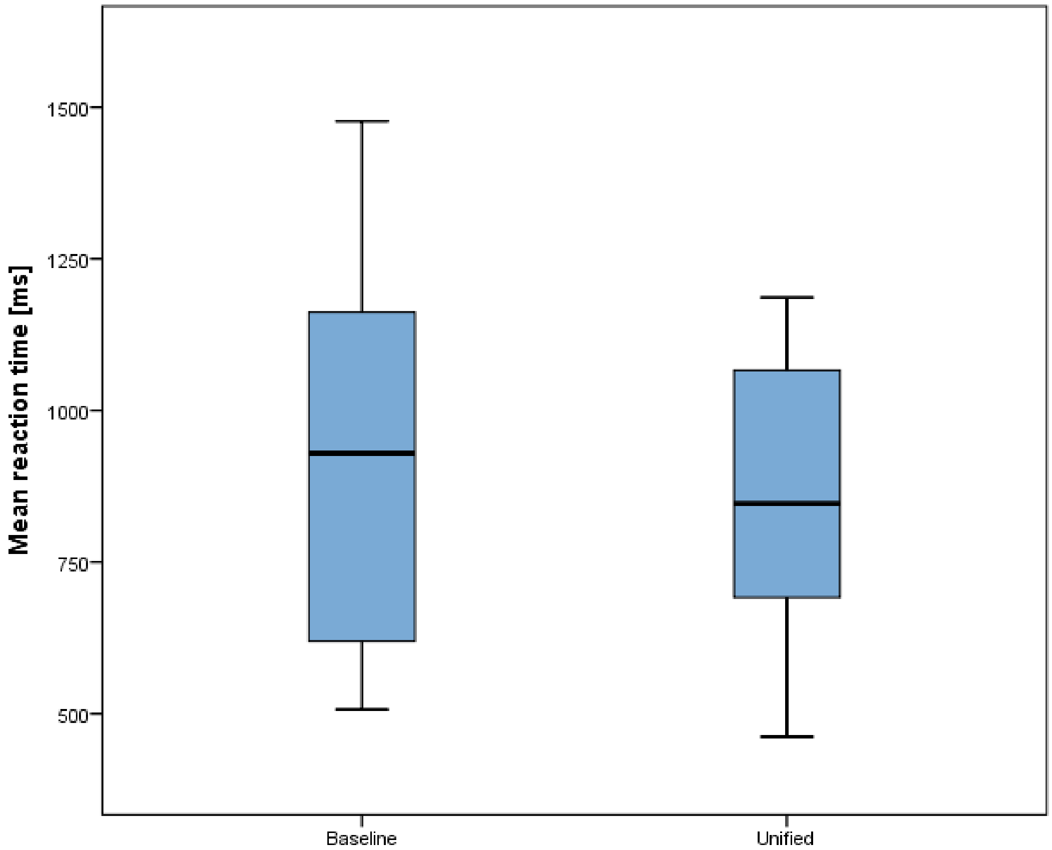


Figure 6-2: Distribution of mean reaction times according to controller.

6.1.2.2 Heart Rate

Because of the difficulties with the ECG, the data presented does not qualify for a good statistical analysis, but it is still presented to show the intended procedure. The mean heart rate was calculated from the raw ECG data, where peaks of the QRS complex indicates a heartbeat. The valid data is presented briefly in table 6-3 and figure 6-3, also indicating missing data points. Notice the large number of missing data points – 7 in total.

Table 6-3: Average Bpm

	Baseline	Unified
N Valid	5	5
N Missing	7	7
Mean	90	85
Median	84	90
Std. Dev.	22,75	16,78
Minimum	67	62
Maximum	127	107

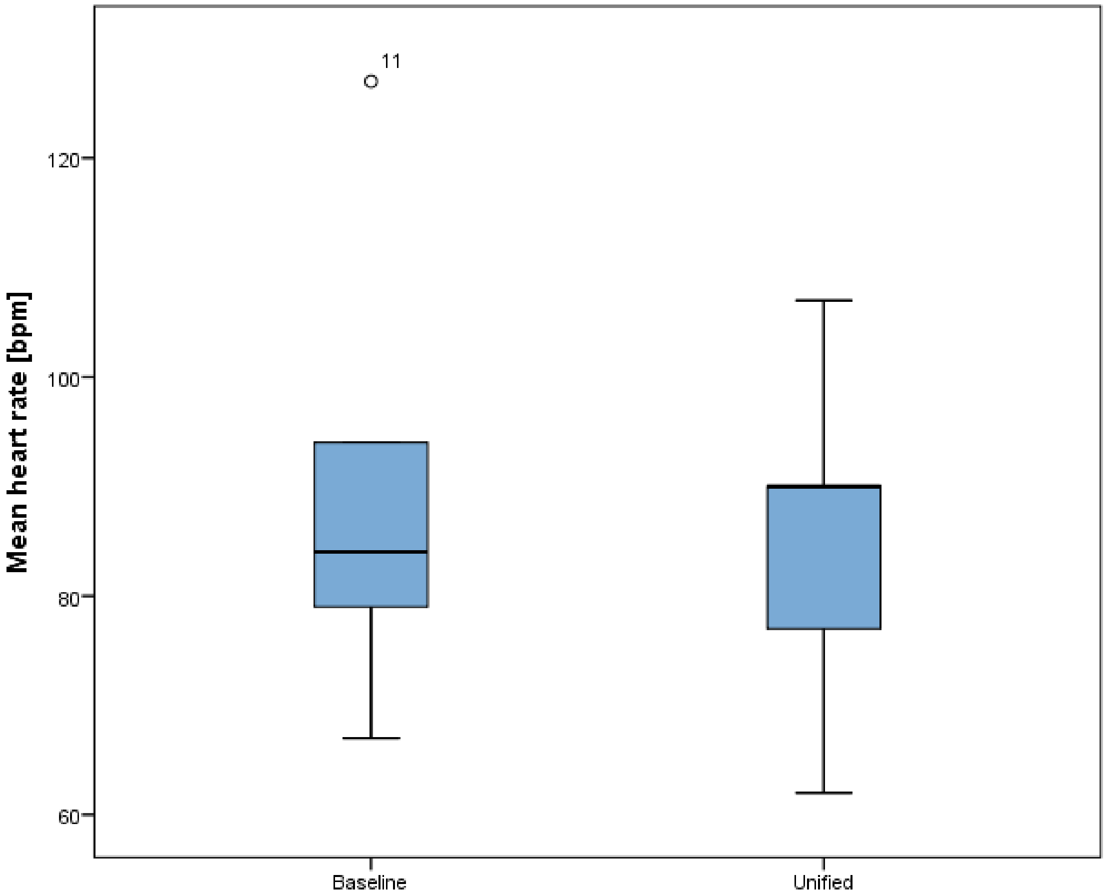


Figure 6-3: Distribution of mean heart rates (bpm). Mild outliers are marked with circles.

6.1.3 Controller Interactions

Diving into the controller interactions, the position of the devices (pitch) on the control interface was continuously logged throughout the scenarios. The changes in this continuous data reveals interactions, which was then counted quantitatively and analyzed further. A summary of the data is presented in table 6-4, with the distributions in figure 6-4.

Table 6-4: Number of interactions with the different devices. The total and average is also included.

		Main Propeller	Bow Thruster	Stern Thruster	Rudder	Interactions total	Interactions avg.
Baseline	N	12	12	12	12	12	12
	Mean	8,1	4,8	6,7	3,2	22,7	5,67
	Median	7,5	5,5	7,0	3,0	21,5	5,38
	Std. Dev.	4,19	3,65	4,91	2,95	8,67	2,167
	Minimum	4	0	0	0	9	2,25
	Maximum	19	10	16	7	38	9,50
Unified	N	12	12	12	12	12	12
	Mean	7,2	4,3	2,4	8,3	22,2	5,54
	Median	7,0	3,0	2,0	6,0	19,5	4,88
	Std. Dev.	3,61	4,41	2,68	7,29	11,09	2,773
	Minimum	2	0	0	0	10	2,50
	Maximum	14	17	7	26	54	13,50

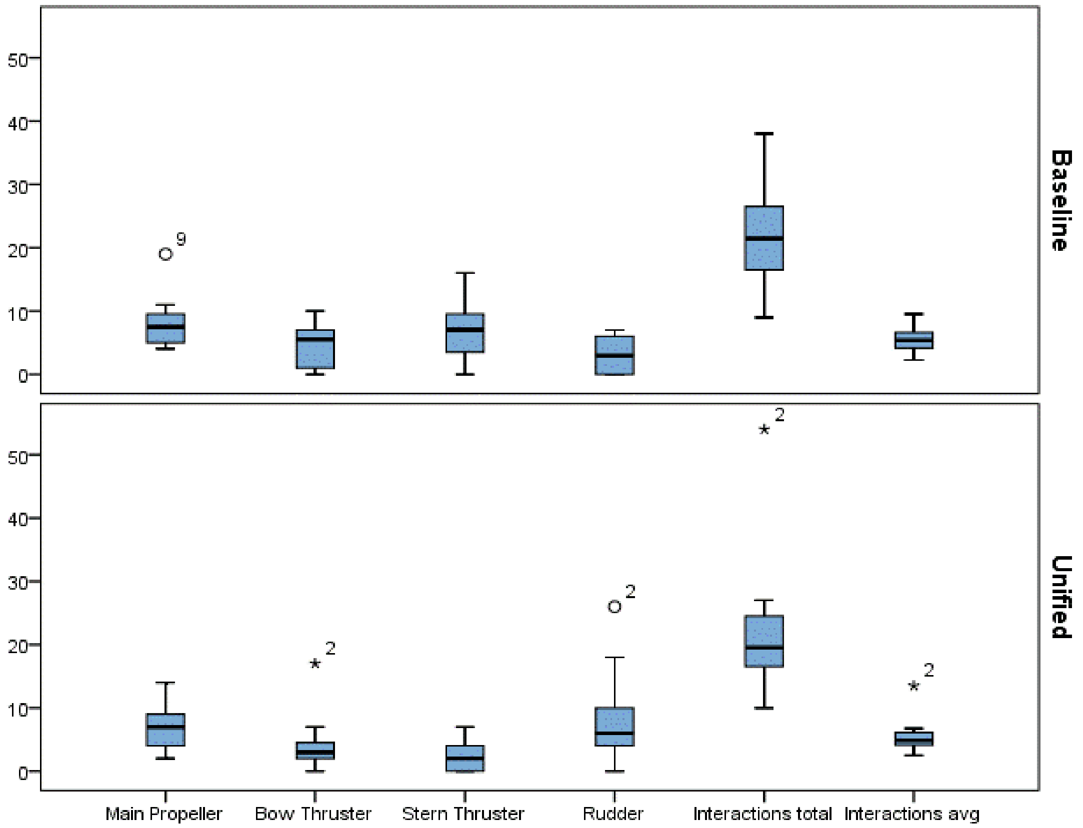


Figure 6-4: Distributions of the controller interactions. Mild outliers are marked with circles and extreme outliers with an asterisk.

To evaluate the extent of interactions, the absolute value of the pitch was summarized for the whole datasets. Note that it is only accounted for the distance traveled between the starting point and WP1 when measuring interactions, not the time duration. This is so due to the decreasing number of participants crossing the next waypoints.

Table 6-5: Summed extent of device pitch

			Main propeller	Bow Thruster	Stern Thruster	Rudder	Extent Avg.
Baseline	N	Valid	12	12	12	12	12
		Missing	0	0	0	0	0
	Mean		31913	26105	32560	24926	29723,73
	Median		24099	21261	31442	23343	24522,25
	Std. Dev.		20955,69	25417,65	31083,11	22247,01	15916,73
	Minimum		16721	0	0	1604	10701,50
	Maximum		91317	77936	96399	74290	66828,25
Unified	N	Valid	12	12	12	12	12
		Missing	0	0	0	0	0
	Mean		42968	28689	17768	29942	31706,40
	Median		39948	23586	9970	21636	29551,25
	Std. Dev.		16471,93	21748,38	21390,66	29029,05	15494,05
	Minimum		20121	3599	0	2563	12134,00
	Maximum		74673	81270	66872	86264	63804,00

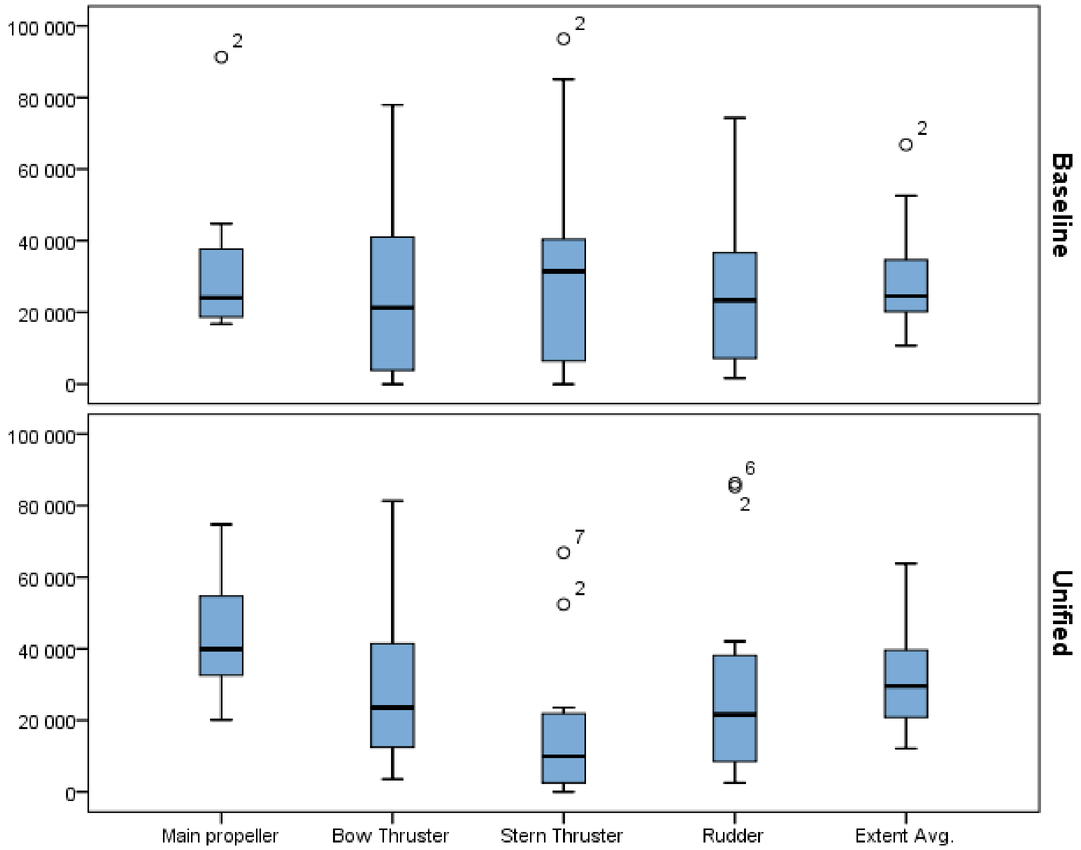


Figure 6-5: Pitch extent distributions. Notice the mild outliers, especially participant 2, marked with circles.

Notice the repeating outlier (P02, figure 6-5) in both interaction distributions for both controllers as well as some single outliers. Although the t-test used later assumes no outliers, all the data points are included in the analysis later on because there is no evidence of data entry or data measurement errors. The outliers are therefore interpreted as genuinely unusual values.

6.1.4 Concept Evaluation

The participants rated the concepts on a five-point Likert scale according to five categories, all ranging from "strongly disagree" to "strongly agree". This corresponds to values 0 – 4 respectively, and the data relating to each controller is shown in table 6-6. The distribution of the ratings is shown in figure 6-6.

Table 6-6: Concept evaluation ratings

		Understanding	Usability	Complexity	Comfort	Purpose	Concept avg.
Baseline	**N**	12	12	12	12	12	12
	Mean	1,75	2,67	1,83	2,58	2,75	2,32
	Median	2,00	3,00	2,00	3,00	3,00	2,40
	Std. Deviation	,754	,888	,835	1,084	1,138	,765
	Minimum	1	1	1	1	1	1
	Maximum	3	4	3	4	4	3
Unified	**N**	12	12	12	12	12	12
	Mean	2,75	2,75	1,75	2,33	2,75	2,47
	Median	3,00	3,00	2,00	3,00	3,00	2,80
	Std. Deviation	1,357	1,138	,965	1,435	1,357	,947
	Minimum	0	0	0	0	0	0
	Maximum	4	4	3	4	4	3

Notice here the large number of outliers in the distribution of usability (see figure 6-6), especially the extreme outliers for the unified controller. Again, as in the previous section, the outliers are treated as genuinely unusual values rather than errors, hence they are included in the further analysis.

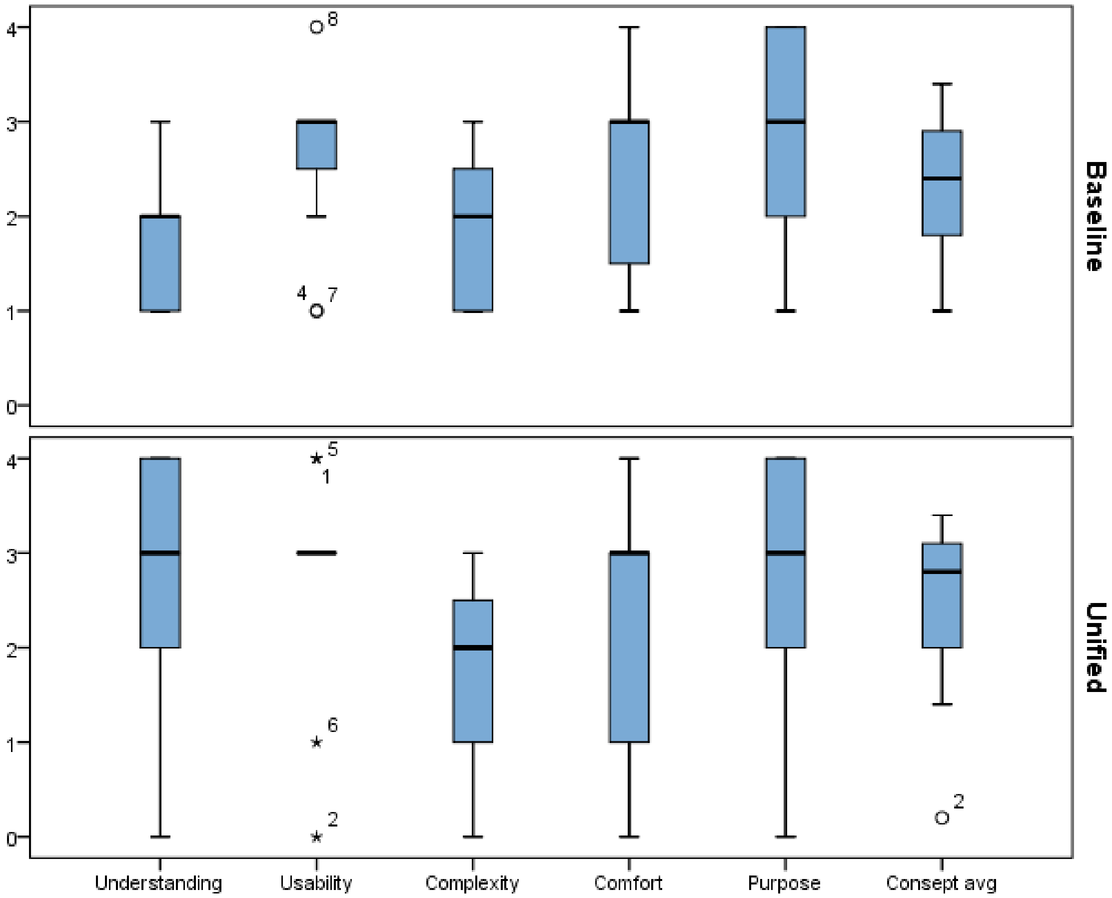


Figure 6-6: Concept evaluation distributions. Mild outliers are marked with circles and extreme outliers with an asterisk.

6.1.5 Performance

During the experiment tasks, the participants' performance by means of distance traveled was recorded. The data in table 6-7 shows the summary of the waypoints crossed with the different controllers and figure 6-7 shows the corresponding distribution.

Table 6-7: Performance in terms of waypoints crossed

	Baseline	Unified
N	12	12
Mean	3,08	2,17
Median	3,00	2,00
Mode	4	2
Range	5	3
Minimum	1	1
Maximum	6	4

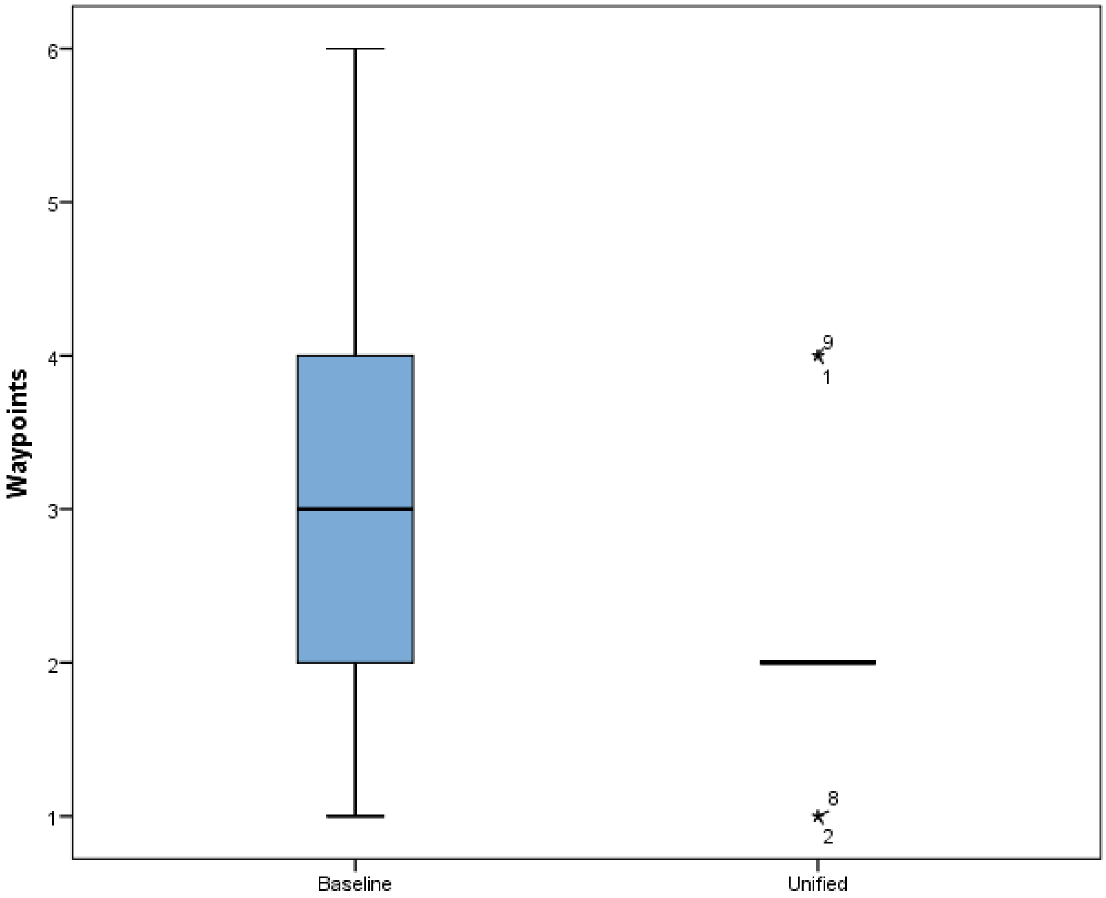


Figure 6-7: Distribution of crossed waypoints.

Again, the unified controller stands out, as its distribution is narrow, but contains several outliers, 4 extreme outliers in total. We see once more the existence of outliers, and they are once more treated as genuine unusual values.

6.1.6 Controller Preference

The last variable to be presented is the controller preference. This is presented in figure 6-8, and shows a two points difference (5 vs. 7) in favor of the Unified controller.

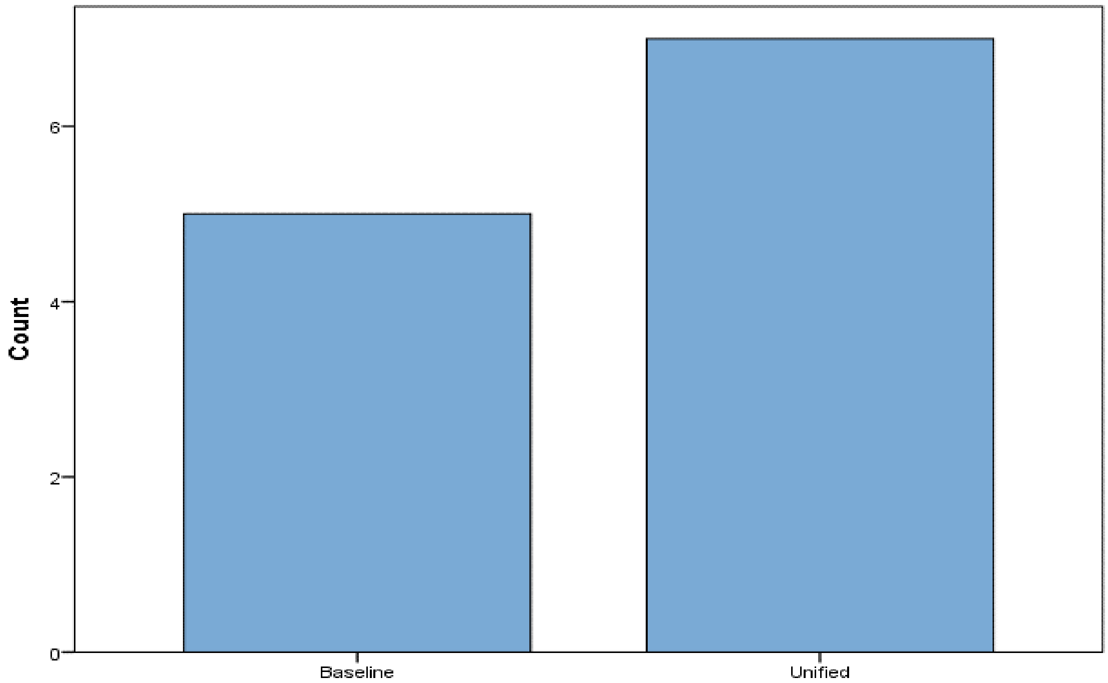


Figure 6-8: Ratings of favorite controller

6.2 Statistical evaluation

This section aims to present the statistical evaluation of the data presented earlier and relate them to the evaluation of the hypotheses. In order to determine the stimuli effects relating to the different groups, a paired samples t-test was performed to test variables measured in round one up against the corresponding in round two according to each controller. As table f - 2 in Appendix F shows, only two variables showed significant difference between the two groups – Mental Effort for the baseline, $t(5) = 2.218$, $p < .05$, and rudder interactions for the Baseline, $t(5) = -2,774$, $p < .05$. In the following evaluation however, the analysis takes advantage of the mixed order of the controllers and compares only differences between the two, treating them as independent cases. This means that all except one analysis satisfies the three main criteria for doing independent samples t-test between the controllers: independent cases, one continuously dependent variable (in this case a scale variable) compared at the time and an independent variable with two categories or levels (Baseline and Unified). The performance analysis uses a Mann-Whitney U test because the variable is ordinal. The independent categories lead to an initially equal sample size in each condition, $N = 12$, but some exceptions are made and highlighted in the following sections due to missing data points or outliers. In an independent samples t-test, one assumption is that the variances are equal, meaning that the two groups are from the same population. As this is not always the case, especially in smaller studies, an alternative t-test is included in the output from SPSS. To test for equal variances, the Levene's test for equality of variance is also included in the SPSS' independent sample t-test, which indicates which of the two rows of results is valid. A significance from Levene's test for equality if variance above p = .05 yields the first row valid, and $p < .05$ yields the second row. This is highlighted in the tables in the following sections.

6.2.1 Testing the Cognitive Load Hypothesis

As the cognitive load hypothesis is tested on two levels, subjectively and objectively, the analysis is split into corresponding categories. Both the subjective and the objective results are tested with independent samples t-tests in the sub sections below.

6.2.1.1 Analysis of Subjective Cognitive Load

Based on the previous mentioned results, the cognitive load related to the controllers is tested as independent samples, with a sample size of $N = 12$ in each condition. The condition refers to the controller at hand – Unified or Baseline – which is the independent variable. The dependent variables are the six TLX sub-scales and the TLX score – the total average score of all the sub-scales. The relation between the two conditions is tested using an independent samples t-test, and the results is presented in table 6-8. For an independent samples t-test, the main output of interest is the significance of difference between the means – sig. (2-tailed) – which should be less than $p = .05$. Note that none of the seven variables significantly differ between the two conditions (all $p > .05$), hence the subjective RTLX evaluation yields no statistical evidence of difference between the cognitive load imposed by the two controllers.

