Joystick for Marine Maneuvering

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

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Master's Thesis 2020
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Cover: The test bench that was developed during the project.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2020

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Abstract

A big part of our modern lives evolves around interpreting feedback sent to us from different devices. Is your phone vibrating and the screen flashing? Odds are someone is trying to call you. Is the light on your stove turned on? Odds are it is activated and hot. To minimize the risk of misunderstandings and accidents, this feedback needs to be clear and self-evident. One way to ensure this, is to develop a product based on user experience. This ensures that the user understands the product, and use it in the way the developer intended.

This project aimed to develop a joystick test bench that could test different kinds of feedback and activation methods. The test bench consisted of both a physical joystick prototype which the user could interact with, as well as a simulator which the physical prototype could be tested on. User studies were performed on the prototype.

The results from the user studies point towards that users would like more feedback on function activation than just visual. The test bench itself can be further developed and used in future studies.

Keywords: joystick, user experience , test bench, simulator, feedback, activation methods, user studies

Acknowledgements

This report comprises a Master's Thesis in Product Development at the department of Industrial and Material Science carried out from January until June 2020 at Chalmers University of Technology.

We would like to give a warm thank you to our supervisor Lars Almefelt for his inspiration, motivation and engagement during this project.

We would also like to thank Sofia Ekman & David Nydahl, our company supervisors from CPAC Systems for their insight, guidance and expertise that greatly assisted the research.

This thesis demanded a big amount of work, dedication and commitment. Still, it could not have been done without the support of several people. Therefore we would like to also direct our sincere gratitude to everyone who has contributed to making this project a success.

Hannah-Maria Elfving & Hannes Winblad, Gothenburg, June 2020

Contents

1

Introduction

This chapter presents the background, scope and objectives of the project.

1.1 Background

In 2005 Volvo Penta launched their new Inboard Performance System (IPS) engines. IPS engines possess the ability to rotate and hence change the direction of the thrust. This makes it possible to translate the boat in one particular direction,(see figure.1). This technology facilitates navigation in cramped places like marinas. In order to take advantage of this new technology, CPAC systems developed a joystick (CPAC, 2020). Since 2005, the joystick has gone through one major re-design, during which new features were integrated and the design updated. Because of the emergence of new features, and the risk of these increasing the complexity of the current interface, another redesign is now needed in order to improve the user experience.

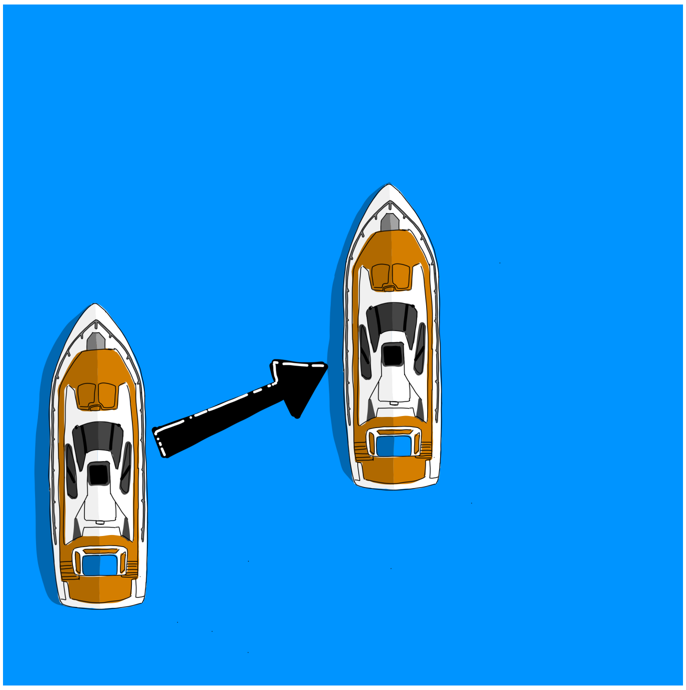

Figure 1.1: Translation of boat

1.2 Purpose

The purpose of this project is to develop a new design concept of the existing joystick focused on user experience and the human machine interaction. The new design should integrate new and future functions without raising the level of complexity of the product, whilst still being able to carry out the same functions as its predecessor. Different kinds of feedback and activation methods will be evaluated.

In addition, a test bench and a simulator should be developed, which will allow for future creative and innovative concept generation and exploration.

1.3 Objectives

This project will evaluate the existing joystick and its functionality, and propose a new design concept. Furthermore, a test bench will be constructed with the objective to perform user studies, compare the design concept to the current design and also to present the concept.

The objective of the design concept is to facilitate the usage for novel users without compromising the experience for seasoned users.

The following subjects will first be investigated in regards to the existing joystick, with the objective of evaluating the current situation, and secondly in order to verify the re-design.

- **Intuity**
  How easy is it for a new user to understand the interface and usage of the product?

- **Integration of new functions**
  How to integrate activation methods for new and future functions, e.g. Assisted maneuvering, without increasing the complexity of the product?

Furthermore, regarding the test bench, the following subject will be investigated;

- **Test bench**
  How to construct a test bench that is easy to use for both developers and user studies?

1.4 Scope & delimitations

The project comprises 1600 man hours, the equivalence of 60 credits. It proceeds until the beginning of June, 2020. The scope of the project needs to be limited due to the time frame, therefore, there are some delimitations to the process;

- Aesthetics and color choices will not be considered.
- Manufacturing techniques and material choices are also outside the scope of the project.
- No predefined internal development process nor design for environment protocols at CPAC will have to be followed.
- The final concept will not be evaluated for other segments than the marine.
- As illustrated in figure 1.2, the main focus, marked with green, will be put on the joystick. Furthermore, the human-machine interface between the user and the navigation system, marked with blue, will be observed. The electronic vessel control system, the engines, hull and environment is outside the system boundary of this project.
- The physical ergonomics of the joystick will not be investigated.

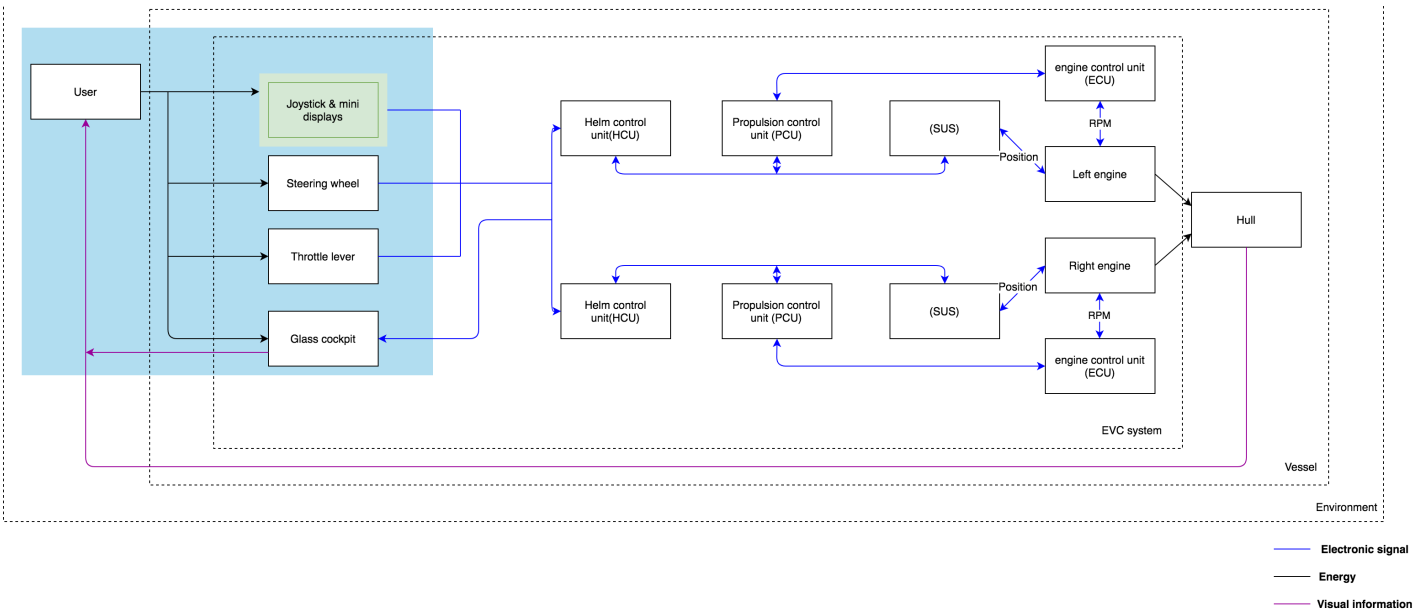

Figure 1.2: Overview of system

1.5 Question formulation

The question formulation is a more detailed description of the objectives. The following questions will be answered during the process;

- **Benchmarking**
  - How is the product being used today and who are the users?
  - What does the market look like, is there similar solutions?

- **Intuity**
    - How easy is it for a novel user to understand the interface and usage of the product?
    - How does the haptic, visual and auditory feedback work today, and how can it be improved?

After having looked into these questions, the following can be answered,

- **New conceptual design**
    - Is there a need to update the joystick, and if so, how?
    - **Test bench**
      How should a test bench be constructed with the objective of it being easy to use for both developers and user studies?

1.6 Reading guide

Each chapter is introduced with a short introduction and explanation of how the chapter is built up. The contents of chapter 2, theoretical frame of reference, act as a basis on which the rest of the report stands. It is meant to be read when referenced in the rest of the report. Each subsection will not be connected to its predecessor, and principles will be presented broadly in chapter 2. In chapter 3, Methodology, the process of the project is explained. Both how the test bench was developed, as well as the reasoning behind it, is explained here. In chapter 4 the results of the project are presented. Both in regards to the user studies and the test bench itself. No methods, theory of back ground of anything will be presented here, only the actual results. The fifth chapter consist of recommendations based on knowledge gained as well as results. In the sixth chapter, discussions on all the prior chapters is carried out. The last chapter of the report is a conclusion of the project.

2
Theoretical frame of reference

In order to create a solid basis from which to develop the new design of the joystick, a theoretical frame of reference needs to be identified. This is done by first defining what is meant by user experience. This is followed by theory about user studies and data collection followed by product development theory and theory of technical components. Lastly, an identification of the current design of the product and a market analysis is presented.

2.1 What user experience is

At its very core, (International Organization for standardization, 2019) defines user experience as, "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service" The term is further developed upon by the use of the term Usability. According to (International Organization for standardization, 2019) usability deal with not only the satisfaction the user experience by using the product but also, with what level of "effectiveness, efficiency" it is carried out. In regards to developing a new version of a product this is especially interesting, as a raised level of both effectiveness and efficiency lowers the amount of resources involved in using the project whilst raising the level of accuracy with which it can be carried out. (International Organization for standardization, 2019).

2.1.1 Why user experience is important

Alben(1996) describes that user experience, if carried out correctly, will create a value for the customer. This value in its turn may be the deciding factor that makes a user choose a product over another. An example of the importance of the user experience comes from the car industry, where research has been going on for years to identify what constitutes a preferable sound when closing a car door. As explained by Parizet, Guyader, and Nosulenko (2008), not only does the car door communicate that the door is closed to the user, but it also greatly impacts the over all impression of the car, which affect the customer purchase behaviour. Therefore it is important to research and understand this.

One way to increase the user experience and usability is to adopt what is called a human-centered design.

2.1.2 Implementation of human-centred design

According to (International Organization for standardization, 2019) Human-centered design is described as, "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques". Interactive systems in this context is described as that which the user interact with to realize a specific goal. This could for example be a car through which one can be transported from point A to B. The main principles of human centred design are according to International Organization for standardization (2019) the following,

- Design based on an understanding of users tasks and environment
- Users are involved throughout design and development
- Design driven and refined by user-centered evaluation
- iterative process
- Design addresses the whole user experience
- the design team includes multidisciplinary skills and perspectives

2.1.3 The interactive system

The interactive system described in section 2.1.2, is supposed to be interacted with by a user through what is called a user interface. The user interface is supposed to be "an interactive system that provides information and controls for the user to accomplish specific tasks". (International Organization for standardization, 2019). In regards to a car, the user interface would be the steering wheel, dashboard and pedals.

2.2 Theory of user studies & data collection

Below, theory of user studies and data collection being used in this project is presented.

2.2.1 Usability test

A usability test is an interaction analysis involving a test person and a proposed design. The participant do realistic tasks using a proposed design represented by either a fully functioning prototype or a simple paper prototype. The test is observed and the data are analyzed, recommendations on improvements are then made. The data collected in the usability test can be quantitative and/or qualitative. Quantitative data can be e.g. time, number of clicks or errors. Qualitative data encourages the participants to think aloud about e.g. likes or dislikes. The test is often documented through video or audio recording.(Bligård, 2018).

The strength of usability testing lies in the possibility to observe the interaction between a user and a product, also it is easy to re-design. The limitations lies in it is heavily resource expensive and the risk of context affects due to un-realistic work environment. (Bligård, 2018).

> "Usability test is often the best interaction analysis method, but the fare most expensive method." (Bligård, 2018)

2.2.2 Exploratory & confirmatory user studies

User studies are often initiated through exploratory methods. Exploratory methods has the goal of generating new ideas and uses most qualitative research. Confirmatory research, as the name implies, has the objective of confirming user requirements discovered during the exploratory phase and does this mainly through quantitative research. (F. McQuarrie, 2006).Qualitative research may involve interviews and focus groups while quantitative research involves surveys(Malmqvist, 2019).

2.2.3 The structure of the user study

Both observations and interviews can be either structured, semi-structured or un-structured. Structured studies means the questions or items for observation, and the order, are pre-defined. In un-structured studies some questions are predefined to make sure they are covered, but if other topics arise, these can be discussed or observed as well. Un-structured studies means no questions or items of investigation are predefined and the researchers role is more passive than in the previous two. (Wallgren, 2019).

2.2.4 Question-based & observation-based studies

There are two main categories of data collection methods; question-based and observation-based (Wallgren, 2019).

2.2.4.1 Question-based studies

Question based studies means you interact with the studied user. Question-based studies can be in the shape of e.g. interviews, focus groups or surveys. Question based studies has it's strengths in; it is fairly time-effective and is really value adding in the exploration of a development phase. (Hvas Mortensen, 2020). According to Hvas Mortensen(2020), interviews are a great way to empathize and give you an in-depth understanding of their values, perceptions, and experiences. Interviews allow you to ask specific questions, while remaining open to exploring your participants' points of view.

2.2.4.2 Observation-based studies

Observation-based studies means you do not interact with the studied user. Observations are an effective way to study situations where you can detect user requirements in the shape of comparisons, assumptions, compensating behaviours, actions, and solutions.(Wallgren, 2019). Observation-based studies can be divided into natural or constructed observation. Natural observations are usually unstructured and the researchers study spontaneous behaviour in a natural environment. Constructed observation means the researchers decide which users should participate, where and when the study should take place and also the structure of the observation. The strengths of using natural observation is the opportunity to generate new ideas.(Mcleod, 2015). According to Mcleod(2015), the benefits from using constructed studies is it is easy to replicate and it is usually less time-consuming.

Observation-based studies is specifically useful because users do not always want to or can describe their problems and requirements. Also they may not even be aware of them and has started to a compensating behaviour. Furthermore, users can sometimes blame themselves for e.g. not understanding the product rather than blaming the design.(Wallgren, 2019).

2.2.5 Participator demographics in qualitative studies

When conducting qualitative user studies, the user demographics are important to consider since the choice of participants will have a great impact on the gathered information. Often, you choose participants with a particular property, e.g. age, gender, product use experience. It is important the participants are part of the identified user group and they need to have experience of the product or the problem. (Wallgren, 2019).

2.3 Product development theory

Below, the product development theory implemented in this project is presented.

2.3.1 Theory about the Kesselring matrix

The kesselring matrix is a concept scoring method. In this matrix, the concepts are evaluated against each other on how well they fulfill the requirements. In addition, the requirements are weighted. The score that each concept gets on the fulfillment of the requirement is multiplied with the weighting of that certain requirement. This method is quite time consuming but provides precision to the assessment, compared to other concept scoring methods. (Almefelt, L., 2019).

2.3.2 Node-based workflows & processes

In order to visualize workflows in a product developing process, black box models can be used. The black box model consists of three parts, a node in which an unknown process takes place, an input of known contents into the box, as well as an measurable output. In computer science this same concept is applied on the concept of nodes, where the node itself consist of the process carried out, whilst being connected to other nodes by inputs and outputs (Fundamentals, 2020).

2.3.3 Theory on prototyping

A functional prototype is close to the full functionality of the end product, e.g. a prototype with a user interface that works for the test data but is not well-designed enough to be integrated in the entire system.(Spacey, 2016).

According to (Steven C. Wheelwright, 1992), prototyping is a key management tool for guiding development projects, and not a technical tool as traditionally viewed. Prototypes answer several questions, e.g. customer reactions and can take many forms. They argue that prototyping is a key to improve effectiveness and efficiency of the development process by contributing with learning about the product and the user. Furthermore, it is stated; prototypes play an important role in the testing and progress of the development project by providing insight in the design and it's ability to meet customer requirements.

2.3.4 Design-build-test cycle

Product development is a learning process, this is the basis of the design-build-test cycle methodology.

> "No matter how much an engineer, a marketer, or a manufacturer may know about a given problem, there are always unique aspects of any new system that must be understood before an effective design may be developed."(Steven C. Wheelwright, 1992)

In order to fully understand the problem at hand, designers must go through several iterations, learning a little more at each cycle. The design-build-test cycle is built up on the phases; design, build and test.

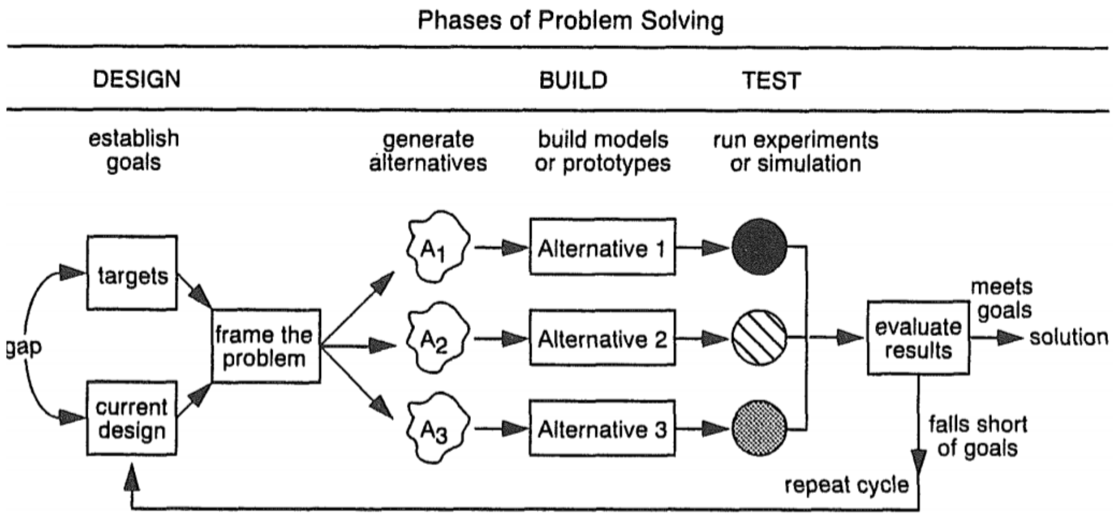

Figure 2.1: The Design-build-test cycle (Steven C. Wheelwright, 1992)

In the design phase the problem is framed, this is crucial, since problems, gaps and customer requirements are often underlying and hard to observe and characterize. When the problem is framed, alternatives for physical models, with the objective of closing the gap between design parameters and specific customer attributes, are generated.

During the build phase, functioning prototypes of the ideas are created. The aim of these prototypes is to allow for testing.

In the test phase, the prototypes are tested. Depending on the objective of the design, either a complete product or a sub-system may be tested. It is crucial to have a well thought through test plan and skilled execution in order to get good information from this phase, even though it may seem pretty straight forward. If the prototypes or models that are tested do not reflect the design intent, there is a risk of an unnecessary amount of iterations need to be conducted.

Conducting a single cycle generates insight and information on the connection between specific design parameters and customer attributes. The next cycle is then built on this as basis, this is repeated until a solution that meets the requirements is generated. (Steven C. Wheelwright, 1992).

2.3.5 Modular design theory

Modular design is a design approach where a product is made out of modules with standardized interfaces. The objective of this design approach is to be able to change singular elements without replacing the entire assembly. Since the interfaces is standardized, new modules can be made to accommodate new requirements, making modular products sustainable over time.(Ramalhete, R, 2017). Furthermore, modular design enables different designers to work on the same product simultaneously, reducing the development time. However, the first phase in modular design methodology may take longer than an integrated design if a design is to be split up in modules and the interface defined.(Fast Product Development, 2020).

2.3.6 Design for assembly theory

When designing a product, it is important to keep the assembly process in mind, this design evaluation method is called Design for Assembly(DFA) and was pioneered by Boothroyd and Dewhurst at the University of Rhode Island (Kent, 2017). The principles of assembly include minimizing part count and designing parts with self-locating and self-fastening features. Furthermore, the design is encouraged to be modular and have a base part to locate other components. (Stienstra, D, 2019).

Kent(2016) describes how DFA enables designers to reduce both the number of parts in an assembly, and also the assembly labour and time. Furthermore, it enables easier manual or automatic handling in assembly.

2.3.7 Theory of Additive manufacturing

Additive manufacturing(AM) or 3D printing is widely used to manufacture physical prototypes. The most popular used AM technique is material extrusion printing. Material extrusion means material is selectively dispensed from a nozzle which is typically heated (Hryha, E., 2019).

When designing for Material extrusion printing, the following restrictions need to be met; First, the sides of the part may not have a smaller inclination than 40°, secondly, no circular holes may have a diameter bigger than 8mm, lastly, the design may not have overhanging features. If the design is preceding these limitations, support structure will need to be added to the print. (Hammar, L., 2019). Support structure can be made of either the same material as the main part, or a softer material that can be manually removed, or the support can be made of a material that is chemically or thermally removed, usually wax(Hryha, E., 2019).

2.4 Theory of technical components

In this section, the theory of the technical components integrated in the test bench is described.

2.4.1 Micro controllers

In order to be able to build custom human interfaces, one can user programmable microprocessors. These can both process inputs and send data to an external component.

2.4.1.1 Arduino

The Arduino UNO is a micro controller with 13 digital pins that can be used to read the status of buttons or sensors. It also has the ability to send information to an external device over USB.