Table 6-8: Independent samples t-test results for RTLX ratings. The test results are highlighted in grey.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Diff.	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Mental Demand	Equal variances assumed	3,970	,059	,389	22	,701	3,750	9,636	-16,234	23,734
	Equal variances not assumed			,389	18,36	,702	3,750	9,636	-16,466	23,966
Physical Demand	Equal variances assumed	,352	,559	,524	22	,606	5,833	11,139	-17,268	28,935
	Equal variances not assumed			,524	21,80	,606	5,833	11,139	-17,280	28,947
Temporal Demand	Equal variances assumed	3,071	,094	,665	22	,513	6,250	9,400	-13,245	25,745
	Equal variances not assumed			,665	19,02	,514	6,250	9,400	-13,424	25,924
Performance	Equal variances assumed	,392	,538	,460	22	,650	5,000	10,870	-17,542	27,542
	Equal variances not assumed			,460	21,94	,650	5,000	10,870	-17,546	27,546
Effort	Equal variances assumed	,433	,517	,130	22	,898	1,250	9,629	-18,720	21,220
	Equal variances not assumed			,130	21,79	,898	1,250	9,629	-18,731	21,231
Frustration	Equal variances assumed	2,977	,098	-,117	22	,908	-1,250	10,656	-23,350	20,850
	Equal variances not assumed			-,117	20,29	,908	-1,250	10,656	-23,459	20,959
RTLX Score	Equal variances assumed	5,073	,035	,490	22	,629	3,583	7,309	-11,575	18,742
	Equal variances not assumed			,490	16,88	,630	3,583	7,309	-11,846	19,012

6.2.1.2 Analysis of Objective Cognitive Load

As a countermeasure to the subjective cognitive load ratings of the RTLX, the difference in mean reaction times from the secondary task and the difference in mean heart rates are tested with the same independent samples t-test procedure as above. The output of interest is again the significance of difference between the means ($p < .05$). The result is presented in table 6-9. Again, no significant value is detected, $t(22) = .589$, $p = .562$, and the results match the ones of the subjective analysis.

Table 6-9: Independent samples t-test of mean reaction times. The test results are highlighted in grey.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Diff	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Mean RT	Equal variances assumed	1,219	0,281	0,589	22	0,562	67,75	114,928	-170,596	306,096
	Equal variances not assumed			0,589	20,39	0,562	67,75	114,928	-171,689	307,189

Moving on, the mean heart rate analysis was performed with the few valid data points available. Although this yields greater risk of invalid test results, the outcome is presented in to show the intended procedure for further research. Notice no significant difference for the means of the average heart rates, $t(8) = .395$, $p = .703$.

Table 6-10: Independent samples t-test for heart rate differences

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Mean heart rate	Equal variances assumed	,248	,632	,395	8	,703	5,000	12,644	-24,158	34,158
	Equal variances not assumed			,395	7,359	,704	5,000	12,644	-24,606	34,606

6.2.2 Testing the Controller Interaction Hypotheses

As the controller interaction is evaluated regarding both extent and number of interactions, the analyses are split accordingly. The number of interactions is analyzed first, followed by the pitch extent analysis.

6.2.2.1 Analysis of Number of Interactions

In the evaluation of the controller interaction, the pitch of the different devices was measured. The results from the independent samples t-test presented in table 6-11 shows two significant results. The stern thruster interactions, $t(22) = 2.634$, $p < .05$, and the rudder interactions, $t(22) = -2.276$, $p < .05$.

Table 6-11: Independent samples t-test of amount of controller interaction. Significant results are highlighted in yellow, and other test results in grey.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Diff	
		F	Sig.	t	df	Sig. (2ailed)	Mean Diff	Std. Error Diff	Lower	Upper
Main Propeller	Equal variances assumed	,050	,825	,574	22	,572	,917	1,597	-2,395	4,228
	Equal variances not assumed			,574	21,54	,572	,917	1,597	-2,399	4,232
Bow Thruster	Equal variances assumed	,049	,826	,303	22	,765	,500	1,653	-2,927	3,927
	Equal variances not assumed			,303	21,24	,765	,500	1,653	-2,934	3,934
Stern Thruster	Equal variances assumed	2,454	,131	2,634	22	,015	4,250	1,613	,904	7,596
	Equal variances not assumed			2,634	17,02	,017	4,250	1,613	,846	7,654
Rudder	Equal variances assumed	3,467	,076	-2,276	22	,033	-5,167	2,270	-9,875	-,458
	Equal variances not assumed			-2,276	14,51	,039	-5,167	2,270	-10,020	-,313
Interaction total	Equal variances assumed	,043	,837	,123	22	,903	,500	4,064	-7,929	8,929
	Equal variances not assumed			,123	20,79	,903	,500	4,064	-7,957	8,957
Interaction avg.	Equal variances assumed	,043	,837	,123	22	,903	,125	1,016	-1,982	2,232
	Equal variances not assumed			,123	20,79	,903	,125	1,016	-1,989	2,239

6.2.2.2 Analysis of Pitch Extent

Following the analysis of the number of interactions, the extent of the control devices' pitch is tested. The data is appropriate for an independent samples t-test, and the results is presented below in table 6-12. Notice no significant difference between the controllers.

Table 6-12: Independent samples t-test of pitch extent. Test results are highlighted in grey.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Main propeller	Equal variances assumed	,017	,899	-1,437	22	,165	-11054,3	7694,5	-27011,8	4903,1
	Equal variances not assumed			-1,437	20,84	,166	-11054,3	7694,5	-27063,5	4954,9
Bow Thruster	Equal variances assumed	,314	,581	-,268	22	,791	-2584,5	9656,8	-22611,5	17442,5
	Equal variances not assumed			-,268	21,49	,792	-2584,5	9656,8	-22639,3	17470,3
Stern Thruster	Equal variances assumed	,950	,340	1,358	22	,188	14791,2	10892,4	-7798,2	37380,5
	Equal variances not assumed			1,358	19,51	,190	14791,2	10892,4	-7966,5	37548,8
Rudder	Equal variances assumed	,558	,463	-,475	22	,639	-5015,8	10557,8	-26911,4	16879,9
	Equal variances not assumed			-,475	20,61	,640	-5015,8	10557,8	-26997,5	16966,0
Extent Avg.	Equal variances assumed	,001	,982	-,309	22	,760	-1982,7	6412,3	-15280,9	11315,6
	Equal variances not assumed			-,309	21,98	,760	-1982,7	6412,3	-15281,5	11316,1

6.2.3 Testing of Concept Evaluation Hypothesis

Further, the concepts were evaluated by the participants on five different dimensions. Again, independent samples t-test was used and the results from the is presented in table 6-13 below. Notice the only significant difference within understandability, $t(22) = -2.607$, $p = .036$.

Table 6-13: Independent samples t-test of concept ratings. Significant results are highlighted in yellow, and other test results in grey.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Diff	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Understand ability	Equal variances assumed	2,607	,121	-2,232	22	,036	-1,000	,448	-1,929	-,071
	Equal variances not assumed			-2,232	17,20	,039	-1,000	,448	-1,944	-,056
Usability	Equal variances assumed	,085	,774	-,200	22	,843	-,083	,417	-,947	,781
	Equal variances not assumed			-,200	20,77	,843	-,083	,417	-,950	,784
Complexity	Equal variances assumed	,271	,608	,226	22	,823	,083	,368	-,681	,847
	Equal variances not assumed			,226	21,55	,823	,083	,368	-,682	,848
Comfort	Equal variances assumed	1,794	,194	,482	22	,635	,250	,519	-,827	1,327
	Equal variances not assumed			,482	20,46	,635	,250	,519	-,831	1,331
Purpose	Equal variances assumed	,442	,513	0,000	22	1,000	0,000	,511	-1,060	1,060
	Equal variances not assumed			0,000	21,35	1,000	0,000	,511	-1,062	1,062
Concept avg.	Equal variances assumed	,268	,610	-,427	22	,674	-,150	,351	-,879	,579
	Equal variances not assumed			-,427	21,07	,674	-,150	,351	-,881	,581

6.2.4 Analysis of Performance

Lastly, the performance between the two controllers are tested based on waypoints crossed. A Mann-Whitney U test was run to determine differences in waypoints crossed between the two controllers. Visual inspection of the distributions of performance scores for both controllers indicated similarity, which is an assumption of the Mann-Whitney U test. The test showed no statistically significant difference in median performance scores, $U = 44$, $z = -1.697$, $p = .114$.

Table 6-14: Mann-Whitney U test of controller performance. Used significance value is highlighted in grey.

Total N	24
Mann-Whitney U	44.0
Wilcoxon W	122.00
Test statistic	44.0
Standard error	16.495
Standardized test statistic (z)	-1.697
Asymptotic Sig. (2-sided test)	.090
Exact Sig. (2-sided test)	.114

6.3 Evaluation of Hypotheses

The statistical tests previously presented was conducted to evaluate the four hypotheses at hand, stated in section 5.1 on page 53. Each of the hypotheses relates to different aspects of the controllers and will be evaluated sequentially in the following sections.

6.3.1 Cognitive Load Hypothesis

Since this hypothesis is analyzed both subjectively and objectively, the statistical results from each test is audited before a summarized evaluation is presented. From the subjective RTLX results in this experiment, it is clear that there is no statistically significant difference between the two controllers evaluated as all p values are far from the significance level of $p = .05$ (all p values are between $p = .513$ and $p = 908$). Moving on to the analysis of the secondary task reaction times, a non-significant result is again obtained, $t(22) = .589$, $p = .562$, which matches the result from the RTLX analysis. The independent t-test of the heart rate data supports the previous observations of insignificant results, $t(8) = .395$, $p = .703$. As all of the above mentioned tests showed no significant results, there is no statistically significant evidence for supporting the proposed hypothesis, hence the null hypothesis still stands after this experiment.

6.3.2 Controller Interaction Hypothesis – Number of interactions

To assess the hypothesis that the Unified controller leads to fewer interactions than the Baseline controller, the number of interactions was analyzed. The results here are interesting, as some of the control devices shows significant difference in means – ‘stern thruster interactions’, $t(22) = 2.634$, $p = .015$, and the ‘rudder interactions’, $t(22) = -2.276$, $p = .033$ – while the others show no statistically significant differences. The stern thruster showed less interactions when used with the Unified controller (M = 2.4, SD = 2.68) versus the baseline controller (M = 6.7, SD = 2.91). Also, it is worth noting that this hypothesis focus on the totality of interactions, thus the average number of interactions – $t(22) = .123$, $p = .903$ – weighs heavier that the others when deciding to accept or reject the hypothesis. Hence, the alternative hypothesis is rejected, and the null hypothesis still stands for the number of interactions with the controllers.

6.3.3 Controller Interaction Hypothesis – Extent of Interactions

Further evaluation of the interactions with the control devices relating to the extent of the pitch (which also relates to the extent of the interactions), led to yet another set of non-significant results. All the data analyzed, with p values being between $p = .165$ and $p = .791$, gives no statistically significant evidence for supporting the alternative hypothesis, hence the null hypothesis is kept. To summarize the two interaction hypotheses, none of the data recorded during this experiment showed statistical differences relating to the interaction patterns with the two controllers.

6.3.4 Concept Evaluation Hypothesis

The last hypothesis is tested with subjective user ratings of the concepts. The analysis showed one statistically significant difference in the 'understandability' dimension, $t(22) = -2.232$, $p = .036$ in favor of the Unified controller (M = 2.75, SD = 1.375) versus the Baseline controller (M = 1.75, SD = 0.754). The other dimensions, as well as the average concept rating, proved no significant differences between the controllers, with p values between $p = .674$ and $p = 1.000$. With these results as foundation, the null hypothesis still stands for the overall concept evaluation, but the Unified controller seems to be easier for users, at least with little to no prior knowledge of ships, to understand. Also, it might be interesting to mention that the Unified controller scored higher when the subject was to choose their overall favorite controller.

7 Limitations and Evaluations

Looking back on the experiment described in this thesis, several aspects are subject for evaluation and improvement. This section aims to elaborate on the limitations of the experimental setup and procedure.

First up is the facilities in which the experiment took place. As the experimental setup chapter (chapter 0, page 53) discuss, the experiment tried to be as realistic as possible, and not a clinical “white-room” experiment. However, since resources and time was limited, and this was a prototype setup, the experiment was carried out in the “cardboard bridge wing” as seen in Figure 5-5 in page 59 and with a computer game as the ship simulator. Connections to real, full size ship simulators was made, but time did not allow for full access to do the experiment in such a location. In the ship simulator computer game, the camera options are also limited, as there is no camera angle from the bridge wing of the ship. Therefore, a bird’s eye view from behind the ship (see figure 5-6, page 63), as the only viable option to get an overview of the ship, was used in all the scenarios. This camera angle is quite far from the real field of view from the bridge wing, but was in this case the best solution.

Figure 7-1: Kongsberg's Polaris ship simulator. Curtesy of Kongsberg Maritime. Retrieved from https://www.km.kongsberg.com, 03.06.16

Further evaluation of the experimental setup reveals limitations of the computer screen setup. The optimal solution for this experiment case would have been to have screens on all three sides of the user with the corresponding image projections, instead of one fixed screen in the front. Unfortunately, the graphics options of "Ship Simulator 2008" does not have this opportunity, as it is made for a single computer screen. In later experiments, a real simulator with a full size bridge wing with surrounding screens/projections as exemplified by Kongsberg Maritime's Polaris ship simulator in figure 7-1, should be implemented for an even more realistic experience. This could eventually increase the seriousness of the experiment as the environment is as close to reality as one gets without being on a real ship.

Further limitations concern the participants of the experiment, which should have more experience and/or knowledge of ships. The participants in this experiment were all scientific engineering students at NTNU, not familiar with the properties of a larger ship, resulting in various results regarding the navigation. Some of the students did not understand how the ship behaved, how to control it or how the different devices affected the ships motion regardless of controller. Such characteristics should be of prior knowledge to the experiment subjects to get more realistic results. However, this experiment benefits from having students with somewhat similar previous experience since this yields somewhat similar results, but is more open for statistical outliers. The effects of the outliers would also be less with more participants in the experiment, thus future experiments should, if possible, have a greater number of subjects.

Moving on to the experimental procedure, learning effects is a great issue when dealing with humans. However, one might argue that participants with previous knowledge of the ships environment and characteristics is less affected by the learning effects of one experimental run-through, compared to the students used in this particular experiment. Further, the statistical evaluation performed on the data from this experiment was done under the assumption that the sum of the data from the two controller presentation orders does not affect the total ratings or objective data. A more elaborate study with a larger sample size ($N > 12$) might therefore be advantageous to perform in order to evaluate order effects and scenario effects for similar experiments. An alternative is to perform the experiment over two or more days, testing one controller at a time and reducing the carry over effects. A third option is to have each participant only run one controller and one scenario, eliminating the need for several scenarios and the effects of the presentation order of the controllers, but this yields a need for a lot of participants for thorough statistical evidence.

Also related to the learning effects in this experiment is the two main scenarios, S1 and S2. As each subject performed both scenarios and they were quite similar, the second scenario will often yield better result. If one were to adapt one of the above mentioned alternatives, such carry over effects would be minimized, and the results would probably be even more independent of each other.

Changing perspective leads to the evaluation of the controllers, which has a central role in this experiment. The two controllers are made to resemble one another in terms of building quality, materials, color and tactile feel. The particular material chosen is 6mm MDF sheets cut in a laser cutter. The drawings for the laser cutter was made from CAD models, and the “sheet parts” was then assembled together to form the controllers. The reason for this building process and material choice is that it allows for rapid prototyping and changes to the models. Further, it makes it fairly easy to produce shell parts so electronic components could fit inside. Although this material does not look or feel like the ones used in real ship interface devices, it worked quite well in the early-phase prototypes for this purpose.

Another limitation relating to the controllers are bias effects discussed in chapter 2.1 and 5.2. If one (or more) of the participants had prior knowledge of larger ships, the Baseline controller would probably be recognized and could therefore induce a bias towards the previous known interface. Although participants were asked to say whether they had previous experience with ships/boats, this experiment did not take this possible bias factor into account, because the question does not indicate what type of ship/boat the subject has knowledge of. Bias towards the old setup might become a greater issue at later stages if one were to conduct similar experiments with ship bridge personnel.

When looking at the statistical analysis and data capturing of this experiment, some key aspects becomes apparent. As mentioned earlier in the thesis, the experiment captures data through a self-made software which was developed by a non-software designer. Although this program worked without flaws during this experiment, a proper synchronization tool should be applied for more extensive research. The reason for making a unique software in this case, was because of trouble with synchronizing all the data on existing software solutions. When the collected data was to be analyzed statistically, most of the data satisfied the initial assumptions, correct type and amount of variables, for an independent t-test.

However, as the result section briefly explains, some of the assumptions of the statistical tests is not met. This includes to: check the variables for normality, as they should be normally distributed; remove statistical outliers if possible; and have independent observations. The latter is somewhat met because of the two inverted controller presentation orders, and partially supported by the paired samples t-test presented in Appendix F. For even greater validity of the results, a more thorough analysis process and data preparation should be conducted, so that as many of the assumptions is met.

Special limitations apply to the analysis of the interaction data and the recordings of ECG. The interaction data is counted qualitatively through printed graphs. Here, a more elaborate method of measuring the number of interactions should be applied. An example is to directly measure the changes rather than the continuous position of the different devices, maybe according to some threshold values (say changes below 20 % is counted as normal, and greater changes is registered as abnormal). As the heart rate analysis in this experiment only cared about mean heart rates, the ECG measurements might be unnecessarily invasive and complicated. Also, the data is harder to capture properly, something the heart rate analysis showed as only 5 out of 12 of the data sets was valid. For further research using mean heart rates to evaluate cognitive load, other measurement tools might be considered more suitable, such as heart rate monitors.

Another area for approval was the experimental background procedure, the tasks carried out by the experimenter behind the scenes. This experiment relied on one man controlling three computers as explained in the experimental setup (chapter 5.5). Although the experimenter did a lot of pre runs of the experiment to accomplish the tasks, it might have been a source of disturbing noise. A more powerful setup which could run the different programs automatically, or more experiment personnel would have solved some of the issues with this setup.

Lastly, the external variables, such as temperature, air quality, time of day, personal mood and so forth, is not accounted for in this experiment. The variables controlled are all mentioned in chapter 0, and relates to the actual, physical execution of the tasks. During the days of conducting the experiment, the weather in Trondheim was warm and clear, which increased the room temperature. This has till now unknown effects, but if controlled it will, in addition the above mentioned improvements, increase the validity of the experimental setup and might lead to some of the implications discussed next.

8 Implications

As the experiment conducted and analyzed in this thesis has results and limitations of various real life applications, this section discusses its possibilities and implications if these limitations would have been accounted for. The discussions in this chapter is highly speculative, and applies the researchers own interpretations of how the results might be applied to other settings of similar nature.

As one of the main goals of this thesis was to introduce Affective Engineering (AE) and Wayfaring in the development of a ship controller interface, the effect of the results might be that controller interactions, cognitive load and undisturbed concept evaluation proves useful in a maritime development setting. The span of the results might even be applied to even greater extents, as the elements from AE applied in this product development approach could be transferred to other development branches, especially related to interfaces.

Revisiting the cognitive load hypothesis (H1), this experiment showed no clear indications to a lower cognitive load with any of the two controllers. However, if the Unified controller were to inflict much less cognitive load on the user, it would have been a clear indication that a small, combined ship controller is worth looking into. As discussed in the theory section, a complex, high-demand environment affects the mental capabilities of the user, and if a new controller were to ease his/hers task significantly, it should be implemented. This would again change how the captains and their crews communicate with and controls the ship, hopefully towards an easier, safer and more responsible environment for both crew, passengers and cargo.

Conclusively, if the alternative hypotheses stated, H1 – H4, would all be accepted, the maritime industry should undergo a great change in how they present a physical interface to the user and how they deal with user integration in the development. As the Unified controller contrasts the old setup by being a lot smaller and more open for individual placements on the ship bridge wing, the whole environment would need adaptions. The thoughts mentioned in section 3.1, regarding the ergonomically adaptive properties of a future SBW comes into play as well. The radical changes apply not only to maritime product developers and designers, but also to legislators applying rules and regulations to the maritime industry all over the world, as these have great influence on how naval products come to be. Because of the resulting implications this development and experiment might have, the author believes this is a valuable source of new knowledge and experience, hence greater experiments of similar approaches should be conducted.

9 Conclusion

This thesis started out with the goal of developing and experimentally test a new ship controller interface with elements from ergonomics and Affective Engineering. To start off, previous knowledge within relevant sciences such as ergonomics, interaction design, prototyping, product development, cognitive load, and measurement techniques was gathered and presented. Then followed a divergent phase looking into new ways of presenting a ship controller interface, and the development of two functional prototypes. Some of the choices made during the development of the Unified controller was intended to contrast and challenge the old and somewhat outdated products and regulations that rules the maritime industry. This controller, as well as a Baseline model was then applied to an Affective Engineering experiment.

The procedure and setup of this experiment was then presented and might serve as a foundation for further analysis of the controlling interactions within a SBW environment, especially related to the control devices. Although the experimental results showed little significance, a trend towards the newly proposed design became apparent from discussions with the subjects upon finishing the experiment.

Lastly, I highly encourage future research and development to apply Affective Engineering to product development, as it might reveal previously unthought-of criterions, experience and knowledge, especially in complex environments.

This page is intentionally left blank.

10 Bibliography

Balters, S., & Steinert, M. (2014). *Decision-making in engineering-a call for affective engineering dimensions in applied engineering design and design sciences*. Paper presented at the Innovative Design and Manufacturing (ICIDM), Proceedings of the 2014 International Conference on.

Balters, S., & Steinert, M. (2015). Capturing emotion reactivity through physiology measurement as a foundation for affective engineering in engineering design science and engineering practices. *Journal of Intelligent Manufacturing*, 1-23. doi:10.1007/s10845-015-1145-2

Becker, L. C., Pepine, C. J., Bonsall, R., Cohen, J. D., Goldberg, A. D., Coghlan, C., . . . Sheps, D. S. (1996). Left Ventricular, Peripheral Vascular, and Neurohumoral Responses to Mental Stress in Normal Middle-Aged Men and Women Reference Group for the Psychophysiological Investigations of Myocardial Ischemia (PIMI) Study. *Circulation, 94*(11), 2768-2777.

Bjørneseth, F. B., Renganayagalu, S. K., Dunlop, M. D., Homecker, E., & Komandur, S. (2012). *Towards an experimental design framework for evaluation of dynamic workload and situational awareness in safety critical maritime settings.* Paper presented at the Proceedings of the 26th Annual BCS Interaction Specialist Group Conference on People and Computers.

Blair-Early, A., & Zender, M. (2008). User interface design principles for interaction design. *Design Issues, 24*(3), 85-107.

Bridger, R. S. (1995). Introduction to ergonomics.

Britton, B. K., & Tesser, A. (1982). Effects of prior knowledge on use of cognitive capacity in three complex cognitive tasks. *Journal of verbal learning and verbal behavior, 21*(4), 421-436.

Brown, T. (2008). Design thinking. *Harvard business review, 86*(6), 84.

Brunken, R., Plass, J. L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational psychologist, 38*(1), 53-61.

Bryant, D. T. (1991). *The Human Element in Shipping Casualties*.

Brünken, R., Steinbacher, S., Plass, J. L., & Leutner, D. (2002). Assessment of cognitive load in multimedia learning using dual-task methodology. *Experimental psychology, 49*(2), 109.

Buettner, R. (2013). Cognitive workload of humans using artificial intelligence systems: towards objective measurement applying eye-tracking technology *KI 2013: Advances in Artificial Intelligence* (pp. 37-48): Springer.

Byers, J. C., Bittner, A. C., & Hill, S. G. (1989). Traditional and Raw Task Load Index (TLX) Correlations: Are Paired Comparisons Necessary? *Advances in Industrial Ergonomics and Safety, 1*, 5.

Camp, G., Paas, F., Rikers, R., & van Merrienboer, J. (2001). Dynamic problem selection in air traffic control training: A comparison between performance, mental effort and mental efficiency. *Computers in Human Behavior, 17*(5), 575-595.

Cao, A., Chintamani, K. K., Pandya, A. K., & Ellis, R. D. (2009). NASA TLX: Software for assessing subjective mental workload. *Behavior research methods, 41*(1), 113-117.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and instruction, 8*(4), 293-332.

Chandler, P., & Sweller, J. (1996). Cognitive load while learning to use a computer program. *Applied cognitive psychology, 10*(2), 151-170.

Cooper, A., Reimann, R., Cronin, D., & Noessel, C. (2014). *About face: The essentials of interaction design*: John Wiley & Sons.

Dahlgaard, J. J., & Nagamachi, M. (2008). Perspectives and the new trend of Kansei/affective engineering. *The TQM Journal, 20*(4), 290-298.

DeLeeuw, K. E., & Mayer, R. E. (2008). A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. *Journal of Educational Psychology, 100*(1), 223.

Di Nocera, F., Camilli, M., & Terenzi, M. (2007). A random glance at the flight deck: Pilots' scanning strategies and the real-time assessment of mental workload. *Journal of Cognitive Engineering and Decision Making, 1*(3), 271-285.

Dow, S. P., Heddleston, K., & Klemmer, S. R. (2009). *The efficacy of prototyping under time constraints.* Paper presented at the Proceedings of the seventh ACM conference on Creativity and cognition.

Edelman, J., & Currano, R. (2011). Re-representation: affordances of shared models in team-based design *Design thinking* (pp. 61-79): Springer.

Ettema, J., & Zielhuis, R. (1971). Physiological parameters of mental load. *Ergonomics, 14*(1), 137-144.

Fredericks, T. K., Choi, S. D., Hart, J., Butt, S. E., & Mital, A. (2005). An investigation of myocardial aerobic capacity as a measure of both physical and cognitive workloads. *International Journal of industrial ergonomics, 35*(12), 1097-1107.

Fry, B., & Reas, C. (2015). Processing (Version 3.0.2) [Software sketchbook]. Retrieved from https://processing.org/

Gerstenberg, A., Sjöman, H., Reime, T., Abrahamsson, P., & Steinert, M. (2015). A Simultaneous, Multidisciplinary Development and Design Journey–Reflections on Prototyping *Entertainment Computing-ICEC 2015* (pp. 409-416): Springer.

Grootjen, M., Bierman, E., & Neerincx, M. (2006). *Optimizing cognitive task load in naval ship control centres: Design of an adaptive interface.* Paper presented at the IEA 16th World Congress on Ergonomics.

Grootjen, M., Neerincx, M., & Veltman, J. (2006). Cognitive task load in a naval ship control centre: from identification to prediction. *Ergonomics, 49*(12-13), 1238-1264.

Hart, S. G. (2006). *NASA-task load index (NASA-TLX); 20 years later.* Paper presented at the Proceedings of the human factors and ergonomics society annual meeting.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology, 52*, 139-183.

Hendy, K. C., Hamilton, K. M., & Landry, L. N. (1993). Measuring subjective workload: when is one scale better than many? *Human Factors: The Journal of the Human Factors and Ergonomics Society, 35*(4), 579-601.

Hess, E. H., & Polt, J. M. (1964). Pupil size in relation to mental activity during simple problem-solving. *Science, 143*(3611), 1190-1192.

Hollnagel, E. (1997). Cognitive ergonomics: it's all in the mind. *Ergonomics, 40*(10), 1170-1182.

Houde, S., & Hill, C. (1997). What do prototypes prototype. *Handbook of human-computer interaction, 2*, 367-381.

IBM. (2015). SPSS Statistics (Version 23): IBM.

International Ergonomics Association, I. (2016). Definition and Domains of Ergonomics.

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science, 154*(3756), 1583-1585.

Kahneman, D., Beatty, J., & Pollack, I. (1967). Perceptual deficit during a mental task. *Science, 157*(3785), 218-219.

Kakizaki, T. (1984). Relationship between EEG amplitude and subjective rating of task strain during performance of a calculating task. *European journal of applied physiology and occupational physiology*, *53*(3), 206-212.

Karlsson, E. A., & Solvang, F. O. (2015). A human-centred approach to the development of a ship bridge wing. 71.

Kerr, B. (1973). Processing demands during mental operations. *Memory & Cognition*, *1*(4), 401-412.

Kim, J., & Wilemon, D. (2002). Focusing the fuzzy front-end in new product development. *R&D Management*, *32*, 269-279.

Kohlisch, O., & Schaefer, F. (1996). Physiological changes during computer tasks: responses to mental load or to motor demands? *Ergonomics*, *39*(2), 213-224.

Kum, S., Furusho, M., & Fuchi, M. (2008). Assessment of VTS Operators' Mental Workload by Using NASA Task Load Index. *日本航海学会論文集*(118), 307-314.

Leifer, L. J., & Steinert, M. (2014). Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning *Management of the Fuzzy Front End of Innovation* (pp. 141-158): Springer.

Leikanger, K. K. (2016). Prototyping an Experimental Setup for Understanding Affective Response in a Ship Bridge Scenario.

Libelium. (2013). e-Health Sensor Platform Complete Kit V2.0 for Arduino, Raspberry Pi and Intel Galileo. https://www.cooking-hacks.com/documentation/tutorials/ehealth-biometric-sensor-platform-arduino-raspberry-pi-medical.

Lim, Y.-K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *15*(2), 7.

Matin, E. (1974). Saccadic suppression: a review and an analysis. *Psychological bulletin*, *81*(12), 899.

May, M. (1999). *Cognitive aspects of interface design and human-centered automation on the ship bridge: the example of ARPA/ECDIS integration.* Paper presented at the Human Interfaces in Control Rooms, Cockpits and Command Centres, 1999. International Conference on.

Meinel, C., & Leifer, L. (2010). *Design thinking research*.

Meshkati, N., Hancock, P. A., Rahimi, M., & Dawes, S. M. (1995). Techniques in mental workload assessment.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*: Cambridge University Press.

Moray, N. (1988). Mental workload since 1979. *International reviews of ergonomics, 2,* 123-150.

Nagamachi, M. (1995). Kansei engineering: a new ergonomic consumer-oriented technology for product development. *International Journal of industrial ergonomics, 15*(1), 3-11.

Nilsson, R., Gärling, T., & Lützhöft, M. (2009). An experimental simulation study of advanced decision support system for ship navigation. *Transportation research part F: traffic psychology and behaviour, 12*(3), 188-197.

Norman, D. A. (2005). Human-centered design considered harmful. *Interactions, 12*(4), 14-19.

Noyes, J. M., & Bruneau, D. P. (2007). A self-analysis of the NASA-TLX workload measure. *Ergonomics, 50*(4), 514-519.

O'Donnell, R. D., & Eggemeier, F. T. (1986). Workload assessment methodology.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist, 38*(1), 1-4.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational psychologist, 38*(1), 63-71.

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429.

Paas, F. G., & Van Merriënboer, J. J. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational psychology review, 6*(4), 351-371.

Potsdam, I. D. L. (2015). Fritzing (Version 0.9.2b.64).

Reid, G. B., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. *Advances in psychology, 52,* 185-218.

Reid, S. E., & De Brentani, U. (2004). The fuzzy front end of new product development for discontinuous innovations: a theoretical model. *Journal of product innovation management, 21*(3), 170-184. doi:10.1111/j.0737-6782.2004.00068.x

Reinertsen, D. G. (1999). Taking the fuzziness out of the fuzzy front end. *Research-Technology Management, 42*(6), 25-31.

Rubio, S., Díaz, E., Martín, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *Applied Psychology, 53*(1), 61-86. doi:DOI: 10.1111/j.1464-0597.2004.00161.x

Sharp, H., Rogers, Y., & Preece, J. (2007). *Interaction design: beyond human-computer interaction* (2 ed.): Wiley.

Smith, P., & Reinertsen, D. (1991). *Developing new products in half the time*: Van Nostrand Reinhold Books, New York, NY.

Steinert, M., & Leifer, L. J. (2012). 'Finding One's Way': Re-Discovering a Hunter-Gatherer Model based on Wayfaring. *International Journal of Engineering Education, 28*(2), 251.

STUDIOCOAST PTY, L. (2016). vMix (Version 17.0.0.76 x64). Retrieved from http://www.vmix.com/software/

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science, 12*(2), 257-285.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and instruction, 4*(4), 295-312.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Cognitive load theory, explorations in the learning sciences, instructional systems, and performance technologies 1: New York, NY: Springer Science+ Business Media.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational psychology review, 10*(3), 251-296.

Tsang, P. S., & Velazquez, V. L. (1996). Diagnosticity and multidimensional subjective workload ratings. *Ergonomics, 39*(3), 358-381.

U.K. P&I Club. (1992). The United Kingdom Mutual Steam Ship Assurance Association (Bermuda) Limited: Analysis of Major Claims.

Ulrich, K. T., & Eppinger, S. (2012). Product Design and Development, 2012: McGraw-Hill, New York, NY.

van Gog, T., & Paas, F. (2012). Cognitive load measurement *Encyclopedia of the Sciences of Learning* (pp. 599-601): Springer.

Van Orden, K. F., Limbert, W., Makeig, S., & Jung, T.-P. (2001). Eye activity correlates of workload during a visuospatial memory task. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(1), 111-121.

VSTEP. (2008). ShipSim.com - Ship Simulator 2008. Retrieved from http://www.shipsim.com/products/shipsimulator2008

Wickens, C. D. (1984). Processing resources in attention. I Parasuraman, R. & Davies, DR (Eds): Varieties of Attention: Academic Press, London.

Wickens, C. D. (1987). Information processing, decision-making, and cognition. *Handbook of human factors*, 72-107.

Xie, B., & Salvendy, G. (2000). Prediction of mental workload in single and multiple tasks environments. *International Journal of Cognitive Ergonomics, 4*(3), 213-242.

This page is intentionally left blank

Appendix A Experiment Questionnaire and NASA RTLX

The questionnaire used during the experiment, and the original RTLX version.

The pictures presented in this appendix represent the pages of the digital survey used in during the experiment. Lastly, the NASA RTLX paper and pen version used as foundation for the digitally adapted RTLX of this survey is presented.