2.4.1.2 Seeeduino

Similar to the Arduino, the Seeeduino has 13 digital pins which also can be used to read the status of different components, but it differs in the sense that it also has 12 extension ports on the front to which components can be connected.

Figure 2.2: The Arduino micro controller(elektor, 2020).

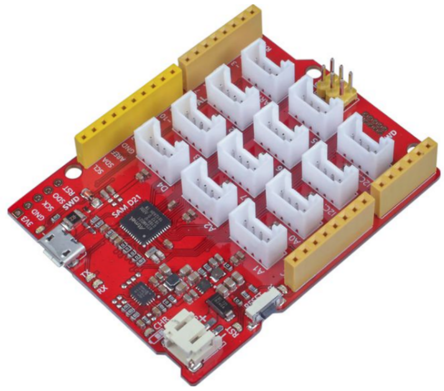

Figure 2.3: The Seeeduino micro controller (elfa, 2020).

2.4.2 Theory about CAN data

CAN, or Controller Area Network, is a communication protocol characterized mainly by the ability to assign priority to messages (Di Natale, 2008). CAN data is commonly used in electronic systems to enable components to communicate with each other over what is called a CAN bus. The Penta joystick communicates with the rest of the EVC system over a CAN bus.

2.5 The current design of the product

In 2005, Penta launched their IPS engines that has forward facing, rotating propeller pods, which can be positioned separately. In order to maneuver the propellers, an electronic vessel control system (EVC) was used.

With the introduction of electronic control of the IPS-engines, it was realized that a vessel now could perform complex movements as rotations around one point and translation along vectors, as can be seen in figure 2.4 and figure 2.5. These movements could intuitively be translated into joystick movement, where translations would be mapped to x-y movements and rotations could be mapped to rotations of the top part of the joystick. The movement of the IPS-engines could be controlled in the background by a system, whilst the user could focus on their surroundings and using the joystick.

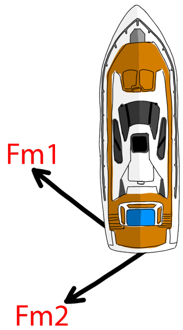

Figure 2.4: Force vectors from IPS-engines

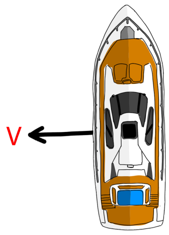

Figure 2.5: Resulting movement of boat depending on engine force vector

In 2005, the Volvo Penta Joystick was launched with the main objective of maneuvering the boat in low speeds, facilitating the docking procedure. The procedure could be carried out in two different speeds, the default speed and the high mode, where the latter was used in case of high lateral currents or wind. In 2009, the joystick went through a major re-design. The shape was updated to go in line with the updated throttle lever and the dynamic positioning system(DPS) was introduced and integrated into the joystick. The DPS works as a digital anchor where the boat is positioned with the aid of the engines and a GPS module. In 2009, also the joystick driving function was integrated, this makes it possible to use the joystick in full speed together with the autopilot, where the speed is controlled using the throttle lever and the direction using the joystick.

Figure 2.6: Current design of the Volvo Penta Joystick (Volvo Penta, 2020)

Figure 2.7: Previous design of the Volvo Penta Joystick (BoatDiesel, 2020)

2.6 Market analysis

In this section, similar products currently on the market are presented. The joysticks are bought as add-ons to the steering system, and are mounted by professional boat builders, i.e. it is not an over the counter product which the users can install themselves. The price of the product include installation.

2.6.1 Competing products

The following products exist in the same marine segment as the Volvo Penta joystick.

2.6.1.1 Seastar Optimus 360

The Seastar Optimus 360 is a control device developed by Seastar solutions. The device in combination with an electric control system is made to be retrofitted into existing outboard motor solutions. It enables the vessel to rotate, and translate independently. This movement is achieved by using actuators to manipulate the engine position, and a component to change the rpm of the motor. This product does not offer the DPS, nor joystick driving function.

Figure 2.8: The Seastar Optimus 360 joystick (Boating Magazine, 2020)

2.6.1.2 Mercury marines Axius

The mercury marines axius is a control device developed by Mercury Marine. The device can be used in combination with both Mercury Marine inboard motors, as Zeus, and outboard motors, as Verado. The device enables the user to independently decide the rotation and translation of a vessel. It also offers the skyhook feature which has the same function as volvo's DPS. In order to execute the sideways movement with the Mercury joystick. There are no mentions of any joystick drivinging functionality.

Figure 2.9: The Mercury marines Axius (Mercury Marines, 2020)

2.6.1.3 Xenta joystick

The Xenta joystick can be used to steer larger yachts by retrofitting its control system onto an existing system. The device is developed by the Italian company Xenta and is used on larger vessels with inboard engines. The system rely on stern thrusters in order to facilitate movements both in translation and rotation. The joystick does not offer a DPS, nor joystick driving function.

Figure 2.10: The Xenta joystick (Aqua Marine, 2020)

2.6.1.4 JCS by Yacht control systems

Is a control device that can be used on boats equipped with inboard motors and bow thrusters. The device enables the boat to carry out complex rotation and translation movements during use. The JCS is developed by Yacht controller. The joystick does not offer the joystick driving function, nor the DPS.

Figure 2.11: The JCS (Boat Mag International, 2020)

2.6.1.5 Joystick maneuvering system (JMS) by ZF

The JMS is developed by the company ZF, and can be used on both Pod-engines, similar to the IPS, and traditional shaft line propulsion systems. Bow thrusters need to be integrated in the systems for joystick functionality. In order to use the joystick, the system needs to have either ZF-Pod engines or ZF shaft line propulsion systems. This limits the use of the JMS to ZF products. It can aid the user with executing complicated translation and rotation movements when at sea. The functionality of the JMS relies on using a bow thruster in combination with the main engines.

Figure 2.12: The Joystick Maneuvering system (ZF, 2020)

2.6.1.6 Yanmar JC10/20

The Yanmar JC10 and JC20 are control devices developed by Yanmar Marine. The JC10 is meant to be used in combination with Yanmar stern drive ZT370, and JC20 in combination with Yanmar shaft drive 8LV. JC10 does not demand a bow thruster while the JC20 does. It facilitates the ability to independently rotate and translate the vessel. A third party autopilot system can be integrated with the Yanmar JC10/20, but there is no mention of any joystick driving functionality. There is a positioning system similar to the DPS called Position keeping system.

Figure 2.13: The Yanmar JC10/20 (Yanmar Marine, 2020)

2.6.1.7 Cummins joystick

Cummins has two different types of joysticks. One joystick works with the Mercury marine Zeus system and the other with their own inboard engines together with a bow thruster. The one compatible with Zeus offer the same functions as the MerCruiser Axius. The latter mentioned only works in low speed and is solely used for docking.

Figure 2.14: The Cummins joystick (Båtliv, 2020)

2.6.2 Similar products with other use areas

As mentioned above, further solutions used to control systems outside the marine segment has also been looked into.

2.6.2.1 Control stick JAS Gripen

The JAS Gripen control stick is used to control the movement of the fighter jet JAS Gripen. Since the device is supposed to be operated by a highly knowledgeable operator, lots of functions can be integrated into the design in the form of buttons. A user unaware of what these buttons do would probably find it difficult to use the device.

Figure 2.15: The Jas Gripen Control stick (x plane, 2020)

2.6.2.2 Media control unit in cars

The media control unit used in most cars with media center integration employ the same function integration, but may differ in design. In difference to the JAS control stick, this device is supposed to be used by a user with no prior knowledge about its use. It therefore needs to be intuitive and easy to understand. Hence, every button is named.

Figure 2.16: A Car Media Control unit (Xotic Tech, 2020)

2.6.2.3 Construction equipment control stick

The construction equipment control stick is designed with the knowledge in mind that the user will work with it during long periods of time, and therefore it needs to be ergonomic. On the other hand, there are lots of buttons, which may result in an inexperienced user having a hard time using it, whereas a seasoned veteran would operate it with ease.

Figure 2.17: A Construction joystick (Curtis-Wright, 2014)

2.6.2.4 Game Controller

When using one joystick to control both the rotation and translation of a vessel, it is apparent that the ability to rotate will have to be integrated in the design. On the Volvo Penta joystick, this is integrated into the rotation of the shaft. The game controller design on the other hand has divided the function of rotating and translating into two separate joysticks. One controls the translation and the other one the rotation. This may seem complex for the first time user as it needs the simultaneous use of both hands independently, but for someone who have used it a lot, it is very versatile.

Figure 2.18: A Sony PlayStation DS3 (Sony, 2020)

3

Methodology

In this chapter, the product development process applies in the project is first explained. This is followed by a presentation on the methodology on understanding the product, defining areas and improvement and defining the means. After this, the process of understanding the use of the product and defining the use scenarios in explored. This is followed by the user study methodology, and lastly, the methodology for concepts comparison is presented. The principles of human-centered design, presented in section 2.1.2, is applied throughout the developemnt process.

3.1 Product development process overview

The product development process used is visually described in figure 3.1. The process started off by understanding the user needs, during which a deeper understanding of the product was gained, and a requirements specification was created. After this a function means matrix was generated, based on the understanding of the product and literature studies. A morphological matrix was after this created, which in turn was used to generate different concepts that needed to be tested in a test bench. I order to test the concepts, user studies were carried out, followed by elimination of concepts and kesselring matrices. Several kesselring matrices were made, based in different scenarios and different weightings. Recommendations depending on scenarios could after this be given.

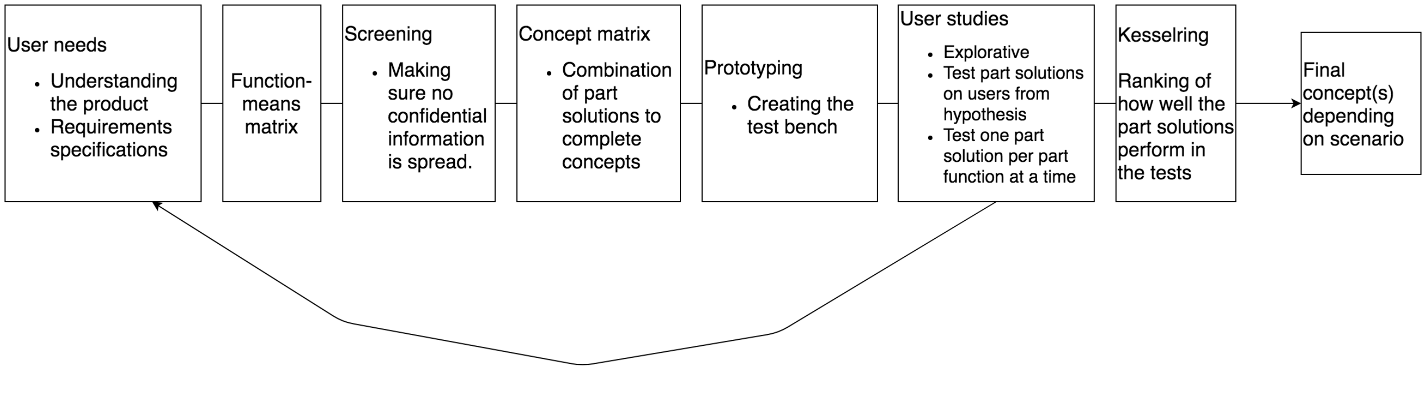

Figure 3.1: An overview of the process workflow

3.2 The process of understanding the product

In order to understand the product, a rigid study on its technicality, function and users had to be carried out. Understanding the product is also the first principle of human-centred design, and enables the developer to identify the context of use for the product.

A study of how the product was being used was conducted by reading literature, watching videos, talking to experts, watching the product being used and using the product. A big part of this study consisted of understanding the joysticks part in the whole system, and also understanding the system. In short, the context in which the product is used. Furthermore, the kind of boats where the joystick could be used was mapped. To fully understand the functionality of the joystick, tests of the product in its actual use environment were conducted by trying it out in a boat. Observations of users interacting with the joystick while driving an actual boat was carried out with the aim to understand how the customer use the product. In this stage the users were also analyzed. To understand the technology and logic behind the system, meetings were held with employees at CPAC, with deep knowledge within the maritime segment of Volvo Penta.

Knowledge from this stage was used to formulate the requirements for the product as well as the context of use. Furthermore, based on the findings in this stage, different user scenarios were identified.

3.3 The process of defining areas of improvement

In order to know what functionality the test bench should have, first the possible areas of improvement had to be investigated. At its most basic, a new version of a product will need to be able to carry out the same functionalities as its precursor. Not in the sense of specific functions, but rather over all functionality. If this is not met, there may be customers that would prefer the older version. In order to make sure this requirement was met, the functionality of the joystick was mapped as described in section 3.1. To understand the areas of possible improvement, first employees at CPAC was asked about their opinion on the joystick, secondly this was complemented by reading reviews on the product, and lastly the product was tested and analyzed.

When the users and the joystick had been analyzed and experts had been interviewed, the requirements on the joystick could be concluded in a requirement specification, see Appendix A. All concepts generated fulfill the basic requirements presented in the requirements specification. Further on, the wishes will be referred to as requirements.

3.4 Defining the means

As described in 2.2, user experience is based in that users has to interact with a product using the human senses. In regards to a joystick users use touch to interact with the joystick, and it in turn interacts with the user by using visuals, haptics and sounds. From this, a conclusion could be drawn that one needed to look at the means to two different problems;

- How can the joystick communicate with the user
- How can the user communicate with the joystick?

From the market benchmark it was found out that most joysticks on the market uses LED's or external screens to indicate what functions are activate at a certain time, as is the case with the current Penta joystick. In the case of the Game controller presented in 2.7.2.4, haptics is also used to convey information to the user. Furthermore, sounds were used to indicate the activation of both the joystick and sometimes also functions on the joystick. In order to activate different functions, users press tactile buttons on most joysticks.

Based on these findings it was decided that looking into both visual, haptic and auditive feedback was interesting in regards to the feedback the user receives from the joystick. It was also decided to look into visuals, audio and haptics in regards to how the user interacted with the product.

With this reasoning as a background, literature studies were carried out with the aim to find what sort of components that existed on the market that could carry out the haptics, audio and visuals.

Below, each of the identified means are described together with hypotheses on their strengths and limitations.

3.4.1 Visual feedback to the user

The most common way to communicate the status of a function to a user is through LED's. LED's are easy to connect to a microcontroller or a custom chip which in turn can turn them on when required. A special type of LED is an LED ring, that can be placed around the joystick base, see figure 2.9. In some applications, as with a computer, touchscreens are used to communicate what functions are activated or not to a user.

3.4.1.1 Hypotheses on the strengths and limitations of LED's

LED's are used in many applications in our everyday life to indicate what functions on a certain product that are activated. This is also the case with the existing Penta joystick. Users will probably understand that the activation of a LED is connected to the state of a function, especially if a sticker or similar with a symbol indicating function is situated next to the LED.

3.4.1.2 Hypotheses on the strengths and limitations of touchscreens

There are two main hypothesis behind usability of a touch LCD. Firstly, since a big part of the worlds population has a phone, it is believed that users will have no trouble understanding how to activate functions on the display. Secondly, as there is no haptic feedback in a touchscreen to indicate that a function has been activated, the user will need to look at the screen a lot, which may be dangerous if driving fast at sea. Furthermore, touchscreens may loose their functionality in wet conditions. It may also be hard for the user to operate a touchscreen if wearing gloves.

3.4.2 Auditive feedback to the user

In order to communicate information auditively, speakers of some sort are most often used. These speakers can vary greatly in size, sound quality and strength.

3.4.2.1 Hypotheses on the strengths and limitations of speakers

Lots of products use speakers to indicate function activation, therefore users would probably understand that a sound signal is associated with function activation, and not have to look at the joystick to understand if a function was activated. If speakers are used as auditive feedback, it has to be used to indicate the activation of a function, as with a short sound signal, and not that a function is activated. If a auditive signal is activated during the time a function is activated, it will irritate and distract the users.

3.4.3 Haptic feedback to the user

Vibration motors, often called rumble motors, are widely used to haptically communicate information to users. Several game controllers use vibration motors to communicate for example when a player drives on a rough gravel road in a driving game. Joysticks with haptic force feedback on the movement has since long existed in the flight simulator community. It has been used to simulate the feeling of flying an actual plane.

Another way of giving haptic feedback to the user is by altering the resistance, opposite the movement, of the joystick.

3.4.3.1 Hypotheses on the strengths and limitations of vibration motors

As is the case with speakers, lots of products use vibrations to indicate the activation of functions. This in turn mean that users would have to look a lot less at the joystick to verify if a function was activated, as vibrations indicate this.

3.4.3.2 Hypotheses on the strengths and limitations of a joystick with haptic force feedback

An active force feedback in the joystick movement could be used to indicate extra information about the boats movement to the user without them having to look at the joystick. Most users are not used to this kind of feedback and would therefore probably have to take some time to understand it. Because this technology was not at hand during the course of this project it could not be evaluated, see chapter 5 & 6.

3.4.4 Haptic communication from the user to the joystick

As mentioned earlier, it was found through the benchmarking that most joysticks used tactile buttons in order to let the user communicate with the joystick. As is the case with the existing Penta joystick. In the literature study it was found that several more ways of letting the user communicate with the joystick could be implemented. In some TV's there exist touch sensors that detect if a user press a certain surface in the border of the screen, and turn on the screen if a press is detected. IR sensors have also been used for these kinds of applications, where they detect if an object is close enough to the sensor and if so send a signal to an external component. touchscreens are an example of a combination of both a visual feedback and way for a user to haptically communicate with a product. A common example of this is the screens built into phones which can both show the user relevant information whilst enabling them to communicate with the phone through touch.

3.4.4.1 Hypotheses on the strengths and limitations of tactile buttons

Tactile buttons are used on the current joystick, and will act as a reference throughout the study. As is believed with the touchscreen, users will probably have to look at the button in order to determine their position and status.

3.4.4.2 Hypotheses on the strengths and limitations of IR/capacitance sensor

Both a capacitive touch sensor and an IR sensor could be implemented in similar manner, and therefore they have the same hypothesis. Firstly, there may be problems with both IR and touch sensors being covered in some manner, which may impact the viability of the sensor. Secondly, as the user will have no way of determine where the activation surfaces are situated, as the sensors are mounted under the surface, they will probably have to look at the joystick a lot when activating functions. Furthermore, nor capacitive touch or IR sensors work in wet conditions.

3.4.5 Auditive and haptic communication from user to the joystick

Both the users voice and vision can be used for activation of functions. In some products voice recognition is used to let the user for example call people, as in the case with a phone. The users eye position can also be used to evaluate where they are looking, and thereby activating functions.

3.4.5.1 Hypotheses on the strengths and limitations of voice and visual command

Both voice and visual command are hard to use when driving a boat since there is lot of background noise and you need to keep your eyes on the sea. Because of this, it was decided that both these technologies were too complicated to evaluate and too inaccurate, and therefore they were discontinued.

3.4.6 Conclusion on defining the means

In order to evaluate which components that needed to be included in the test bench, it was concluded that an evaluations of what functionalities to activate and how to give feedback about this should be carried out. A matrix containing all functionalities, as well as the means through which they can be carried out, was constructed. This matrix can be seen in figure 3.3. This matrix lay basis for what components to include in a test bench.

Functions	Means		
Auditive feedback from joystick to user	Speakers		
Haptic feedback from joystick to user	Vibration motor		
Visual feedback from joystick to user	LED	Touch screen	
Communication from user to joystick	Tactile buttons	Touch screen	IR/Touch sensor buttons

Figure 3.2: An overview of functions and means

After having identified the means, these could be combined into concepts that should be tested in the user studies. Beyond solely combining the means, it was also decided to have both one concept where the tactile buttons were placed on the base, and also one where the buttons were placed in the handle. Furthermore, because of technical limitations, the touchscreen could not be combined with audio or haptic feedback. The concepts that were generated are presented below.

Concept	Communication from user to joystick	Communicaion from joystick to user
1	Tactile buttons placed on joystick base	LED
2	Tactile buttons placed on joystick base	Speaker and LED
3	Tactile buttons placed on joystick base	Vibration motor and LED
4	Tactile buttons placed on joystick base	Speaker, vibrationmotor and LED
5	Tactile buttons placed in joystick handle	LED
6	Tactile buttons placed in joystick handle	Speaker and LED
7	Tactile buttons placed in joystick handle	Vibration motor and LED
8	Tactile buttons placed in joystick handle	Speaker, vibrationmotor and LED
9	Touch sensor buttons/IR placed on joystick base	LED
10	Touch sensor buttons/IR placed on joystick base	Speaker and LED
11	Touch sensor buttons/IR placed on joystick base	Vibration motor and LED
12	Touch sensor buttons/IR placed on joystick base	Speaker, vibrationmotor and LED
13	Touch screen placed on joystick base	Touch screen

Figure 3.3: The concepts generated to be tested in the user study

In addition to the concepts presented in figure 3.3, also a concept with an LED ring was studied on the users. This concept was chosen to go through with since it was fairly easy to integrate into the design of the test bench, and also the simulator code. As this concept is a special variation on the led concept, it is presented outside of the other concepts in order to not confuse it with the led concept.

3.5 Understanding the product in use and defining the different user scenarios

After having identified and analyzed the different users, it was concluded that they differ a lot from each other. Furthermore, the future use area of the joystick is uncertain. This made it hard to determine which user requirement to rank higher than another. With this in mind, it was determined that different concept evaluations should be carried out, for different user scenarios. Below, the different scenarios are described.

3.5.1 User scenario 1 - Low speed in crammed spaces

This is similar to how the joystick is being used today. In this scenario, the joystick mostly is mostly used for docking in low speeds in crammed spaces. It is hence of utter importance that the user do not mistakenly activate a function since this could risk e.g. a collision. Because of this, in this scenario, it is important to be able to differentiate buttons from each other visually and haptically.It is also important to have robust technology since you should be able to locate the joystick in an outdoor environment. The robustness of the design is more important than the ability to easily push new updates of the joystick.

3.5.2 User scenario 2 - Freedom for the developers

In this scenario it is of great importance for the developers to be able to push updates of the functionality and the software of the joystick. Also, the designer values the fact of not having too many design constraints when constructing the joystick. In this scenario, the joystick is mostly located indoors or the touchscreen technology has advanced and is now fit for outdoor environments.

3.5.3 User scenario 3 - High speed driving, with a lot of function activation/deactivation

In this scenario, the user activates functions several times per trip, taking away the importance of being able to visually locate the buttons. In this scenario, the joystick is not used in crammed spaces making it of less importance to not activate the wrong function. Furthermore, because the user is travelling at high speeds, it is deemed important that the user does not loose visual focus on what is going on around them.