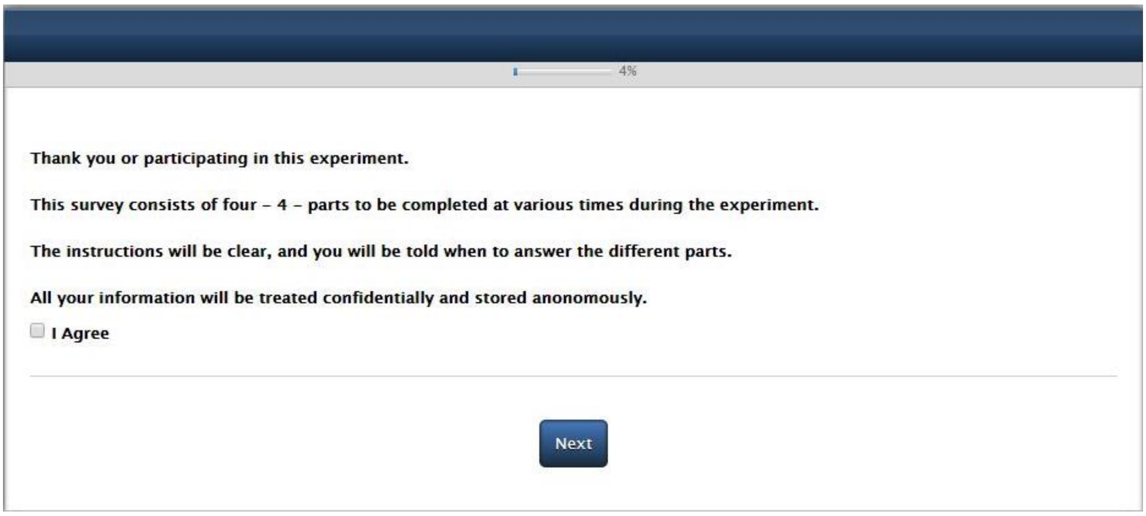


Figure A - 1: Survey page 1

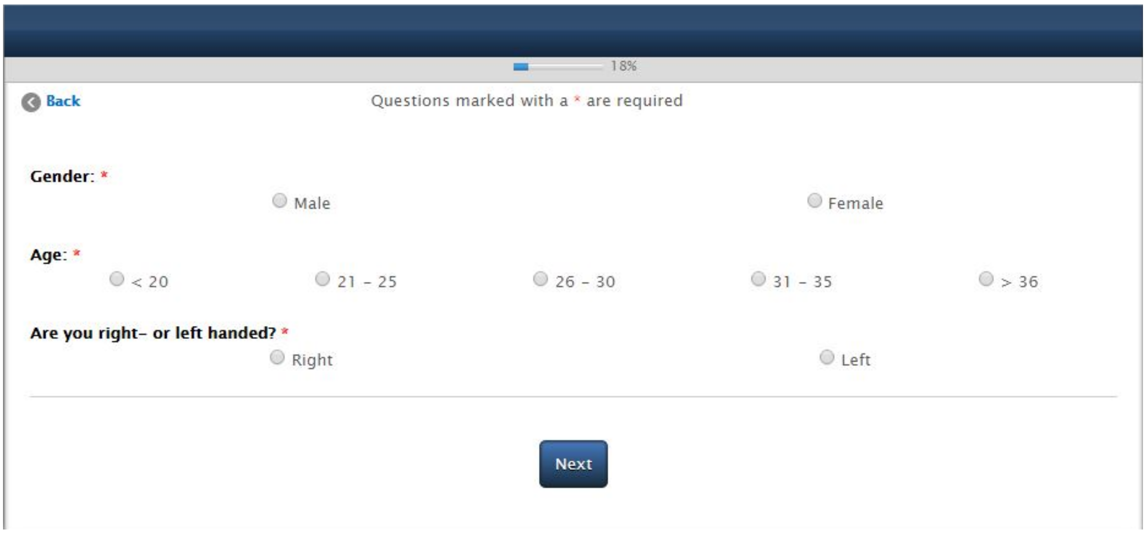


Figure A - 2: Survey page 2

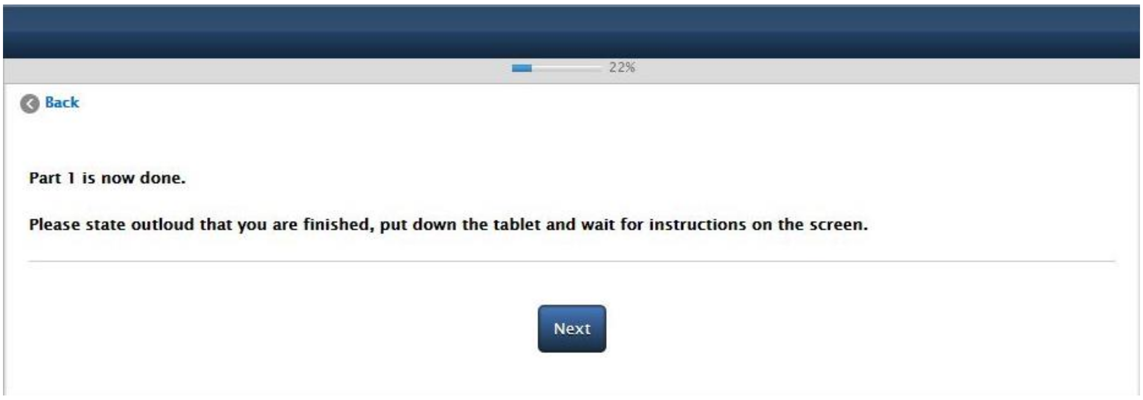


Figure A - 3: Survey page 3

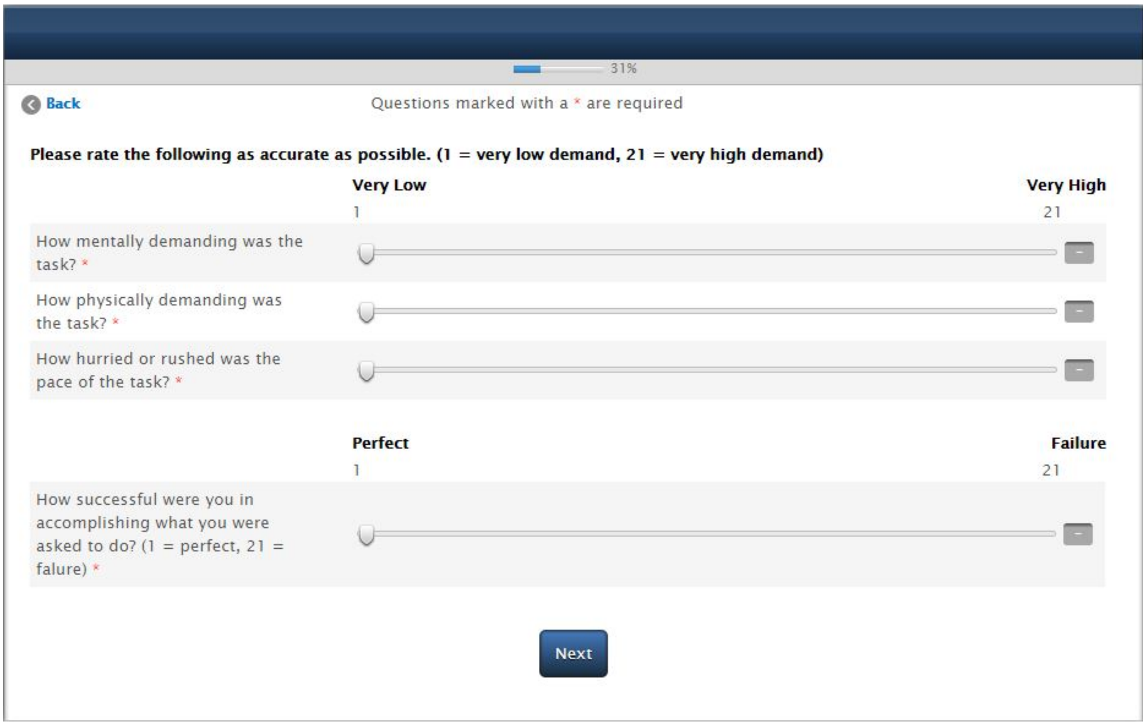


Figure A - 4: Survey page 4

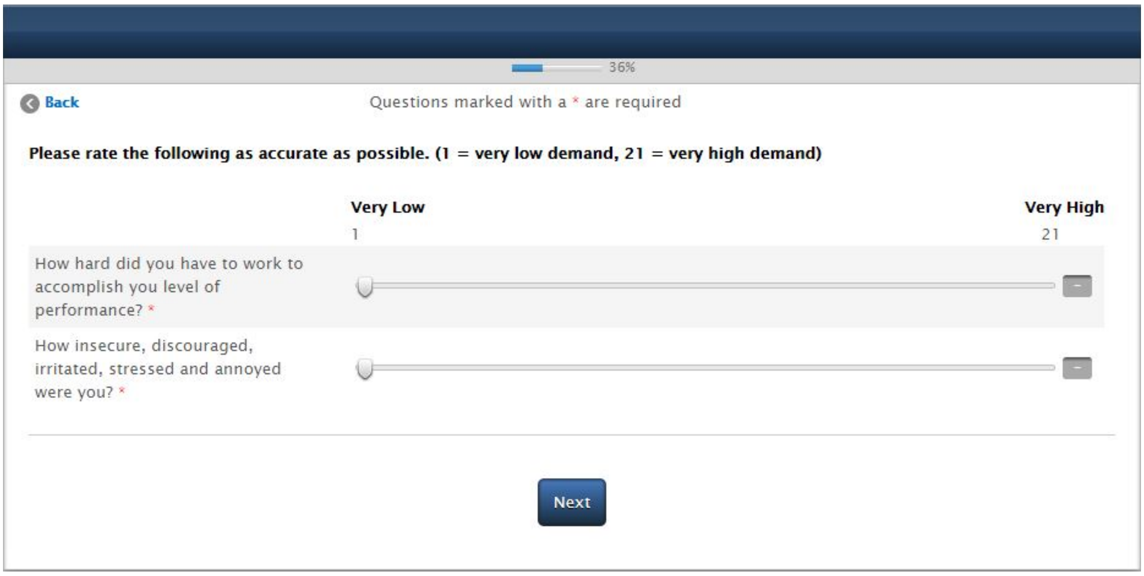


Figure A - 5: Survey page 5

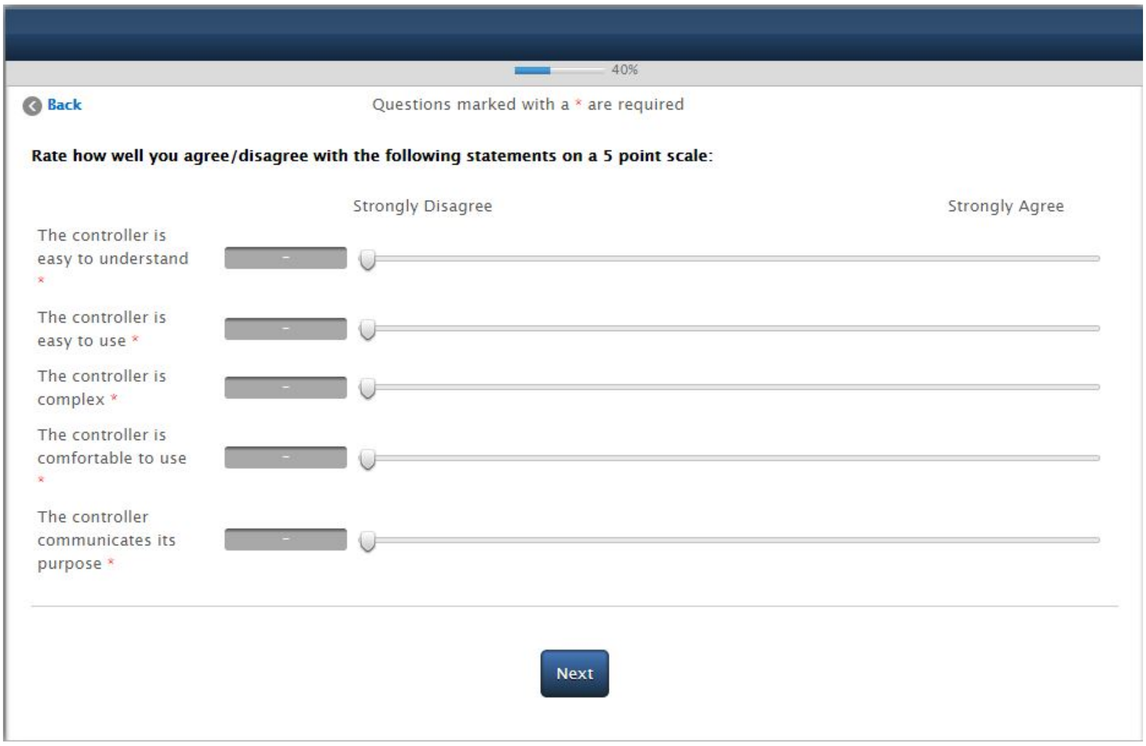


Figure A - 6: Survey page 6

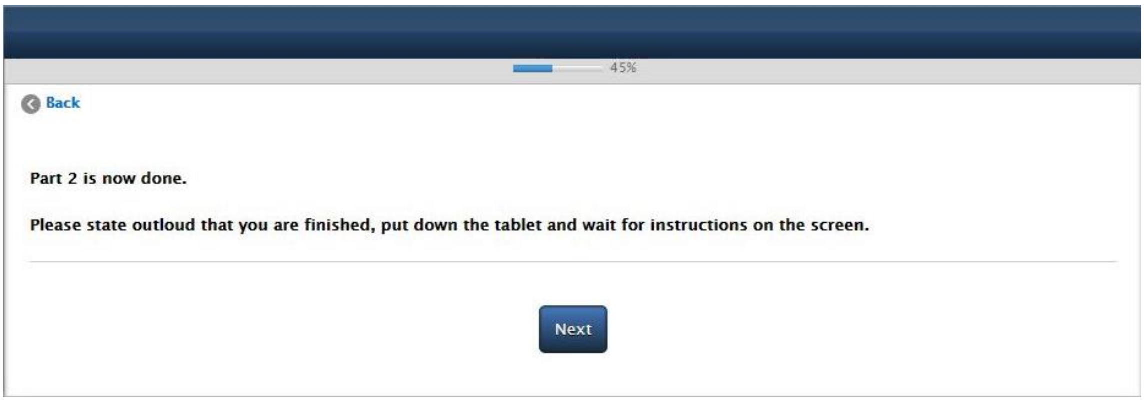


Figure A - 7: Survey page 7

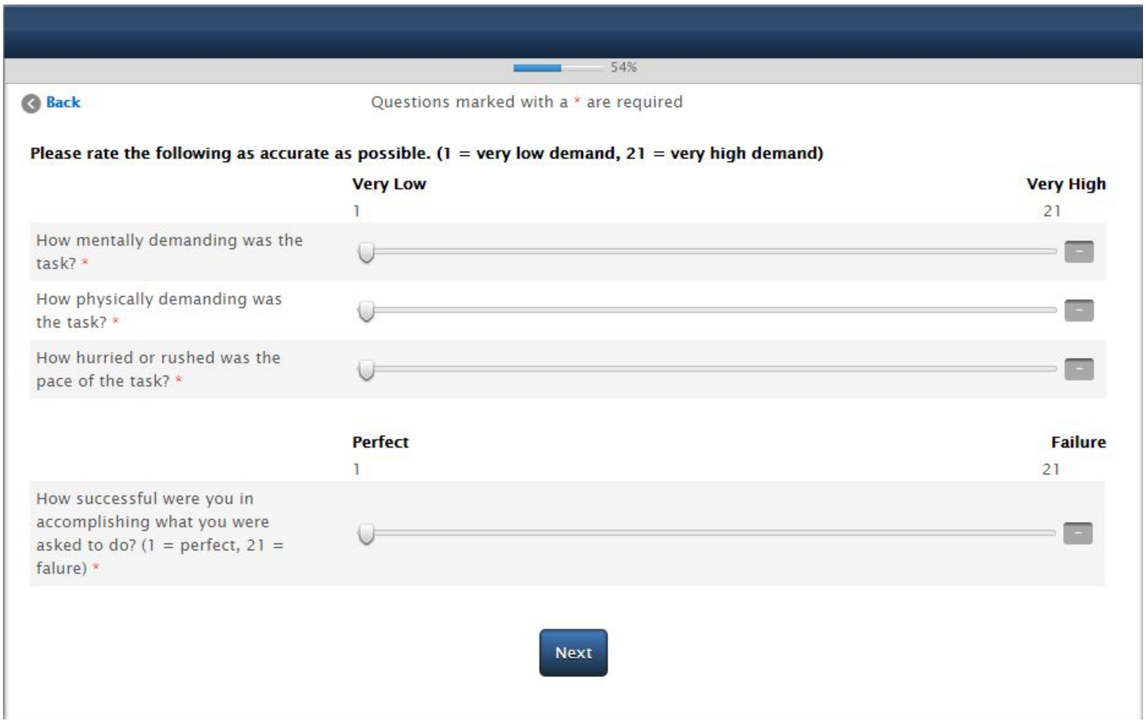


Figure A - 8: Survey page 8

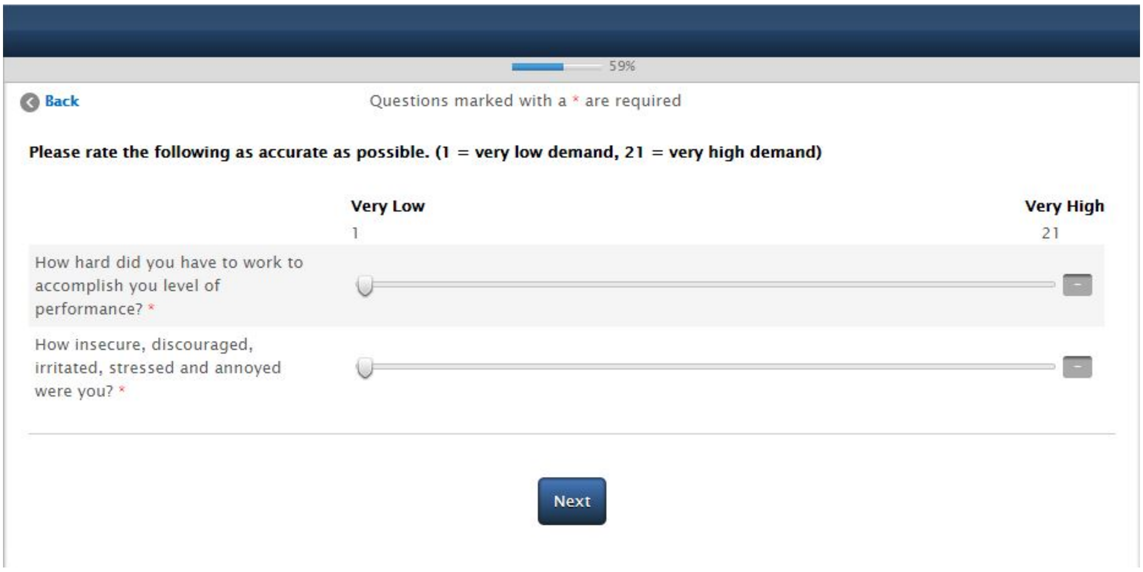


Figure A - 9: Survey page 9

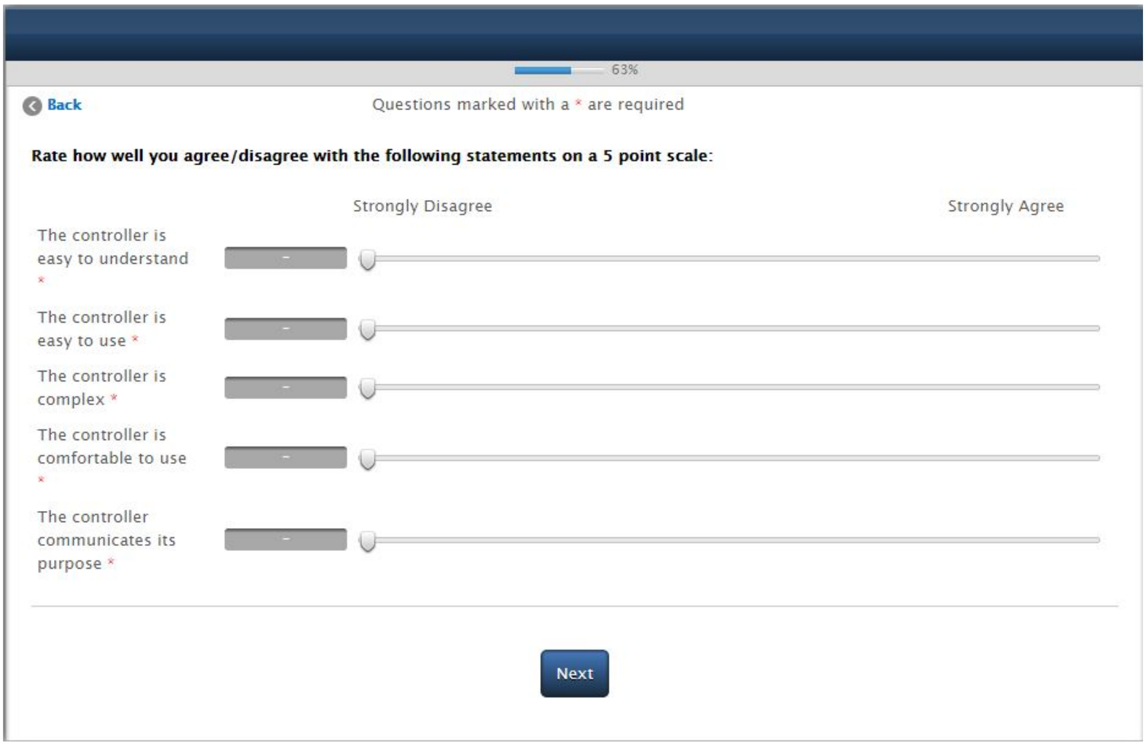


Figure A - 10: Survey page 10

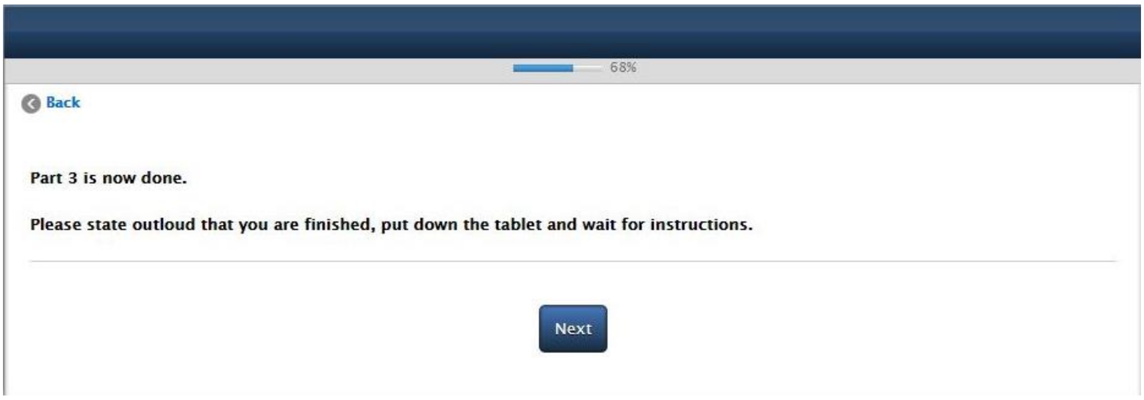


Figure A - 11: Survey page 11

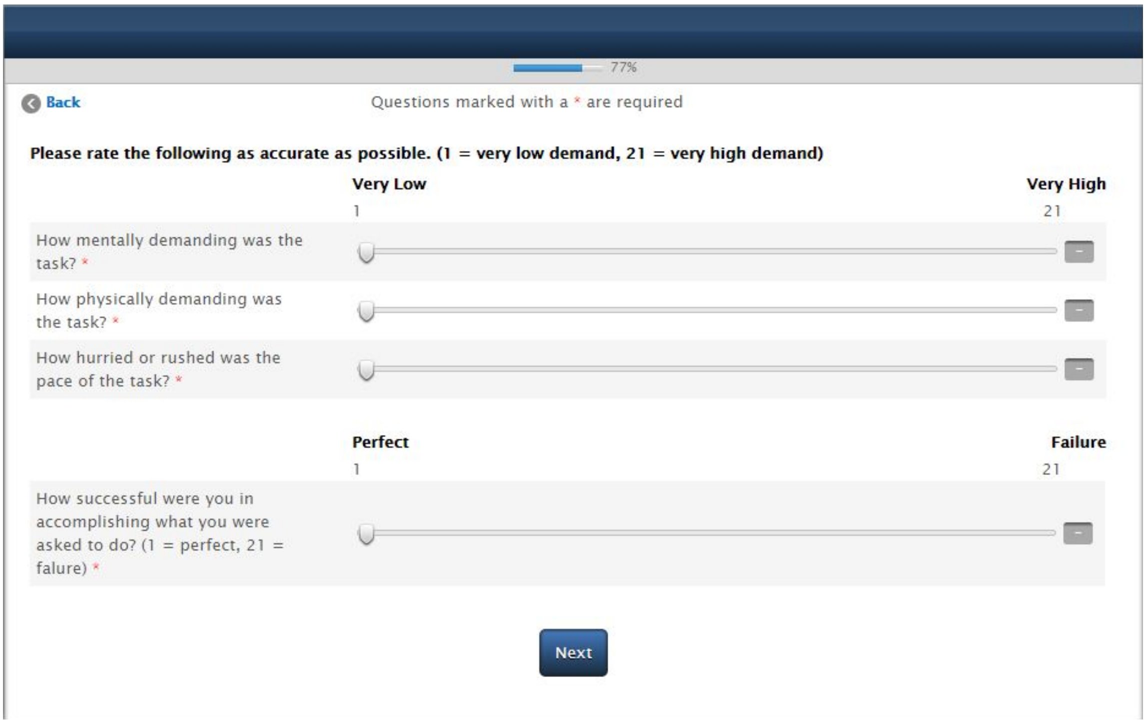


Figure A - 12: Survey page 12

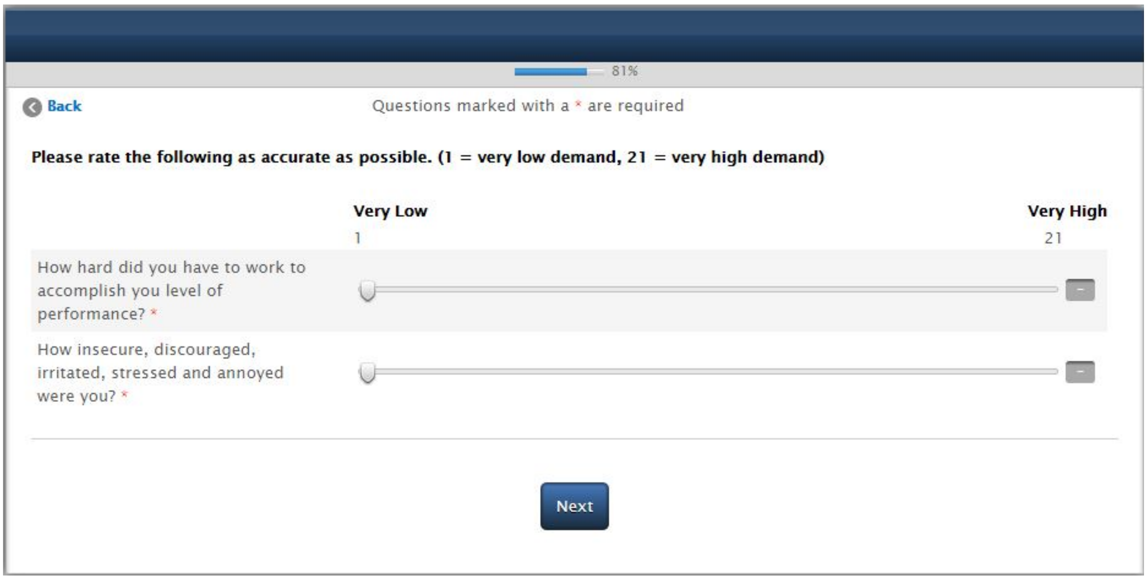


Figure A - 13: Survey page 13

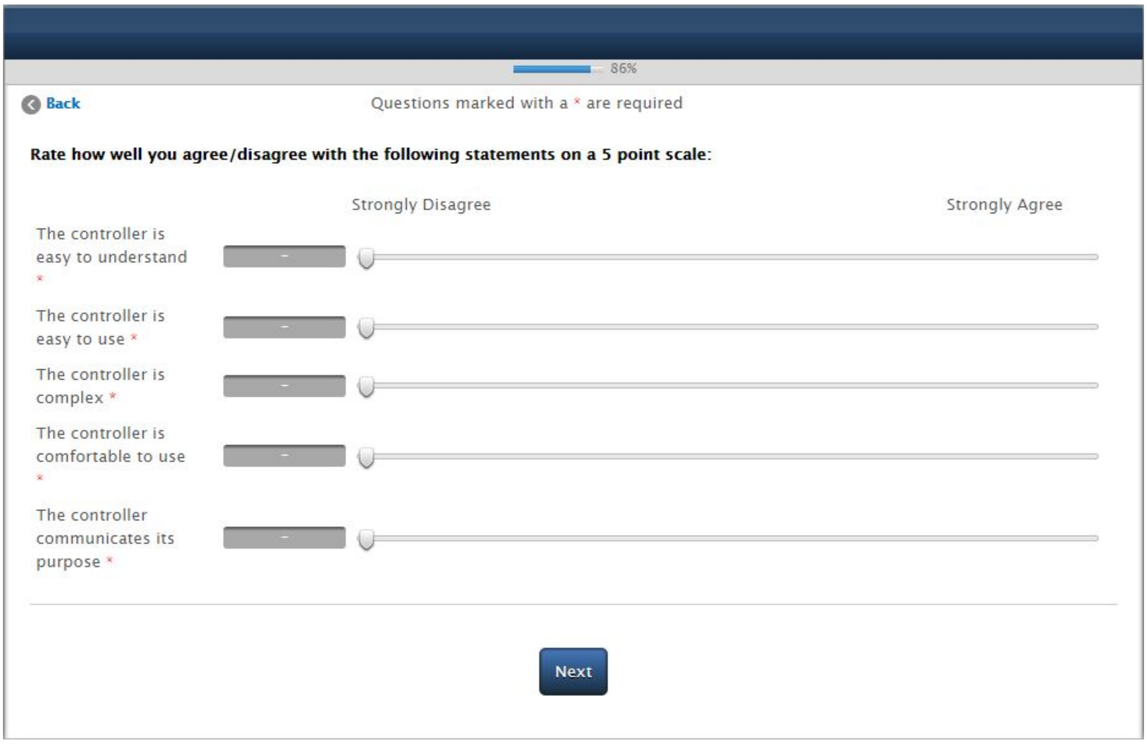


Figure A - 14: Survey page 14

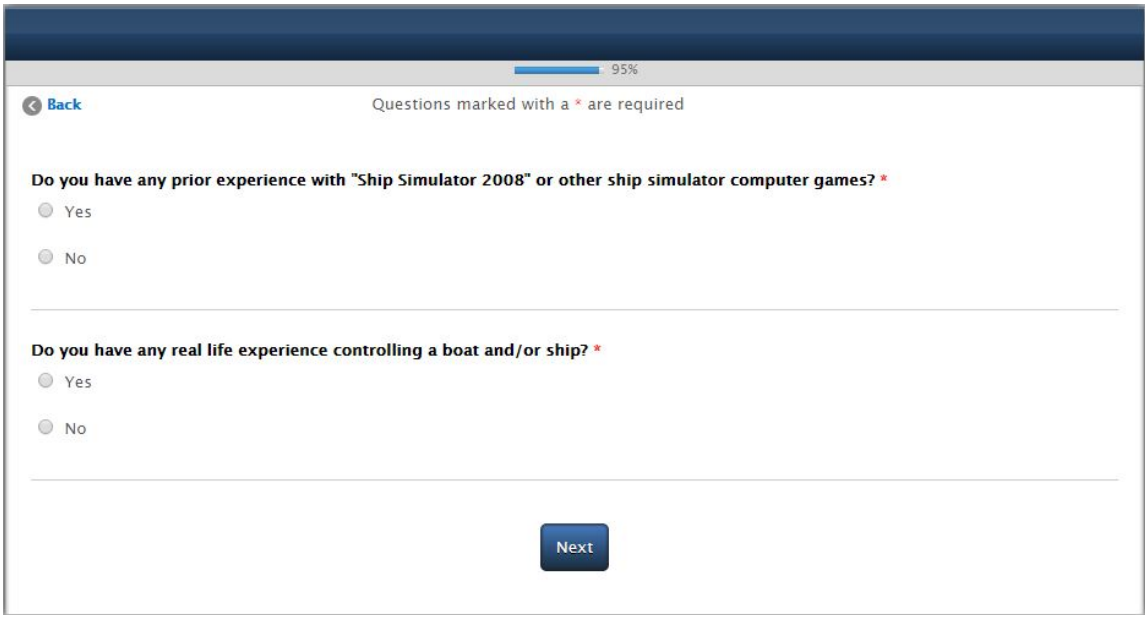


Figure A - 15: Survey page 15

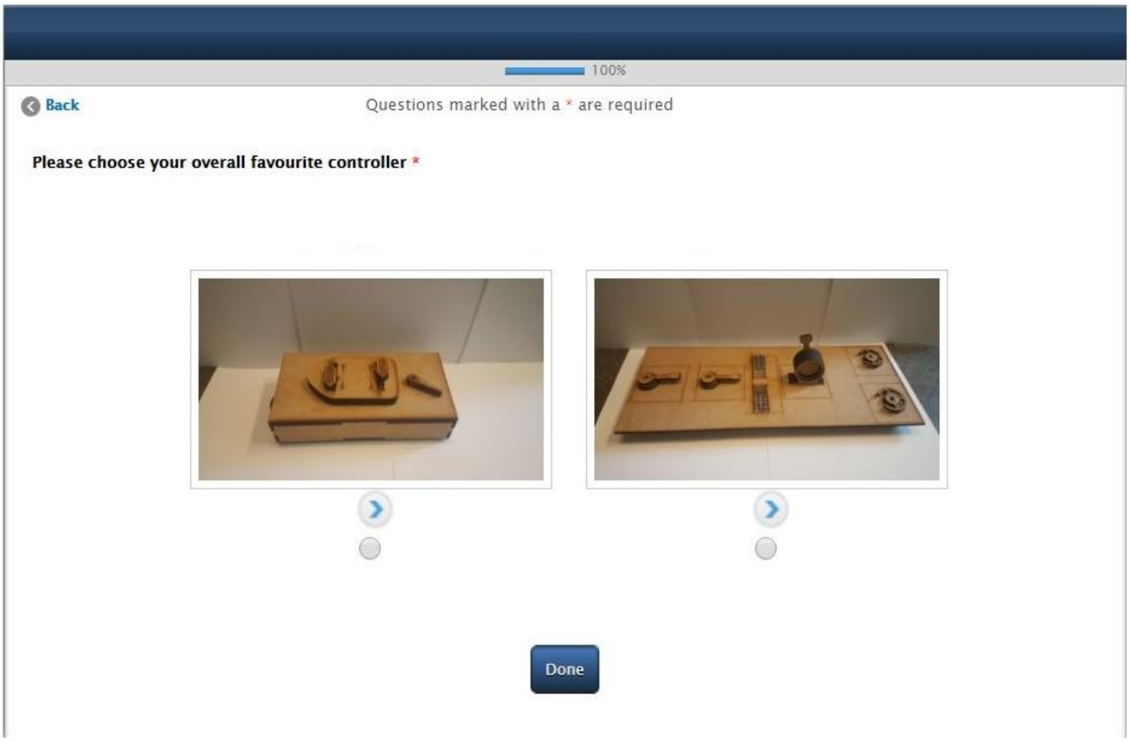


Figure A - 16: Survey page 16

NASA Task Load Index[1]

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 were you?

Very Low — Very High

[1] NASA TLX, paper and pencil version, developed by Hart and Staveland (1988), retrieved from http://humansystems.arc.nasa.gov/groups/tlx/downloads/TLXScale.pdf, 21.05.2016.

Appendix B Arduino Controller Setup and Code

The first part of this appendix present the schematics of the controller Arduinos made with Fritzing (Potsdam, 2015).

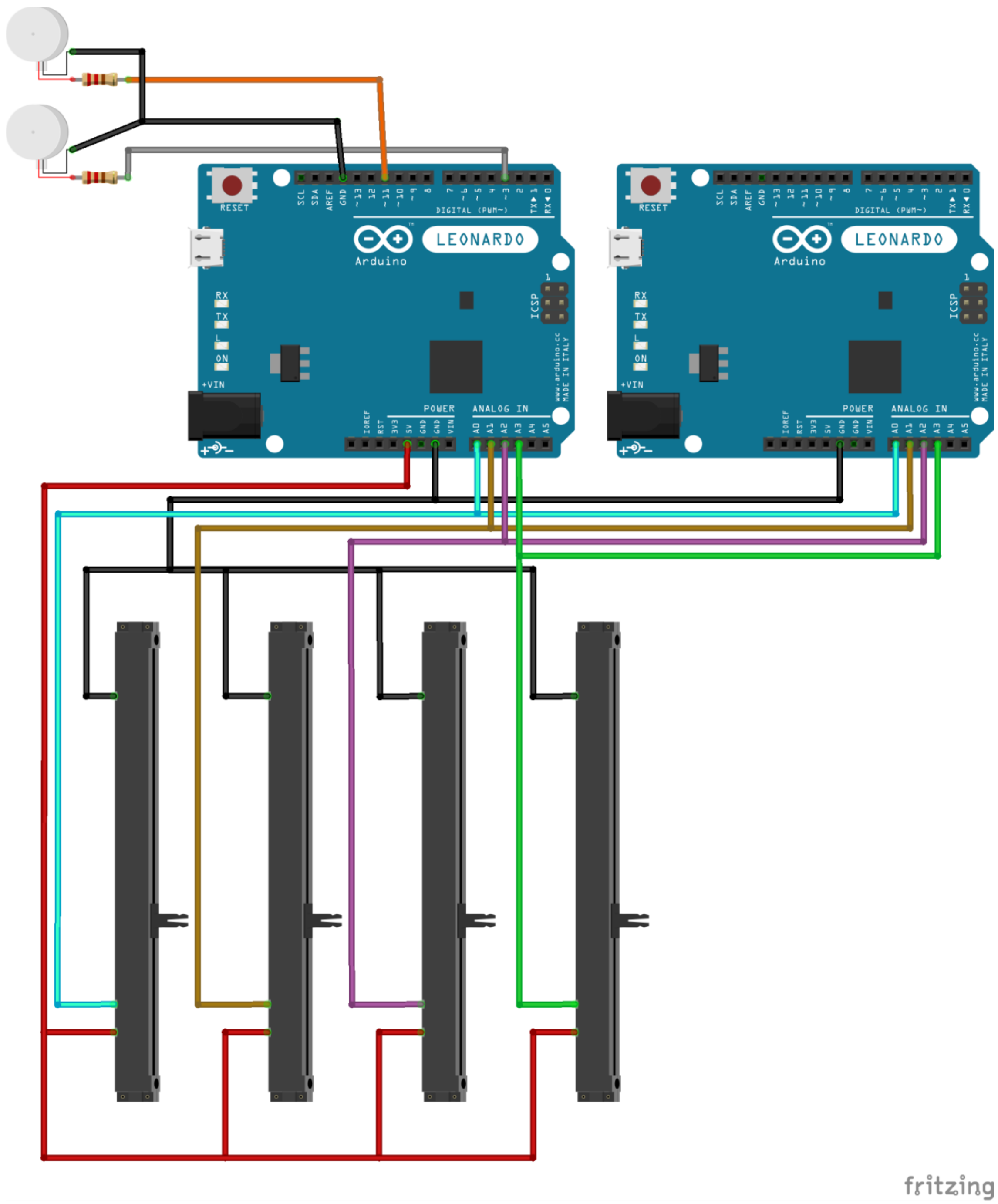


Figure B - 1: Unified microcontroller schematics

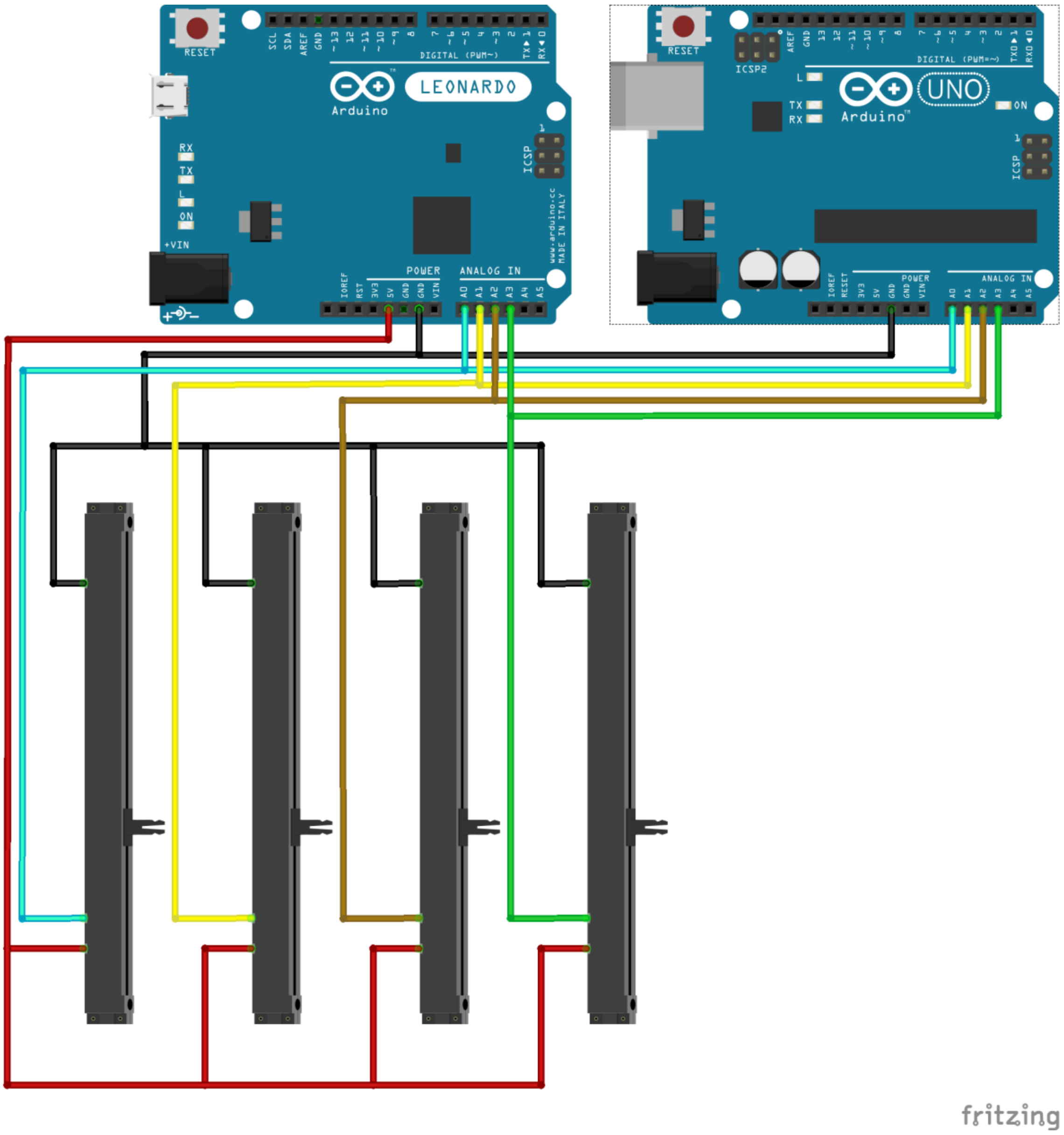


Figure B - 2: Baseline microcontroller schematics

The following code was uploaded on the game controlling Arduinos in the Baseline and Unified controller. They are very similar to one another, with slight adjustments in potentiometer calibration and the addition of haptic feedback in the Unified controller.

Arduino code for the Baseline controller.

```
/*
 * This sketch must be run of arduino IDE 1.6.5 or earlier versions.
 * This is for the controller in BASELINE controller
*/

const bool initAutoSendState = true;          // Auto update to
library

const int prop = A0;          // Main propeller potmeter pin
const int bowThr = A1;        // Bow Thruster potmeter pin
const int aftThr = A2;        // Aft Thruster potmeter pin
const int rudderPot = A3;     // Rudder potmeter pin

// Joystick axis decleration
unsigned int propeller = 0;
unsigned int bowThruster = 0;
unsigned int aftThruster = 0;
unsigned int rudder = 0;


void setup(){
  Serial.begin(9600);
  Joystick.begin();
}

void loop(){
  // ------------ Reading of controller ---------------------
  propeller = analogRead(prop);
  int propPercent = map(propeller, 0, 1023, -100, 100);
  propeller = map(propeller, 0, 1023, 0, 255);
  Joystick.setThrottle(propeller);

  rudder = analogRead(rudderPot);
  int rudderPercent = map(rudder, 0, 1023, -100, 100);
  rudder = map(rudder, 0, 1023, 0, 255);
  Joystick.setRudder(rudder);

  bowThruster = analogRead(bowThr);
  int BTPercent = map(bowThruster, 0, 1023, 100, -100);
  bowThruster = map(bowThruster, 0, 1023, 127, -127);
  Joystick.setXAxis(bowThruster);

  aftThruster = analogRead(aftThr);
  int ATPercent = map(aftThruster, 0, 1023, 100, -100);
  aftThruster = map(aftThruster, 0, 1023, -127, 127);
  //aftThruster = map(aftThruster, 0, 1023, 127, -127);
  Joystick.setYAxis(aftThruster);

  // ----------- Debugger ---------------
  serialPrinter(propPercent, BTPercent, ATPercent, rudderPercent);
}


String checkDir(int val) {
```

```
  String a = "0";
  if (val <= 0) a = "0";
  else a = "1";
  return a;
}

String int2str(int a) {
  String res;
  if (a < 10){
    res = "00" + String(a);
  }
  else if (a < 100){
    res = "0" + String(a);
  }
  else{
    res = String(a);
  }
  return res;
}

void serialPrinter(int prop, int bt, int at, int rudder) {
  String dirProp = checkDir(prop);
  String dirBT = checkDir(bt);
  String dirAT = checkDir(at);
  String dirRudder = checkDir(rudder);
  String strValueProp = int2str(abs(prop));
  String strValueBT = int2str(abs(bt));
  String strValueAT = int2str(abs(at));
  String strValueRudder = int2str(abs(rudder));
  Serial.println(dirProp + strValueProp + dirBT + strValueBT +…
dirAT + strValueAT + dirRudder + strValueRudder);
}
```

End of Baseline controller code

Arduino code for the Unified controller

```
/*
 * This sketch needs to be run of arduino IDE 1.6.5 or earlier!
 * This is for the conroller arduino in UNIFIED_3
*/
const bool initAutoSendState = true;       // Auto update to
library

const int prop = A0;          // Main propeller potmeter pin
const int bowThr = A1;        // Bow Thruster potmeter pin
const int aftThr = A2;        // Aft Thruster potmeter pin
const int rudderPot = A3;     // Rudder potmeter pin
const int btMotorPin = 3;     // Vibration motor pin, Output
const int atMotorPin = 11;
int btVibTimer[] = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0};
int btVibOutput;
float btVal = 0;
int atVibTimer[] = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0};
int atVibOutput;
float atVal = 0;

int vibInterval = 80;

// Joystick values decleration
unsigned int propeller = 0;
unsigned int bowThruster = 0;
unsigned int aftThruster = 0;
unsigned int rudder = 0;

void setup(){
  Serial.begin(9600);
  Joystick.begin();
  pinMode(btMotorPin, OUTPUT);
  pinMode(atMotorPin, OUTPUT);
}

void loop(){
  // ------------ Reading of controller ---------------------
  propeller = analogRead(prop);
  int propPercent = map(propeller, 0, 1023, -100, 100);
  propeller = map(propeller, 0, 1023, 0, 255);
  Joystick.setThrottle(propeller);

  rudder = analogRead(rudderPot);
  int rudderPercent = map(rudder, 0, 1023, -100, 100);
  rudder = map(rudder, 0, 1023, 0, 255);
  Joystick.setRudder(rudder);

  bowThruster = analogRead(bowThr);
  int BTPercent = map(bowThruster, 0, 1023, -100, 100);
  bowThruster = map(bowThruster, 0, 1023, -127, 127);
  Joystick.setXAxis(bowThruster);

  aftThruster = analogRead(aftThr);
  int ATPercent = map(aftThruster, 0, 1023, -100, 100);
  aftThruster = map(aftThruster, 0, 1023, 127, -127);
  Joystick.setYAxis(aftThruster);

  // ----------- Vibration code ---------------------------------
  btVibOutput = btVibrationStrength(abs(BTPercent));
  atVibOutput = atVibrationStrength(abs(ATPercent));
```

```
  analogWrite(btMotorPin, btVibOutput);
  analogWrite(atMotorPin, atVibOutput);

  // ----------- Debugger ---------------
  serialPrinter(propPercent, BTPercent, ATPercent, rudderPercent);

}

String checkDir(int val) {
  String a = "0";
  if (val <= 0) a = "0";
  else a = "1";
  return a;
}

String int2str(int a) {
  String res;
  if (a < 10)
  {
    res = "00" + String(a);
  }
  else if (a < 100)
  {
    res = "0" + String(a);
  }
  else
  {
    res = String(a);
  }
  return res;
}
//------------------------------------------------------
int vibTreshold (float val) {
  float testVal = val / 20;
  float testValPrev = testValPrev / 20;
  int tresholdCounter;
  if (testVal != testValPrev) {
    tresholdCounter = 1;

    while (testVal > 1) {
      testVal = testVal - 1;
      testValPrev = testValPrev - 1;
      tresholdCounter++;
    }
    if (testValPrev > 1 || testVal >= 1) {
      return (tresholdCounter);
    }
    else {
      return (0);
    }
  }
  testValPrev = val;
}
//--------------------------------------------------------
int btVibrationStrength (int val) {
  int treshold;
  int motorPower;
  bool vibEnable = false;
  if (val >= 101) {
    motorPower = 255;
    return (motorPower);
  }
  else {
```

```
    treshold = vibTreshold(abs(val));
    btVibTimer[treshold] = vibInterval;

    for (int m = 0; m < 10; m++) {
      if (btVibTimer[m] > 0 ) {
        btVibTimer[m]--;
        motorPower = (255 / 7) * m;
        vibEnable = true;
      }
    }
    if (!vibEnable) {
      motorPower = 0;
    }
    return (motorPower);
  }
}
//-----------------------------------------------------------
int atVibrationStrength (int val) {
  int treshold;
  int motorPower;
  bool vibEnable = false;
  if (val >= 101) {
    motorPower = 255;
    return (motorPower);
  }
  else {
    treshold = vibTreshold(abs(val));
    atVibTimer[treshold] = vibInterval;

    for (int m = 0; m < 10; m++) {
      if (atVibTimer[m] > 0 ) {
        atVibTimer[m]--;
        motorPower = (255 / 7) * m;
        vibEnable = true;
      }
    }
    if (!vibEnable) {
      motorPower = 0;
    }
    return (motorPower);
  }
}
//-----------------------------------------------------------
void serialPrinter(int prop, int bt, int at, int rudder) {
  String dirProp = checkDir(prop);
  String dirBT = checkDir(bt);
  String dirAT = checkDir(at);
  String dirRudder = checkDir(rudder);
  String strValueProp = int2str(abs(prop));
  String strValueBT = int2str(abs(bt));
  String strValueAT = int2str(abs(at));
  String strValueRudder = int2str(abs(rudder));
  Serial.print(dirProp + strValueProp + dirBT + strValueBT + dirAT
+ strValueAT + dirRudder + strValueRudder);
}
```

End of Unified controller code

Appendix C Arduino Secondary Task Setup

The secondary task button was controlled by an Arduino Uno, and included an LED, a piezo buzzer and a pushbutton. The schematics and illustrations are shown below in Figure C - 1 and C - 2, and the code is presented on the next page.

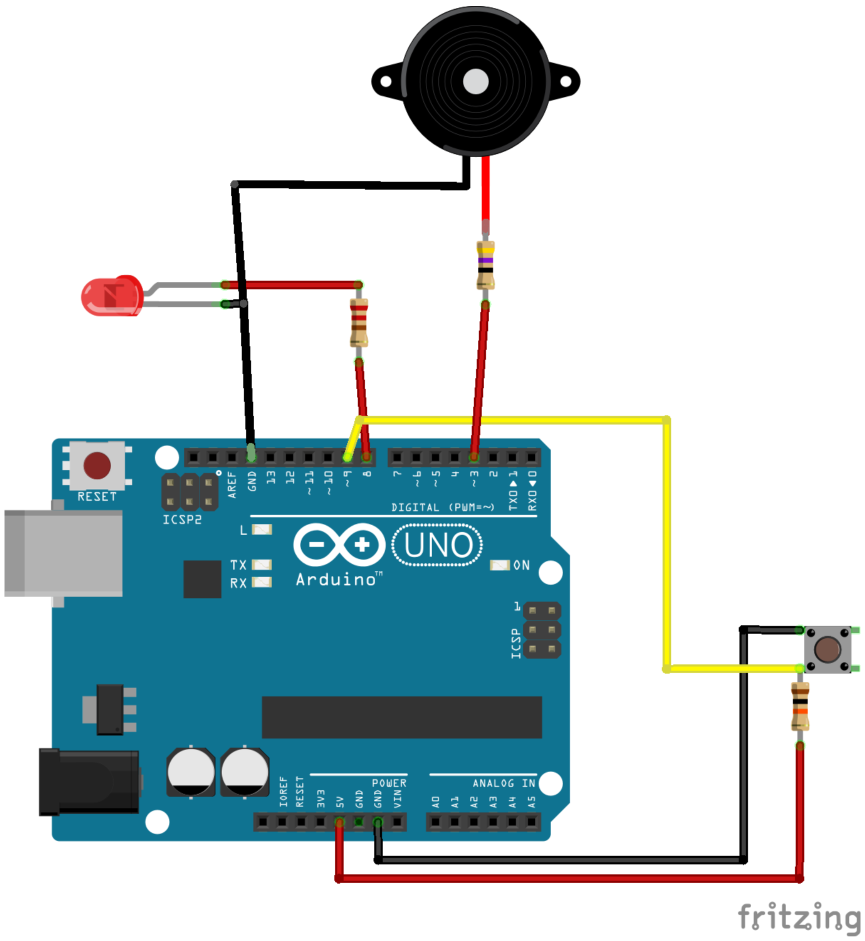


Figure C - 1: Schematics of secondary task button

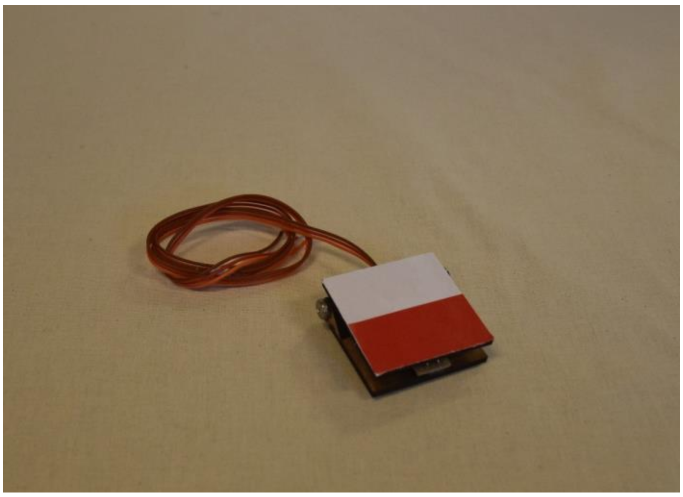


Figure C - 2: Shell of alarm button

Arduino code for the secondary task alarmbutton

```
const int ledPin = 8;
const int button = 9;
const int buzzerPin = 3;

int buttonState;
float interval, timer, currentTime, reactionTime;
float limit = 12000;
float limitInterval = 6000;
int counter = 0;

int note = 261;
int noteTime = 10000;

void setup() {
  Serial.begin(9600);
  pinMode(ledPin, OUTPUT);
  pinMode(button, INPUT);
  randomSeed(analogRead(A4));
  interval = random(limit, limit + limitInterval);
  reactionTime = 0;
  Serial.println();
  Serial.println("***********************");
  Serial.print("Start interval: ");
  Serial.println(interval);
  Serial.println("***********************");
}

void loop() {
  currentTime = millis() - timer;

  if (currentTime >= interval) {
    digitalWrite(ledPin, HIGH);
    tone(buzzerPin, note, noteTime);
    timer = millis();
    buttonState = digitalRead(button);
    while (buttonState == LOW) {
      buttonState = digitalRead(button);
    }
    digitalWrite(ledPin, LOW);
    reactionTime = millis() - timer;
    noTone(buzzerPin);
    timer = millis();
    interval = random(limit, limit + limitInterval);
    counter++;
    Serial.println(reactionTime, 0);
    while (counter > 12) {
      digitalWrite(ledPin, LOW);
      Serial.println("END");
      for (;;) {}
    }
  }
}
```

This page is intentionally left blank.

Appendix D Data Synchronization program

Appendix D goes here.

This appendix present the synchronization program made specifically for this experiment setup, see dialog box in figure d - 1. It was made in a software called Processing (Fry & Reas, 2015), and read the recording Arduinos from the controller, and the ECG data from an Arduino-eHealth kit (Libelium, 2013). The data are saved in a unique file (.txt format) with timestamps at 30Hz. The schematics as well as the code are presented below.

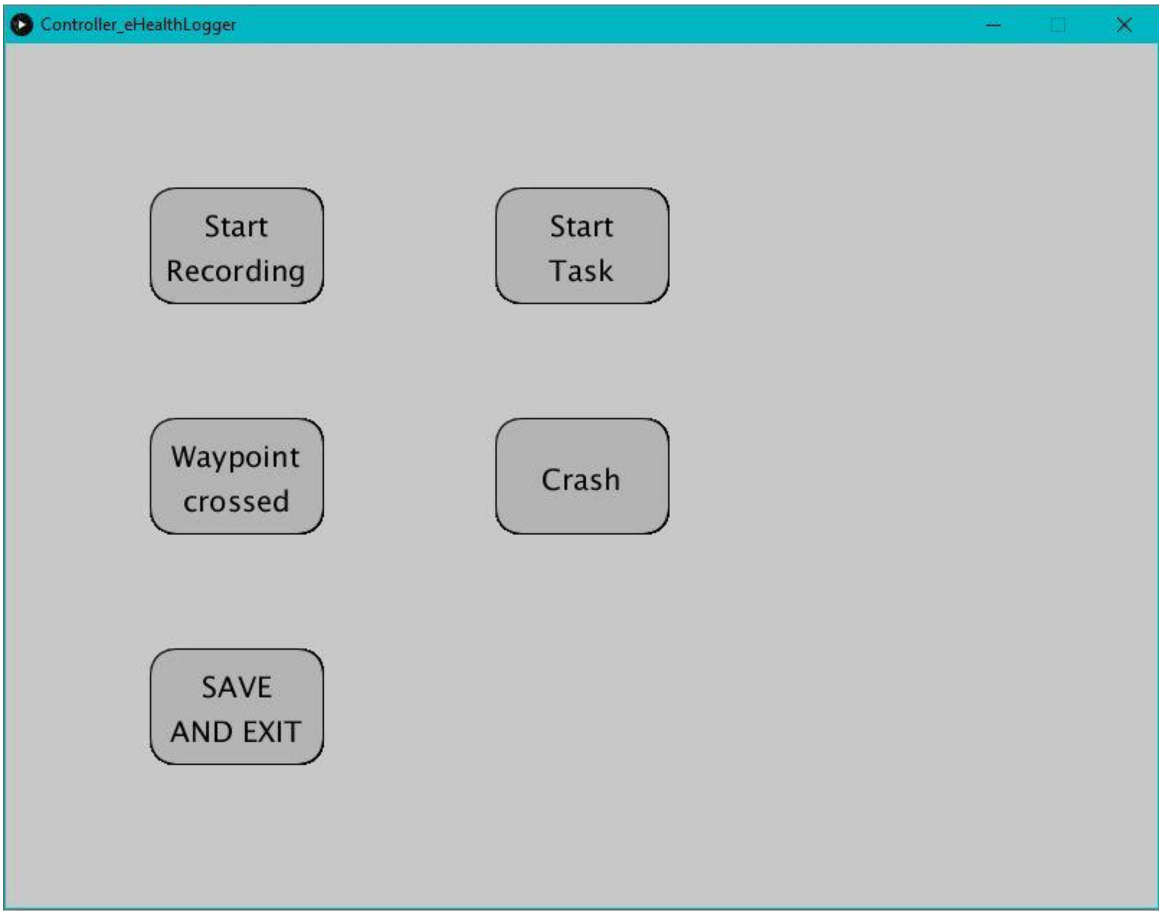


Figure D - 1: Synchronization program dialog box

Code for data synchronization software (Processing).

```
import processing.serial.*;
import cc.arduino.*;

Arduino controller1; //creates arduino object
Serial eHealth;
String val = "0.00";
int lf = 10;

PrintWriter log;
String date = str(month()) + "_" + str(day());
String time = str(hour()) + "." + str(minute()) + "." +…
str(second());
String fileName = date + "_" + time + "_raw.txt";

int btPin = 1;
int atPin = 2;
int rudderPin = 3;
int propPin = 0;
int btVal, atVal, rudderVal, propVal;

float timer, currentTime;

float w = 120;
float h = 80;
float r = 20;
float x1 = 100;
float y1 = 100;
float x2 = x1 + 2*w;
float y2 = y1;
float x3 = x1;
float y3 = y1 + 2*h;
float x4 = x2;
float y4 = y3;
float x5 = x1;
float y5 = y4 + 2*h;

boolean starter = false;
int task = 0;
int wp = 0;
int crash = 0;
int counter;
String eHealthStr;
int farge;

void setup() {
  size(800, 600);
  background(200);
  printArray(Arduino.list());
  controller1 = new Arduino(this, Arduino.list()[0], 57600);
  eHealth = new Serial(this, Serial.list()[2], 57600);
  eHealth.bufferUntil(lf);

  controller1.pinMode(btPin, Arduino.INPUT);
  controller1.pinMode(atPin, Arduino.INPUT);
  controller1.pinMode(propPin, Arduino.INPUT);
  controller1.pinMode(rudderPin, Arduino.INPUT);

  log = createWriter(fileName);
  timer = millis();
  log.println(";************UNIFIED CONTROLLER************");
```

```
  log.println("Time[ms];Main propeller [%];Bow thruster [%];Stern
thruster [%];Rudder [%];Task [n];Waypoints [n];Crash [n];ECG [V]");

  stroke(0);
  noFill();
  frameRate(30);
  textAlign(CENTER, CENTER);
  counter = 0;
  starter = false;
  farge = 180;
}

void draw() {

  drawButtons();
  btVal = controller1.analogRead(btPin);
  btVal = int(map(btVal, 0, 1023, -100, 100));
  atVal = controller1.analogRead(atPin);
  atVal = int(map(atVal, 0, 1023, -100, 100));
  propVal = controller1.analogRead(propPin);
  propVal = int(map(propVal, 0, 1023, -100, 100));
  rudderVal = controller1.analogRead(rudderPin);
  rudderVal = int(map(rudderVal, 0, 1023, -100, 100));

  eHealthStr = new String(val);
  currentTime = millis()-timer;

  if (starter) {
    if (counter == 0) {
      timer = millis();
      counter = 1;
    }
    farge = 250;
    log.print(round(currentTime) + ";" + propVal + ";" + btVal +…
";" + atVal + ";" + rudderVal + ";" + task + ";" + wp + ";" + crash…
+ ";" + eHealthStr);
  }
  if (mousePressed) mousePress();
  debugger();
}
void drawButtons() {
  fill(farge);
  rect(x1, y1, w, h, r);
  rect(x2, y2, w, h, r);
  rect(x3, y3, w, h, r);
  rect(x4, y4, w, h, r);
  rect(x5, y5, w, h, r);
  fill(0);
  textSize(20);
  text("Start\nRecording", x1 + w/2, y1 + h/2);
  text("Start\nTask", x2 + w/2, y2 + h/2);
  text("Waypoint\ncrossed", x3 + w/2, y3 + h/2);
  text("Crash", x4 + w/2, y4 + h/2);
  text("SAVE\nAND EXIT", x5 + w/2, y5 + h/2);
  fill(255);
}

void mousePress() {
  if (mouseX>x1 && mouseX <x1+w && mouseY>y1 && mouseY <y1+h) {
    //log.println("Recording start");
    starter = true;
    delay(25);
```

```
  } else if (mouseX>x3 && mouseX <x3+w && mouseY>y3 && mouseY <y3+h)
{
    //log.println("Waypoint crossed");
    wp++;
    delay(100);
  } else if (mouseX>x2 && mouseX <x2+w && mouseY>y2 && mouseY <y2+h)
{
    task++;
    delay(100);
  } else if (mouseX>x4 && mouseX <x4+w && mouseY>y4 && mouseY <y4+h)
{
    //log.println("Crash");
    crash++;
    delay(100);
  } else if (mouseX>x5 && mouseX <x5+w && mouseY>y5 && mouseY <y5+h)
{
    log.flush();     // Writes the remaining data to the file
    log.close();     // Finishes the file
    delay(200);
    exit();
  }
}
void debugger() {
  print(round(currentTime));
  print(";");
  print(propVal);
  print(";");
  print(btVal);
  print(";");
  print(atVal);
  print(";");
  print(rudderVal);
  print(";");
  print(task);
  print(";");
  print(wp);
  print(";");
  print(crash);
  print(";");
  print(eHealthStr);
}

void serialEvent(Serial p)
{
  val = p.readString();
}
```

End of data synchronization software code

This page is intentionally left blank.

Appendix E Computer Specifications

Table E - 1: Computer specifications and connections

	Dell Precision T1700	Asus X550J	Acer Aspire 4820TG
Processor	Dual core 3.60 GHz	Quad core 2.5GHz	Dual core 2.26 GHz
RAM	16 GB	12 GB	4 GB
Graphics	NVIDIA Quadro K550	NVIDIA GeForce GTX 850M	ATI Mobility Radeon HD 5470
Running	Simulator game	Synchronization software and vMix	PowerPoint
Connected to	Joystick Arduino (Controller)	Recording Arduino (Controller) and two web cameras	Stimuli screen

Appendix F Stimuli Testing

Stimuli test for controller presentation order.

Table F - 1: Descriptive statistics of stimuli test

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Mental Demand B1	65,00	6	24,900	10,165
	Mental Demand B2	42,50	6	29,112	11,885
Pair 2	Physical Demand B1	42,50	6	23,822	9,725
	Physical Demand B2	31,67	6	34,010	13,884
Pair 3	Temporal Demand B1	42,50	6	26,972	11,011
	Temporal Demand B2	39,17	6	29,903	12,208
Pair 4	Performance B1	60,83	6	27,824	11,359
	Performance B2	43,33	6	26,204	10,698
Pair 5	Effort B1	69,17	6	19,083	7,791
	Effort B2	46,67	6	26,013	10,620
Pair 6	Frustration B1	42,50	6	26,220	10,704
	Frustration B2	38,33	6	35,166	14,357
Pair 7	Mental Demand U1	44,17	6	19,083	7,791
	Mental Demand U2	55,83	6	15,303	6,247
Pair 8	Physical Demand U1	20,83	6	28,882	11,791
	Physical Demand U2	41,67	6	19,664	8,028
Pair 9	Temporal Demand U1	30,83	6	13,571	5,540
	Temporal Demand U2	38,33	6	22,061	9,006
Pair 10	Performance U1	55,00	6	32,404	13,229
	Performance U2	39,17	6	16,558	6,760
Pair 11	Effort U1	58,33	6	9,832	4,014
	Effort U2	55,00	6	31,623	12,910
Pair 12	Frustration U1	52,50	6	18,908	7,719
	Frustration U2	30,83	6	20,595	8,408
Pair 13	RT_B1	941,00	6	287,777	117,484
	RT_B2	924,17	6	374,554	152,911
Pair 14	RT_U1	854,00	6	243,636	99,464
	RT_U2	875,67	6	256,488	104,711
Pair 15	Understanding_B1	1,83	6	,983	,401
	Understanding_B2	1,67	6	,516	,211
Pair 16	Usability_B1	2,67	6	,816	,333
	Usability_B2	2,67	6	1,033	,422
Pair 17	Complexity_B1	1,67	6	,816	,333
	Complexity_B2	2,00	6	,894	,365
Pair 18	Comfort_B1	2,50	6	,837	,342
	Comfort_B2	2,67	6	1,366	,558
Pair 19	Purpose_B1	3,17	6	,753	,307
	Purpose_B2	2,33	6	1,366	,558
Pair 20	Understanding_U1	3,17	6	1,169	,477
	Understanding_U2	2,33	6	1,506	,615
Pair 21	Usability_U1	3,33	6	,516	,211
	Usability_U2	2,17	6	1,329	,543

Pair 22	**Complexity_U1**	1,83	6	,753	,307
	Complexity_U2	1,67	6	1,211	,494
Pair 23	**Comfort_U1**	2,83	6	,983	,401
	Comfort_U2	1,83	6	1,722	,703
Pair 24	**Purpose_U1**	3,00	6	1,265	,516
	Purpose_U2	2,50	6	1,517	,619
Pair 25	**WP_B1**	2,50	6	1,871	,764
	WP_B2	3,67	6	,516	,211
Pair 26	**WP_U1**	2,67	6	1,033	,422
	WP_U2	1,67	6	,516	,211
Pair 27	**Int_WP1_MP_B1**	8,83	6	5,269	2,151
	Int_WP1_MP_B2	7,33	6	3,077	1,256
Pair 28	**Int_WP1_BT_B1**	4,33	6	3,882	1,585
	Int_WP1_BT_B2	5,17	6	3,710	1,515
Pair 29	**Int_WP1_ST_B1**	5,67	6	4,457	1,820
	Int_WP1_ST_B2	7,67	6	5,538	2,261
Pair 30	**Int_WP1_R_B1**	1,50	6	2,074	,847
	Int_WP1_R_B2	4,83	6	2,858	1,167
Pair 31	**Int_WP1_MP_U1**	7,50	6	4,278	1,746
	Int_WP1_MP_U2	6,83	6	3,189	1,302
Pair 32	**Int_WP1_BT_U1**	2,83	6	1,722	,703
	Int_WP1_BT_U2	5,67	6	5,922	2,418
Pair 33	**Int_WP1_ST_U1**	1,67	6	1,862	,760
	Int_WP1_ST_U2	3,17	6	3,312	1,352
Pair 34	**Int_WP1_R_U1**	6,17	6	6,555	2,676
	Int_WP1_R_U2	10,50	6	7,918	3,233
Pair 35	**Int_WP1_MP_B1_I**	25563,83	6	10623,489	4337,021
	Int_WP1_MP_B2_I	38263,00	6	27504,366	11228,610
Pair 36	**Int_WP1_BT_B1_I**	23819,20	5	17840,499	7978,514
	Int_WP1_BT_B2_I	37982,00	5	31396,589	14040,981
Pair 37	**Int_WP1_ST_B1_I**	25423,20	5	18776,998	8397,329
	Int_WP1_ST_B2_I	50265,00	5	38482,890	17210,072
Pair 38	**Int_WP1_R_B1_I**	18713,67	6	16059,006	6556,062
	Int_WP1_R_B2_I	31138,17	6	27172,274	11093,035
Pair 39	**Int_WP1_MP_U1_I**	37991,00	6	15803,327	6451,681
	Int_WP1_MP_U2_I	47944,50	6	16962,468	6924,899
Pair 40	**Int_WP1_BT_U1_I**	24230,83	6	17921,951	7316,606
	Int_WP1_BT_U2_I	33147,67	6	25916,792	10580,486
Pair 41	**Int_WP1_ST_U1_I**	20064,00	4	31346,890	15673,445
	Int_WP1_ST_U2_I	24410,75	4	19880,326	9940,163
Pair 42	**Int_WP1_R_U1_I**	16543,83	6	16665,418	6803,628
	Int_WP1_R_U2_I	43339,50	6	33843,290	13816,465

Table F - 2: Paired samples t-test of controller order

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Mental Demand B1 - Mental Demand B2	22,500	24,850	10,145	-3,578	48,578	2,218	5	,077
Physical Demand B1 - Physical Demand B2	10,833	50,933	20,793	-42,618	64,284	,521	5	,625
Temporal Demand B1 Temporal Demand B2	3,333	44,907	18,333	-43,794	50,461	,182	5	,863
Performance B1 - Performance B2	17,500	35,882	14,649	-20,156	55,156	1,195	5	,286
Effort B1 – Effort B2	22,500	20,187	8,241	1,315	43,685	2,730	5	,041
Frustration B1 - Frustration B2	4,167	49,741	20,307	-48,033	56,367	,205	5	,846
Mental Demand U1 - Mental Demand U2	-11,667	17,795	7,265	-30,342	7,008	-1,606	5	,169
Physical Demand U1 - Physical Demand U2	-20,833	43,522	17,768	-66,507	24,840	-1,173	5	,294
Temporal Demand U1 - Temporal Demand U2	-7,500	27,704	11,310	-36,573	21,573	-,663	5	,537
Performance U1 - Performance U2	15,833	36,799	15,023	-22,785	54,452	1,054	5	,340
Effort U1 – Effort U2	3,333	35,730	14,587	-34,163	40,830	,229	5	,828
Frustration U1 - Frustration U2	21,667	33,862	13,824	-13,870	57,203	1,567	5	,178
RT_B1 – RT_B2	16,833	478,116	195,190	-484,919	518,585	,086	5	,935
RT_U1 – RT_U2	-21,667	416,400	169,995	-458,652	415,318	-,127	5	,904
Understanding_B1 - Understanding_B2	,167	1,472	,601	-1,378	1,711	,277	5	,793
Usability_B1 - Usability_B2	0,000	1,673	,683	-1,756	1,756	0,000	5	1,000
Complexity_B1 - Complexity_B2	-,333	1,633	,667	-2,047	1,380	-,500	5	,638
Comfort_B1 - Comfort_B2	-,167	1,722	,703	-1,974	1,641	-,237	5	,822
Purpose_B1 - Purpose_B2	,833	1,941	,792	-1,203	2,870	1,052	5	,341
Understanding_U1 - Understanding_U2	,833	1,941	,792	-1,203	2,870	1,052	5	,341
Usability_U1 - Usability_U2	1,167	1,835	,749	-,759	3,092	1,557	5	,180
Complexity_U1 - Complexity_U2	,167	1,722	,703	-1,641	1,974	,237	5	,822
Comfort_U1 - Comfort_U2	1,000	2,530	1,033	-1,655	3,655	,968	5	,377
Purpose_U1 - Purpose_U2	,500	2,074	,847	-1,676	2,676	,591	5	,580
WP_B1 – WP_B2	-1,167	1,602	,654	-2,848	,515	-1,784	5	,135
WP_U1 – WP_U2	1,000	1,265	,516	-,327	2,327	1,936	5	,111
Int_MP_B1 - Int_MP_B2	1,500	5,468	2,232	-4,238	7,238	,672	5	,531
Int_BT_B1 – Int_BT_B2	-,833	5,456	2,227	-6,559	4,892	-,374	5	,724
Int_ST_B1 – Int_T_B2	-2,000	6,812	2,781	-9,148	5,148	-,719	5	,504
Int_ R_B1 – Int_ R_B2	-3,333	2,944	1,202	-6,423	-,244	-2,774	5	,039

Int_ MP_U1 – Int_ MP_U2	,667	5,164	2,108	-4,753	6,086	,316	5	,765
Int_ BT_U1 – Int_ BT_U2	-2,833	6,338	2,587	-9,484	3,818	-1,095	5	,323
Int_ ST_U1 – Int_ST_U2	-1,500	5,089	2,078	-6,841	3,841	-,722	5	,503
Int_R_U1 – Int_R_U2	-4,333	11,656	4,759	-16,566	7,899	-,911	5	,404
Int_MP_B1_I - Int_MP_B2_I	-12699,17	32653,53	13330,75	-46966,95	21568,62	-,953	5	,385
Int_BT_B1_I - Int_BT_B2_I	-14162,80	34055,99	15230,30	-56448,90	28123,30	-,930	4	,405
Int_ST_B1_I - Int_ST_B2_I	-24841,80	31453,91	14066,62	-63896,99	14213,39	-1,766	4	,152
Int_R_B1_I - Int_R_B2_I	-12424,50	20458,84	8352,29	-33894,74	9045,74	-1,488	5	,197
Int_MP_U1_I - Int_MP_U2_I	-9953,50	26277,41	10727,71	-37529,95	17622,95	-,928	5	,396
Int_BT_U1_I - Int_BT_U2_I	-8916,83	35694,88	14572,37	-46376,32	28542,65	-,612	5	,567
Int_ST_U1_I - Int_ST_U2_I	-4346,75	46620,46	23310,23	-78530,31	69836,81	-,186	3	,864
Int_R_U1_I - Int_R_U2_I	-26795,67	40382,40	16486,05	-69174,40	15583,06	-1,625	5	,165

This stimuli order test shows little difference between the two orders of controller presentation. The two significant results (out of 42 pairs) is highlighted in yellow. This results might indicate a low order effect when evaluating the controllers in this experiment.

This page is intentionally left blank.

Appendix G Experiment Procedure – Table

What	**Where**
Slide 1	ACER
Hook up ECG	SUBJECT
Start webcam	ASUS
Slide 2	ACER
Fill out Q.	SUBJECT
Slide 3	ACER
Start Task 0	DELL
Slide - blank	ACER
End Task 0	DELL
Slide 4	ACER
Fill out Q. – Part 2	SUBJECT
Slide 5	ACER
Slide 6	ACER
Slide 7	ACER
Start Task 1	DELL
Start Recording	ASUS
Start Alarm	ARDUINO
Slide – Blank	ACER
End Task 1	DELL
Slide 8	ACER
End Recording	ASUS
Fill out Q. – Part 3	SUBJECT
Restart ShipSim	DELL
Change controller	Mockpit
Slide 9	ACER
Slide 10	ACER
Start Task 2	DELL
Start Recording controller	ASUS
Slide blank	
End Task 2	DELL
Slide 11	ACER
End Recording	ASUS
Fill out Q. – Part 4	SUBJECT
Slide 12	
End webcam	ASUS

Appendix H Experiment Slides

Welcome to this experiment.

This screen will show instructions during the experiment.

Please read them and follow.

Please fill out the questionnaire
on the tablet to your right.

Follow the instructions in the survey.

The main screen will now show a ship simulator

Your task is to navigate freely and get a feel for how the game works.

Please use the keyboard arrows in front of you and ignore the other features on the table.

Task 1 is now done.

Please continue with the questionnaire on the tablet and follow the instructions given

The controller to your right is a ship controller.
It has devices for controlling the following:

- Main propeller
- Rudder
- Bow thruster
- Stern thruster

[Hint: The thrusters will only work when sailing very slow.]

On the table in front of you is a button.

This should be pressed once every time the alarm sounds and the light above the screen illuminates.

Please press it as fast as you can when the alarm goes off.

You will now be presented with Task 2.

The aim is to move the ship from one dock to another using the ship controller to your right.

Please follow the green waypoints in the game.

Your criteria are:

- Fuel consumption
- Time used
- Damage to ship

The second task is now done.

Please pick up the tablet to your left, continue the questionnaire and follow the instructions given.

You will now have a new controller to your right.
It has devices for controlling the following:

- Main propeller
- Rudder
- Bow thruster
- Stern thruster

[Hint: The thrusters will only work when sailing very slow.]

You will now be presented with Task 3.

The aim is to move the ship from one dock to another using the ship controller to your right.
Please follow the green waypoints in the game.

Your criteria are:

- Fuel consumption
- Time used
- Damage to ship

The third task is now done.

Please pick up the tablet to your left, continue the questionnaire and follow the instructions given.

Thank you for your participation!

Please wait for the instructor.

This page is intentionally left blank.

Appendix I Pre Master Thesis

This page is intentionally left blank.

Erik Andreas Karlsson

Ferdinand Oddsønn Solvang

A human-centred approach to the development of a ship bridge wing

Project Thesis in Mechanical Engineering

Trondheim, June, 16

Supervisor: Ph.D. Martin Steinert

Teaching Assistant: Matilde Bisballe Jensen, Heikki Sjøman

Norwegian University of Science and Technology

Faculty of Engineering Science and Technology

Department of Engineering Design and Materials

NTNU
Norwegian University of Science and Technology

Abstract

The shipping industry is one of the world's most important trading businesses, carrying the majority of international trade items. The recreational part of shipping, such as cruises, is also a popular way to spend the holidays for many passengers across the world. Therefore, it is a huge responsibility resting on the captains and their crew to sail safely across the world, as well as shorter domestic routes, bringing both cargo and passengers safely to their destination. In this research, we set out to explore the possibilities of the bridge wing, trying to innovate the way one controls the ship, and the design of the bridge wing. The traditional design of a ship bridge wing forces the captain to operate under stressful conditions, often with difficult physical positions. A design thinking mindset, in combination with the wayfaring model is used to innovate the bridge wing, with a user-centered approach. The areas of focus are bridge wing design, FOV, console design and informational feedback. More than 30 prototypes has been made, tested and evaluated during the course of this project. We have come up with a new design suggestion for the bridge wing console, defined needs and limitations of the bridge wing and suggested a new environment, expanding the freedom of the captain and crew during docking and undocking. The suggestions made in this research are concepts, meaning that an in-depth analysis should be done at a later stage, as well as the final optimizations. Suggestions to further directions are also presented.

Acknowledgements

This project originates from initial work at the research facility TrollLabs at NTNU assigned by Kongsberg Maritime during the summer of 2015. The research done during the summer, led to a good foundation for further product development, which ultimately resulted in this report. First, we would like to thank our advisor Martin Steinert for introducing us to this assignment and Kongsberg Maritime, and for welcoming us at TrollLabs and making “mini-trolls” out of us. Through TrollLabs, we have been given valuable insight in early stage product development. We must also thank our teaching assistant Heikki Sjöman and Matilde Bisballe Jensen for helping us move forward in times of need. Special thanks goes to the officers at M/S Color Magic and M/S Polarlys for kindly letting us aboard their bridge and learn about their work, as well as the visit and trial run at SMSC. At last, we thank Pål Gunnar Eie and Espen Strange from Kongsberg Maritime for presenting this challenge and giving us the opportunity to work with them.

Table of contents

List of Figures

List of tables

Abbreviations and definitions

SBW	Ship bridge wing
FOV	Field of view
ECDIS	Electronic chart display
DT	Design thinking
KM	Kongsberg Maritime
AR	Augmented reality
VHF	Very High Frequency radio Communication with other vessels, dock crew, etc.
UHF	Ultra-High Frequency radio Communication with on-board crew
SMSC	Ship Modelling & simulation Centre AS, located in Trondheim
Conning display	Overview display containing heading, velocity, rate of turn, wind, propeller/thruster power and direction and rudder angle and other vital navigational information.
Captain	The ships top commander.
Mates	Different officer rankings below captain. Range from First Mate to Third Mate. (various names exist)
Lookout	Person observing surroundings during sailing.

1 The potential of the ship bridge wing

1.1 The challenge

The initial challenge from Kongsberg Maritime was very open, and called "Next Generation Ship Bridge". As the ship bridge in total is a huge and complex environment, discussions led to the more specified challenge of rethinking and further developing the ship bridge wing. Four central focus areas developed: Rethink the console design; rethink the bridge wing design; Increasing the field of view (FOV); and information feedback to the user. In this report, the way of working and the ideas provided are presented in detail, through several prototypes, analysis, tests and visits to ships. In total, we have been to three ship visits whereas one in action, a ship simulator, in contact with education personnel from "Høgskolen i Ålesund" and consulted with an interaction designer. We have made a testing environment, built a low-level ship simulator, conducted two field of view analyses, built some 30-40 physical prototypes, and performed countless tests of prototypes, acting as a captain for several hours in total.

In this report, we will first present some context and background to the subject, followed by theory describing our methods. Then follows a summary of our visits, our findings on relevant information technology and an introduction to our four main console principles, floor-, ceiling-, body-, and rail consoles, as well as the presentation of several ideas and selected prototypes. Finally, we summarize and discuss our findings and knowledge, and present suggestions to further work along with a conclusion.