3.6 Test bench methodology

In a user study, both a test bench with concepts to be tested, and a use case in which to test it is needed. In this project, these components are presented in the shape of a physical test bench the user can interact with, and a simulator that simulates the experience of driving a boat.

3.6.1 Test bench overview

In order to simplify the explanation of how the test bench is both physically and digitally connected, figure 3.4 was created. The dotted arrows mean digital communication, and the filled in arrows represent physical contact between components. The colors represent different sub-systems that will be further presented below.

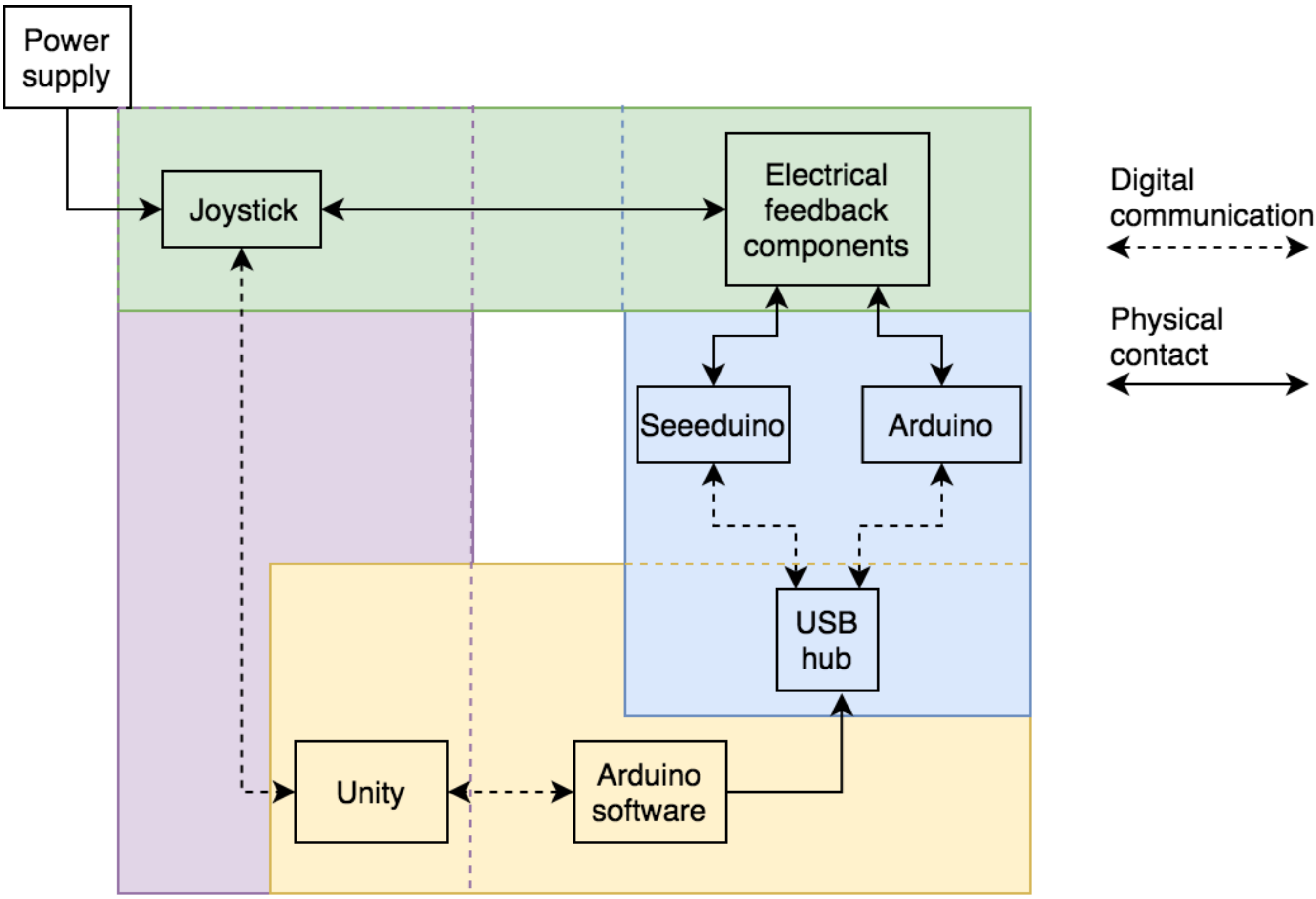

Figure 3.4: An overview of the test bench components

3.6.2 Test bench development workflow

With modern tools as CAD software, it is possible to assemble a product virtually before manufacturing. This to make sure that everything fits and can be mounted. When this is verified, manufacturing can begin. Since the test bench is supposed to facilitate the testing of different components by users, its important to always take the principles of human-centred design into consideration. The main design requirement is always that a user should be able to operate the test bench. By utilizing this development workflow, it could be ensure that the final test bench can be manufactured and assembled without having to do too many revisions.

3.6.3 Test bench - The making of the communication with the electrical components

The need for developing a test bench was based in the reasoning that a user needs to interact with something when carrying out the user studies. This something needed to be able to communicate the visual, haptic and auditive feedback to the user whilst processing the user input, and making modifications to the simulation.

In order to present the test bench in an comprehensive way, each function it needs to be able to carry out will be presented followed by the software and electronics that makes it work.

3.6.3.1 Test bench - Electrical components overview

The test bench exists for two reasons, to communicate stimuli to the user, and to communicate user-input to the simulation. Below, each function is described followed by the software and hardware that makes it run.

The core of the test bench consist of the metallux joystick base, an Arduino uno rev3, a Seeeduino cortex M+ as well as an powered USB-hub. The arduino and seeeduino facilitates the feedback to the user and button-statuses, whereas the metallux-joystick facilitates the user-input on the joystick. In essence, there are two parts of the physical test bench. One part concerns the reading of CAN-data, figure 3.6, and the other, figure 5.1the processing of user button inputs and user feedback communication. Both parts are connected to a computer over USB.

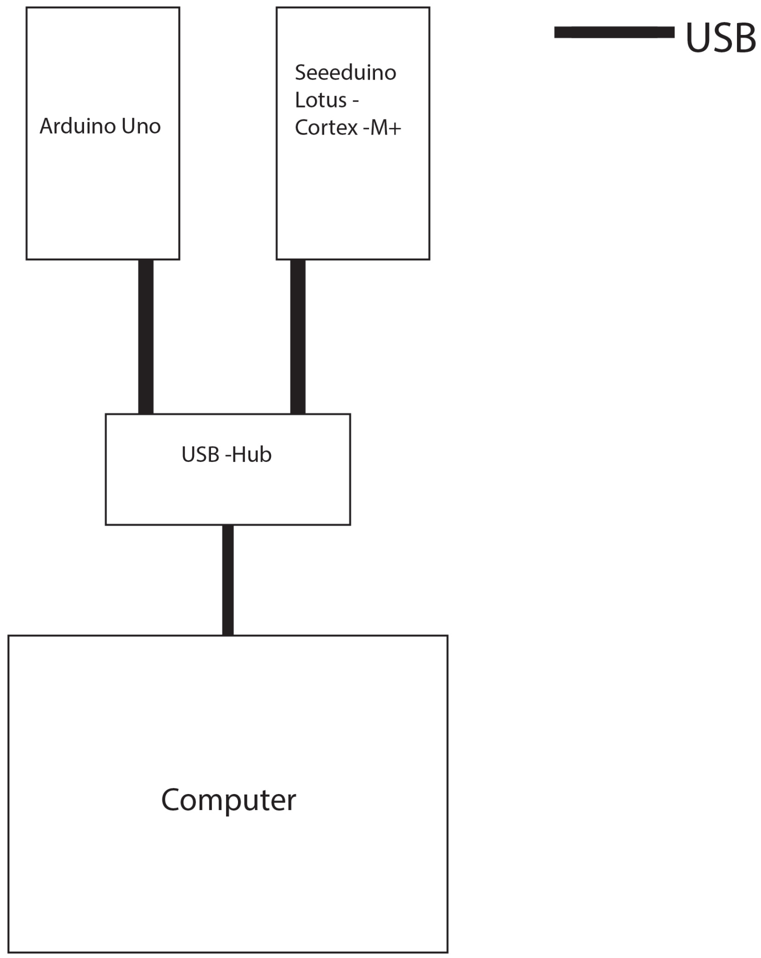

Figure 3.5: The connection of the seeeduino and arduino to pc over USB

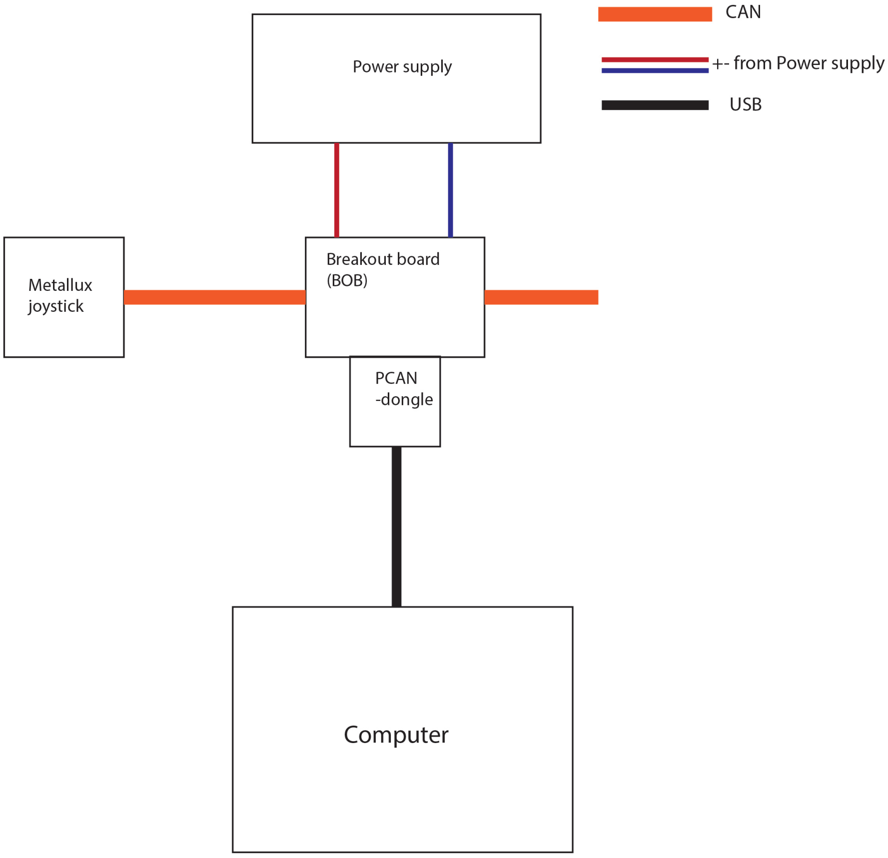

Figure 3.6: The connection of the metallux joystick to pc over CAN bus and USB

3.6.3.2 User-input

The user needs to be able to communicate what functions to activate, and what to deactivate to the simulation. It also needs to communicate this information in a manner that does not slow down the simulation too much. In order to realize this, the subsystem presented in figure 3.7 was created.

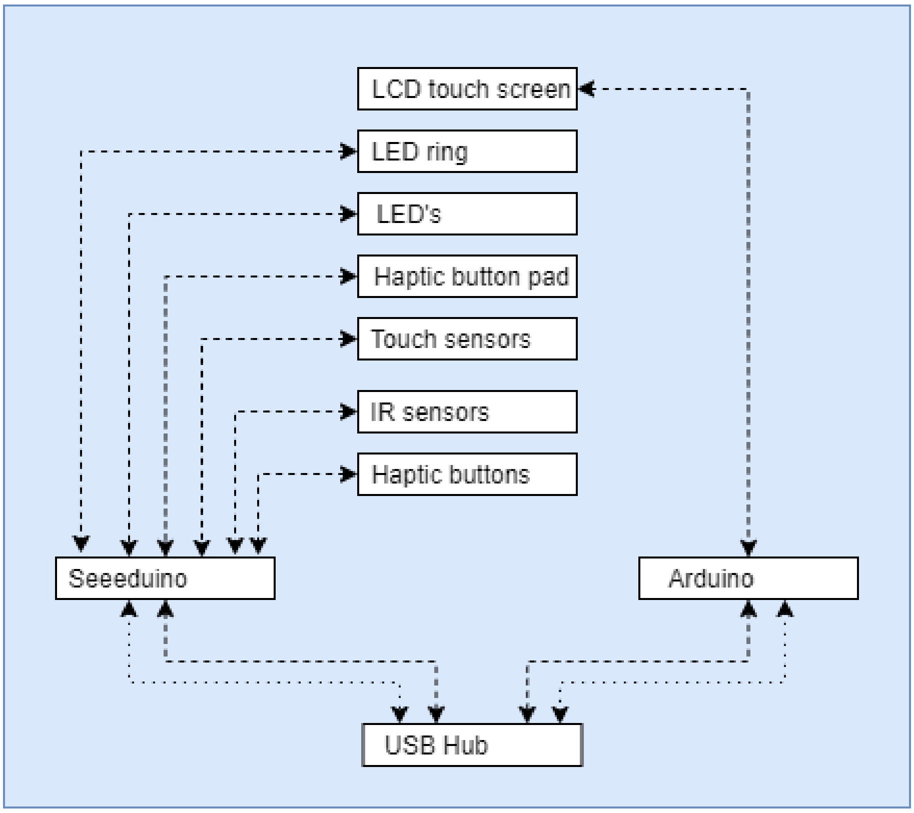

Figure 3.7: An overview of the test bench components

As explained above, the test bench is based on the metallux joystick as well as one seeeduino and one arduino uno rev3. The Seeeduino can be used to detect button presses, and also communicated this to the simulation, whereas the arduino is used as the base for a touch LCD screen.

By use of the arduino IDE, code was developed that every time the seeeduino runs the void loop() function reads the status of each button and checks if it differs from the last status. For example, if a user was to press a button the seeeduino would register a change of status on the button circuit and communicate the status of each button to the simulation. This circuit is visualized in figure 3.8

This logic behind the collection of user inputs could also be used when reading data from IR- and touch sensors. Since both sensors communicate either HIGH or LOW to the Seeeduino depending on if they measure and object nearby, nothing needs to be changed in the code when switching between sensors and buttons. Each sensor has a female Seeeduino connection, to which a male connector needs to be connected. Each connector is built up of four inputs as in figure 3.9.

By connecting GND of all sensors together and to a common ground on the seeeduino, as well as connecting 3v3 of all sensors to the same 3v3 pin on the seeeduino, the sensors could be connected to the board with eases. The Nc connector did not need to be connected to anything, and the SIG of each sensor was connected up to a digital pin on the seeeduino.

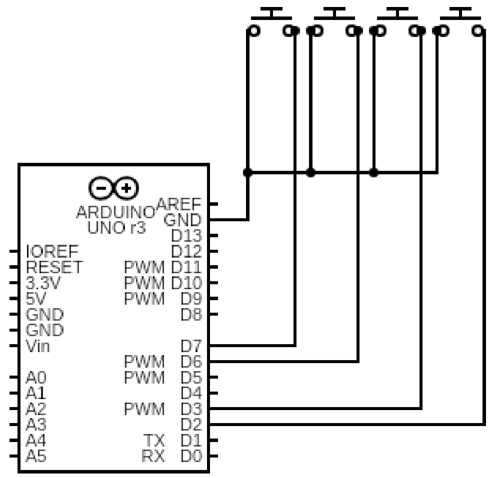

Figure 3.8: The connection of buttons to the Seeeduino

Figure 3.9: The four connectors on the Seeeduino cable

This enabled the reading of status of each sensor.

3.6.3.3 User-input communication

When the button status has been read, it needs to be communicated to the simulation.

In order to not slow down the simulation to much, components needed only to communicate their status when their status change. For example, if a button was pressed and thereby a circuit closed, there was only need to communicate that the circuit has been closed, not that it was closed. The same for when the circuit was opened.

This communication was made over usb using the SerialUSB.write() function on the seeduino. A simple function, called sendData(), facilitating communication, was called each time the seeeduino detected a button status change was also written.

```
void sendData() {
    SerialUSB.write("<");
```

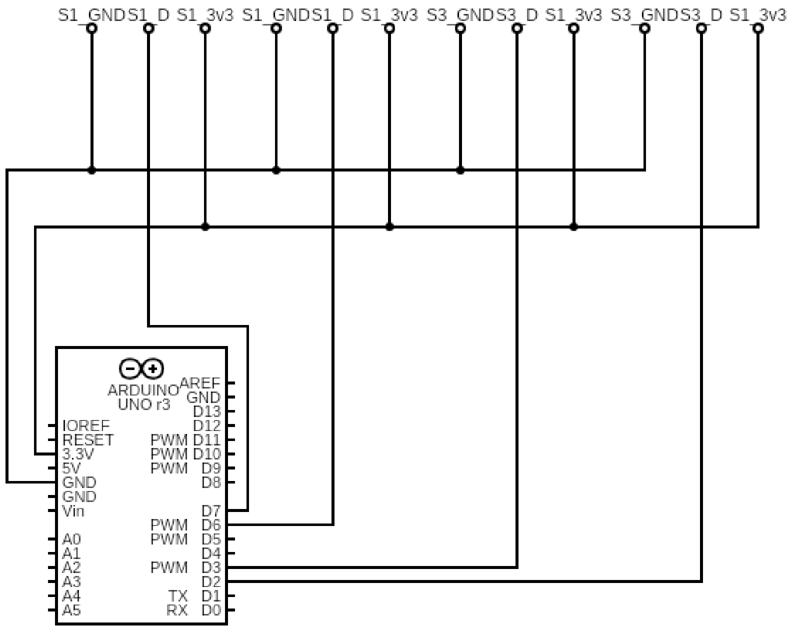

Figure 3.10: Four sensors connected to the seeeduino

```
    SerialUSB.write(buttonState1);
    SerialUSB.write(buttonState2);
    SerialUSB.write(buttonState3);
    SerialUSB.write(buttonState4);
    SerialUSB.flush();
}
```

Listing 3.1: sendData function

Each time a change in button status was detected, the sendData() function was called upon and the data was sent to the simulation.

3.6.3.4 Visual feedback - LED's

One way for the user to understand what functions are activated, is to let the test bench communicate this through turning on LED's in accordance with what functions are activated.

In figure 3.38 the simple circuit used for turning on LED's can be seen, here digital ports D8-D11 are initialized and used as outputs for turning on or off the LED's.

```
const int ledPin1 = 8;
const int ledPin2 = 9;
const int ledPin3 = 10;
const int ledPin4 = 11;
void Start() {
  pinMode(ledPin1, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(ledPin3, OUTPUT);
```

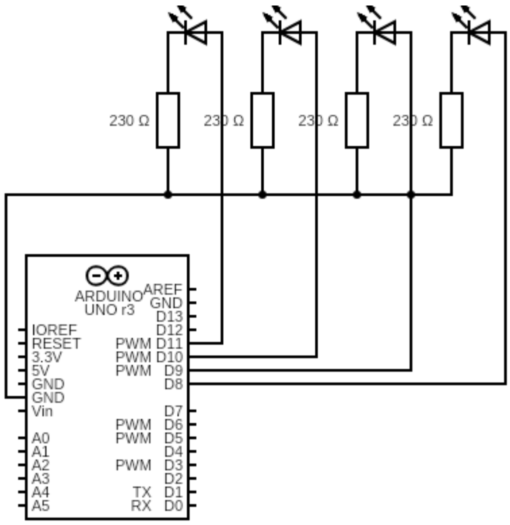

Figure 3.11: The connection of LED's to the Seeeduino

```
  pinMode(ledPin4, OUTPUT);
}
```

Listing 3.2: Assigning LED values

3.6.3.5 Visual feedback - touchscreen

In order to implement a touchscreencomponent in the test bench, a arduino with specialized touchscreensoftware was used. To the arduino a touchscreenwas connected. This touchscreencould then display virtual buttons whilst constantly checking for finger presses. When a press is detected, the software checks if the press was inside any of the areas on the display where a button is displayed. If so, it logs what button was pressed and communicates with Unity on a computer over USB. This is done in the same manner as the user input communication presented in the code in figure 3.1.

3.6.3.6 Auditive feedback - Speakers

By connecting a speaker to the Seeeduino in accordance with figure 3.38, it is possible to have full control over when the speaker fires and what sound it makes. This opens up the possibility of putting in sounds in the main void loop() of the seeeduino code. A function called sound() was created and called on each time the seeeduino registered a button press. The function starts of checking the status of a Boolean value called speakerStatus, which if false prohibits the speaker to emit sound, and thereby enables the user to completely turning of the sound buy changing one value in the code. The main body of the function was based on code available from Seeed Technology Co.,Ltd (2020a).

```
void sound(uint8_t note_index, int arr[])
{
```

```
  if (speakerStatus){
    for(int i=0;i<15;i++)
    {
        digitalWrite(SPEAKER,HIGH);
        delayMicroseconds(arr[note_index]);
        digitalWrite(SPEAKER,LOW);
        delayMicroseconds(arr[note_index]);
    }
  }
```

Listing 3.3: LED function

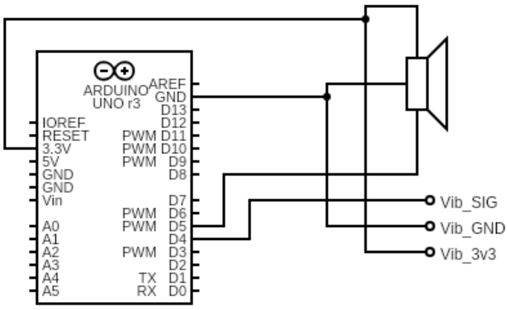

Figure 3.12: The connection of a speaker to the Seeeduino

3.6.3.7 Haptic feedback - Vibration motor

As well as using sound to indicate feedback about the state of a function, one can utilize vibrations. There exist a simple but usable vibration motor available from Seeedstudios, the grove vibration motor. By connecting this motor to ground as well as 3v3 and a digital pin, data can be written to the motor that makes it turn when nessecary. As with the speaker, there exist some main code from Seeed Technology Co.,Ltd (2020b) which can be utilized. The code in listing 3.4 is based on the code from Seeed Technology Co.,Ltd (2020b).

```
void vibrateMotorOn()
{
  if (vibration)
  {
    digitalWrite(vibrPin, HIGH);
  }
  else {}
}
void vibrateMotorOff()
{
  if (vibration){
   digitalWrite(vibrPin, LOW);
  }
  else {}
}
```

Listing 3.4: Vibrationmotorfunction

Each time the motor should start vibrateMotorOn() is called upon, when it is to stop, vibrateMotorOff is called upon. This means these two functions can be included in void loop() and thereby when a button press is recognised, the motor vibrates. As wait() does not work when used inside a function, vibrateMotor() had to be divided into vibrateMotorOn() and vibrateMotorOff(). These two could then be called upon in the main loop, loop(), with a wait() inbetween them.

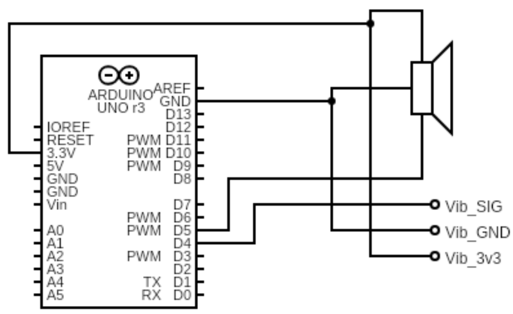

Figure 3.13: The connection of a vibration motor to the Seeeduino

3.6.4 Test bench - Creating the mechanical design

In order to for the user to interact with the sensors and electronics there had to be a physical interface between the two. This interface was created in the shape of a plug and play test bench where different modules can be altered depending on the desired analysis. This way, only one test bench has to be developed onto which different components can be connected.

3.6.4.1 Creating the overall design

Figure 3.14: The complete assembly of the test bench

In order to develop the test bench, an idea generation was carried out. The idea generation phase was based in an exploitative session where several concepts were visualized both in drawings and in CAD software. Several concepts were created with the basic requirement of being comparable to the existing Penta joystick, and also to accommodate the electrical components identified in the previous step. An overview of the components that needed to be physically connected to each other, can be found below in figure 3.15. Each arrow represents a physical connection.

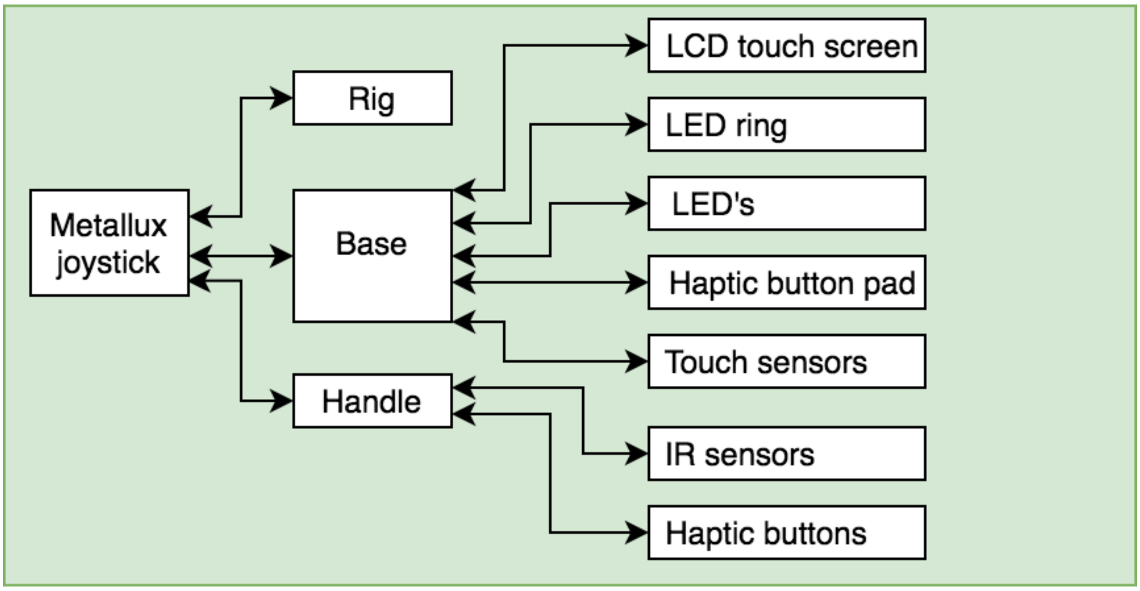

Figure 3.15: An overview of the physical connections between components

First of all, it was decided that the handle would need to be bigger than the Penta joystick since it was going to hold buttons and chords. Also, when having buttons on the joystick, it was decided that it needed to be ergonomically fit. As mentioned earlier, the most important thing is that the user should be able to operate the test bench. A literature study on the size of an average hand palm was conducted. With this data as basis, the handle was designed to be about 85mm high and a diameter of 40mm (Söderström, 2019). Also the handle should not have any sharp corners or edges and should sit comfortably in your hand. The handle was created using CAD, making it possible to import a manikin and see how it fit in the hand, see 3.16.

Furthermore, the base of the test bench was decided to be similar to the size of the Penta joystick but at the same time it needed to hold all the additional electronics.

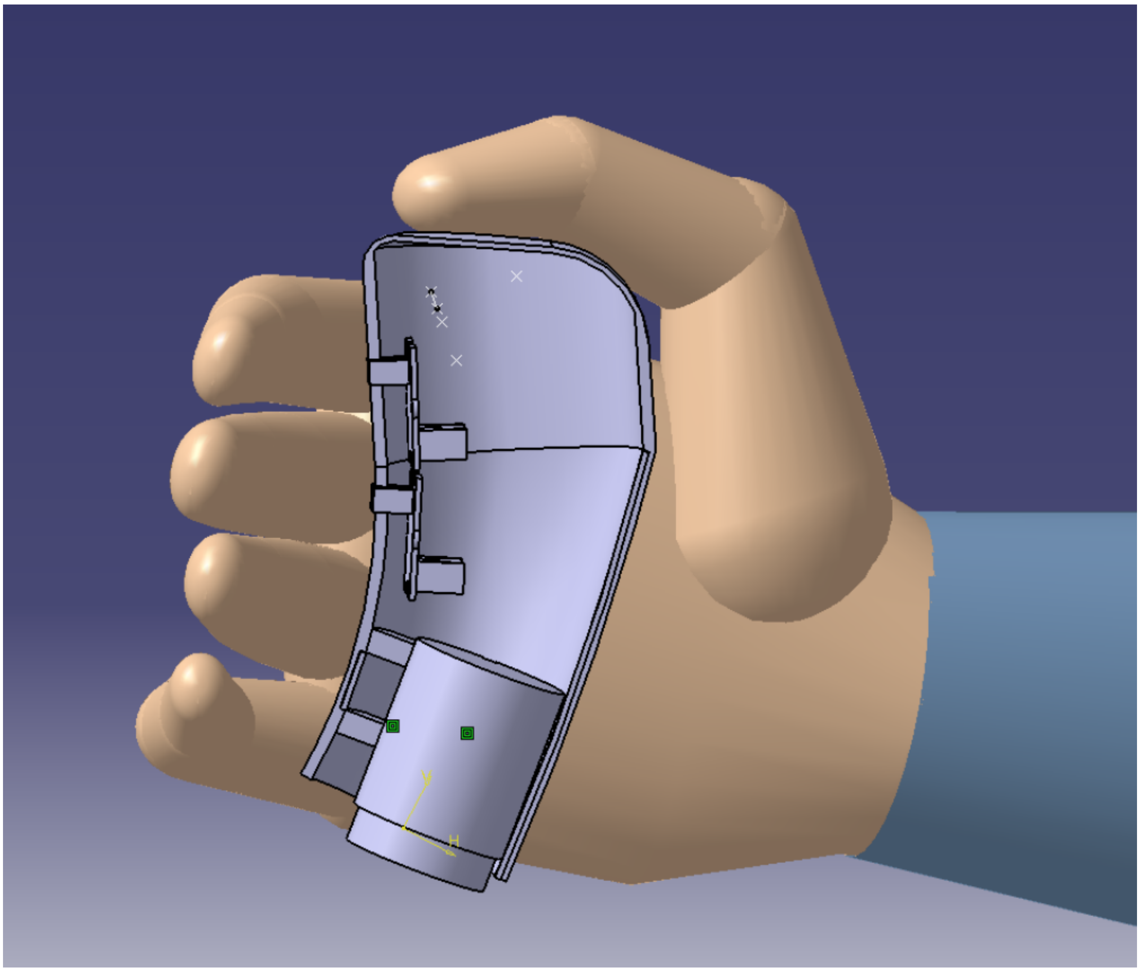

Figure 3.16: By inserting a manikin into CATIA, the shape and size of the handle could be tested.

3.6.4.2 Making the test bench modular

In order to accommodate the swapping of components during testing it was discovered that the test bench would need to be modular. Furthermore, this made it possible to test other electrical components, that are not included in this project.

As can be seen in 3.17 & 3.18, the base of the test bench consists of of one center piece that houses the metallux joystick and circuit board, to this piece you can add different modules depending on where you want your electrical component to sit. The different modules are, in turn, also modular in the sense that you can change the electrical component module because they all have the same dimensions, see figure 3.21. In the same way, you can swap the handle depending on which component, e.g. tactile buttons or IR sensors, you wish to try. An overview of the handles can be seen in figure 3.20.

Figure 3.17: The metallux joystick.

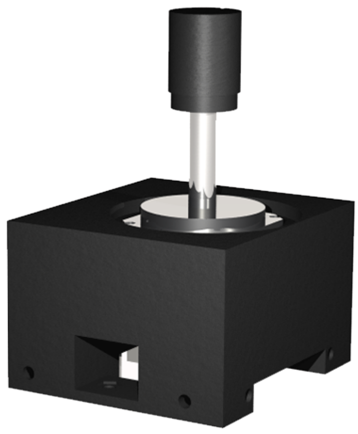

Figure 3.18: The metallux joystick placed in the centerpiece of the modular test bench design.

Figure 3.19: The test bench with the metallux joystick, centerpiece, handle and a module.

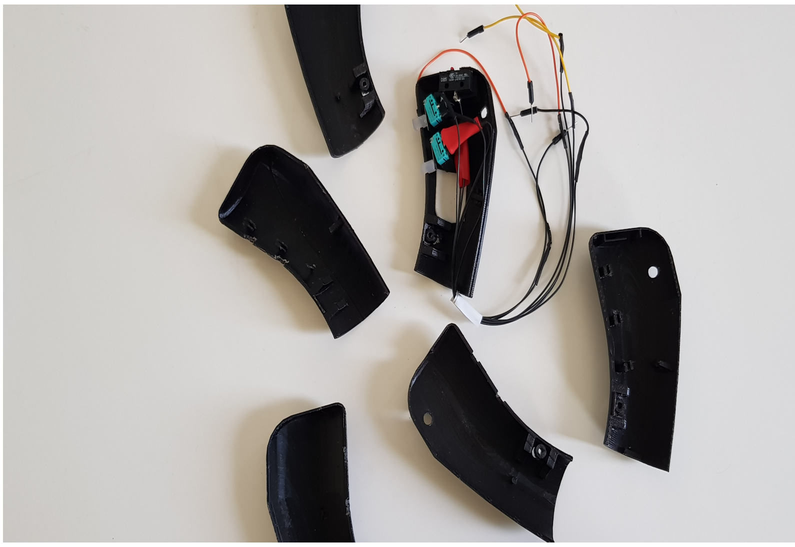

Figure 3.20: Some of the different handles that were developed.

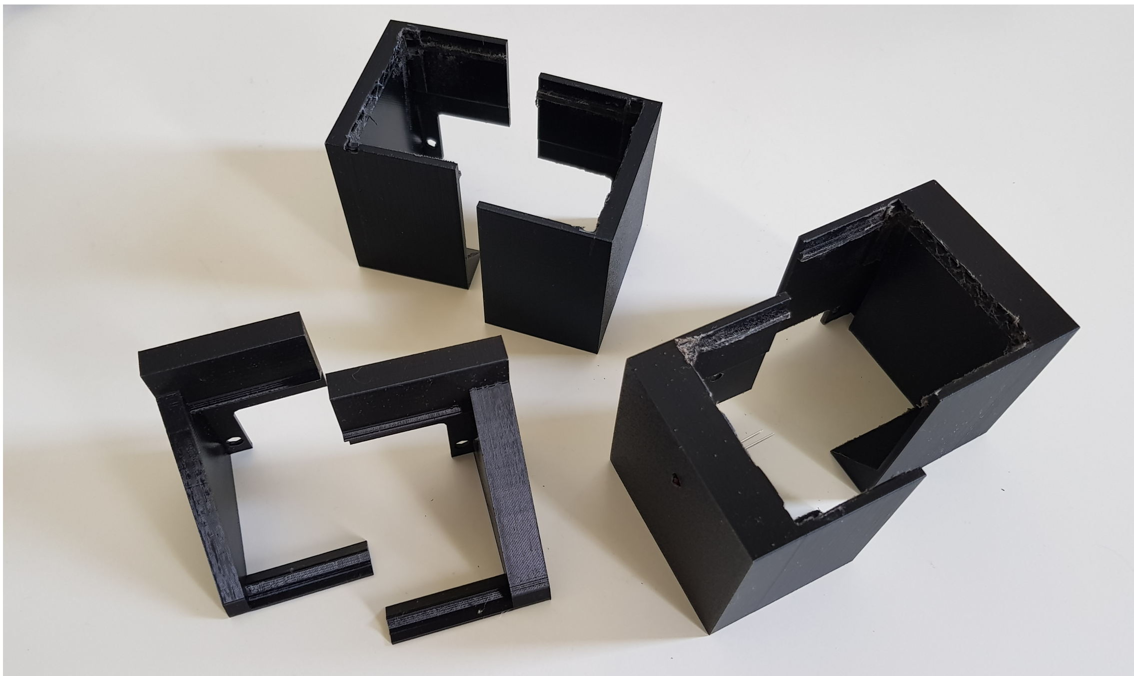

Figure 3.21: Some of the different modules that were developed.

Figure 3.22: The plates that were to house the different activation components were made to be the same size as the touchscreen.

3.6.4.3 Deciding where to place the electrical components

A further question discovered during these sessions was, where on the joystick the different components presented in section 3.4 should be placed. A new session, with the objective of deciding this, was carried out. From this session, it was concluded that;

- Activation surfaces can be placed everywhere on the joystick handle as long as it is not in the way of the users hand.
- Activation surfaces can be placed on three main areas of the joystick body, on the front, on the left side and on the back. The right side of the joystick is turned away from the user and will therefore not be suitable for button placement. This can be seen in figure 3.23, figure 3.24 and figure 3.25 below.

Figure 3.23: The centerpiece with a module in the front

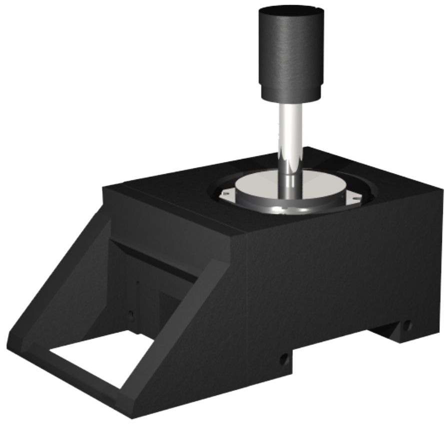

Figure 3.24: The centerpiece with a module on the left side

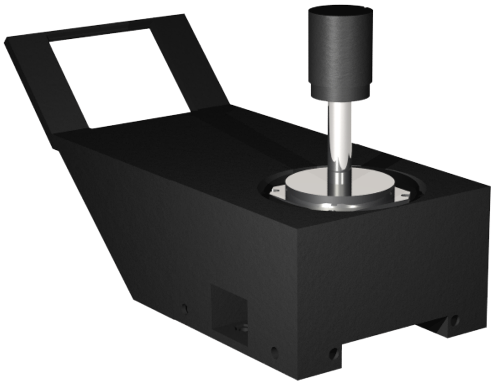

Figure 3.25: The centerpiece with a module in the back

During this session, further questions regarding how a component could be placed on each area on the joystick base were raised. It was concluded that the angle of the components were interesting to look into, because of this the modules were design to have three different angles; 0°, 45° and 90°. These modules can be seen below in figure 3.26, figure 3.27 and figure 3.28. A module with a 135° angle, see figure 3.29, was also designed. This could be mounted on the back of the main body of the joystick.

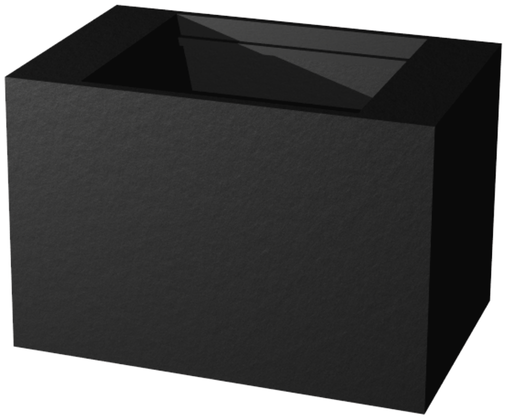

Figure 3.26: 0° module

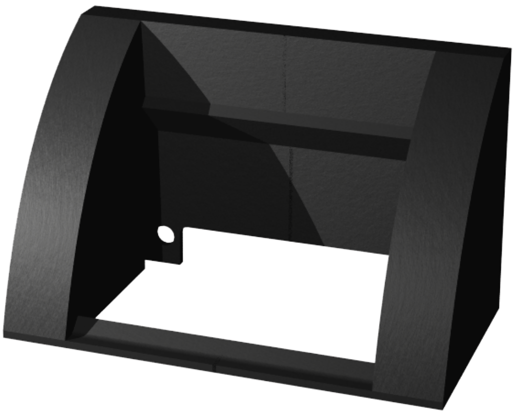

Figure 3.27: 45° module

Figure 3.28: 90° module

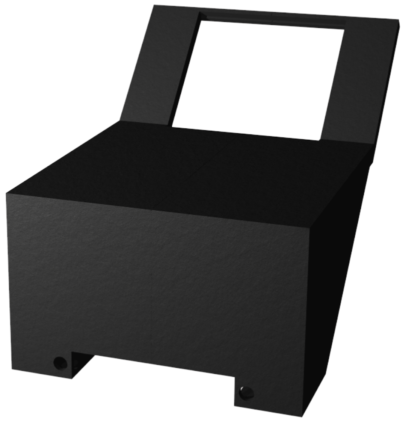

Figure 3.29: 135° module

3.6.4.4 Designing the test bench with assembly in mind

As described in 2.3.8, a lot of time can be saved if designing a product with assembly in mind. In order to realize the ideas from the work shops, CAD models were created in CATIA V5. In addition, all third party electrical components were also modelled in CATIA. Each one on the models were assembled digitally into concepts to ensure that no errors regarding the physical interface between the components were made.

Furthermore, since each module was to be mounted onto the center piece, it was necessary to make sure that a small screwdriver could fit into each module to fasten it. This can be seen below in 3.30 & 3.31 where the opening on the side is big enough for a screwdriver to fit. Bolt holes placed in areas where it was deemed hard to reach was equipped with a counterbore where the nuts could be glued on.

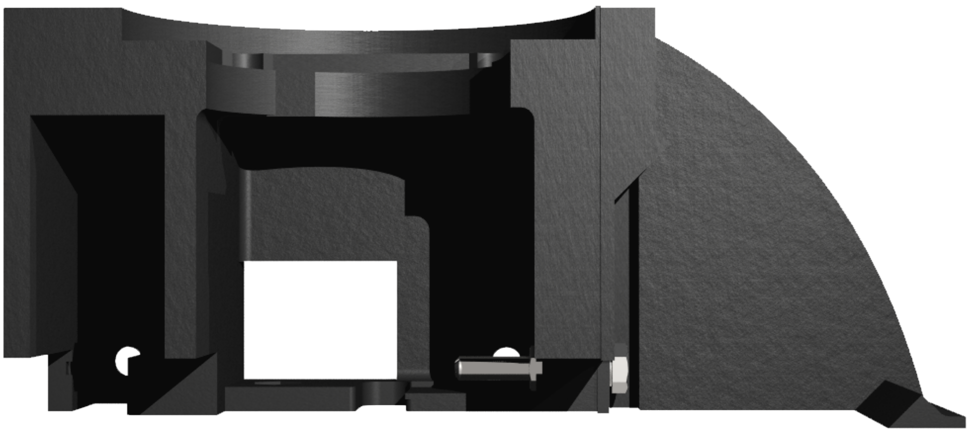

Figure 3.30: Attachment of a module to the centerpiece using a bolt and a glued nut.

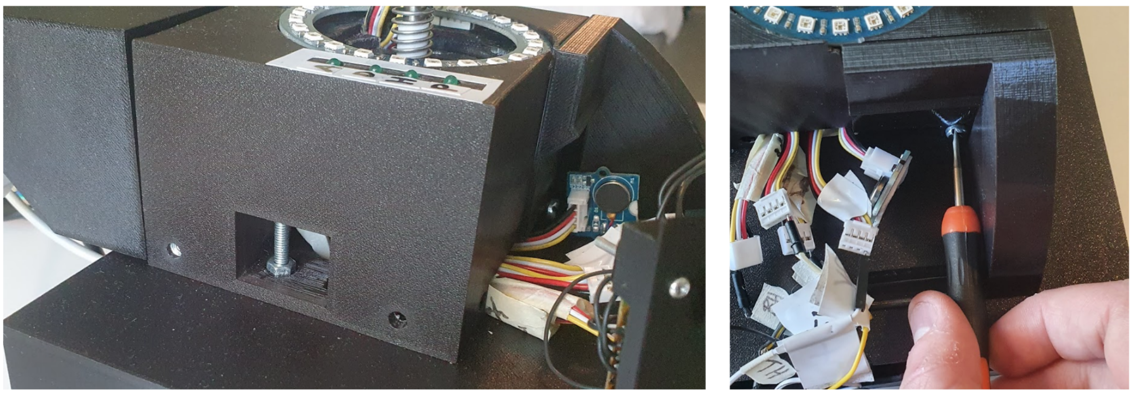

Figure 3.31: The modules are designed in such a way that a screwdriver can be used.

3.6.4.5 Designing the test bench with usability in mind

Since the test bench was also supposed to be used by a user, it was important that it was strong enough to withstand use. Areas that were more likely to withstand a greater force were therefore designed to be a bit thicker in order to carry a greater load.