1.2 Motivation

The shipping industry is an old, proud and well renowned industry, especially as a part of Norwegian history. It spans from 5000 years BC, the oldest known drawing of a vessel with sails (Carter, 2006), until today, when the world's merchant shipping carries a substantial amount of all international trade. Another considerable amount of shipping is in passenger transport, handling close to 400 million in 2012 in EU countries alone (Eurostat, 2014).

There are many drawbacks with the different aspects of bridge wings as of today (autumn 2015), and the opportunities for improvement are many. The extent of the shipping industry allows for a considerable potential, and when presented with the opportunity and challenge of this project, we saw it as a chance to utilize our own interests in building prototypes, and to offer the shipping industry a perspective on the challenge of product development.

Further, this challenge was not to be restricted by existing regulations, so these are therefore neglected, and our ideas was open to any direction.

Figure 1: Color Magic with highlighted ship bridge wing

1.3 Bridge wing design

Bridge wings of today are custom designed to fit their ship. Many large cargo vessels only have outboard bridge wings without consoles, while passenger ships such as cruise ships with the bridge in the front of the ship have inboard bridge wings. This works as an extension of the main bridge, from which the ship can be manoeuvred, see Figure 1. Some ships, for instance certain icebreaker ships, even have all of their main bridge equipment placed out on the bridge wing. This creates a need for a larger sized bridge wing.

Even though they are different, all bridge wings have one main purpose in common: maximizing the view over the sides of the ship. However, although bridge wings are custom designed to fit their own ship, they often tend to resemble each other in many ways and bear many of the same weaknesses: Windows do not reach all the way down to the floor, floor windows are, if present, too small or poorly placed and structural beams creates blind zones. All of these issues compromises the FOV.

1.4 Console design

Consoles on bridge wings are like the bridge wings themselves, designed and arranged after precise rules and the customer's requirements. The user is rarely included in the decision, and console suppliers are often bound by regulations that creates limitations to the console design. As a result, consoles often end up taking up a big part of the space on the bridge wing, reducing the ship officers' freedom of movement, see Figure 2. Many of today's consoles are also completely fixed, giving no possibilities for personal adjustments. The person in control of the ship will have to make do with the position of the console as is, and must therefore stand on roughly the same spot the entire time the ship is being manoeuvred from the bridge wing, even though the wanted view might be blocked from this position. Other issues involve the information feedback, such as the conning display and ECDIS, sometimes displayed on screens that are difficult to read due to light conditions. The console panel is usually filled with a large number of buttons that for most cases are not being used at all during a bridge wing operation.

Figure 2: A traditional ship bridge wing console.

1.5 Regulations

The highly conservative shipping industry is directed by strict regulations and laws based on experience, thus working as a drawback while innovating parts of the industry. It proves hard to come up with new solutions that do not resemble the old ones. In regulations from certification companies, some of the specifications states the size of consoles, and modules in millimetres, thus leading to longer transition times between technology upgrades. Therefore, such regulations are ignored during this project, to make for a more open design space.

2 Early phase, human-centred approach

2.1 The Fuzzy Front-End Phase

When excluding the regulations from the equation, the potential of the bridge wing is vast. To explore this potential, the project started from scratch, at the very beginning of, in particular, new product development. This is often referred to as the *fuzzy front-end* (FFE) phase, a term made popular by Smith and Reinertsen (1991) and defined as the period of evolving an idea from an opportunity, to the point when the product is defined and ready for development and organizational absorption (Kim & Wilemon, 2002; Reid & De Brentani, 2004). This includes idea- and concept generation, formulation and assessment (Moenaert, De Meyer, Souder, & Deschoolmeester, 1995; Murphy & Kumar, 1997), as well as identifying opportunities, formulate product strategy and executive reviews (Khurana & Rosenthal, 1997).

The FFE is an ambiguous phase in new product development (Steinert & Leifer, 2012), with a lot of potential (Reinertsen, 1999), but can be hard to truly leverage and understand according to Kim and Wilemon (2002). It consists of a number of divergent and convergent iterations. Common philosophies and processes to manage the steps of the FFE are Design Thinking (DT) (Brown, 2008), and Wayfaring (Gerstenberg, Sjöman, Reime, Abrahamsson, & Steinert, 2015; Leifer & Steinert, 2014; Steinert & Leifer, 2012).

2.2 Design thinking philosophy

According to Tim Brown, Design Thinking is:

> "*... a methodology that imbues the full spectrum of innovation activities with a human-centered design ethos. By this I [Brown] mean that innovation is powered by a thorough understanding, through direct observation, of what people want and need in their lives and what they like or dislike about the way particular products are made, packaged, marketed, sold, and supported.*"(Brown, 2008, p. 1).

This methodology is applicable to almost any circumstance where humans are involved. It encourages gathering of as much knowledge as possible through multidisciplinary teams,

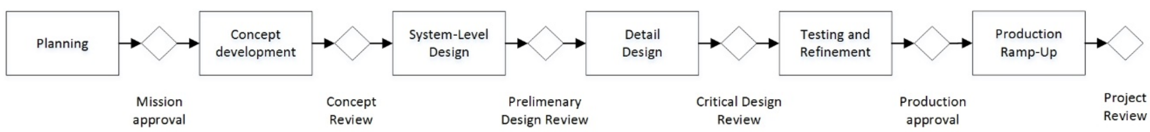


Figure 3: Generic stage-gate model

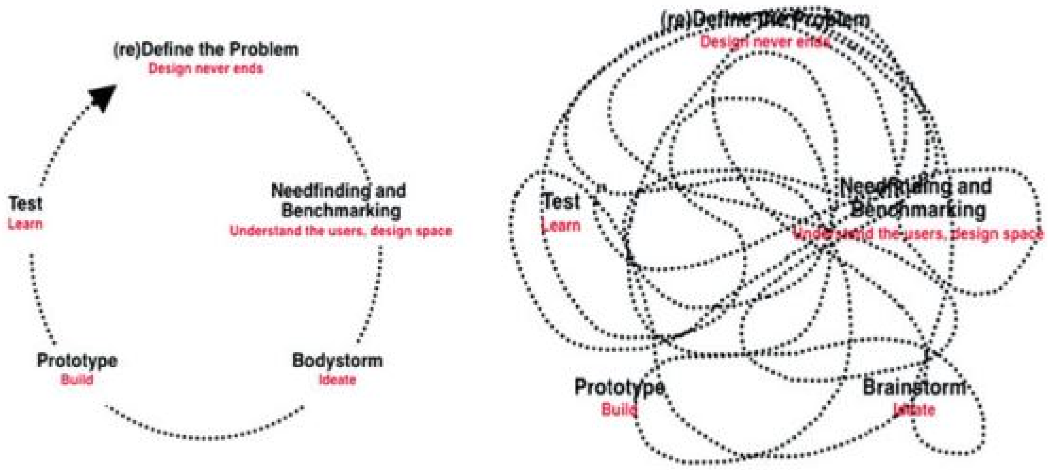


Figure 4: Design thinking model.

applying multiple points-of-view concurrently (Leifer & Steinert, 2014). Where models that are more traditional such as the stage-gate model by Ulrich and Eppinger (2012) illustrated in Figure 3, goes through predefined steps in a linear way, DT consists of several “spaces” or “states of mind” one loops through several times as ideas evolve and is redefined according to Brown (2008). He defines these spaces as “Inspiration”, “Ideation” and “implementation”. In the inspiration space, you explore problems and/or opportunities, and the ideation is when you diverge and generate ideas to eventually test. The implementation is when you bring the project out to the market. Brown further states that a design thinker is not necessarily a designer, although the name might be confusing. However, to fully appreciate the philosophy of DT, one should enter certain characteristics – the ability to empathize with the user, or stakeholder, understanding their needs, activities and desires; an experimental mind, asking questions and exploring possibilities; and a collaborative working environment, including multiple disciplines (Brown, 2008). The design thinking mentality is embraced at IDEO, an internationally reconditioned design firm. Meinel and Leifer (2010) has depicted the process more elaborate, consisting of five major steps, as presented in Figure 4, from "Design Thinking Research" by Meinel and Leifer (2010, p. xiv). This figure shows a common visualization of the DT process to the left, and a more realistic DT approach to the right.

2.3 Wayfaring as a product development process

Wayfaring, visualized in Figure 5 by Gerstenberg et al. (2015, p. 413), as a product development process first described by Steinert and Leifer (2012) in the Hunter-Gatherer Model, and later in detail by (Gerstenberg et al., 2015), works on a time basis, rather than

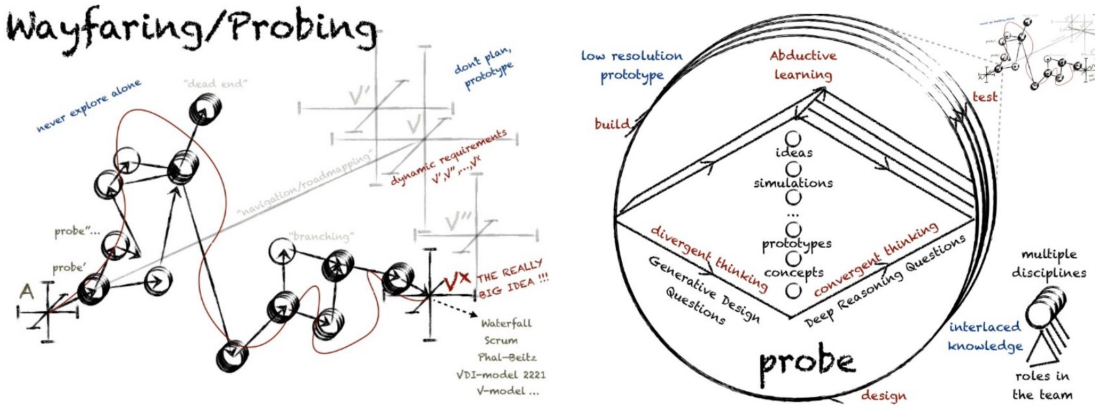


Figure 5: Wayfaring model, and probing activity.

an output or milestone basis, applied in the early pre-requirement stages. The model depicts parallel processes in multiple directions, and even dead ends. Wayfaring in front-end concept generation approaches the problem through probing, see Figure 5 by Gerstenberg et al. (2015, p. 414). Probing is the act of iteratively designing, building and testing ideas through divergent and convergent activities. Prototypes works as representations of the ideas, and conveys its intentions, allowing for fast learning through interaction and visualization. In terms, these learnings will help define the requirements of the concept(s) developed to undertake previously unknown solutions. As no one can accurately define what is yet unknown, in particular in complex situations (Snowden & Boone, 2007), a Wayfaring approach has great potential when dealing with such complex challenges according to Gerstenberg et al. (2015), which is often related to radical innovations and new product development.

2.4 Prototypes

In Wayfaring and Design Thinking, prototypes are invaluable. They convey the developers' or designers' ideas and solutions both inside teams, and to users, and helps understand the situation and user perspective. A good prototype is one that communicates the desired design idea (a function, feature or any other quality) and its characteristics, in an efficient way, so that it may serve as a foundation for discussion, testing, evaluation and learning (Lim, Stolterman, & Tenenberg, 2008). A broader more ambiguous definition is proposed by Houde and Hill (1997), saying that no matter the medium, a prototype is any form of portrayal of an idea. It may be of low or high resolution, demonstrate a critical function, an alpha- or beta prototype, an environmental model, in full-scale or small-scale, a functional prototype or as a layout proposal or CAD-model etc. and the possibilities are endless, see illustrations in Figure 6. This figure also shows a low-resolution prototype, and one of higher resolution.

What kind of prototype you make depends on where you are in the process. Early on, the models are often simple, and keep functions separated, while they later become gradually more complex, implementing functions and attributes.

Figure 6: Different resolution prototypes.

The prototype definitions from both Lim et al. (2008) and Houde and Hill (1997) allows for a prototype to be more than a physical manifestation. As Buchenau and Suri (2000) explains, it may also be to experience the activities imposed to or by the product or service at hand, what they call "Experience Prototyping". This is to gain first-hand encounters and knowledge, and may or may not include a physical prototype or product.

The act of probing and fast learning through iterations in the early stages of development implies fast prototyping to test particular ideas (Leifer & Steinert, 2014), thus resulting in low resolution prototypes. The ability to learn from such rapid models is the driver of the Wayfaring process according to Leifer and Steinert, and the iterations increases the likelihood of a good result (Dow, Heddleston, & Klemmer, 2009).

3 Application of theory

The project described in this report is a result of the challenge to rethink and further develop the ship bridge wing, given by Kongsberg Maritime. In order to present something new that is unaffected by previous models and existing regulations, the project needed to start from scratch. Thus, requiring us to engage in the fuzzy front-end (FFE) phase of new product development, including empathizing, idea- and concept generation, with a basis in the previously described theory.

3.1 Mind-set and process

In this pre-master project, we do not strictly follow a development model or structure, but are inspired by two models; Design Thinking and Wayfaring, explained in the previous chapter. DT, which revolves around the user(s) and Wayfaring which focuses on following hunches and nuggets, thought us to focus on: empathy, understanding the user perspective; defining the problems as they arise; prototyping and testing ideas; and learning through iteration cycles. To maximize the outcome and precision of key decisions along the way, one should involve the user regularly. However, as will be explained in the discussion, it proved difficult to engage in this regular dialog with the user.

We focused on empathizing, understanding the situation for the users today, trying to see what impacts our ideas and prototypes had on their activities. We performed four visits, described in chapter 5.1, to ships, and other stakeholders to gain such an understanding. We even joined a captain and First Mate on the bridge as they docked and undocked in Kiel and Oslo respectively.

This knowledge was applied to the process of Wayfaring. Gerstenberg et al. and Steinert & Leifer shows through the model in Figure 5, the need for an open and continuously hungry mind in order to come up with the next big idea. This mind-set is utilized in several design directions, both in series and in parallel, leading to constant learnings and discoveries. The knowledge from each step builds upon each other and adopts new information from different disciplines along the way. Through this project, several rounds of such iteration and learning cycles, aided by prototypes, has been conducted to improve the outcome, an effect confirmed by the experiment conducted by Dow et al. (2009).

Throughout this pre-master project, there has been four focus areas (see Appendix A – Assignment Text), which all connects to the ship bridge wing. This resulted in parallel processes, jumping back and forth between the different focus areas depending on our current progress. As FOV is an important criterion for the SBW design, they are merged in the same engineering design process, while the information feedback, and console design were separated.

3.2 Prototyping and testing

As mentioned in the previous section, prototypes, which we in total made above 30 of, plays an important role during this development process. This includes rapid small-scale models, multi-resolution prototypes, ship simulators, full-scale models, CAD models and others, made out of different materials with diverse tools. We have especially used low-resolution prototypes, typically simple cardboard models, to rapidly test and evaluate ideas. The evaluation then led to the decision to keep on going, or discard the concepts or some of its attributes, as one of the core ideas in Wayfaring. However, an important notice, which we ran into ourselves, is that prototyping without clear intentions might be a waste of time.

Further, to increase our understanding of the activities on the SBW and how they may be affected by our ideas, concepts and prototypes, we utilized experience prototyping (Buchenau & Suri, 2000). In practice, we built a SBW environment and a low-resolution simulator (see chapter 7) to enhance the feeling of interacting with a ship during testing and evaluating design ideas.

3.3 Process evaluation

During this pre-master project consisting of rethinking and further developing the ship bridge wing, we have encountered everything from moments of high enthusiasm and eye opening experiences to ambiguous meltdowns and wall staring as a part of our journey. We found that new product development and innovation has several difficulties, and the ambiguity it conveys might be both good and bad at times. However, the uncertainty and openness of the task also implies a lot of potential, as it opens up for solutions and ideas in numerous directions.

Along the way, tools from the methods described in chapter 2 have helped us to structure and follow through with our challenge. Prototypes, in particular, has been central, as both authors embrace every opportunity to build stuff and get their hands dirty. Wayfaring as a mind-set when conducting new product development has proved efficient during this project, along with a practical way of dealing with challenges along the way. As mentioned, this project is not directed by strictly following any process, but the iterative application of different mentalities, made our ideas evolve towards an outcome defined along the way.

4 Bridge wing preconditions

4.1 Definitions

As a basis for the project described in this report, the following definition of a ship bridge wing will be used:

A ship bridge wing is an extension of the ship bridge, the "pilothouse" of a vessel, reaching out towards or slightly beyond both sides of the ship. It allows bridge personnel, such as captains and officers, to increase their overview of the shipside while manoeuvring in narrow waterways and/or docking.

The SBW is, while being used, commonly populated with two persons from the bridge crew: one steering the ship; and one controlling communication, on-shore and on-board activities. In this report, we define them as following:

Captain	The person steering or manoeuvring the ship
First Mate	The person handling communication and other ship tasks

It is important to notice that this is not a general definition of the norm at sea, but strictly limited to this report, in order to ease the descriptions and discussions in the following chapters. As chapter 5 elaborates, different crews have their own routines as to whom are in control of what.

4.2 Limitations

Through insights from the meetings described in chapter 5, we established a set of limitations, or criterions that would define the rest of our work. These were necessary to define our scope, or design space because of the limitless amount of possibilities the numerous ship designs create. Limitations and prerequisites taken into account is listed below:

- Focus on mid- to large size vessels
- Two persons on the ship bridge wing, as described in the previous section
- No regulations or certifications considered
- Evaluation and discussion mostly based on cruise ships, such as M/S Color Magic

4.3 Stakeholder analysis

Figure 7 shows an overview of the various stakeholders and their interests for SBWs. As shown, the user is not directly linked to the designers/developers, but only through the shipyard and the owner. There might be however, that the developers and users communicate while the ship is in for repairs or updates. Further, the figure shows that the bridge crew actually does some quick fixes to the bridge by their own to accommodate for poor or missing solutions.

As mentioned, this project focuses on the user represented by “BW Personnel” in the figure and somewhat on the bridge wing (highlighted in grey), not on satisfying existing regulations and owners, which is often the case today. By increasing the value for the direct user, we decrease the problems and need for constant updates due to bad designs, as well as the crew’s workarounds and adaptations. The decrease in changes and upgrades also pays out to the owner, as their ships need less time and visits to the shipyard and technicians. In addition, more satisfied users lead to more satisfied owners, which in turn might result in more sales and better relations between developers/manufacturers and ship owners (buyers). Dotted lines in the figure, originating from the “BW personnel”, mark these value transactions. The discussions with some of the stakeholders are presented in chapter 5.1.

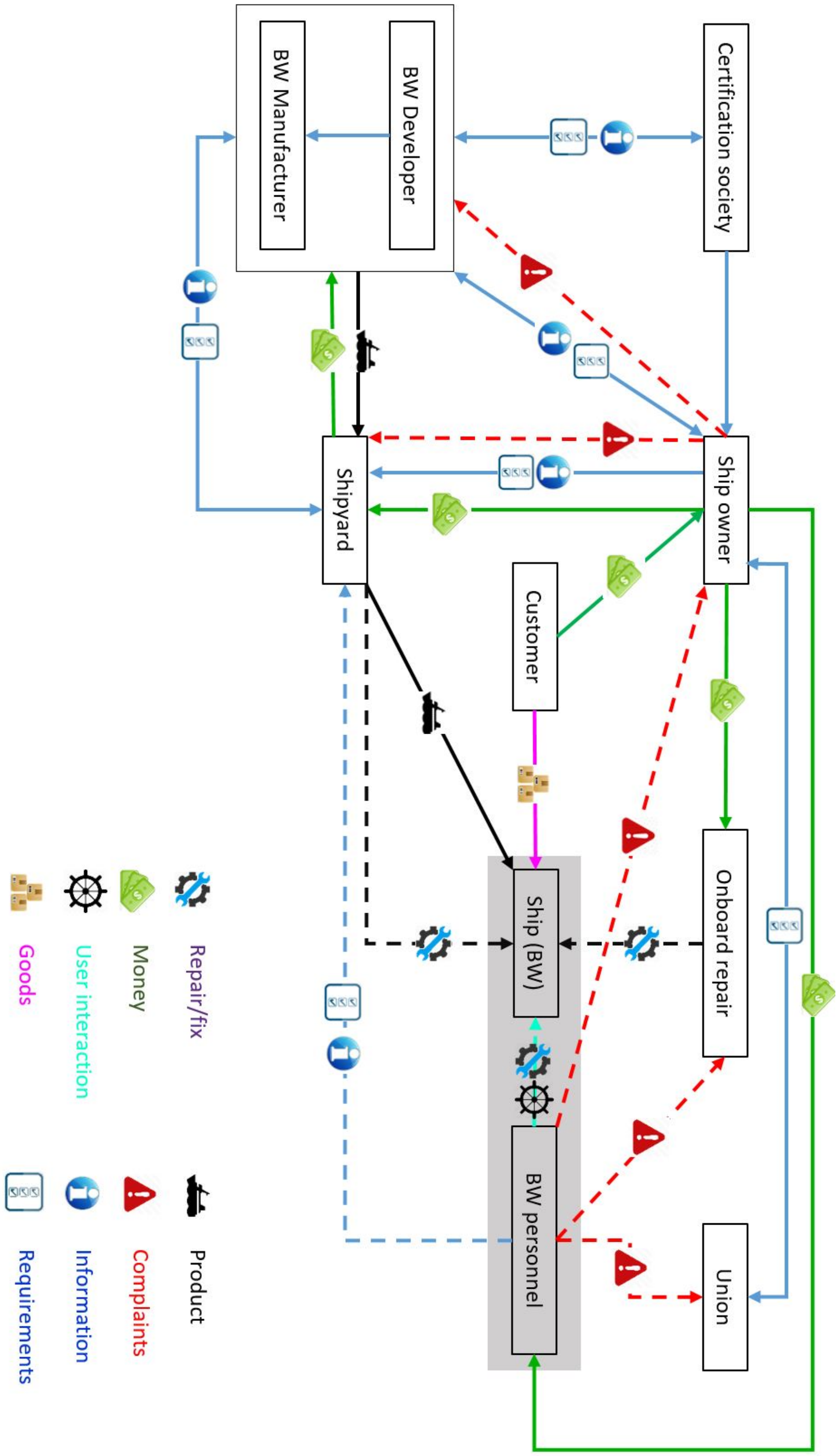


Figure 7: Stakeholder and value chain map.

5 Exploring today's Ship Bridge

5.1 Visits

Several visits made to ships during the entire project helped to increase the understanding of the bridge wing, and to kick-start the empathizing. The following subsections summarizes the visits.

5.1.1 Color Line 1

- **Visited:** Color Line, bridge of M/S Color Magic at Hjortnes dock in Oslo.
- **People spoken to:** Young mate.
- **Discoveries**
  - They use approximately a quarter of available buttons and controllers on the panel during docking.
  - The captain was in charge of communications and was overseeing the operation, while First Mate steered the ship.
  - During darkness: the one not manoeuvring the ship controls lights.
  - Natural hierarchic, but friendly relations.
  - No systems stopping the user from operating engines against each other.
  - Information screens are hard to see because of bright ambient light
  - Self made and fitted cupholders on the rails.
  - A small line is drawn on a window with a marker. This is used as a reference to align with outside references to know where to stop the ship.

5.1.2 Color Line 2

- **Visited:** Bridge of M/S Color Magic during undocking in Oslo and docking in Kiel.
- **People spoken to:** Captain and First Mate (both middle-aged).
- **Discoveries**
  - Relaxed atmosphere. The officers are confident and experienced on their tasks.
  - Highly unusual event occurred: Lost power on main engine no. 3 causing loss of 2/4 bow thrusters and 2/2 stern thrusters. The captain is puzzled for

a few seconds, and then decides to switch of malfunctioning engines on the console and fix the problem later when back on the main bridge.

Figure 8: First Mate in action at SBW

- First Mate operates the controllers behind him while undocking, see Figure 8.
- Uses autopilot most of the time during the voyage.
- The ship was manoeuvred into the bay of Kiel manually.
- Rudder is operated by the lookout on a separate console on commands from the First Mate.
- Other German vessels in the bay insists on speaking German instead of English which is the international nautical language, forcing the captain to speak German over the VHF.
- Command over the ship is switched to the bridge wing before turning the ship 180 degrees to back into the dock.
- Powerful side wind makes it more difficult to control the ship because the ship geometry makes the wind turn the ship.
- Lost momentum backwards into the dock because the First Mate lost his concentration for a brief moment. This resulted in higher fuel consumption.
- CCTV mounted at the stern of the ship is used to see when to stop the ship. It is placed such that the end of the ship is out of visual range. They must rely on lines drawn on the dock.

5.1.3 SMSC, Ship Simulator

- **Visited:** Ship Modelling and Simulation Centre (SMSC) in Trondheim. A training facility with several full size ship simulators.
- **People spoken to:** A simulator technician and a ship navigation instructor.
- **What was seen and done:**

  - We were shown their different simulators and got to try their largest one, where we were given a task consisting of docking a mid-sized oil tanker.
  - There was no console on the bridge wing. To dock the ship, one stood on the bridge wing giving information about the distance from the dock, while the other would steer the ship «blind» from the main bridge relying on commands and the conning display.
- **Discoveries**
  - We learned that their consoles were mostly fixed and used for any kind of setup with different ships.
  - It was difficult to compensate for the delay in the ships movement caused by the ships inertia.
  - We were easily hung up with the conning display to get the ship's heading right, losing focus on the outside. It was hard to keep the heading steady.
  - The lack of depth perception on the screen was also challenging.
  - The bridge was dark to make the projections more visible, thus making it hard to see the controllers.
  - Bridge wings and consoles are in general custom made to fit their specific ship.
  - Ships usually do not have supporting systems to aid the captain during docking.
  - Almost no weather conditions stop ship crews from docking. During heavy fog or darkness, the captain rely on radar and communication with dock crew.
  - SMSC trains captains and mates from around the world, providing simulators and instructors. The most common reasons for failing an exam are:
    - Wrong procedures according to regulations
    - Misunderstanding instructions/orders
    - Overuse of controllers
    - Misjudgements during critical situations

5.1.4 Hurtigruten

- **Visited:** Ship bridge of M/S Polarlys at the dock in Trondheim.
- **People spoken to:** The captain (older male).

- **Discoveries**
    - The captain steers the ship from the SBW while First Mate handles communication, hatches, alarms, etc.
    - The First Mate is stationed at the opposite bridge wing to keep an eye at the other shipside. When close to the dock, the First Mate moves to the main bridge, or to the captain.
    - The captain was satisfied with the status quo on the console's placement, although the console panel layout was poor.
    - Long distance between controllers for rudder and thruster.

Figure 9: Small floor window

    - The Conning display was not faced towards the user's position
    - Poor contrast on screens. The crew made a quick fix with tinted foil covering the screens.
    - All buttons light up with equal strength
    - A window pillar was placed right behind the captain's position blocking the FOV.
    - Windows reached only half way down to the floor.
    - A problem with full covering windows are poor isolation. This is solved with heated windows on some ships. This function makes it too warm when turned on and too cold when turned off.
    - A small window in the floor, with poor position gave minimal FOV increase.

5.2 Pain Points at the Ship Bridge Wing

From our interviews, visits, trips and navigation trials we found several pain points and rooms for improvement.

- Console
    - Poor positioning of controllers in relation to each other
    - Large console housing
    - A lot of redundant buttons
    - Awkward steering position for user
- SBW
    - Many blind spots
    - Tight around the console
        - Mainly because of a large console
    - Relatively small windows
    - Large window frames
- FOV
    - Distracted by window frames
    - Small, low-resolution CCTV cameras show hidden surroundings
    - Varying light conditions
        - At times making it difficult to see information screens
- General
    - A lot of self-made quick fixes
        - Covering up bright screens
        - Manual distance markers
        - Cup holders bought and mounted by crew
    - Little information of ships surroundings
        - Distance to objects/dock
        - What happens on the other side of the ship?

These pain points compose the foundation of which areas to focus on during the development of the concepts, as described in the following chapters. The majority of time and effort is concentrated on the improvement of the console, but the project started at attacking the pain points concerning information feedback by searching for technologies involving this, as described in the next chapter.

6 Information Technology

6.1 Initial Technology Analysis

A search for different technologies to improve the user experience at SBWs were conducted. The initial method was to look at different technologies, both in use today and future ones, from environments that are comparable or resembles that of a SBW. We mainly searched for other technologies among different transport segments. This research led to an overview over following industries:

- Automotive industry
- Aviation
- Air traffic control
- Railroad
- Shipping
- Construction cranes
- Touch screen technology

Significant findings from the industries was different types of information feedback applicable for SBWs, mostly from the aviation and automotive industry. What was found most interesting was different ways of using heads-up display on the windows of the SBW to give the officers practical information overview. Another key finding was tactile technology implemented in touchscreens. One could replace many of the buttons not frequently used, for instance by microfluidic touchscreens, making the relevant buttons "pop up" when needed. However, this topic is only briefly covered in this report, as the main focus of this project has been the user's working position in the SBW.

6.2 Testing Technologies

At *NorShipping*[1], we learned about several companies that are developing products to improve feedback from bridge consoles and controllers. One of the innovations that are ongoing by companies are haptic feedback in power controllers. However, the entire portfolio of presented technologies at *NorShipping* followed the industry's strict regulations, which is not a demand for the concepts in this report. Instead, tests were performed based on the technologies mentioned in chapter 6.1, that we could not find on a ship today. The purpose was to assess to which degree the different technologies would improve feedback and information presented to the user.

[1] An annually, well-established trade fair in the shipping industry. http://messe.no/en/nor-shipping/

Figure 10: Augmented reality prototype.

6.2.1 Augmented Reality and Head-Up Display

The first test simulating augmented reality was performed at a mock-up SBW (described in detail in chapter 7). After a round of ideation, the setup was rapidly prototyped using the materials that was available at the time being. A semi-transparent plastic foil, drawn across the front of the SBW, represented the windows. The contours of major objects across the workshop floor, in this case acting as obstacles at sea, was highlighted for the user by drawing them on the plastic sheet, see Figure 10. This exposed the weakness of using head-up display on the windows for this purpose, which could only visualize the correct image from a stationary point of view. For the contours to outline the present objects correctly from any position the user might stand, he would have to wear spectacles with augmented reality technology, or the projection would need altering depending on the user's position. Drascic and Milgram (1996) elaborates these issues (among others) and calls them: *viewpoint dependency mismatch*, the alignment between the point-of-view and the projection; *interposition failure*, the fact that far objects in real world cannot block near objects; and *accommodation mismatch,* that objects interacting with the real world are projected on a screen, and not on the physical object. This technology has great potential, but is put on hold in this project because of the difficulties and need for high precision.

6.2.2 Panel Controllers

As our visits to different ships showed, most of the interactions the user have with the ship during SBW operations, happens through the console panel, particularly through

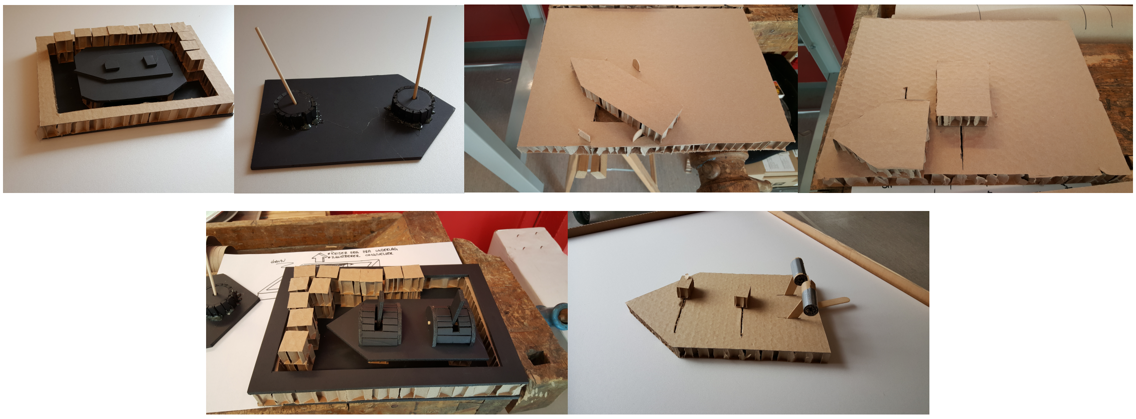


Figure 11: Various prototypes of controllers

navigational controllers. During the period of empathizing, it was discovered that there might be potential in improving the interactions between the user and controllers, including feedback from the ship and its movement. This resulted in a few ideas that were rapidly prototyped; some involving the technologies discovered, see Figure 11.

A common concept for most of the prototypes was having a panel or controller shaped as a ship. The idea was that this would make it easier to eliminate confusion caused by the orientation of the console relative to the ship. Two of the panel prototypes were shaped as a ship with controllers placed on the panel relative to where their controlled actuators are located on the ship itself. Two other prototypes represents a panel in the form of a detailed ECDIS with a single ship shaped controller with the contours of the harbour being elevated on the panel using microfluidic technology or micro actuators.

7 Console Development

During the period of empathizing, we found that many of the controllers, buttons, screens etc. is not frequently used, maybe not at all by the person actually steering the ship. In addition, most of the larger ships (on which we are focusing) have two officers present at all time while manoeuvring from the bridge wing, as described in chapter 4. These observations led to some insights defining the scope of the console designs.

- The captain only steers the ship through bow/stern thrusters, rudders, main engines and/or azimuth thruster(s).
  - **Insight: Make smaller, less cluttered steering-focused console**
- The First Mate operates communication, alarms and all other tasks on the bridge.
  - **Insight: Separate a lot of the features from the "drivers console"**
- Should not be a physical or visual obstacle.
  - **Insight: minimize the console's impact on the FOV**

We chose to focus mostly on the design of the module, rather than the layout of the controllers during this phase. Most of our console suggestions therefore focuses on the structure and the shape of the consoles, and our goal is to optimize the console body. However, we have utilized some simple visual controllers, both physical and drawings, to symbolize the control panel.

In order to test and evaluate the console concepts, we constructed a SBW environment consisting of a frame in the shape of a bridge wing, size-equivalent to that of a mid-size ship. The construction, built approximately 5 meters above ground upon a shipping container, had an overview of the workshop floor. Through several rounds of ideating around possible ways to make a console on a SBW, we ended up prototyping and testing four main principles: floor-, ceiling-, rail- and body console. The models, trials and errors, built upon each other through an iterative process, continuously highlighting new critical functions and criterions of the consoles. The following sections describes these iterations.

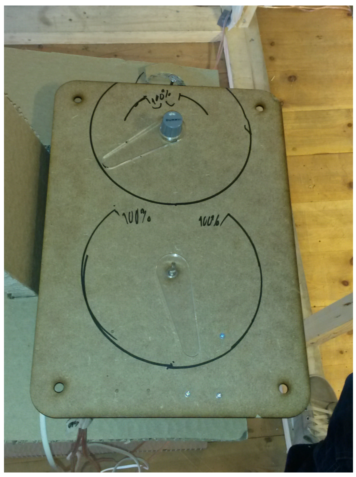


Figure 12: Simulator panel

7.1 Simulator

During ideation, we found that it was desirable to have a way of simulating the docking experience, not fully, but at the very least as a way of differentiating between the usability of the different consoles. Since the testing environment was fixed to a shipping container, the best option was to simulate the docking through moving the "dock" itself on the workshop floor, represented by a large cardboard plate. Inverted motions ensured a feeling of docking a vessel, and two thruster handles controlled the speed of the motions. The forward and backwards motion was excluded for simplicity. The simulator panel is shown in Figure 12.

7.2 Ceiling Console

7.2.1 First Version – C01

Our first prototype of a ceiling based console, was made by foamboard, and was also demonstrated as a rail console and a body console (see chapter 7.4 and 7.5). The foamboard mock-up tied to the ceiling using a rope, demonstrated the ability to freely move the console around, letting the captain choose his position based on personal preferences and needs.

Learnings: Needs further development

Positive outcomes: Free movement

7.2.2 Second Version – C02

This originated from a workshop at TrollLabs with KM. Some modifications were needed to make it fit to the SBW model that we made at the workshop. A frame was built to demonstrate free movement in the horizontal plane. The frame was reused for all the following ceiling prototypes. This prototype also demonstrated height adjustment, simply by lifting the console panel up its cardboard column. It further showed that a column holding the console from the ceiling, as seen in Figure 13, could be very disturbing for the captain's FOV. Even held in such a way that the view was not obstructed, the mere presence of the column close to the users head can be too distracting.

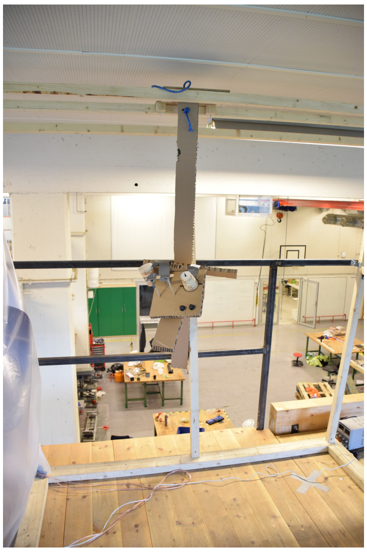


Figure 13: Second ceiling console.

Learnings: Column distracting FOV

Positive outcomes: Free movement

7.2.3 Third and Fourth Version – C03 & C04

The next iterations of ceiling console prototypes was built with stiffer columns. The third version shown in Figure 14, had a fixed column going down with an L-shape and had three degrees of freedom; translation in the horizontal plane and rotation about its vertical axis. The fourth version had three more joints, taking care of height adjustment and rotation of the console panel.

Figure 14: Ceiling console, version three

These versions was built with focus on solving the issue with an interfering column. They were therefore made such that the vertical part of the column reached down behind the user, connected to the panel through other beams with either fixed (C03) or rotational joints (C04). In this way, the column itself did not interfere with the immediate surroundings of the user, which proved to be favourable. What we also learned with C04 was that two joints on the column is redundant. One joint on the column in addition to a pivoting panel should be sufficient. The ceiling concept was nevertheless abandoned because other prototypes showed more potential and because of the challenges of supporting large objects from above.

Learnings: Moment in arm. Somewhat obstructed FOV because of panel.

Positive outcomes: Ergonomic working position.

7.3 Floor Console

7.3.1 First and Second Version – F01 & F02

The very first floor console prototype consisted only of a seat from an office chair, with a piece of illustrative paper on top. The second floor console, as can be seen in Figure 15, was made of cardboard, and included the ability to adjust the height, as well as some illustrative controllers. Both the first and second floor console prototype also made it possible to test different positions of a possible floor console.

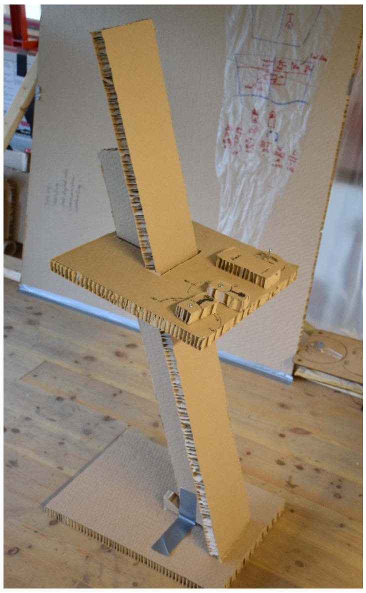


Figure 15: Floor console, version two.

The prototypes led to the realization that the positioning and shape of the console may lead to an obstruction for the user's movement of legs and arms. The large, angled stand from version two, as well as the large foundation of the office chair hinders the user's legs to move freely. The console should rather be built to increase the space underneath the top panel in addition to feature a simple locking mechanism for height regulation. Further, when positioned in front of the user, the construction should occupy as little of the FOV as possible to not disturb the operation.

As mentioned, this smaller floor console's ability to be moved around proved that such a design, even as a fixed one, gave the user many possibilities in terms of working positions as well as freeing up a lot of space in the SBW.

Learnings: Decrease size of base. Rotation of console might lead to confusion.

Positive outcomes: Flexible working positions.

7.3.2 Third Version – F03

This floor console prototype included the ability to adjust the angle of the leg and control panel, see Figure 16. Although height adjustment is not included directly, tilting the whole stand will adjust the height to some extent. We wanted to test the feature of a console mounted at the lower part of the outwards facing window, including the ability to move it along the edge of the bridge wing.

Figure 16: Third version floor console

This model led to the discovery that the panel, though a lot smaller than in today's ships, might actually disturb the captains FOV when placed in front. Further, it also proved that a full range of tilt of the console panel, as well as the whole column proved to be superfluous. Testing showed that horizontal arm movements are less tiring than vertical when operating the console.

Learnings: Full tilt range unnecessary. Panel disturbing FOV.

Positive outcomes: Split the console in two.

7.3.3 Fourth Version – F04

As F03 showed a tendency to disturb the FOV, a new design was necessary. The console was split into two parts, see Figure 17, with the user in the middle. This allowed for a less compromised FOV, as well as an open plan solution. The thought behind it is to utilize both hands during navigation, splitting critical functions to each hand. This permits the option of splitting front/back controllers or thrusters and engines between the two control panels. However, a closer look into the effects of multitasking might be necessary in order to evaluate whether it affects the captain negatively.

Figure 17: Fourth version floor console

This model also enhanced the differences in preferred console height between different users. This might be because it offers the option of resting ones arms and/or elbows on the console while navigating. Further, by keeping the two consoles free from placement restrictions, it was found preferable to make the width between the modules adjustable, depending on personal preferences and size. The advantages of letting the user face outwards without having to operate a console behind him, and giving a clear FOV gave reasons to further develop this design.

Learnings: Width adjustment preferable. Reduce base size.

Positive outcomes: Free FOV. Height adjustment. Flexible working positions.

7.3.4 Fifth Version – F05

The first three prototypes of floor consoles had different designs that were all discarded due to various reasons. The fifth version builds upon the previous one, F04, but now with only one leg and with the top plate wrapped around the back of the user as shown in Figure 18. The console as a whole takes up more space than previous floor consoles, but by wrapping the console around the user, it gives him/her an option to use it as a "stand-up-chair", and get physical support during navigation.

Figure 18: Floor console, version five

The prototype further includes width adjustment and tilt, both at the top plate, and in the footrest, along with a slight horizontal rotation of the control panels. The ability to tilt this console was found superfluous, though it gave this exact model a rough height adjustment capability. The control panel rotation proved not so important.

This was still a rough prototype, but the design was found interesting enough to test a more elaborate console.

Learnings: Tilt not necessary.

Positive outcomes: Width adjustment. Free FOV.

7.3.5 Sixth Version – F06

This is a more robust and elaborate version of F05, and is shown in Figure 19. This does not have a tilt function, but instead a telescopic function that provides height adjustment. It gives the opportunity to lean one's arms on the console panel, or operate the controls with stretched arms if this is preferred. This version is also width-adjustable and includes a locking mechanism. It is released by pulling handles underneath the panel.

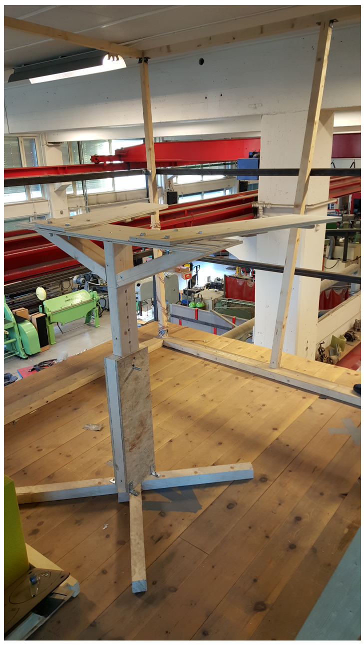


Figure 19: Version six of the floor console

Among observations done during testing was that the panel sides could steal important parts of the FOV when the console is in an elevated position with the user leaning against the back of the console. We also discovered that the angle that the panel sides was given could be undesirable compared to having the sides point straight forward. This spoke towards making the angle adjustable to some degree, thus also improve the action of stepping in or out of the console. The last argument is however also a big weakness with this type of console. It will inevitably occupy a substantial part of the floor area, and the user must go around to step into the console. This action can be simplified by splitting the console in two parts with each side having its own base, allowing the user to step directly into the working position.

Learnings: Split console completely in two. Continuous adjustments.

Positive outcomes: Width adjustments with lock. Height adjustment.

7.4 Rail Console – R01 & R02

The prototype mentioned in 7.2.1 was reused to rapidly test the concept of a rail-mounted console. The intention was to bring the console in front of the user, thus making it easier to focus on both the controllers and working perimeter outside the ship. A second version made to fit in the mock-up SBW, see Figure 20, and tested with the simulator, proved that such a console would occupy a significant part of the FOV, even though it could be moved along the rail according to the user. In addition, if the console should be placed on the forwards or backwards facing railings, the controllers' directions would shift, possibly confusing the captain. These two drawbacks shifted the focus over on other console concepts.

Figure 20: Rail console, second version

Learnings: Obstructs FOV. Tiring arm movement

Positive outcomes: Placed directly in front of user.

7.5 Body console – B01 & B02

Once again, the prototype mentioned in 7.2.1 and 7.4 (C01 and R01) was reused, this time to visualize and experience a body mounted console, in this case strapped to the waist by a belt. Another foamboard console (B02) was built, narrower than the previous and with a more ergonomic transition to the human body. This model also tried to utilize the vertical sides of the console, see Figure 21, by placing controller interfaces around the sides. The body console prototypes were discarded due to the challenges of adapting the consoles to different body shapes and sizes

Figure 21: Second version body console with side panel controllers.

Learnings: Control handles move relative to the ship when the user moves. Hard to adjust to different users' shapes and sizes.

Positive outcomes: Statically in the immediate proximity relative to the user.

8 Field of view analysis

The single most important feature of a bridge wing is to maximize the overview of the ships port or starboard surroundings, primarily facing the dock, another ship during lightering, and an oilrig during loading/unloading, or as viewpoint to increase overview during narrow waterway navigation. This critical function needs to be carefully considered and optimized so that the captain and his crew could focus their concentration on controlling the ship safely during various operations. Therefore, in this study, there was a critical need for a better understanding of the FOV on the SBW. To improve the knowledge about this feature, small-scale models, approximately 1:15, made out of foam board represented different designs, all made rapidly. In the following sub-sections, the setups used to evaluate the FOV is presented in detail.

The need for an undisturbed view of the ships side when docking is confirmed through several visits to ships, as well as a full size ship-simulator. Many of today's ships have large blind spots from the steering position of the bridge wing, both of the ships side and surroundings. The blind spots is often a result of small windows, large window frames and solid floors and walls.

8.1 Field of view analysis – setup 1

The small scale models of the bridge wing, cut out foamboard with windows, was fitted at the top of a whiteboard with a small LED lamp inside, shown in Figure 22. The LED, placed where a captain usually stands during operation, represented his eyesight. The emitted light flowed through the windows, and the structure casted shadows dependent of the design. The setup included three different designs, and their shadows were outlined in different colours by hand in order to compare the different FOVs.

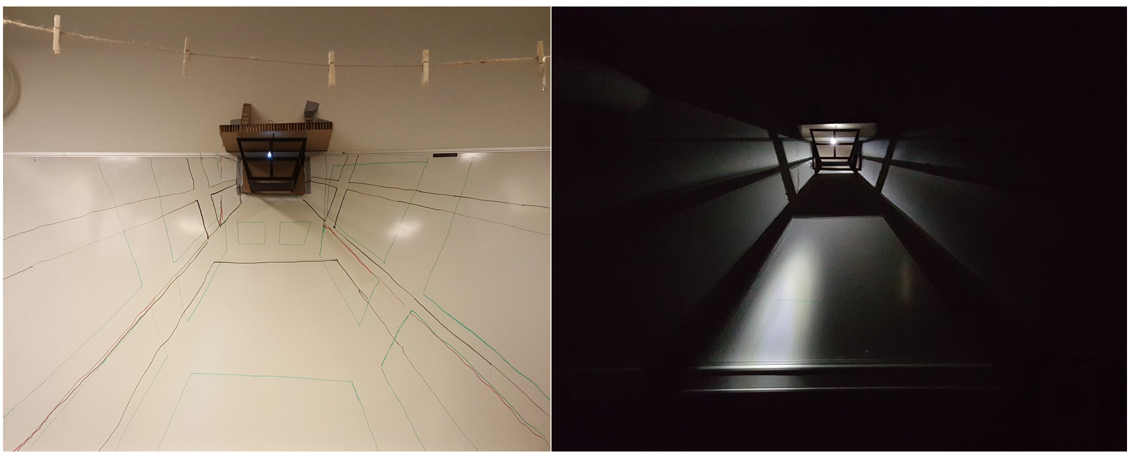


Figure 22: FOV analysis, setup one and two.

FOV setup 1 predicted the field of view inwards and along the shipside, and to some extent directly below the bridge wing, shown in the right figure. The main view in the outward direction from the ship (directly towards the camera above) was not included in this setup. The final outlines of the shadows from all the models is presented to the left in Figure 22.

8.2 Field of View Analysis – setup 2

To incorporate a more complete FOV in the analysis, a large cardboard box measuring 1,2m x 1,2m x 2m (W x L x H), was made. The small models from setup 1, including a stronger LED light, hung at the top of the far wall in the cardboard box. The light casted shadows and light at the surrounding walls and floor, see Figure 23. This meant that the height of the bridge wing represented was about 28m, and a blind spot of 1m in real life corresponded to a shadow of 6,5cm in the box. The setup characterizes a FOV spanning 180 degrees horizontal and vertical, thus representing the user’s ability to turn his or her head, completing the FOV necessary from a bridge wing. As in setup 1, the contours from the shadows was sketched to compare the FOV from the different designs. This setup resulted in a more extensive mapping of the FOV from the different designs. The outcome is discussed in the following chapter.

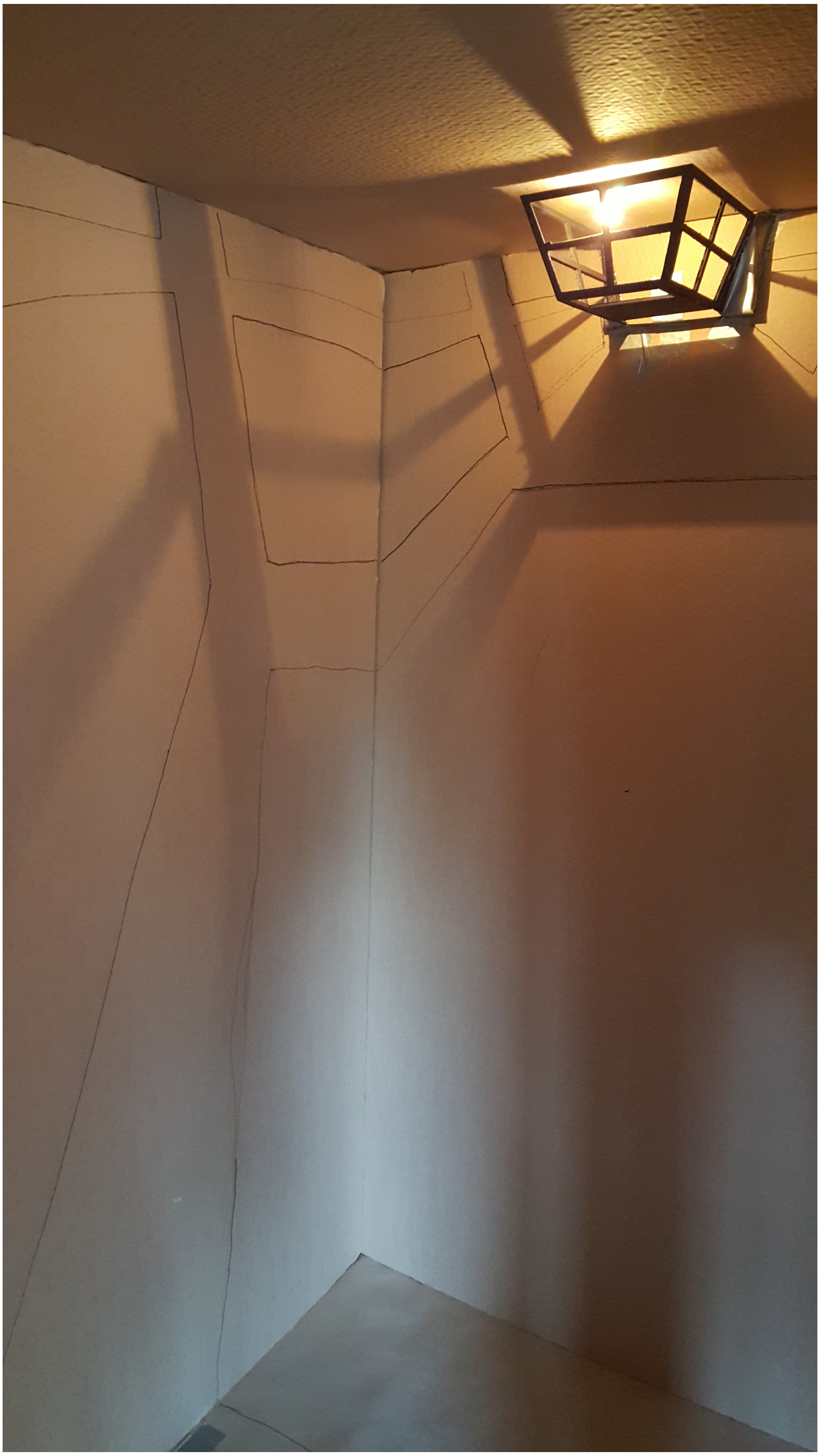


Figure 23: FOV analysis, setup 2.

9 Outcomes

9.1 Bridge wing environment

After a long period of searching for technology and developing the concepts for consoles, we looked back to the different tasks for the two officers on the SBW. An idea came to mind that the console could be divided into two parts, each focusing on the different officers' individual tasks. If the captain is manoeuvring the ship while the First Mate is

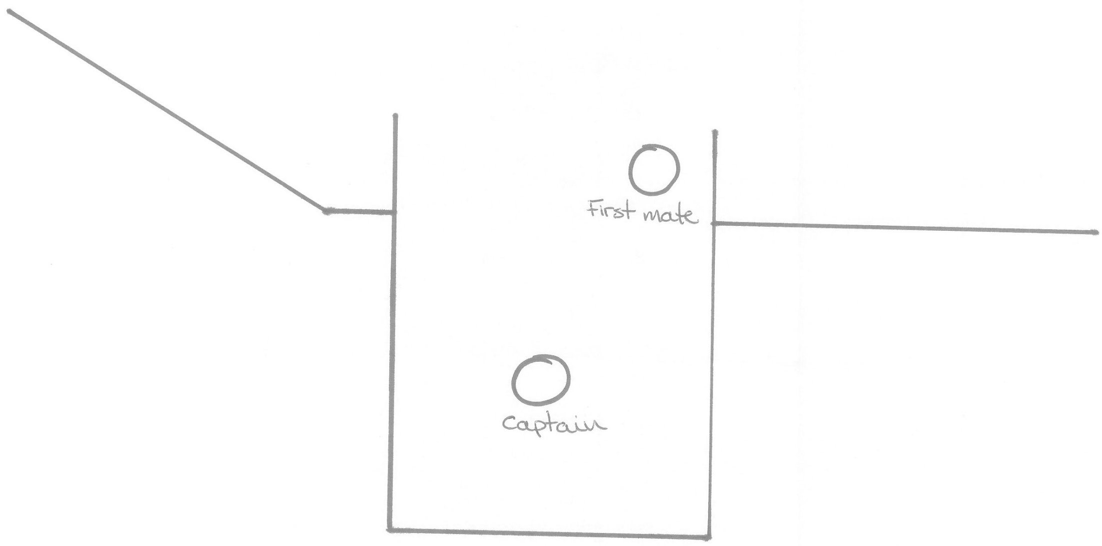


Figure 24: Top view illustration of positions in the SBW (size not to scale).

handling communications, alerts and power switches, they are using independent parts of the console. If the console is split into two parts, the First Mate's console can then be placed further back, and thus clearing up space on the SBW for the captain, see Figure 24.

9.1.1 The captain's position

Three main areas must be taken into account for the person manoeuvring the ship; FOV, control handles, and feedback from the ship.

A good FOV requires good visibility through the windows and few obstructions. Large windows reaching down to the floor with the least amount of interfering beams and a floor window large enough and placed in such a way that the edge of the dock is visible from any position that the captain might stand, satisfies a good FOV. Further, the window should be implemented with automatic brightness adjustment, and could include a head up display, as long as the information displayed is useful and not stealing the attention.

The captain's console needs to contain any controllers for manoeuvring the ship. This means rudder control, and power controls for main propellers or azimuth thrusters and stern and bow thrusters. Any other action buttons can be left for the First Mate.

Even though current SBW consoles often contains conning display, ECDIS and radar display, only conning displays give relevant information during docking. ECDIS have too low resolution to actually see the dock and details in the harbour, and the radar is not relevant in close proximity to the quay. This means that one can reduce the captain's screens to just the conning display. Other information that could be of interest are distances from the ship to dock or objects at sea and current depth. This information could also be appropriate to show on the windows by head up display, but this needs more testing. Our general thought is that such information should be easily visible, and could be placed at the peripherals of the windows.

9.1.2 The First Mate's position

While the captain manoeuvers the ship, the First Mate takes care of the other tasks. He needs to be able to switch on or off the power for different engines, take care of alarms, use the ship horn and communicate with other ship personnel and crew outside the ship. He also has interest in information from conning display. If projected on the windows this would be visible for both. The relevant buttons can be placed as a panel on the wall besides the First Mate (Figure 24), together with communication tools such as VHF and UHF. To prevent a scattered panel full of buttons, the panel could be a feedback touchscreen with an additional conning display and buttons appearing if needed.

9.1.3 Field of view

Our analysis of the SBW design and FOV led to the discovery that minor changes could improve the situation of today's designs, if one assumes the same bridge wing position (see section 9.1.1). Further, to increase the FOV beyond what is visible to the human eye from the SBW, one could take advantage of augmented reality. "Projecting" what lies on the other side of and behind the ship, on to the shipside visible from the bridge wing in action, see Figure 25. The black lines indicates obstacles, and the red area illustrates the ships boundaries.

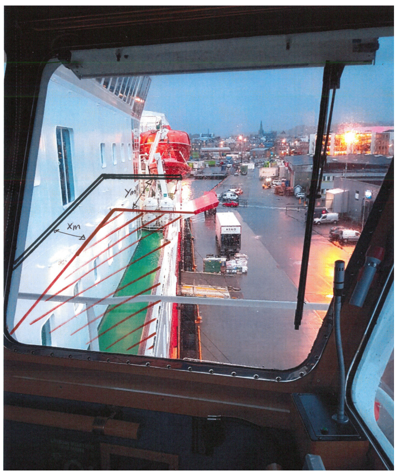


Figure 25: Augmented reality on the shipside.