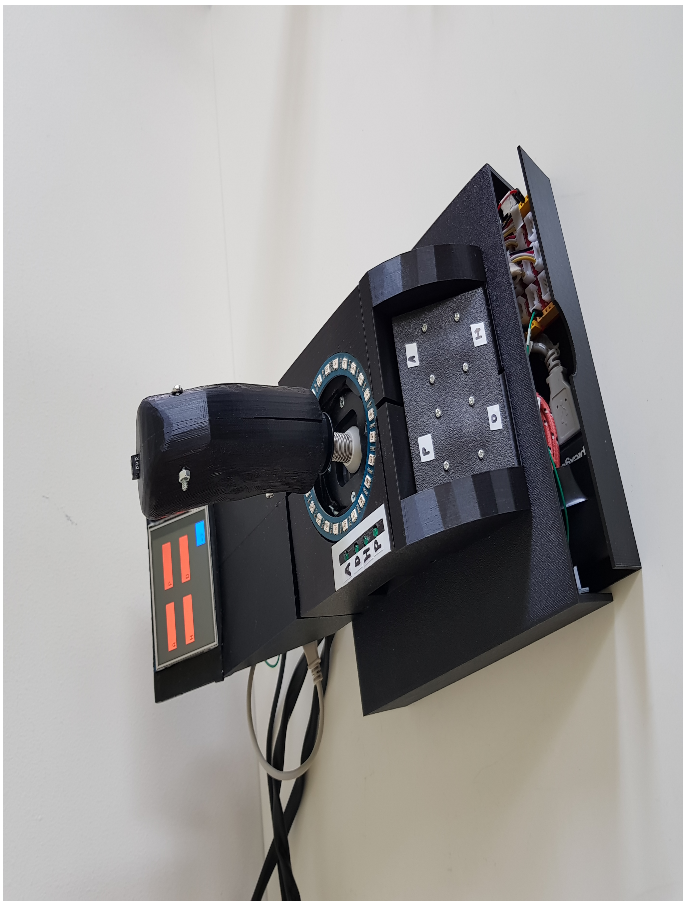

Figure 3.32: The drawer underneath the test bench with the purpose of hiding away components and enabling hot switching.

It was decided that users should not be distracted by the cords and electrical components that built up the internals of the joystick. With this in mind, a drawer was placed underneath the joystick, which in turn could be pulled out when hot swapping components during testing. This drawer can be seen in 3.32 & 3.31. Furthermore, the chords that needed had to be connected to a power supply or to the computer was drawn through a hole in the back of the drawer.

3.6.4.6 Designing the test bench with manufacturing in mind

In order to manufacture the test bench in a fast and reliable way, it was decided to look into the possibility of using Additive Manufacturing(AM), or 3D printing which is the common name for it. As declared in section 2.3.7, AM puts several constraints on the design of the models. Because of this, models were designed with a certain printing direction in mind, leaving it with little to no need of support structures. The model in figure 3.33 only need support structures in the holes. If the part had been printed in any other direction it would have resulted in more support structures and therefore more post production fixes.

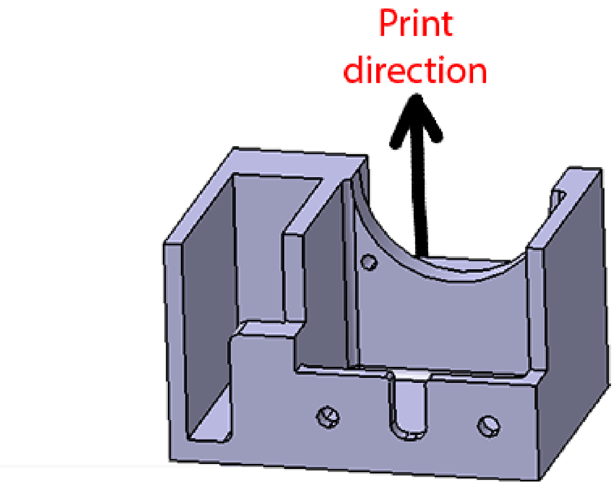

Figure 3.33: The direction of the print.

3.6.4.7 Conclusion of the mechanical design

A lot of time and effort was put into making the mechanical design of the test bench. Because the assembly, use and manufacturing was considered in each step of the process, only one setup of the test bench had to be printed.

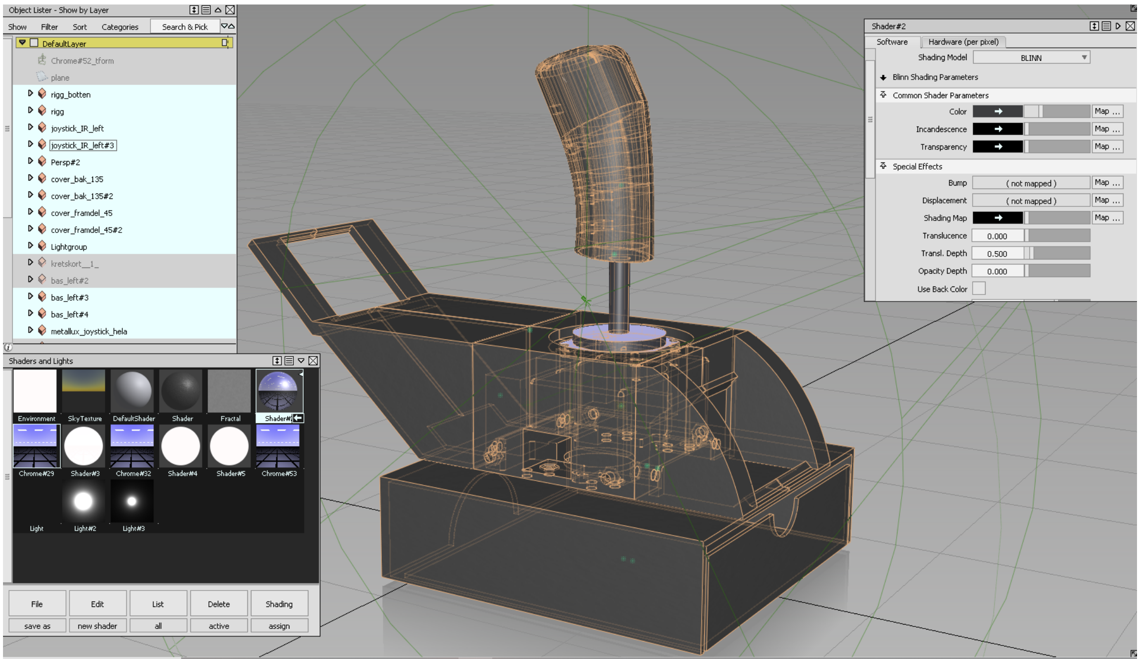

Figure 3.34: Overview of all 3D models.

3.6.5 Developing the simulator

In order to evaluate a test bench its is necessary to create an environment in which it can be tested. The ideal environment would be in the scenario where the actual joystick is used on a boat. When developing a test bench there is a possibility that components and code stop working or work in an unintended way. This in combination with a sharp situation at sea may result in disaster. With this reasoning as a basis it was decided that a simulation could be used as environment. This comes with the drawbacks that some factors of the real environment may not be able to be conveyed to the user, which could result in faulty or poor data.

3.6.5.1 Simulator overview

The simulator has three main objectives. To read and process user input, To read and process joystick data from the metallux joystick, and the simulation of a boats movement on water. there are many ways to realize this, the only important part is that a user needs to be able to manipulate the position and rotation of the boat by the use of the test bench, whilst activating/deactivating functions. One could build a simulation engine from the bottom up with all relevant components for the simulation to work, or one could utilize an existing game engine. A good compromise of both is a game engine as Unity or Unreal Engine, where one can utilize the game engine to manage the rendering of each frame whilst still having control over user input and what to render. Unity utilizes scripts written in C# to control the user input and the manipulation of sprites, whilst Unreal uses C++. Unreal is also mainly focused on 3D rendering and applications, where as Unity can be used for both 2D and 3D. As the main part of the project is to research user feedback and not to develop a simulator, it was decided that a 2D simulation in unity would be sufficient enough. The Simulation should be able to communicate with both the metallux joystick, Arduino and Seeeduino, as can be seen in figure 3.35. The USB-hub in this figure, represents the data coming from the Seeeduino and Arduino, as it has to travel through the hub to reach the simulation.

3.6.5.2 Simulator functionality

There exist four main functions the user should be able to activate in Unity, Function1, Function2, Function3 and Function4. These are essential to mimic the actual use case for the test bench. In order to activate each of the functions, there are checks in the main Unity C# code that identifies if a button was pressed or not. Each check is built in the same way, as the code in listing 3.5.

```
if (Button1Pressed) //If a buttonpress is identified ButtonPress = true.
            {
                if (Function1) //bool that respresent the current status of the function
                {
                    //Functionspecific code for activated function
```

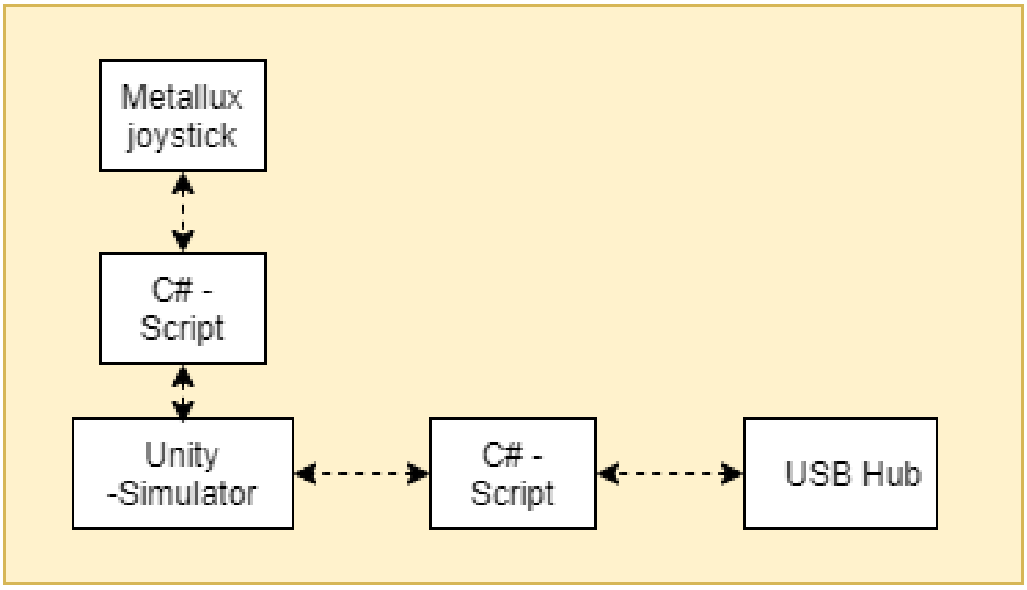

Figure 3.35: An overview of the in-data to Unity

```
                    Function1 = false;
                }
                else
                {
                    //Functionspecific code for deactivated function
                     Function1 = true;
                }
            }
```

Listing 3.5: Button press functionality

Each of the four functions utilizes this same check with their own buttonxState and Functionx status. The drawback with using this kind of check is that if a button consistently gives a value of true when activated, the function will flicker on and of time and time again. To avoid this further button-logic needs to be implemented that only sets the value of button1Pressed to true the frame the button is pressed, and then reset it to false the next frame.

3.6.5.3 User-input processing in Unity

As the application developed in unity calls on void Update() when drawing each frame, every instruction within the function will be carried out before each frame. This means that it is possible to check buttons statuses or check if there is any input from an external device before each frame. This comes with the possible pitfall that if an external device constantly sends data to unity ,the speed of the simulation may be severely crippled. This was observed several times when trying to read data from the metallux-joystick base whilst simultaneously reading data from the seeeduino. A workaround for this problem is to make a check of the length of the data from the seeeduino before reading it. If the length is zero, then there is no point in trying to read it. The seeeduino, as mentioned earlier, only send data if there is a status change on any of the buttons. As the seeeduino send data according to the function described in the code in listing 3.1, Unity also needs to read the data in the same manner. To do this, a C# script was written that first checks weather there is any data coming from the seeeduino, then it checks is the data is the symbol $<$, if that is the case, it reads the following four values from the seeeduino in as the status of each of the four buttons. This code can be viewed in listing 3.6

```
void Update()
{
 buffer_length = sp.BytesToRead;
            if (buffer_length != 0)
            //If the length of data not equal to 0
            {
                if (sp.ReadByte() == 60) //int 60 to str = "<"
// Check if seeeduino sent "<"
                {
//If true, read next 4 as status of each button. Either 0 or 1
                    knapp1 = sp.ReadByte();
                    knapp2 = sp.ReadByte();
                    knapp3 = sp.ReadByte();
                    knapp4 = sp.ReadByte();
                }
            }
}
```

Listing 3.6: Button status reading in Unity

3.6.5.4 Joystick data processing in Unity

As the Metallux-joystick communicates over a CAN bus, as can be seen in 3.36 below, there is need of either building a device able to read this information or utilizing an existing device.

$$\Big[xdata, xdata, ydata, ydata, zrotation, zrotation, buttonStatus, frameCounter\Big]$$

Figure 3.37: CAN-data

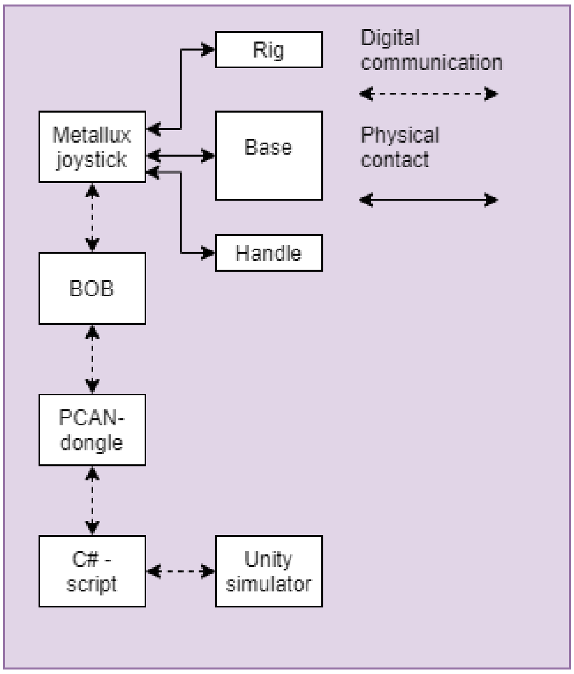

Figure 3.36: An in detail overview of what is connected to the metallux joystick

At CPAC there was the possibility of borrowing a PCAN-USB which could be connected to a break out box (BOB) over serial communication. A power source in the form of a power supply was connected to the BOB to drive the joystick. This in turn meant that the CAN-data on the buss could be read into the computer directly over USB when combined with a PCAN-USB driver on the computer. In order to read the data into unity, there was also the need of using a API developed by PCAN to communicate with the PCAN-driver in the computer. This API and a .dll was available from PCAN in C# which meant that the data could be read straight into Unity through a C# script . The CAN-data read from the Joystick through the API comes in the form of an TPCANMsg object, which has the method DATA which in its turn is an array with 8 elements. This array consists of,

It was found out that the metallux joystick used in the test bench did not always send the data expected on the bus. Sometimes the data would include instances where the DATA array would consist of only zeros for each element. These instances of zeros were ignored.

3.6.5.5 Simulation of boat movement

In Unity image files can be imported as sprites which can be manipulated and rendered each frame.

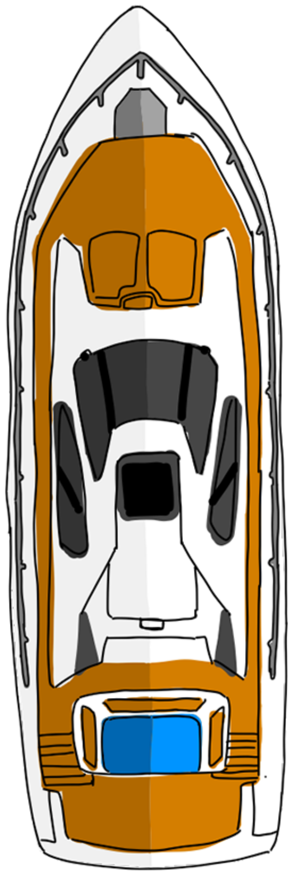

Figure 3.38: .PNG of a boat, imported to Unity to be used as sprite

In order to simulate the movement of a boat at sea, a sprite of a boat was used. In order to control the sprite, a 2DRigidbody was introduced as described in (Unity Technologies, 2020). This 2DRigidbody object then has lots of interesting properties that will be used later. This sprite could then be controlled in Unity through data from external devices such as the Metallux joystick, by the use of a c# script. The CAN data DATA array presented in figure 3.37, includes x-,y-, and z-vales which can be used to control the sprite. The values range from 0-31 depending on the position of the joystick. For making it easier to translate the joystick into a movement of the boat sprite, the range of the data was changed to instead be from -15 to 16. To simulate a somewhat realistic behaviour of the boat sprite when it travels through the water, simple fluid-dynamic equations were used. From fluid dynamics we know,

$$F_d = 1/2\rho v^2 C_d A \tag{3.1}$$

which can be heavily simplified as,

$$F_d = v^2 C \tag{3.2}$$

This simplification is based in that we no longer take the geometry of the boat into consideration when it is translating throughout the water in different directions. We have simplified $1/2\rho * A$ to C. This is not physically correct as A would change depending on what direction the boat translates, but it still works well enough the simulate the slow down of a boat in this application. Since F_d in the simplified equation still depends on the speed of the boat v^2, a gradual slow down will take place, and the magnitude of C can be used to decide how fast the slow down should be. As the boat sprite has the 2DRigidbody, 2DRIgidbody.AddForce(x,y) can be used to add a force in a certain direction and of a certain magnitude each frame. This is used throughout the code to update the position of the boat. The engines will put a certain force on the boat in the direction calculated from the CAN data, which will result in the boat moving through the water at a certain speed. F_d will meanwhile be applied in the opposite direction of the boats movement. This results in that, when the user stops manipulating the position of the boat through the joystick, the boat will slow down as if the force of F_d was continuously counteracting its movement.

3.6.5.6 LED ring communication

After having understood the product, in section 3.2, as well as defined the means, in section 3.4, it was established that there could be of interest to communicate what direction the boat has compared to the direction the user moves the joystick and therefore tries to make the boat move to. As a boat on water has the aforementioned behaviour of inertia, presented in section 3.6.5.5, the boat may move in one direction during a short time whilst a counteracting force slows it down and changes the direction of movement in accordance with the joystick position.

In Unity each Rigidbody2D has a velocity property, Rigidbody2D.velocity() which according to the Unity manual (Unity Technologies, 2020) consists of a Vector2 with x- and y-values representing both the direction and magnitude of the velocity. As the vector from the joystick also comes in the form of a x- and y-value, one can do a simple check on the angle between each vector to determine weather the user is applying force in the direction of movement or in the opposite direction of movement. According to the Unity documentation one can calculate the angle between two vectors using Vector2.Angle(new Vector2, new Vector2). By using this function, with the first Vector2 as the velocity of the boat rigidbody, and the second the x- and y-values of the joystick data, the check can be performed and it can be determined if the user is pointing the joystick in the direction of velocity or not. This information can then be sent in the form of an integer to the Seeeduino, which displays the correct colour and direction on the LED ring. The LED ring consists of 24 individually addressable LED's, where both color and brightness can be manipulated. It was decided that red color should be used for the case where the user is not pointing in the direction of movement, and green color should be used when the user is pointing in the direction of movement. To simplify the process of identifying directions and communicating data, the LED ring was divided into four quadrants with seven LED's in each. The Unity code starts of by checking the direction of the joystick compered to the velocity of the boat, as explained above, if the angle is bigger than 90°, it is determined that the user is pointing the joystick away from the movement of the boat. A second check is done to determine if the angle is between, 0-45°, 45-135° or 135-180°, compared to a vector that always point forward from the boat. This in turn decides the direction the light should point. These two checks combined result in eight cases that can be sent to the Seeeduino.

Case one to four, the LED's turn on with red color and in all directions as can be seen in figure 3.39.

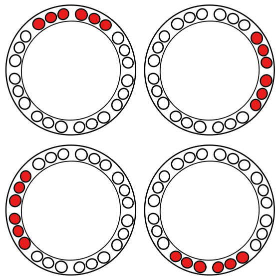

Figure 3.39: The different directions the LED ring can light up red.

In case five to eight, the LED's light up green in the four different directions, as can be seen in figure 3.40.

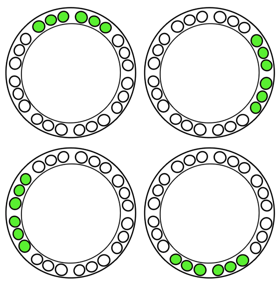

Figure 3.40: The different directions the LED ring can light up red.

As mentioned, each case is represented by a number from zero to eight. When Unity has decided what case should be activated, by use of the methods described above, the number of the decided case is sent in the form of a string to the seeeduino. The seeeduino then checks what number has been sent, and activated one of the cases presented in figure 3.39 and figure 3.40.

In summary, Unity calculated what direction and color the LED's should light up with, and send the information forward to the seeeduino. The seeduino in turn activates LED's in accordance with the case that has been transmitted, both in regards to what LED's to activate and what colour they should have. This is done every time the user changes direction of the joystick, or when the direction of the boats velocity change direction.

3.7 User studies methodology

To be able to draw conclusions regarding activation types and different types of feedback, it was decided that user studies were to be carried out. The user studies consisted of two parts, a test during which users operated the boat in the simulation described in section 3.6.5 whilst being observed, and a interview part where they evaluated the test bench in different regards. In order for the tests to not take too much time, it was decided that no combination of activation types would be tested at the same time. Three test users got to participate in the studies. Each one of the concepts described in section 3.4 were individually tested by the users.

3.7.1 User studies setup

The user studies were carried out in an apartment with the test bench connected to a computer and the computer connected to a TV over HDMI. The user was placed in front of the TV with the test bench mounted on a separate chair in a height and placement as if it had been situated in the armrest of a chair, as can be seen in 4.3. Each user would also be filmed during the test in order to ease the user data collection. These recordings were later evaluated to retrieve the test data.