9.2 Console design

An early evaluation of the four main types of consoles was done after making the basic ship simulator for the mock-up SBW. The console panel was placed on 4 simple prototypes, representing a floor, rail, ceiling and body based console. An evaluation sheet was created with categories covering important user concerns. These were ranked by operating the simulator for a given period with each of the setups. This gave us a certain overview over advantages and disadvantages about each of the setups, but not enough to pinpoint which would be the most preferable. The individual preferences were too far apart to give an idea of which to focus on at that moment. The key findings, after visiting ships and weeks of prototyping and testing, are:

- Placing the user in front or behind the console have their strengths and weaknesses
    - Placing the user behind the console, means that a part of the FOV inevitably will be stolen, thus forcing the user to move himself or the console to see behind it. However, the handles are placed in a comfortable position relative to the user during SBW operations.
    - Placing the user in front of the console, means that the user must reach backwards or turn around when looking out from the ship to operate the handles. The advantage is that this setup will in most cases not interfere with the FOV.
- Space is desirable. Consoles should take up as little space in the SBW as possible.
- Support beams that carry ceiling based consoles can be of considerable disturbance if placed close to the user's head.
- Floor based console can obstruct the users leg movement.
- The console can be split in two units, one for each of the two officers working on the SBW, since they have different tasks.

Table 1: Characteristics and placement identification and evaluation of the consoles.

Characteristics	C01	C02	C03	C04	F01	F02	F03	F04	F05	F06	R01	R02	B01	B02		
Tilt		○	○	●			●		●						**Integration**	**Symbol**
Height adj.	○	●		○	○	●	○	●	○	●					Fully	●
Width adj.									○	●					Semi	○
Rotation	○	●	●	●	●	○	○	○	○	○					**Evaluation**	**Colour**
Controls in front	○	○	○	○	○	○	●				●	●	●	●	Keep	
Controls behind	○	○	○	○	○	○	○	○		○					Preferrable	
Controls on the side	○	○	○	○	○		○	●	●	●	○	○			Discard	
Placment															Inconclusive	
Cieling	●	●	●	●												
Center floor					○	○	○	●	●	●						
Front floor					○	○	●									
Rail											●	●				
Body													●	●		

Further, the prototypes and tests led to a series of both predicted and unpredicted outcomes and learnings. Table 1 summarizes the characteristics of the consoles, and presents an evaluation of each of them. This table highlights which prototype lead to the discovery of what characteristics to keep, discard or needed more work before a deciding upon it. The attributes mentioned in Table 1 does not include a dedicated solution to how such a trait may be implemented, but it states whether it should be present or not. Other pros and cons of the different consoles and concepts are presented in Table 2.

Table 2: Pros and cons of console prototypes

Console		***Pros***	***Cons***
Ceiling	C01	• Free movement • Various positions	• Complex motions
	C02	• Free movement • Height adjustment	• Obstructing FOV • Close to the head
	C03	• Open FOV	• Close to the head
	C04	• Flexible panel position •	• Too many joints
Floor	F01	• Free horizontal movement • Positioning freedom	• Large base
	F02	• Height regulation • Occupies small space	• Tilted away from user
	F03	• Many steering positions • Adjustable tilt	• Obstructs FOV
	F04	• Opens FOV • Height regulations • Separates aft and bow controllers	• Large stands
	F05	• Physical support • Width adjustment	• Tilting as height regulation
	F06	• Height adjustment • Width adjustment • Opens FOV	• Fairly large
Body	B01	• User free to move • Constant position in relation to user	• Long extension from body • Shift in direction according to ship
	B02	• Same as B01 • Fixed to user	• “universal” design
Rail	R01	• In front of user • Frees up space	• Occupies FOV
	R02	• Same as R01	• Occupies FOV • Promotes up/down arm movement

The console concepts, which by the authors’ opinions shows the most potential so far is in particular F06, but also C04, see Figure 26. The ceiling console, C04, is showed to the left, and the floor console, F06, to the right. However, they should both go through further iterations, as discussed in the following chapter.

Figure 26: The most promising consoles so far.

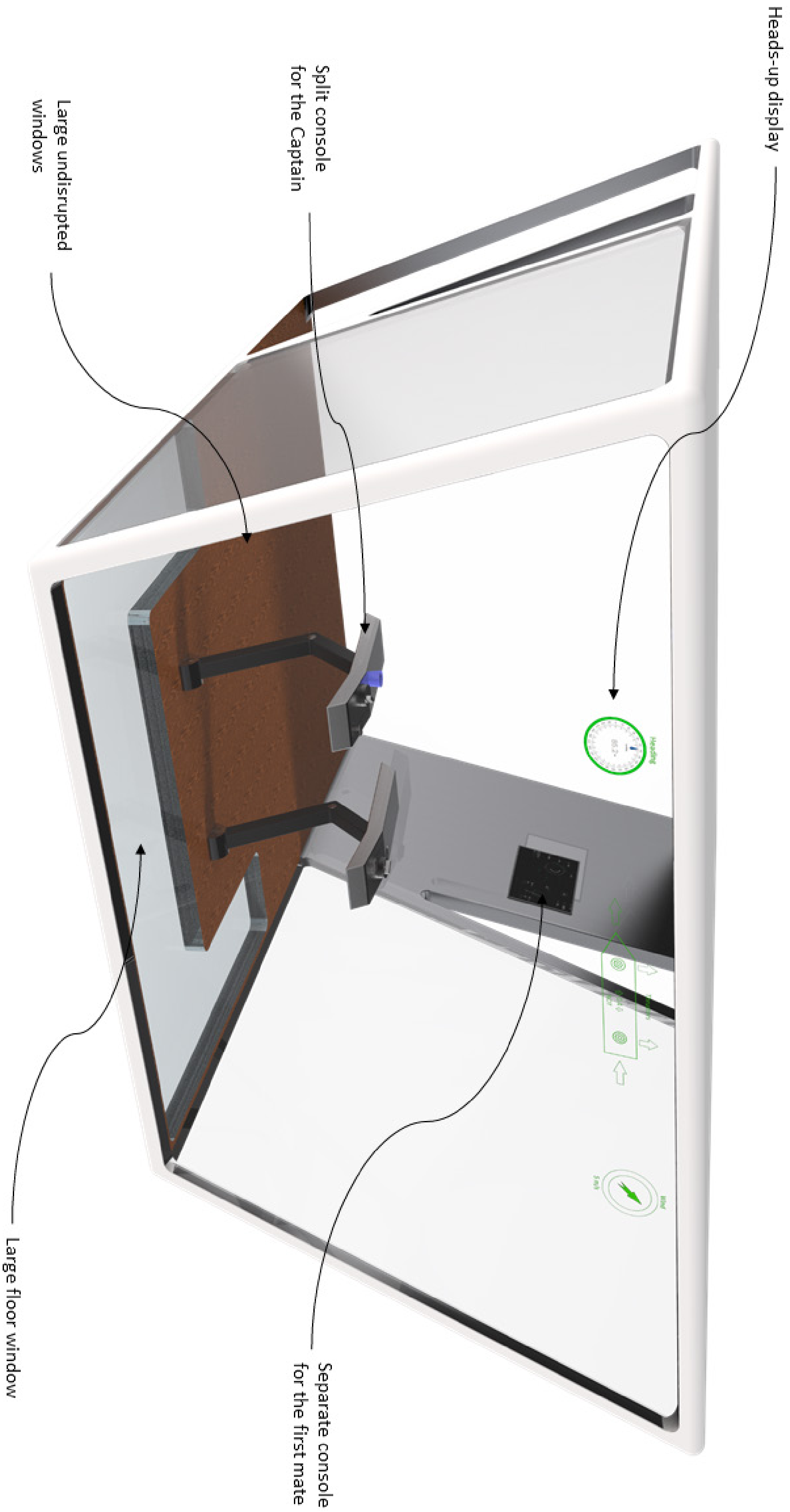


Figure 27: Future concept proposition

10 Discussion and Further Work

A ship bridge, with its responsibility and demand for reliability to both the direct and indirect users, should support and ease the bridge personals duties, rather than forcing them to adapt and make workarounds. Of course, certain aspects will need compromising, but the goal of every development change should be to adapt to the user, not the other way around. The fact that we in this report focus on easing the captain and his crews everyday job, through minimizing the impact from the consoles, increasing their perception of the surroundings and isolate tasks performed by different persons, cannot be done without certain requirements and compromises. For instance, the statement from section 7.3.1, that a smaller floor console results in various possible working positions, requires a substantial reduction in the consoles size, implying a reduction in the number of buttons and controllers on the consoles surface.

The reason for all the buttons and controllers available on the SBW is regulations and rules from certification societies and laws. Although these regulations have been fully ignored throughout this project to increase the innovativeness, we are still well aware of the need for redundancies for safety. With a console setup such as described in section 9.1, all the critical functions in the SBW should be well within reach for both officers, in case one is incapacitated.

After having looked at several console designs and setups to improve the SBW, it is still no indication to what is the ultimate console. Personal preferences is an important factor. From the people we have interviewed, opinions and preferences have been diverse, even amongst ourselves. Along with the fact that people come in different shapes and sizes, this indicates that personal adjustments is an important consideration when designing consoles.

It is important to notice the difference between the different consoles when considering the individual concept's characteristics presented in Table 1. A floor console would need other attributes than a ceiling console and so on, thus resulting in the different decisions of which characteristics to keep and/or discard. As Table 1 also shows, the rail and body console lacks further evaluations. This is because their potential was considered less than that of the ceiling and floor console at an early stage, thus resulting in more work and iterations on the two latter. As the work progressed, the split floor console showed the most potential. When testing the last prototype, F06 (to the right in Figure 26), we found that it may profit from being two separate modules, instead of originate from the same stand behind the user, thus open up for more flexibility. Figure 27 shows a suggested future concept with key findings from this project is implemented and highlighted. A runner up concept is the latest ceiling console C04, though test proved that we could reduce the number of joints. This console further requires a firm locking mechanism combined with smooth movement possibilities to ensure a flawless operation. To solve the problem of a console panel in front of the user, it might be split to resemble that of the floor console.

When we made the decision to split the steering console (F04, F05 and F06), we offered the captain an option to multitask in a more natural way. This resembles that of a crane or excavator, where multitasking (using both hands simultaneously) works well. However, a captain on a ship may not need to perform simultaneous adjustments to the same extent as a crane or excavator, but it grants the ability to separate the bow and stern power controllers and thereby decreasing the chances of turning the wrong controller. The split console also offers a great deal of personal adjustments.

To account for the FOV beyond that visible to the naked eye, i.e. behind the ship, we suggested augmented reality as a solution. This option has its difficulties and challenges, especially because of the dynamic positioning of the captain. As Drascic and Milgram (1996) mentions, the problem of aligning the projections with the ever-changing point of view of the captain is solved mathematically, but lacks accuracy in measurement of the captains point of view and practical implementation. As far as our research goes, this level of detail is still not accounted for without the use of on-body attachments, which might disturb the user.

As the User is central and highly dependent on the solution developed in this project, it would be preferable to engage in a more frequent communication and testing with them. However, it proved difficult to get naval officers, crewmembers, simulator crew and other stakeholders to visit us at NTNU, as well as bringing our prototypes to them, especially with the later, larger prototypes. In addition, the shipping industry is highly conservative, directed by harsh regulations. By presenting our ideas verbally, which many stakeholders perceives like very radical ideas, led to restrained answers and discussions. We did unfortunately not manage to get on board a more modern ship during our research, but at NorShipping, we saw several proposals for new ship bridge designs, consoles, modules, control stations and tools. Some of which, however, had similar pain points as older models, which increased our interest in the project.

Another user and stakeholder we would like to involve more in the future work is the younger naval officers, both undergoing education and newly graduated. When reaching out to them towards the end of this semester, we met a more intrigued and optimistic group, thus the potential for good, non-restrained feedback is higher. A more elaborate research on and connection to such stakeholders would be preferable in the future work needed to develop the next generation ship bridge wing.

As our outcomes of this project does not include implementation of controllers, or interactions with them, a more elaborate research concerning the controllers and how to adapt them to the users should be done in the future, preferably by reducing the amount. In addition, a more detailed process of evaluating how the attributes from Table 1 may be solved and implemented is yet to be determined, as well as optimize the combination of the aspects covered. The console dedicated to the First Mate also needs further testing and development.

11 The development process outcome

In DT and Wayfaring manners, we have gone through a non-linear process of empathizing, immersing, ideating, prototyping, testing and evaluating. Our way of approaching the challenge of reinventing the SBW with a focus on the user started with an initial round of ideating around who the users are and what they do in a SBW. We brought low-resolution prototypes on visits to different stakeholders and got a wider perspective considering their feedback during further prototyping. Since we during the project have focused on consoles, FOV and information (prioritized in that order), we have solved “progress-stops” in between evaluation and redefining by moving on to one of the other focus areas. In this way, we have managed to get new fresh ideas once moving back to the previous focus area.

One thing that has made especially this product development project challenging is the scale of the user environment. Ships have proportions that make it challenging to imagine how a product like a SBW or anything in it, will work in its proper environment during prototyping. Even our test area 5 meters above a workshop floor becomes small compared to standing on a ship’s bridge wing situated five times higher above a harbour dock.

During this project, we have many times reached ambiguous situations that have been challenging to handle. After finishing and testing prototypes, we have many times met a dead end. We have experienced that finishing a prototype made us ask questions such as; “what do we learn from this?” and “what’s next?”. Many times during a session of ideating, we have reached a conclusion that we had met before. However, after every ambiguous jam, we have managed to spin out of it. We have, during our project, been well trained within rapid prototyping, and increased our skills in solving ambiguous moments such as described.

The process of rethinking the ship bridge wing led to a good starting point for further concept development for both SBW consoles and the SBW as a total.

12 Conclusion

Findings from this project contemplates several different areas. Considering consoles, high degrees of mobility is probably not a particularly important issue as the user remains within a small space most of the time. Locking it in position is on the contrary crucial, and so is toughness against occasional bumps and vibrations. The ability to make adjustments is another area of focus. Ship officers come in different sizes and a completely fixed console does not give a good working position for everyone, proved through ship visits. While on the subject of adjustments, another problem area is the effect of turning the console. By allowing the console panel to rotate, the new direction and position of the controllers may lead to confusion. Having the console or parts of it, in front of the user may also deteriorate the FOV. By taking these factors into account and prototyping different console setup, we have reached a design with the prototype called F06, that we feel is a good foundation towards a final concept. As of now, this concept does not require new technology to be invented, but it might be a struggle to bend the rules and regulations for it to enter a real ship bridge wing.

Another important focus area has been the SBW as a working platform. To optimize the environment, the most important factors are maximizing the FOV and making the space in the SBW as free as possible. Concerning the FOV, big windows reaching from floor to ceiling, as well as a floor window large enough and placed such that the user sees directly down at the ships waterline will satisfy the FOV. User information, further enhanced by displaying conning data on the windows, will increase the navigational attention of the captain, as long as it does not disturb the view. In addition, information regarding distances, projected routes and surroundings may also be projected on the windows, though alignment issues of augmented reality needs further development.

This project ultimately led to a suggestion for reconfiguring the workspace for the two people working in the SBW. The captain stands in the outer part of the SBW controlling the ship, where the FOV is at its most complete, supported by an adapted console. The First Mate stands behind him with a console panel controlling communication and other actions depending on the situation. Whether this leads to the best concept remains uncertain, since the development is still at an early phase.

It is important to point out that the research done throughout this project is not by far finished. The last prototype built is in no way a final concept, but it builds upon a series of steps in the right direction of establishing one. After all, the last prototype had aspects that could have been improved and this shows potential for further work.

13 Bibliography

Brown, T. (2008). Design thinking. *harvard business review, 86*(6), 84.

Buchenau, M., & Suri, J. F. (2000). *Experience prototyping.* Paper presented at the Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques.

Carter, R. (2006). Boat remains and maritime trade in the Persian Gulf during the sixth and fifth millennia BC. *Antiquity, 80*(307), 52-63.

Dow, S. P., Heddleston, K., & Klemmer, S. R. (2009). *The efficacy of prototyping under time constraints.* Paper presented at the Proceedings of the seventh ACM conference on Creativity and cognition.

Drascic, D., & Milgram, P. (1996). *Perceptual issues in augmented reality.* Paper presented at the Electronic Imaging: Science & Technology.

Eurostat. (2014). Passanger Transport Statistics. Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_transport_statistics

Gerstenberg, A., Sjöman, H., Reime, T., Abrahamsson, P., & Steinert, M. (2015). A Simultaneous, Multidisciplinary Development and Design Journey–Reflections on Prototyping *Entertainment Computing-ICEC 2015* (pp. 409-416): Springer.

Houde, S., & Hill, C. (1997). What do prototypes prototype. *Handbook of human-computer interaction, 2*, 367-381.

Khurana, A., & Rosenthal, S. R. (1997). Integrating the fuzzy front end of new product development. *Sloan management review, 38*, 103-120.

Kim, J., & Wilemon, D. (2002). Focusing the fuzzy front-end in new product development. *R&D Management, 32*, 269-279.

Leifer, L. J., & Steinert, M. (2014). Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning *Management of the Fuzzy Front End of Innovation* (pp. 141-158): Springer.

Lim, Y.-K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction (TOCHI), 15*(2), 7.

Meinel, C., & Leifer, L. (2010). *Design thinking research*.

Moenaert, R. K., De Meyer, A., Souder, W. E., & Deschoolmeester, D. (1995). R&D/marketing communication during the fuzzy front-end. *Engineering Management, IEEE Transactions on, 42*(3), 243-258. doi:10.1109/17.403743

Murphy, S. A., & Kumar, V. (1997). The front end of new product development: a Canadian survey. *R&D Management, 27*(1), 5-15. doi:10.1111/1467-9310.00038

Reid, S. E., & De Brentani, U. (2004). The fuzzy front end of new product development for discontinuous innovations: a theoretical model. *Journal of product innovation management, 21*(3), 170-184. doi:10.1111/j.0737-6782.2004.00068.x

Reinertsen, D. G. (1999). Taking the fuzziness out of the fuzzy front end. *Research-Technology Management, 42*(6), 25-31. Retrieved from <Go to ISI>://WOS:000083524900007

Smith, P., & Reinertsen, D. (1991). *Developing new products in half the time*: Van Nostrand Reinhold Books, New York, NY.

Snowden, D. J., & Boone, M. E. (2007). A leader's framework for decision making. *harvard business review, 85*(11), 68.

Steinert, M., & Leifer, L. J. (2012). 'Finding One's Way': Re-Discovering a Hunter-Gatherer Model based on Wayfaring. *International Journal of Engineering Education, 28*(2), 251.

Ulrich, K. T., & Eppinger, S. (2012). Product Design and Development, 2012: McGraw-Hill, New York, NY.

Appendix A – Assignment Text

THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

PROJECT WORK AUTUMN 2015
FOR
STUD.TECHN. Erik Karlsson & Ferdinand O. Solvang

Next generation ship brigde wing

Neste generasjon skipsbrovinge

Rethink and further develop the ship bridge wing, by focusing on the following aspects:
- Console design
- Bridge wing design
- Field of view
- Information feedback with special regards to haptic and/or tactic touchscreens

The work is a combination of literature, experimental and free early stage conceptual prototyping activities. The indented outcome level should allow feasibility decision to commence R&D projects and work as repository for a possible academic publication in 2016.

Formal requirements:

Students are required to submit an A3 page describing the planned work three weeks after the project start as a pdf-file. A template can be found on IPM's web-page (https://www.ntnu.no/ipm/prosjekt-og-fordypningsemner).

Performing a risk assessment is mandatory for any experimental work. Known main activities must be risk assessed before they start, and the form must be handed in within 3 weeks after you receive the problem text. The form must be signed by your supervisor. Risk assessment is an ongoing activity, and must be carried out before starting any activity that might cause injuries or damage materials/equipment or the external environment. Copies of the signed risk assessments have to be put in the appendix of the project report.

No later than 1 week before the deadline of the final project report, you are required to submit an updated A3 page summarizing and illustrating the results obtained in the project work.

Official deadline for the delivery of the report is 15 December 2015 at 3 p.m. The report is to be delivered in two paper copies and one electronic version via email to iipmprosjekt@ivt.ntnu.no.

When evaluating the project, we take into consideration how clearly the problem is presented, the thoroughness of the report, and to which extent the student gives an independent presentation of the topic using his/her own assessments.

The report must include the signed problem text, and be written as a scientific report with summary of important findings, conclusion, literature references, table of contents, etc. Specific problems to be addressed in the project are to be stated in the beginning of the report and briefly discussed. The report should not exceed thirty pages including illustrations and sketches.

Additional tables, drawings, detailed sketches, photographs, etc. can be included in an appendix at the end of the thirty page report. References to the appendix must be specified. The report should be presented so that it can be fully understood without referencing the Appendix. Figures and tables must be presented with explanations. Literature references should be indicated by means of a number in brackets in the text, and each reference should be further specified at the end of the report in a reference list. References should be specified with name of author(s) and book, title and year of publication, and page number.

Contact persons:

At the department : Martin Steinert, TBD
From the industry : Espen Strange (KM)

Martin Steinert
Supervisor

NTNU
Norges teknisk-naturvitenskapelige universitet
Institutt for produktutvikling og materialer

Appendix B – Risk Assessment

NTNU	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
HMS		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Enhet: Department of engineering design and materials **Dato: 2015.09.07**

Linjeleder:

Deltakere ved kartleggingen (m/ funksjon)**:** Martin Steinert, veileder/ Erik Karlsson, student/ Ferdinand O. Solvang, student
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Prosjektoppgave student Erik Karlsson og Ferdinand O. Solvang. Nest generation ship bridge

Er oppgaven rent teoretisk? (JA/NEI)**: Nei** *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Erik Karlsson og Ferdinand O. Solvang*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs workshop.	EK/FOS	Romkort	Romkort		
1a	Bruk av roterende maskineri	EK/FOS	Maskinens brukermanual	Ukjent	Ukjent	
1b	Bruk av laserkutter	EK/FOS	Maskinens brukermanual	Ukjent	Ukjent	
1c	Bruk av 3D printer	EK/FOS	Maskinens brukermanual	Ukjent	Ukjent	
1d	Bruk av skjæreverktøy	EK/FOS	Ukjent			
1e	Bruk av samenføynigsmidler (lim og lignende.)	EK/FOS	Produktets brukermanual og datablad	Datablad	Ukjent	

2	Tilstedeværelse ved arbeid utført av andre.	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	
3	Eksperimentelt arbeid	EK/FOS	Egen risikovurdering- må gjøres for hvert enkelt eksperiment		Prosessavhengig	

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet	Vurdering av konsekvens:				Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
			(1-5)	Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)		
1	Bruk av Trolllabs workshop.								
1a-i	Bruk av roterende maskineri	Stor kuttskade	2	D	A	A	D	2D	Sørg for at roterende deler er tilstrekkelig sikret/dekket. Vær nøye med opplæring i bruk av maskineri.
1a-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iii		Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iv		Flygende spon/gjenstander	3	C	A	A	B	3C	Bruk øyevern og tildekk hurtig roterende deler (Fres og lignende.)
1a-v		Feil bruk-> ødelagt utstyr	3	A	A	C	A	3C	Vær nøye med opplæring i bruk av maskineri
1b-i	Bruk av laserkutter	Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1b-ii		Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Bruk hansker ved håndtering av varme materialer.

1b-iii		Øyeskade-laser	2	D	A	A	C	2D	Bruk øyevern! Skru av laser når maskinen ved oppsett.
1b-iv		Brann	2	B	A	D	C	2B	Vær nøye med opplæring i bruk av maskin. Ha slukkeutstur tilgjengelig
1c-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskin.
1c-ii		Innhalering av plast/ printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern/ vernebriller
1c-iii		Feil bruk-> ødelagt maskineri	3	A	A	C	A	3A	Vær nøye med opplæring i bruk av maskin.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk skapre verktøy og riktig skjæreunderlag
1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk skapre verktøy og riktig skjæreunderlag
1e-i	Bruk av samenføynigsmidler (lim og lignende.)	Eksponering på øyet	2	D	A	A	B	2D	Bruk øyevern, ha datablad tilgjengelig
1e-ii		Eksponering hud	4	A	A	A	A	4A	Bruk hansker, ha datablad tilgjengelig
1e-iii		Eksponering åndedrett	4	A	A	A	A	4A	Bruk åndedretsvært/ god ventilasjon. Ha datablad tilgjengelig.

1e-iv		Søl	4	A	B	A	A	4A	Ha papir/ rengjøringsmateriell tilgjengelig. Ha datablad tilgjengelig.
2	Tilstedeværelse ved arbeid utført av andre.	Se andres risikovurdering om sikkerhet betviles.	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg.
3-i	Eksperimentelt arbeid	Vann-drukning	1	A	A	A	D	1E	Bruk redingsvest i båt og lignende.
3-ii		Elektrisitet- strøm	3	B	A	A	A	3V	Typisk lite energi involvert. Bruk isolerte verkøty
3-iii		Ulykke på skip	1	D	D	B	B	1D	Følge regler og prosedyrer ombord

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5

Gradering	Menneske	Ytre miljø Vann, jord og luft	[illegible]	[illegible]
E Svært Alvorlig				
D Alvorlig				
C Moderat				
B Liten				
A Svært liten				

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS						
KONSEKVENS	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge	Beskrivelse
Rød	Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul	Vurderingsområde. Tiltak skal vurderes.
Grønn	Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.

Appendix J Risk Assessment

NTNU HMS	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Enhet: Department of engineering design and materials **Dato: 2016.02.01**

Linjeleder: Torgeir Welo

Deltakere ved kartleggingen (m/ funksjon)**:** Martin Steinert, veileder/ Erik Karlsson, student
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Masteroppgave student Erik Karlsson. Next generation ship bridge

Er oppgaven rent teoretisk? (JA/NEI)**: Nei** *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Erik Karlsson*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs workshop.	EK	Romkort	Romkort		
1a	Bruk av roterende maskineri	EK	Maskinens brukermanual	Ukjent	Ukjent	
1b	Bruk av laserkutter	EK	Maskinens brukermanual	Ukjent	Ukjent	
1c	Bruk av 3D printer	EK	Maskinens brukermanual	Ukjent	Ukjent	
1d	Bruk av skjæreverktøy	EK	Ukjent			
1e	Bruk av samenføynigsmidler (lim og lignende.)	EK	Produktets brukermanual og datablad	Datablad	Ukjent	
2	Tilstedeværelse ved arbeid utført av andre.	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	

NTNU / HMS	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

3	Eksperimentelt arbeid	EK	Egen risikovurdering- må gjøres for hvert enkelt eksperiment		Prosessavhengig	

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet (1-5)	Vurdering av konsekvens: Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
1	Bruk av Trolllabs workshop.								
1a-i	Bruk av roterende maskineri	Stor kuttskade	2	D	A	A	D	2D	Sørg for at roterende deler er tilstrekkelig sikret/dekket. Vær nøye med opplæring i bruk av maskineri.
1a-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iii		Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iv		Flygende spon/gjenstander	3	C	A	A	B	3C	Bruk øyevern og tildekk hurtig roterende deler (Fres og lignende.)
1a-v		Feil bruk-> ødelagt utstyr	3	A	A	C	A	3C	Vær nøye med opplæring i bruk av maskineri
1b-i	Bruk av laserkutter	Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1b-ii		Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Bruk hansker ved håndtering av varme materialer.

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

1b-iii		Øyeskade-laser	2	D	A	A	C	2D	Bruk øyevern! Skru av laser når maskinen ved oppsett.
1b-iv		Brann	2	B	A	D	C	2B	Vær nøye med opplæring i bruk av maskin. Ha slukkeutstur tilgjengelig
1c-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskin.
1c-ii		Innhalering av plast/ printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern/ vernebriller
1c-iii		Feil bruk-> ødelagt maskineri	3	A	A	C	A	3A	Vær nøye med opplæring i bruk av maskin.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk skapre verktøy og riktig skjæreunderlag
1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk skapre verktøy og riktig skjæreunderlag
1e-i	Bruk av samenføynigsmidler (lim og lignende.)	Eksponering på øyet	2	D	A	A	B	2D	Bruk øyevern, ha datablad tilgjengelig
1e-ii		Eksponering hud	4	A	A	A	A	4A	Bruk hansker, ha datablad tilgjengelig
1e-iii		Eksponering åndedrett	4	A	A	A	A	4A	Bruk åndedretsvært/ god ventilasjon. Ha datablad tilgjengelig.

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

1e-iv		Søl	4	A	B	A	A	4A	Ha papir/ rengjøringsmateriell tilgjengelig. Ha datablad tilgjengelig.
2	Tilstedeværelse ved arbeid utført av andre.	Se andres risikovurdering om sikkerhet betviles.	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg.
3-i	Eksperimentelt arbeid	Vann-drukning	1	A	A	A	D	1E	Bruk redingsvest i båt og lignende.
3-ii		Elektrisitet- strøm	3	B	A	A	A	3V	Typisk lite energi involvert. Bruk isolerte verkøty
3-iii		Ulykke på skip	1	D	D	B	B	1D	Følge regler og prosedyrer ombord

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Sannsynlighet vurderes etter følgende kriterier:

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	Menneske	Ytre miljø Vann, jord og luft	Øk/materiell	Omdømme
E Svært Alvorlig	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
D Alvorlig	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C Moderat	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
B Liten	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A Svært liten	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens
Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

Til kolonnen "Kommentarer/status, forslag til forebyggende og korrigerende tiltak":
Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.

NTNU	Risikomatrise	utarbeidet av	Nummer	Dato
HMS/KS		HMS-avd.	HMSRV2604	08.03.2010
		godkjent av		Erstatter
		Rektor		09.02.2010

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS						
	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge		Beskrivelse
Rød		Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul		Vurderingsområde. Tiltak skal vurderes.
Grønn		Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.