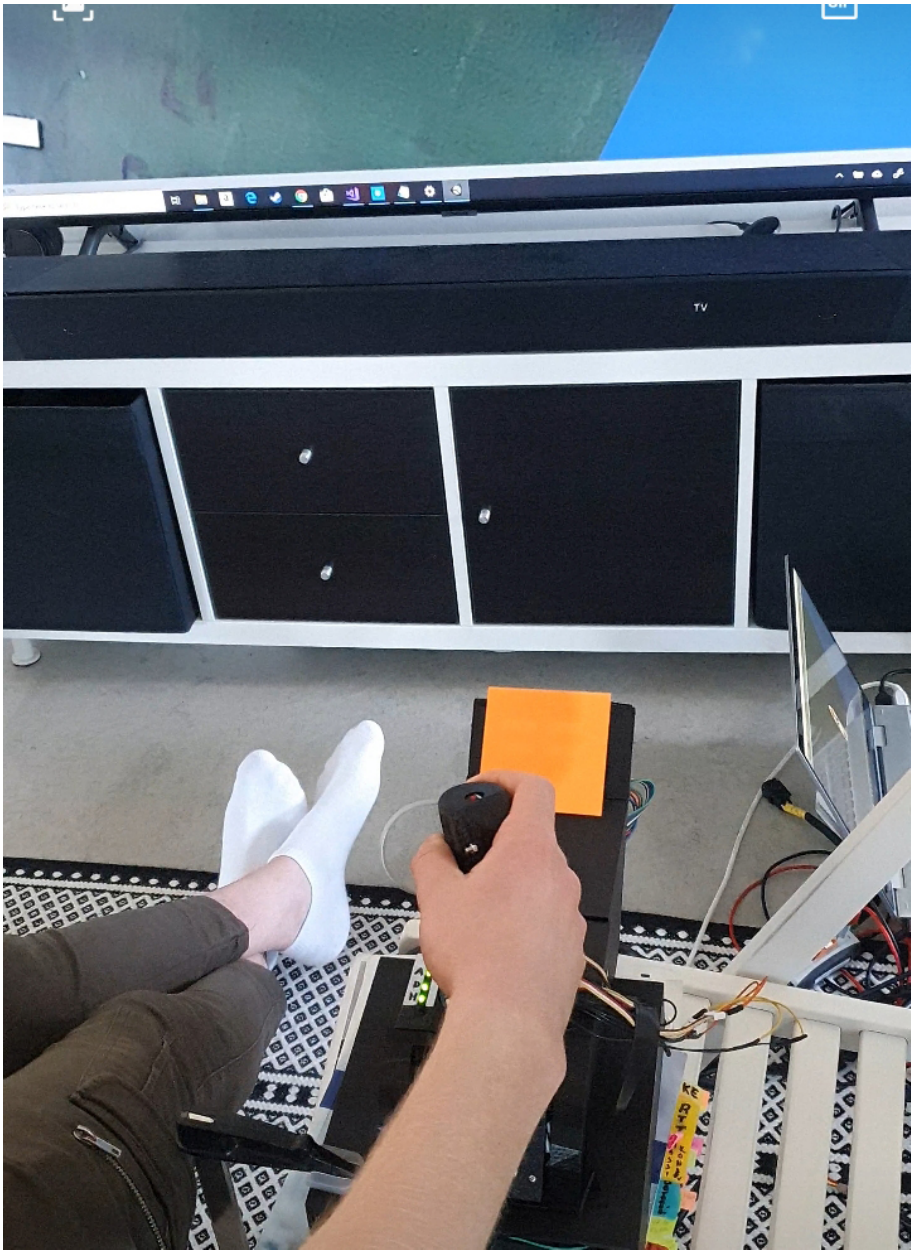

Figure 3.41: A test person during performing a user study.

3.7.2 User study - Observations

As mentioned, the first part of the user study consisted of observing the user whilst taking notes. In addition, the user studies were performed in a constructed manner, as described in 2.3.4. As the studies aim to verify or reject hypothesis it is important that they are easy to replicate and carried out several times in the same manner.

The route marked in 3.42 was used in each one of the user studies. The users were during the study asked to activate functions on the concept at hand whilst traversing the route. The numbers in figure 3.42 stands for the approximate position the users were told to activated a function. The functions were activated in the following order;

1. Start the joystick
2. Activate Function 1
3. Activate High mode
4. Activate Joystick driving
5. Deactivate Joystick driving
6. Activate High mode
7. Deactivate High mode
8. Activate DPS

Variations of what functions to activate at what time were carried out in order to change things up and keep the user concentrated and focused. Function 1 act as a template for an undisclosed functionality.

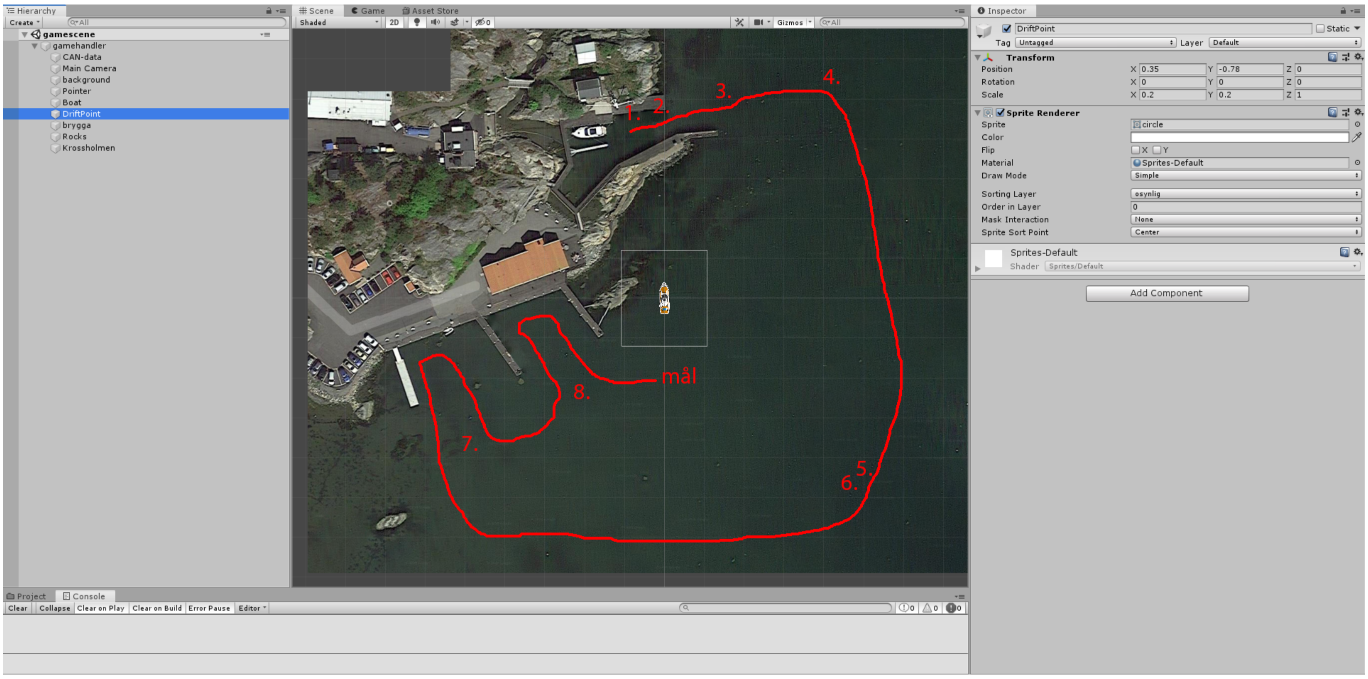

Figure 3.42: The route that the users in the study were asked to drive.

3.7.3 User study - Interviews

After each route, users were asked a set of questions which were the same for each user and each concept. The questions were as follows;

- What did you think about the possibility of finding the correct activation surface?
- What did you think about the possibility to activate the correct function?
- What did you think about the possibility to determine if a function was activated/deactivated?
- What did you think about the possibility to determine what functions that currently are activated?
- What was your over all impression?

3.8 Comparing the remaining concepts to each other using kesselring matrices

The interviews were followed by a comparison between the concepts using a kesselring matrix.

Before this, it was concluded that not every concept needed to be evaluated in the kesselring matrices. Because the user scenarios varied a lot, not one activation type were deemed better than another in the user studies. Because of this, one concept for each activation type went through to the kesselring matrices. The concept that went through had both visual, auditive and haptic feedback. There were two exceptions, both the touchscreen and the Penta joystick had only visual feedback, because of technical limitations.

As explained in section 3.5, the user scenarios varied a lot. Because of this one kesselring matrix were done for each scenario. The factor that varied between the matrices were the weight of the different requirements. These different weighting will be presented in chapter 4.

The result from the kesselring matrices was one winning concept for each user scenario.

3.9 Conclusion of methodology

For this section it can be concluded that, a test bench has been developed in accordance with the product development process presented in figure 3.1. Furthermore, an explorative user study has been carried out. In addition, a framework for user studies as well as scenarios through which the data can be evaluated has also been developed. With this as a basis further user studies and analysis of the results can be carried out.

4

Results

In this chapter, the results from the project is presented. The chapter is commenced by a presentation of the test bench, after this, the results from the qualitative user studies are presented. The chapter is concluded by a presentation of the strongest concept for each user scenario.

4.1 Final test bench

On of the main results from this project is the test bench test bench that has been developed and used in the user studies.

Figure 4.1: A 3D model of the test bench.

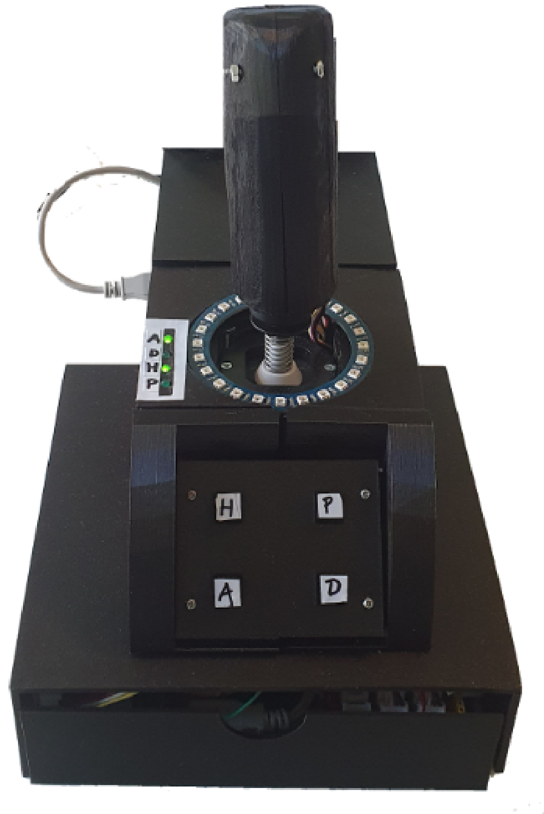

Figure 4.2: The test bench.

In difference to the existing test benches at CPAC, this test bench only incorporate the joystick, not the entire boat electronics, and is small and portable. If future development is done in regards to developing new joystick handles and new button layouts, interfaces, or over all design, this test bench will be able to act as an exploratory first step where initial testing can be done with lots of concepts being tested with ease. The joystick handle for example is already 3D printed on the current set up, so a new joystick handle with further ergonomics and functionalities can easily be printed and mounted onto the test bench. Using this test bench will enable a developer to quick and easily test lots of ideas, which opens up the possibility for even more creative and innovative thinking.

4.1.1 Modularity

As the test bench is built with being modularity in mind, it has both mechanically and software-wise the ability to integrate new functionalities and components if required. Modules the size of the touch-screen can be mounted onto the main body of the joystick, and as long as the required sensors can fit onto the module. The code that was developed is not sensor dependant as long as the sensors are compatible with an Arduino's 5v or 3v3 connections. This makes future updates of touch sensors or more advanced touchscreens possible. This enables a future user of the test bench to carry out new test that were not even defined during this project, without having to do too much change of the actual software or hardware. As all parts except the electronics were 3D printed, from CAD files, it is easy to remodel or change whatever required, print new modules and connect them to the joystick.

4.1.2 Replaceability

The test bench is built to be able to be dissembled and reassembled as see fit. Therefore, if a component breaks or get damaged during testing, only the damaged component will need to be replaced, in stead of the entire test bench. Except the metallux joystick, no complex or hard to find components have been used in the test bench, which means replacement part can be found in most electronic-component stores.

4.1.3 Simulation

Not only has a mechatronic solution been developed for the joystick itself, but also a simulation in which the joystick can be tested. This simulation be be further updated and developed to implement whatever functionalities a future developer require. The simulation only needs data from a joystick, and not an entire boat system, so smaller scale test regarding only the joystick itself, and its functionality, can be carried out. The simulator is developed to read and interpret data from the Penta joystick, so as long as whatever is connected to it send the same kind of data, it should be compatible with the simulation.

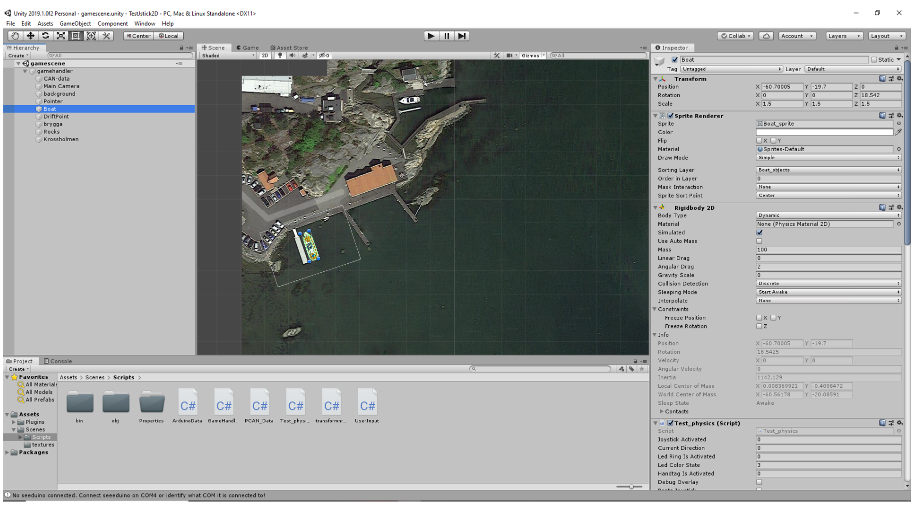

Figure 4.3: The Unity application

4.2 Results from the user studies

Below, the results from the qualitative user studies are presented through extracts from the comments by the three users that participated in the tests. The transcripts can be found in full in Appendix B.

4.2.1 Tactile buttons, placed on the joystick base

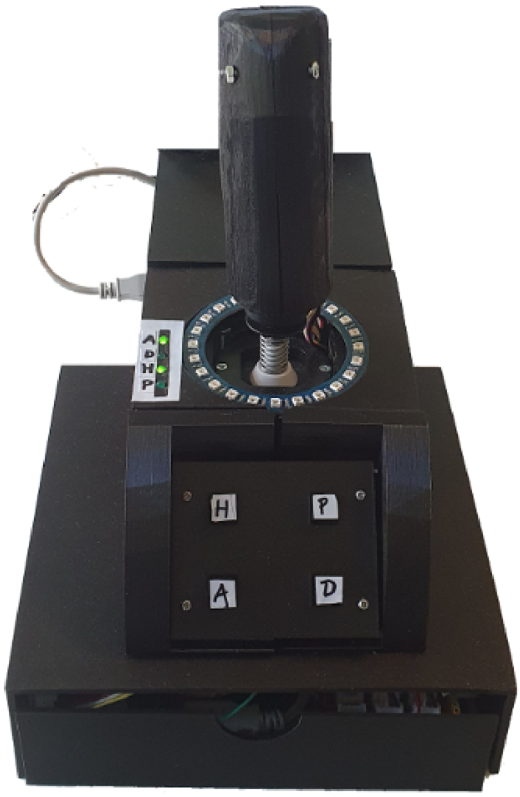

Figure 4.4: The joystick with tactile buttons, placed on the joystick base.

The interviewees found it easier to locate the right activation place using tactile buttons, compared to touch sensor buttons. They felt it was easier to locate the right button because they did not have to look at it every time. When testing this concept, the order of the buttons were not the same as the order of the LED's, like in the concept with the touch sensor buttons, all interviewees found this confusing. The interviewees spent less time looking at the buttons, but still they looked down almost every time when asked to activate a function.

When asked about their opinion on having tactile buttons that stayed pushed in, one interviewee expressed that this would be a good idea since one could tell if a function was activated. The interviewee expressed that this was more trustworthy than having an LED visually signaling the state of a function. When asked why this was, the interviewee explained that it felt more convincing because it looked like the circuit was closed.

All interviewees found that the placement of the buttons forced them to sit in an non-ergonomic position when activating the functions with their left hand.

4.2.1.1 Tactile buttons, placed on the joystick base, with visual feedback

The interviewees liked this concept better than the touch sensor button with visual feedback. The interviewees expressed that they got auditive and haptic feedback from pushing the buttons. Although, one interviewee did not like this concept because the buttons did not have a good feel to them, and this was more obvious if there were no sound signal or vibration.

> "Designing a tactile button with a good feel to it is harder, and more important, if you do not have a sound signal nor vibration to complement it"

4.2.1.2 Tactile buttons, placed on the joystick base, with visual and haptic feedback

None of the interviewees noticed the vibration and hence the same results applies as for the concept with only visual feedback.

4.2.1.3 Tactile buttons, placed on the joystick base, with visual and auditive feedback

When compared to the concept with both auditive and haptic feedback, one interviewee did not like having vibration signaling activation of functions, and because of it, preferred this concept.

4.2.1.4 Tactile buttons, placed on the joystick base, with visual, haptic and auditive feedback

The interviewees either did not notice the vibration or did not like it. One interviewee pointed out that it could be hard to notice auditive feedback when om an actual boat, it being a noisy environment. Some interviewees liked the user experience of having both visual, haptic and auditive feedback together with the tactile buttons. One interviewee wanted to give this concept a 10/10 if the LED's had been placed on the buttons.

4.2.2 Touch sensor buttons, placed on the joystick base

Figure 4.5: Touch sensor buttons, placed on the joystick base.

The interviewees were not overly positive to the touch sensor pad. Some mentioned that it did not feel like something that belonged on a boat since it could get wet and loose functionality because of it. Furthermore they explained how they would like to be able to activate functions without having to look at the buttons.

> "I want to keep my eyes forward, and then I would like to feel where the right button is...like the blinkers on a car..."

When asked about their opinions about having touch sensor buttons compared to haptic buttons, one interviewee expressed that it looks nice with a smooth surface but of the functionality is affected negatively.

> "A smooth surface is nice and all, but it feels like the nice cutlery you have for Christmas, they are nice to look at but you can't use them to cut meat"

But the interviewees also expressed that from the developers point of view, it could be beneficial to have touch sensor buttons because it gives less design constraints.

The interviewees had mixed opinions about the placement of the buttons. Some interviewees expressed that it did not feel very ergonomic having to twist their back to be able to reach the buttons with their left hand and that they would rather have the buttons placed in front of them or to their left.

4.2.2.1 Touch sensor buttons, placed on the joystick base, with visual feedback

The interviewees understood that the visual feedback was the only solution when it came to communicate that a function was activated/deactivated, but they would have wanted it placed differently, either on the actual button or in their field of view when looking forward. When asked about the feedback about the activation/deactivation of functions, they also expressed that they did not like the fact that they had to look down at the LED's every time.

4.2.2.2 Touch sensor buttons, placed on the joystick base, with visual and haptic feedback

The opinions from the interviewees differed greatly when it came to the haptic feedback. One interviewee loved the vibration, one interviewee did not notice the vibration and one liked it but thought it sent the wrong message.

The last interviewee associated vibration with something negative, and hence, having the vibration communicate that a function was activated/deactivated felt confusing. The interviewee also suggested that perhaps the vibration could signal that a function was deactivated, and that a sound could signal that the same function was activated. Furthermore, the interviewee did not like the fact that it was the same feedback for all functions and rather suggested that it could be different vibrations or sound signals. Lastly, the interviewee expressed that if a vibration were to be integrated in a design, it should vibrate where you are pressing, i.e. in the button, only and not in the handle as well. This interviewee did not like the feeling of the vibration in the handle at all.

4.2.2.3 Touch sensor buttons, placed on the joystick base, with visual and auditive feedback

As mentioned above, the interviewees found it hard to tell if a function was activated or deactivated without looking at the joystick. One interviewee did not like the vibration in the handle at all and hence thought this feedback was the best if touch sensor buttons were to be integrated in the design. The interviewees mentioned that it could be hard though to hear the sound signal when on bout where there is probably a lot of noise.

4.2.2.4 Touch sensor buttons, placed on the joystick base, with visual, haptic and auditive feedback

Two of the interviewees did not notice the haptic feedback and one did not appreciate this feedback, hence, the results from 4.2.1.3 applies to this concept as well.

4.2.3 Touchscreen, placed on the joystick base

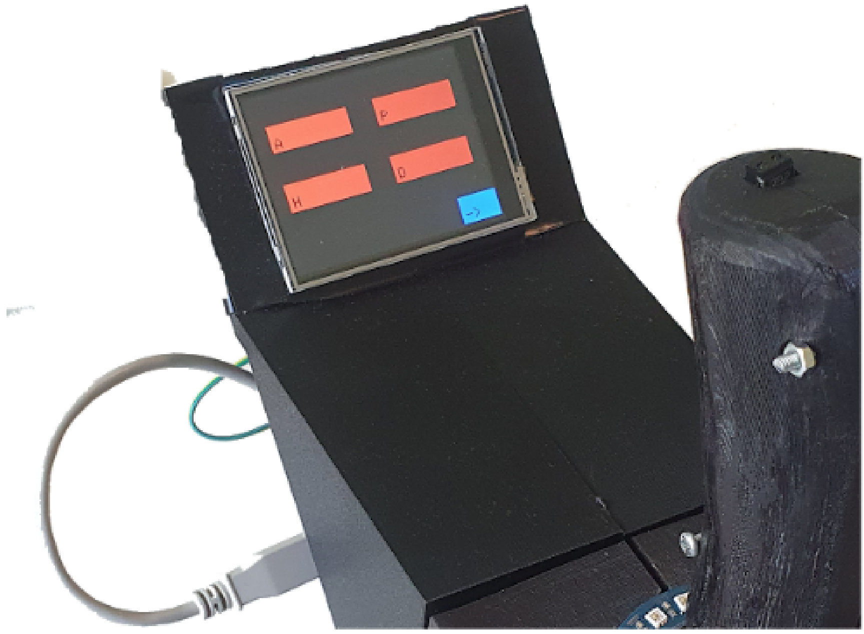

Figure 4.6: Touchscreen, placed on the joystick base.

There was a mix of impressions of the touchscreen among the interviewees.

All interviewees pointed out, and was positive about the fact that the visual feedback was situated at the same place where you activated a function. Furthermore, one interviewee expressed that the sole advantage of a touchscreen was the placement of the visual feedback.

> "I prefer the touchscreen because you get the visual feedback on the same place as you activate a function, but aside from this, I would not prefer it"

All interviewees expressed that they did not trust the functionality of a touchscreen as much as they did for tactile buttons. Among the concerns were how the screen would function if it got wet or if you had to wear gloves. One interviewee expressed that it felt more futuristic with a touchscreen than with tactile buttons. The same interviewee expressed that a touchscreen was preferred above touch sensor buttons. Furthermore, some interviewees expressed that it was easier for a developer to make updates to a touchscreen than to tactile buttons and also it did not give as many design constraints.

When asked about the positioning of the touchscreen, different opinions arose. On the one hand it was a good placement since you did not have to let go of the view of the surroundings completely. Also, one interviewee expressed that it felt more ergonomic since you could rest your wrist on the joystick base when maneuvering the touchscreen. Furthermore, if you use your left hand to activate functions, one interviewee expressed that this did not affect the maneuverability of the joystick as much as when the buttons were placed in front of the joystick, it did not block the movement and forcing the user to use their wrist instead of their whole forearm to maneuver as was expressed as an advantage. On the other hand, it could affect the design and visual impression of the product in a negative way since it made it bigger and bulkier. All interviewees expressed that they would prefer to have it placed on the left or in front of them.

4.2.3.1 Touchscreen, placed on the joystick base, with visual feedback

All interviewees were positive to the fact that the visual indicators were placed on the same placed as the buttons. They found this making it easier to keep focus on your surroundings. One interviewee expressed that the colors used, green and red, can not be distinguished if you are color blind. None of the interviewees expressed that they missed auditive or haptic feedback.

4.2.4 Tactile push buttons, placed in the joystick handle

Figure 4.7: Tactile push buttons, placed in the joystick handle.

The first impression of this concept was really positive from all interviewees. When asked question after the test, the interviewees found this activation type to be beneficial in some situations and in others to rather be counterproductive.

> "If the functions will be activated often and a lot, it is feasible to have them on the handle. If not, if they will only be activated a couple of times per journey, there is really no point in having them in the handle."

Two of the interviewees mentioned that they played a lot of PlayStation and found this concept to be similar to that of a video game controller, see figure 2.18, these two interviewees were positive to the placement of the tactile buttons. They mentioned that since the buttons were placed in the same order as the LED's, it was easy to understand which button activated what function. All interviewees mentioned though, that if you do not activate/deactivate the functions that often, it would probably be hard to remember which button was connected to which function. The interviewee that had not played that much PlayStation activated the wrong function a couple of times, compared to the PlayStation players who did not activate the wrong function one single time.

When asked if the buttons could be in the way when trying to maneuver the joystick the interviewees did not think this was that big of a problem. All interviewees placed their hand with their fingers between the buttons, and some mentioned that there could be a risk of pressing the lower button with your middle finger unintentionally. One interviewee did not think the buttons were intrusive since they were small and the placement was well thought through. The interviewee added that if they would be even better placed, ergonomically this could take them the final step to completion.

> "I did not think the buttons were intrusive because they were small, if they would be even more ergonomically placed, like the old Microsoft flight controllers where the buttons are integrated in the design, this could take them the final step. But having them like this, this helps a lot I think."

4.2.4.1 Tactile push buttons, placed in the joystick handle, with visual feedback

The interviewees did not like this concept that much. They felt it was unsatisfying to not have any feedback except the visual.

> "I wanted to look at the LED every time, I did not trust only the mechanical click sound as feedback."

The same interviewee expressed that the experience was more confused and the impression was worse than the other concepts with the buttons placed in the handle.

4.2.4.2 Tactile push buttons, placed in the joystick handle, with visual and haptic feedback

The interviewees found this concept to be better than the previous one, but not as good as the later two. One interviewee was not pleased with the vibration since it did not have a nice feel to it.

4.2.4.3 Tactile push buttons, placed in the joystick handle, with visual and auditive feedback

The interviewees were generally pleased with this concept, more so than with the two previous mentioned concepts. One interviewee did not like the vibration and hence preferred this concept.

4.2.4.4 Tactile push buttons, placed in the joystick handle, with visual, haptic and auditive feedback

The interviewees were generally positive to this concept. One interviewed expressed that the combination of the beep from the speaker and the mechanical click sound from the button was a good combination that gave a nice experience. One interviewee mentioned that it would have been beneficial to have a variation in the feedback depending on which function was activated and deactivated and whether it was activated or deactivated.

4.2.5 LED ring, placed in the joystick base

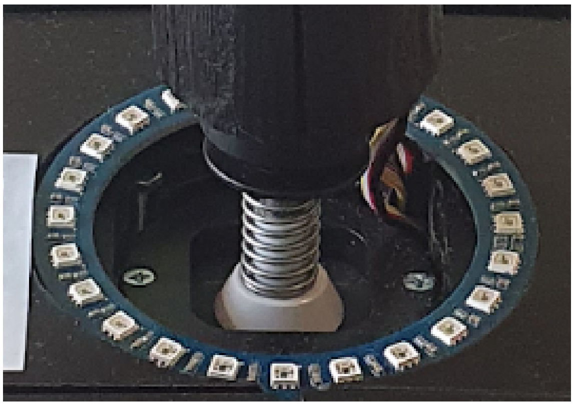

Figure 4.8: LED ring, placed on the joystick base.

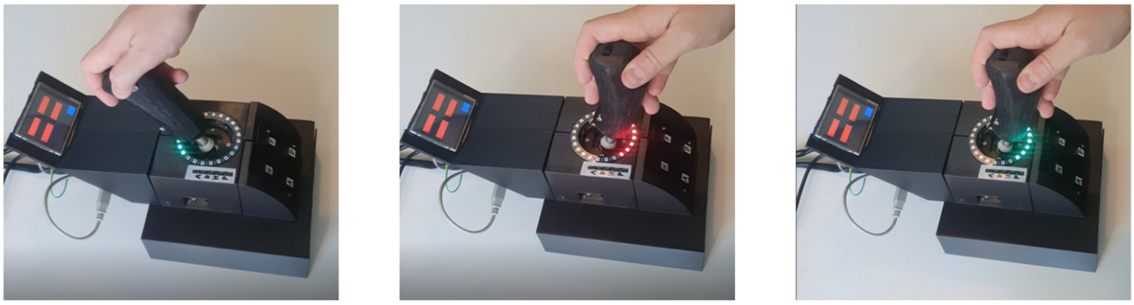

Figure 4.9: The LED ring in use.

All interviewees understood what the colors on the LED's displayed. The interviewees contributed with a lot of feedback on this feature.

One interviewee expressed that there was no real need to have the red light because you know which way you are going. When asked if it could help with understanding the inertia of the boat, the interviewee explained that, considering this, it could in fact help. The same interviewee had never driven a boat and explained that it could help when landing at the dock, so that you do not hit the gas too hard thinking the engines does not respond, when in fact, it is the inertia acting on the boat. Furthermore, the interviewee expressed that it could could contribute with an understanding to novel drivers about the correlation between the joystick and the movement of the boat.

One interviewee, that had experience of driving a boat liked the function of having a color signaling that the boat was going in another direction than the direction of the joystick. When asked if this feature could be helpful when maneuvering a boat, the interviewee was not sure and expressed that you would not really want to look down at the joystick too much while driving. The same interviewee added that if the driver is inexperienced, it could probably help, and added that, even though the owner of a boat is usually experienced, it happens pretty often that it is somebody else, like a family member, who is driving.

All interviewees liked having the LED ring and most were positive to the feature of having it signaling the movement of the joystick. Although, one interviewee expressed that it would probably be better to have the color showing only the movement of the boat;

"If I'm going full speed forward and hitting the reverse, I would want it to be red until the boat changes it's direction. I already know which way I'm pushing the joystick"

One interviewee liked the colors but expressed that you should watch out for having the light too bright or using strong colors, and also that red is a warning color and should probably not be used for anything else than this. According to the interviewee, calmer colors like white or yellow was preferred. Strong colors signaled that the product was cheap. A few and well thought through colors showed that the product was smart and well engineered. The interviewee mentioned that being a product development student probably affected this opinion.

"I think I like simplicity, this has probably to do with me being a Product Development student. More colors would feel cheaper. I would prefer to have it clean but it is probably personal, perhaps it could be a good idea to give the user possibility to decide on the colors."

Another interviewee expressed that you could have the LED being brighter if you pushed it further, but that this would probably impair the experience more rather than it being the helpful. The interviewee mentioned that it would only be interesting to know if something is happening or not, not how much. The same interviewee suggested that you could have different colors depending on the difference between the movement of the joystick and the movement of the boat;

"If I would have full speed backwards and wanted to stop, I would push it(the joystick) full speed forward, then maybe I would want it to go from red to orange to yellow to green. Signaling that now my action is starting to give response on the movement of the boat, making it easier to meet the boat."

4.3 Presentation of the strongest concept for each user scenario

Depending om the user scenario some concepts were deemed stronger than others. The winning concept for each of the user scenarios are presented below.

4.3.1 User scenario 1 - Low speed in crammed spaces

In this scenario, being able to easily identify placement of activation surfaces visually, being able to haptically identify the placement of activation surfaces and a high level of robustness was deemed as important requirements, and was therefore weighted heavily in figure 4.10. In the matrix one can see how the strongest concept was tactile buttons placed on the joystick base, see figure 4.11.

		Concepts											
		Ideal		Penta joystick		Touch sensor buttons on base front		Touchscreen on base back		Tactile buttons on base front		Tactile buttons in joystick handle	
Criteria	**Weight**	S	T	S	T	S	T	S	T	S	T	S	T
The user should be able to differentiate the activation buttons from each other visually	5	5	25	4	20	4	20	5	25	4	20	2	10
The user should be able to differentiate the activation buttons from each other haptically	5	5	25	4	20	2	10	0	0	4	20	4	20
The user should get feedback about the activation/deactivation of a function visually	3	5	15	5	15	5	15	5	15	5	15	5	15
The user should get feedback about the activation/deactivation of a function auditive	2	5	10	5	10	5	10	5	10	5	10	5	10
The user should get feedback about the activation/deactivation of a function haptically	2	5	10	2	4	5	10	5	10	5	10	5	10
The movement of the boat as compred to the movement of the joystick should be communicated to the user	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be a visual feedback on the joystick about the direction of the boat	1	5	5	0	0	0	0	0	0	0	0	0	0
It should not be apparent for others than the user that the joystick is activated	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be support for activation of future functions	3	5	15	1	3	3	9	5	15	1	3	1	3
The buttons should be integrated into the joystick design	5	5	25	5	25	5	25	5	25	5	25	5	25
The user should not mistakenly activate the wrong function	5	5	25	4	20	2	10	4	20	4	20	2	10
It should be apparent what function a feedback signals	1	5	5	0	0	0	0	0	0	0	0	0	0
The user should look down at the joystick as few times as possible during use	4	5	20	2	8	2	8	2	8	2	8	4	16
The addition of new functions should cost as little as possible	3	5	15	2	6	3	9	4	12	2	6	2	6
There should be as few design requirements as possible with the product	2	5	10	2	4	4	8	5	10	2	4	2	4
The product should have a high level of robustness/low level of complexity	5	5	25	4	20	3	15	1	5	4	20	4	20
		85	**240**	**42**	**155**	**47**	**149**	**50**	**155**	**45**	**161**	**43**	**149**

Figure 4.10: Kesselring low speed in crammed spaces

Figure 4.11: The strongest concept in Scenario 1 - The joystick with tactile buttons, placed on the joystick base.

4.3.2 User scenario 2 - Freedom for the developers

In this scenario, support for activation of future functions, as few design requirements as possible, the addition of new functions should cost as little as possible, was deemed as important requirements, and was therefore weighted heavily in figure 4.12. In the matrix one can see how the strongest concept was as touchscreen placed on the backside of the base.

		Concepts											
		Ideal		Penta joystick		Touch sensor buttons on base front		Touchscreen on base back		Tactile buttons on base front		Tactile buttons in joystick handle	
Criteria	Weight	S	T	S	T	S	T	S	T	S	T	S	T
The user should be able to differentiate the activation buttons from each other visually	5	5	25	4	20	4	20	5	25	4	20	2	10
The user should be able to differentiate the activation buttons from each other haptically	3	5	15	4	12	2	6	0	0	4	12	4	12
The user should get feedback about the activation/deactivation of a function visually	3	5	15	5	15	5	15	5	15	5	15	5	15
The user should get feedback about the activation/deactivation of a function auditive	2	5	10	5	10	5	10	5	10	5	10	5	10
The user should get feedback about the activation/deactivation of a function haptically	2	5	10	2	4	5	10	5	10	5	10	5	10
The movement of the boat as compred to the movement of the joystick should be communicated to the user	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be a visual feedback on the joystick about the direction of teh boat	1	5	5	0	0	0	0	0	0	0	0	0	0
It should not be apparent for others than the user that the joystick is activated	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be support for activation of future functions	5	5	25	1	5	3	15	5	25	1	5	1	5
The buttons should be integrated into the joystick design	5	5	25	5	25	5	25	5	25	5	25	5	25
The user should not mistakenly activate the wrong function	5	5	25	4	20	2	10	4	20	4	20	2	10
It should be apparent what function a feedback signals	1	5	5	0	0	0	0	0	0	0	0	0	0
The user should look down at the joystick as few times as possible during use	4	5	20	2	8	2	8	2	8	2	8	4	16
The addition of new functions should cost as little as possible	5	5	25	2	10	3	15	4	20	2	10	2	10
There should be as few design requirements as possible with the product	5	5	25	2	10	4	20	5	25	2	10	2	10
The product should have a high level of robustness/low level of complexity	1	5	5	4	4	3	3	1	1	4	4	4	4
		85	**245**	**42**	**143**	**47**	**157**	**50**	**184**	**45**	**149**	**43**	**137**

Figure 4.12: Kesselring Freedom for the developers

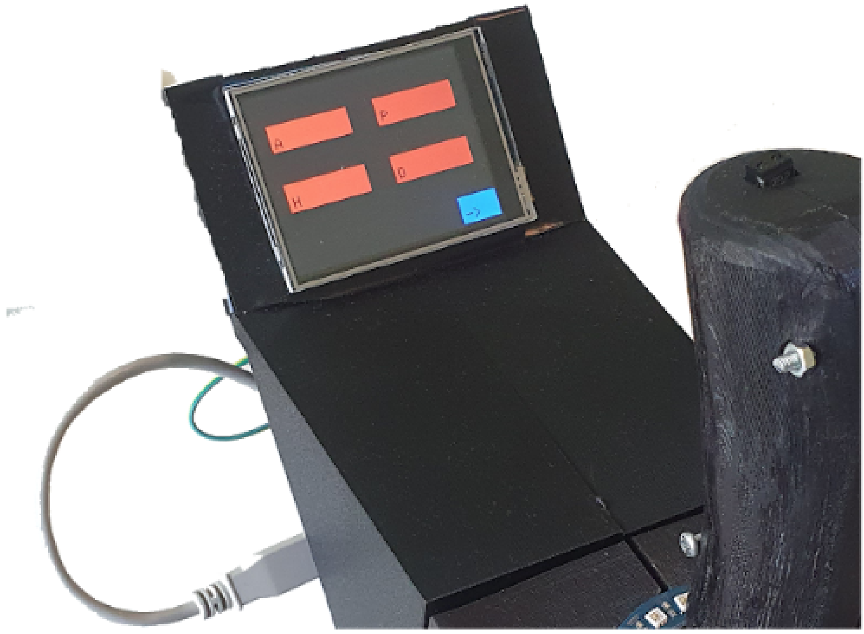

Figure 4.13: The strongest concept in Scenario 2 - Touchscreen, placed on the joystick base.

4.3.3 User scenario 3 - High speed driving, with a lot of function activation/deactivation

In this scenario, The user should look down at the joystick as few times as possible during use, was deemed as important requirements, and was therefore weighted heavily in figure 4.14. Whilst, the user should be able to differential the activation buttons from another visually, was weighted low. In the matrix one can see how the strongest concept was tactile buttons placed on the backside of the joystick handle.

		Concepts											
		Ideal		Penta joystick		Touch sensor buttons on base front		Touchscreen on base back		Tactile buttons on base front		Tactile buttons in joystick handle	
Criteria	**Weight**	S	T	S	T	S	T	S	T	S	T	S	T
The user should be able to differentiate the activation buttons from each other visually	2	5	10	4	8	4	8	5	10	4	8	2	4
The user should be able to differentiate the activation buttons from each other haptically	5	5	25	4	20	2	10	0	0	4	20	4	20
The user should get feedback about the activation/deactivation of a function visually	3	5	15	5	15	5	15	5	15	5	15	5	15
The user should get feedback about the activation/deactivation of a function auditive	2	5	10	5	10	5	10	5	10	5	10	5	10
The user should get feedback about the activation/deactivation of a function haptically	2	5	10	2	4	5	10	5	10	5	10	5	10
The movement of the boat as compred to the movement of the joystick should be communicated to the user	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be a visual feedback on the joystick about the direction of the boat	1	5	5	0	0	0	0	0	0	0	0	0	0
It should not be apparent for others than the user that the joystick is activated	1	5	5	0	0	0	0	0	0	0	0	0	0
There should be support for activation of future functions	3	5	15	1	3	3	9	5	15	1	3	1	3
The buttons should be integrated into the joystick design	5	5	25	5	25	5	25	5	25	5	25	5	25
The user should not mistakenly activate the wrong function	2	5	10	4	8	2	4	4	8	4	8	2	4
It should be apparent what function a feedback signals	1	5	5	0	0	0	0	0	0	0	0	0	0
The user should look down at the joystick as few times as possible during use	5	5	25	2	10	2	10	2	10	2	10	4	20
The addition of new functions should cost as little as possible	3	5	15	2	6	3	9	4	12	2	6	2	6
There should be as few design requirements as possible with the product	2	5	10	2	4	4	8	5	10	2	4	2	4
The product should have a high level of robustness/low level of complexity	5	5	25	4	20	3	15	1	5	4	20	4	20
		85	**215**	**42**	**133**	**47**	**133**	**50**	**130**	**45**	**139**	**43**	**141**

Figure 4.14: Kesselring High speed driving, with a lot of function activation/deactivation

Figure 4.15: The strongest concept in Scenario 3 - Tactile push buttons, placed in the joystick handle.

5
Recommendations

A mentioned in 4.1, not only has user studies been carried out, but a test bench has also been developed for further studies. Therefore, there are two main recommendations, firstly, in regards to the user studies carried out, and secondly in regards to the test bench that has been created.

5.1 Plan for further development regarding the user studies

For further user studies, it is recommended to both perform quantitative studies along with extensive qualitative studies.

5.1.1 Recommendation on quantitative studies

In order to verify the findings presented in the cases in 4.3, there needs to be further quantitative studies where lots of users are involved in testing. It is therefore recommended that quantitative studies be carried out to verify the findings. The results from a study with only three participants should not lay basis for the development of a new joystick. Further quantitative studies would verify or falsify that which can be concluded from the results.

5.1.2 Recommendations on further qualitative studies

External factors as sounds and vibrations from a boat were not able to be replicated in the studies, and therefore should be implemented in future qualitative tests, to make sure that the findings presented in 4.3 still carries over to the actual real use case.

5.2 Future development recommendations in regards to the test bench

During the development phase, several different means of communicating feedback was discussed. Some of these ideas could not be realized due to shortage of time or lack of relevant knowledge. These different ideas will be presented below. As presented in 4.1, the modularity of the test bench will enable a future developer to test most of these concepts with relative ease.

5.2.1 The phone app

One idea is to replace the entire set of keys in the front with a phone connected to the joystick through lightning port or USB-C/3. The activation of functions as well as sound and haptic feedback could be managed through the phone. An app consisting of the desired function could be developed, that in turn communicates with the joystick over its button interface, or directly on the CAN bus. Custom software and hardware would have to developed to facilitate and execute the communication onto the buss as well as communicating over the button interface.

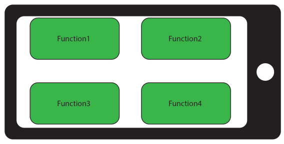

Figure 5.1: Idea on how the phone app could look like

The user would then activate functions on the phone in stead of using physical buttons. Having a phone acting as keypad would introduce one more possible source of failure in the system, and probably open up to possible vulnerabilities, especially if the phone communicated over the bus. Serious security measurements would have to be taken into consideration if taking this approach. One way could be to build a custom chip that can sit between the phone and the button interface that both translates the data and checks the contents of the data sent from the phone to make sure no malicious instructions can be sent over the button interface.

In addition, it must be considered a touchscreen can error in the presence of water and if the user is wearing gloves. In order to have a product that is easy to upgrade and also reliable, it would be interesting to look into having a screen together with a navigation device, see example in section 2.6.2.2, in this way you disconnect the activation part from the screen since this is where the limitations are.

5.2.2 Active haptic feedback in joystick movement

In the user tests users expressed great liking of the led-ring design. The only drawback was that they had to look at the joystick in order to receive the feedback about the direction of the boats velocity compared to their joystick direction. If this functionality instead could be translated into active haptic resistance in the joystick, users would get the necessary feedback without having to look at the joystick. When the boat is moving in one direction but the user points the joystick in the opposite direction a force could be applied on the joystick in the opposite direction of the joysticks movement. We believe this would be of great interest to investigate further. Since the Unity code already has checks implemented that compares the boats velocity to the joystick direction, this functionality of active haptic feedback could relatively easily be implemented and tested. The main thing needed to be further developed in regards to the code would be the communication from Unity to a potential joystick over the CAN-buss through the PCAN-adapter.

Though the PCAN-Api already has a function for writing on the buss, which simplifies the implementation. A joystick base with haptic feedback that communicates over a CAN-buss would be necessary in that case. Since all users expressed interest in the LED-based feedback we strongly recommend that active haptic feedback is further looked into, as it most likely is a even clearer and more useful implementation. In order to maintain quality and functionality with the implementation, ISO 9241-910:2011 Should be used as a basis as it covers the concept of force feedback extensively.

5.2.3 Feedback of function status separated from the joystick

In all cases users had to look at the joystick in order to determine what functions are activated at a certain time. This distracts the users from what actually is important, to be vigilant about the environment in which the boat is operated. If one was to somehow change where the status of the buttons is presented so that the users would not have to look at the joystick, users would be able to maneuver the boat in a safer and more controlled manner. On way to do this is projecting the status of each button onto the front window of the boat, or display it on the glass cockpit. As can be seen in figure 2.6, the current design of the joystick also implements visual feedback about function status in the button pad in the front. Since all users commented on this, we recommend that this is further looked into.

5.2.4 Button placement in joystick handle

During the user studies several users expressed their liking in having buttons placed in the joystick handle as long as the buttons controlled functions that needed to be activated a lot. Especially if the functions were active while the button was pressed. From the results, it can be concluded that users had a tendency to watch the joystick a lot less when having buttons integrated in the handle. Two users expressed the similarities of the joystick handle and a game controller. Neither one said they look at the controller while playing but still they know what button to push. The same was observed when using the joystick handle with buttons, as they tended to look a lot less at the joystick itself, and more at the screen with the simulation. We therefore recommend that buttons placement in the joystick handle should be looked into if the user is to activate functions frequently, but that the placement itself could be basis for a new study.

Also, all users pointed out that they would like to be able to activate functions using their left hand, since you are now required to cross your arms to reach the buttons. Because of this, it would be interesting to look at having the activation area placed to their left or in front of them. Furthermore, it would be interesting to look at selective placement of the activation area. Meaning the user could decide where to place the activation components. This could be solved e.g. by having the activation area attached to a pole, around which it could rotate.

In addition, the possibility of having touch sensors placed in the joystick handle could be investigated. One application where this could be beneficial is if the joystick is to be activated when the user grips it. There is a handle with IR-sensors in it that could be used for these studies.

6
Discussion

What did we find out whilst carrying out this project? Did it go the way we planned? Why? Why not? In this section this will be discussed.

The goal throughout the project was to carry out user studies in a scenario as close to reality as possible, also a test bench was to be constructed. Both these objectives have been met. The initial plan was to have a main focus on the user studies. Because of COVID-19, the main focus shifted to making a modular plug and play test bench instead.

There are two main deliverables from this project, the test bench and the exploratory user study along with a proposed methodology for further studies.

The result from the exploratory user studies are different depending on the user scenario. This was deemed as a good way to go since the future use of the joystick is uncertain at the time. The results from the user studies will need to lay base for future confirmatory user studies.

The test bench is modular and deemed easy to use in future studies.

6.1 Discussion on user studies

The user studies are exploratory and will need to be be complemented by confirmatory and quantitative studies. In addition, it would be interesting to perform tests on an actual boat. If the robustness of the CAN data from the test bench was to be improved, this would be possible.

6.1.1 Discussion on user base

In total three tests were carried out using the test bench. This is greatly important to keep in mind when reading and interpreting the recommendations and results. Had not the social distancing principles been carried throughout the world during the user-studies part of this project, the user base would probably have been a lot bigger.

The users in the studies conducted in this project were all in the same age-span of 25-27 years. One had been driving a boat and two had not. Also, one user was allowed to drive around using the simulator for a while before the test, making the user representing an experienced user of the joystick.

6.1.2 Discussion on user study environment

The user studies were carried out in a safe and non-stressful environment in an apartment. This scenario varies greatly from the actual scenario where a user is distracted by vibrations and loud sounds whilst having to navigate through crammed spaces. This means that some results regarding both auditive and haptic feedback may come into question as they were tested in an environment where the users were not impacted by the external sounds and vibrations present in an actual boat.

6.1.3 Discussion on the tests of the Penta Joystick in the user studies

The over all goal was to be able to let users test both the developed test bench and the Penta joystick in the same test and on the same premises, to have a comparison between the two. The communication of joystick position and activation of functions on the joystick worked well, but the visual and auditive feedback on the Penta joystick were not able to be activated. This may have impacted the user experience of the Penta Joystick for the worse and thereby skewed the results somewhat. A further study with these feedback activated would be necessary.

6.1.4 Discussion of possible symbiosis of solutions

In the user tests carried out, each activation component has been tested separately. For example, buttons in the joystick handle was not tested in combination with a touchscreen. The reason why this was not tested was the time limitation of the project. It would be interesting to study symbiosis of activation types since they would probably affect one another.

6.1.5 Discussion of the placement of the activation components

The activation components were only tested at one position. The touch sensors were tested in the front of the base, the touch screen was tested on the back and the tactile buttons were tested on the base front and in the handle. It would be of interest to try placing these components on other positions, the test bench is equipped for it.

In addition, placement of the activation components to the left of the centerpiece was not tested. It was deemed that this placement would be in the way when the user would sit down and that the user could possibly tear off the module. Despite this, it would be interesting to see of this hypothesis is true. The test bench is ready for these tests since there are side modules printed.

6.1.6 Discussion on the use of kesselring matrices

Product development is no exact science in the sense that quantification of functionalities and the level at which a concept achieves a function, has to be scored by the developers who carry out the methods. This will and always do result in biases being included. As is the case of a kesselring matrix, where both the weighting of requirements and the actual score a concept receives is most often is based on the understanding of the developers. This may result in some concepts receiving higher scores rather because the developers subconsciously, or consciously, gave them higher scores than that they actually performed better.

6.1.7 Dynamics of actual boats

In order to actually implement any of the proposed concepts, it is important to take the dynamics of a real boat into consideration. A real boat will have a certain engine able to produce a certain magnitude of thrust, as well as a gear box able to change the magnitude of the thrust over a set period of time. Both these principles impact the ability of a user to control the movement of the vessel. The maximum magnitude of the thrust will impact the maximum speed of the boat, whereas the gearbox will decide how fast a user can change the amount of thrust and thereby the speed of the boat. As every boat has a certain weight as well as geometry, it may react faster or slower to the users commands. This in turn may impact the use of haptic or visual feedback about the joystick position compared to the movement of the boat.

6.2 Discussion on the test bench

As there is no implementation of two-way communication between either the Seeeduino and Arduino to Unity, there is no way to sanity check the status of each button. A more robust system would be able to within certain time intervals check if the button-status in Unity is the same as on both the touch-screen and the LED's on the Seeeduino. As of right now, it is possible to activate a function on the touch-screen without the correct LED turning on.

Since the Seeeduino has to manage all button inputs as well as the speaker, vibration motor and the LED ring, there are not enough inputs to manage it all at once. Besides, the LED ring needs data from Unity whilst the buttons need to send data to Unity, which is not possible to do all at once as of right now. For this project it was reasonable to use Arduinos as they are easy to develop for, but for a future, and even more robust test bench, one should consider a custom chip which could manage all this at once. Especially in regards to any implementation of the LED ring, as it could read joystick data directly from the CAN bus instead of receiving it from Unity.

A way to manage all the communications whilst keeping the frame rate high in the simulator is to implement multi threading for the simulator. This would enable Unity to update each frame whilst at the same time reading and writing to the components. This would mean a re-writing of the code for the simulation.

The usage of touch buttons on a product that is meant to be used in stressful situations, may be problematic, as the identification of where the touch button is situated cannot be carried out without activating the function, if no other indication exist.

From early on it was decided that stickers were to be placed on each touch surface in order to help the user identify where the button was situated. This severely crippled the performance of the sensor which led to users having to press hard and several times on the touch surface in order to activate it. It was mentioned several times by users that this strongly impacted their score of the solution even though they liked the concept.

After discussions with experts at the company we understood that there is a great importance that the joystick does not activate by mistake when not in use. The idea with having sensors in the joystick handle that measured if there was a hand on the joystick grew from this reasoning, as the joystick would not be able to be activated when not gripped. This turned out to be harder than expected to implement, and users therefore had problems with activating the joystick over all.

6.2.1 Discussion on the simulator

The simulation itself was built over time whilst understanding of the Unity engine and the C#-language was gradually achieved. This means that some of the basic logic of the simulator uses redundant functions and components that slow the simulation down. As these part build up the basis, it is complex to change them without re-writing parts of the simulation. The decision to develop the simulation in 2D instead of 3D may also have impacted the user studies, as a "bird view" 2D view is by no means as immersive as a "over the shoulder" 3D view. As the interpretation of the data on the CAN bus in written with only the joystick in mind, there is no possibility of including other components, as for example a boat speed throttle, without re-writing this part. Whether this would be a big change or not is as complex question, but it would most certainly take some time.

As presented in 6.0.1.3 there is no sanity check on the status of an function between the simulation or the Seeeduino and the Arduino. This result in function status on the touchscreen not being updated on the LED's and vice verse. This functionality could relatively easily be implemented by before drawing each frame in the simulation, sending the status of each function to the Seeeduino and Arduino and then check if it corresponds to the internal values of button status they have logged. If this is not the case of any of the components, then change it. This was not implemented because of two main reasons. Firstly, since we never test the symbiosis of buttons, there is no point in making their status correspond to each other. Secondly, sending this info before every frame, without it being executed on a different thread, was ruled out as it most certainly would have slowed down the simulation severely.

The implementation and execution of the functions which the boat carries out in the simulation is based on the understanding received from communication with employees at CPAC. Misinterpretation of this information may have resulted in some functions not working as they would on a real boat.

6.2.2 Discussion on the big focus on creating the test bench and simulator

The reason why such a big focus was put on creating the test bench and the simulator was because it was deemed of utter importance to have a product that could be compared to the Penta joystick. In the beginning of the project, the importance of this was discussed, and whether or not a third party joystick could be used instead. Since the test bench is set to evaluate the user experience and not just the functionality, it was deemed of utter importance to have the user experience being as similar as possible to that of the Penta joystick.

6.2.3 Discussion on the choice of making the test bench modular

Making a design modular requires a lot more work than just designing it as a whole. As the objective of the test bench was to investigate different kinds of activation methods and feedback, it was decided that a modular approach would be a good idea as it opened the possibility to exchange components and mount new components without having to do a re-design of the entire component. New modules with new sensors or new feedback methods could also be connected to the test bench in the future because of the modularity.

When developing a modular solution, there has to be lots of work put into DFA and DFM, as every component needs an interface with another component. If this is not done properly, many revisions may have to be created before everything fits. By taking this into consideration early on, only one set of components had to be printed that fit together and were able to be assembled right away. The downside was that development of the test bench took up a big part of the process. On the other hand, developing several revisions would probably have taken the same time if not longer.

The choice of creating a modular test bench made the process more complex, but since one of the main objectives of the project was to make a test bench that could be used in future development processed, it was deemed to be the right decision.

6.2.4 Ethical considerations

When testing the current Penta joystick it was found out that not all users can grip the joystick comfortably. In order for this not being a drawback with the developed handle of the joystick in the test bench, it was decided that most users should be able to comfortably grip it.

It was decided to make the test bench reparable and up-gradable in order to not having it being thrown away and resulting in landfill if something inside breaks. The test bench can now instead be repaired and upgraded as see fit when necessary, and wont have to be thrown away when it breaks.

6.3 Learning outcomes

During the course of the project a learning outcome that could be drawn was the understanding and value of the importance of communication between developer and customer. Sometimes the customer does not have a clear view of what they want whilst the developers believe they develop what the customer desires. If constant and clear communication is not carried out in this case, there is a great risk of misunderstandings and development of an undesirable product. This gains neither side and causes delays. If instead consistent communication between parties and presentation of demos, there is a lot bigger chance of that which is being developed is what the customer desires.

The importance of documenting both code and design of physical components has also been critical throughout the project. There were lots of physical interfaces between components as in figure 6.1, where the measurements of where the bolts and nuts are supposed to be mounted needs to be the same on every module.

Figure 6.1: A slice of the interface between the centerpiece and a module.

The same is true regarding the code, as the code has been created over a long time it was necessary to comment it throughout so not to forget how the script worked.

One can never be ready for a situation like the COVID-19 pandemic, instead one has to find a way around when faced with it. The situation affected the project in the sense that not as many user studies could be carried out as desired. Furthermore, there were no available guidance on how to read the CAN data, how to make a simulator in unity or how to write C# scripts, because of this, many hours was put on learning these skills.

7
Conclusion

Benchmarking the current Penta joystick, understanding what constitutes intuity in a joystick and developing a conceptual design for a new joystick were the main goals of this project. A thorough benchmark of the current Penta joystick and its functionalities was carried out in order to understand what constitutes intuity in regards to different kind of feedback to the user. This knowledge was later applied in order to develop a test bench, in which different kinds of feedback and buttons were tested in order to determine what users prefer. An analysis of these findings was also carried out depending on three scenarios in which the joystick could be used. Further more, the test bench is meant to be used not only in this project but further on into the future, and was therefore developed with modularity, repairability and upgradeability in mind. This all covers the main questions presented in 1.5.

Further development should be carried out in the field of joystick design, and in particular in regards to what feedback users receive. The visual feedback is the main one on the current joystick, but as uncovered, if these are positioned on the joystick, users may have to spend time looking at them while driving which is not ideal. Other feedback as sound and haptic feedback enabled a user to receive this feedback without having to spend too much time looking at the joystick. Further more, the placement of buttons on the joystick play a big role in how the users interact with a joystick.

From all this it can be concluded that further studies and development in the field could be carried out in order to raise the user experience of the product, and with the test bench as a tool, CPAC now has the perfect opportunity to do so.

References

Alben, L. (1996). *Quality of experience.* Available at https://dl.acm.org/doi/pdf/10.1145/235008.235010.

Almefelt, L. (2019). *Systematic design - overview.* Available at https://pingpong.chalmers.se/courseId/10076/node.do?id=5148727&ts=1548074649590&u=-1054933394.

Aqua Marine. (2020). *Xenta systems.* Available at https://www.aquamaremarine.com/uk/xenta-systems/.

Bligård, L. (2018). *L14-method v-interaction analysis hfee 2018.* (PowerPoint presentation)

Boat Mag International. (2020). *Joysticks for everybody with jcs plus by yacht controller.* Available at http://www.boatmaginternational.com/216-joystick-controls-yacht-controller/.

BoatDiesel. (2020). *Volvo penta ips joystick - success from the start.* Available at https://boatdiesel.com/News/Volvo-Penta/N-710/Volvo-Penta-IPS-Joystick-success-from-the-start.cfm.

Boating Magazine. (2020). *Seastar optimus 360 joystick.* Available at https://www.boatingmag.com/2019-seastar-optimus-360-joystick-docking-control/?loc=offramp&lnk=seastar-optimus-360-joystick-docking-control&dom=section-2.

Båtliv. (2020). *Joystick för inombordare från cummins.* Available at https://www.batliv.se/2013/09/17/article6990/.

CPAC. (2020). *Easy boating.* Available at https://cpacsystems.se/marine/.

Curtis-Wright. (2014). *Jc8000 rugged multi-axis joystick controller.* Available at https://www.dimed.eu/media/catalog/product/cache/1/image/650x/040ec09b1e35df139433887a97daa66f/j/c/jc8000.jpg.

Di Natale, M. (2008). *Understanding and using the controller area network.* Available at http://inst.cs.berkeley.edu/~ee249/fa08/Lectures/handout_canbus2.pdf.

elektor. (2020). *Arduino uno r3.* Available at https://www.elektor.com/arduino-uno-r3.

elfa. (2020). *102010228 - seeeduino lotus cortex-m0+-utvecklingskort, seeed studio.* Available at https://www.elfa.se/sv/seeeduino-lotus-cortex-m0-utvecklingskort-seeed-studio-102010228/p/30149402.

Fast Product Development. (2020). *Modular design of products, hardware and software.* Available at http://www.fast-product-development.com/modular-design-benefits-disadvantages.html#modular_design_top.

F. McQuarrie, E. (2006). *The market research toolbox: A concise guide for beginners* (4th ed.). Santa Clara: Sage Publishing.

Fundamentals, S. T. (2020). *Black box testing.* Available at http://softwaretestingfundamentals.com/black-box-testing/.

Hammar, L. (2019). *Design for am.* Available at https://pingpong.chalmers.se/courseId/10406/node.do?id=5202935&ts=1550870117307&u=-1054933394.

Hryha, E. (2019). *Overview of am technologies and materials part 2.* Available at https://pingpong.chalmers.se/courseId/10406/node.do?id=5161460&ts=1548417238569&u=-1054933394.

Hvas Mortensen, D. (2020). *Pros and cons of conducting user interviews.* Available at https://www.interaction-design.org/literature/article/pros-and-cons-of-conducting-user-interviews.

International Organization for standardization. (2019). *Ss-en iso 9241-210:2019.* Available at https://www.sis.se/.

Kent, R. (2017). *Cost management in plastics processing: Strategies, targets, techniques, and tools* (4th ed.). NA: Elsevier.

Malmqvist, J. (2019). *Product planning – needs and opportunities (ppu085), lecture 9: Quantitative data collection.* (PowerPoint presentation)

Mcleod, S. (2015). *Observation methods.* Available at https://www.simplypsychology.org/observation.html.

Mercury Marines. (2020). *Joystick piloting for sterndrives - axius.* Available at https://www.mercurymarine.com/en-gb/se/gauges-and-controls/steering/axius-joystick-piloting-for-sterndrives/.

Parizet, E., Guyader, E., & Nosulenko, V. (2008, jan.). Analysis of car door closing sound quality. *Applied Acoustics 69(1)*, 12-22. ([Online]. Available: https://www.researchgate.net/publication/223501996_Analysis_of_car_door_closing_sound_quality. Retrieved: apr. 5, 2020) doi: 10.1016/j.apacoust.2006.09.004

Ramalhete, R. (2017). *Does a modular design approach future-proof your concept?* Available at https://uxstudioteam.com/ux-blog/modular-design/.

Seeed Technology Co.,Ltd. (2020a). *Grove - speaker.* Available at https://wiki.seeedstudio.com/Grove-Speaker/.

Seeed Technology Co.,Ltd. (2020b). *Grove - vibration motor.* Available at https://wiki.seeedstudio.com/Grove-Vibration_Motor/.

Sony. (2020). *Playstation ds3 controller.* Available at https://media.playstation.com/is/image/SCEA/ds3-black-large-imageblock-us-18nov14?\protect\T1\textdollarTwoColumn_Image\protect\T1\textdollar.

Spacey, J. (2016). *22 types of prototype.* Available at https://simplicable.com/new/prototypes.

Steven C. Wheelwright, . K. B. C. (1992). *Revolutionizing product development* (5th ed.). New York: The free press.

Stienstra, D. (2019). *Introduction to design for (cost effective) assembly and manufacturing.* Available at https://longform.sayan.ee/dfa-dfm.

Söderström, (2019). *Workstation design and hand held tools.* Available at https://pingpong.chalmers.se/courseId/10021/node.do?id=

5076119&ts=1544296342342&u=-1054933394.
Unity Technologies. (2020). *Rigidbody 2d.* https://docs.unity3d.com/Manual/class-Rigidbody2D.html.
Volvo Penta. (2020). *Reglage och joystickar.* Available at https://www.volvopenta.se/marineleisure/sv-se/products/motor-yacht/ranges/inboard-shaft/options/driver-interface-inboard-shaft-my-ml/controls-and-joysticks-for-inboard-shaft.html.
Wallgren, P. (2019). *Qualitative methods.* (PowerPoint presentation)
x plane. (2020). *Jas 39 gripen.* Available at https://www.x-plane.org/home/urf/aviation/gripen/cockpit/gripen-cockpit.html.
Xotic Tech. (2020). *Jdm metal aluminum center console idrive multimedia controller knob decor ring cover for bmw red/ blue.* Available at https://cdn.shopify.com/s/files/1/1899/5021/products/r-2_6459e750-90a7-45f9-8f49-6b99479e4032.jpg?v=1531296854.
Yanmar Marine. (2020). *Jc20.* Available at https://www.yanmarmarine.com/News-detail/YANMAR-JC20-Joystick-Now-Available/.
ZF. (2020). *Joystick maneuvering system.* Available at https://www.zf.com/products/en/marine/products_29109.html.

A
Requirements specification

Source	Field	Requirement	Justification	Evaluation/verification	Req./Wish
Technical test	Cognitive ergonomics	The joystick should be able to controll the translation of a boat	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
Technical test	Cognitive ergonomics	The joystick should be able to controll the rotation of a boat	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
Technical test	Cognitive ergonomics	The function DPS should be able to be activated	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
Technical test	Cognitive ergonomics	The function High Mode should be able to be activated	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
Technical test	Cognitive ergonomics	The functon Joystick docking should be able to be activated	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
Technical test	Cognitive ergonomics	The function pin-steering should be able to be activated	The new version will have to be able to do teh same things as its predecessor	Evaluation of prototype	R
User studies	Cognitive ergonomics	The user should be able to distinguish the buttons apart	It is important that the user understands what button does what	User studies	R
User studies	Cognitive ergonomics	The user should be able to differentiate the activation buttons from each other visually	It is important that the user understands what button does what - through visuals	User studies	W
User studies	Cognitive ergonomics	The user should be able to differentiate the activation buttons from each other haptically	It is important that the user understands what button does what - through haptics	User studies	W
User studies	Cognitive ergonomics	The user should recieve feedback about if a function is activated/deactivated	*Users expressed this as necessary*	User studies	R
User studies	Cognitive ergonomics	The user should get feedback about the activation/deactivation of a function visually	-Through visuals	User studies	W
User studies	Cognitive ergonomics	The user should get feedback about the activation/deactivation of a function auditive	-Through audio	User studies	W
User studies	Cognitive ergonomics	The user should get feedback about the activation/deactivation of a function haptically	Through haptics	User studies	W
User studies	Cognitive ergonomics	The movement of the boat as compred to the movement of the joystick should be communicated to the user	Users have expressed that this probably would rais the cognitive ergonomics	Functional tests	W
User studies	Cognitive ergonomics	There should be a visual feedback on the joystick about the direction of teh boat	One way is through visual feedback	Functional tests	W
User studies	Functional requirements	It should not be apparent for others than the user that the joystick is activated	Some users haev expressed that they do not like it when the joystick makes a sound and everyone in the boat understands that they use a joystick	Functional tests	W
User studies	Functional requirements	There should be support for activation of future functions	Teh joystick should be able to be udated with new functions without a major re-design	Functional tests	W
User studies	Cognitive ergonomics	The buttons should be integrated into the joystick design	Buttons shoudl be placed on the joystick, not on external devices	Functional tests	W
User studies	Functional requirements	The user should not mistakenly activate the wrong function	Safety	User studies	R
User studies	Functional requirements	The user should not mistakenly activate the wrong function	Safety	User studies	W
User studies	Cognitive ergonomics	It should be apparent what function a feedback signals	Cognitive ergonomics	User studies	W
User studies	Cognitive ergonomics	The user should look down at the joystick as few times as possible during use	Safety	User studies	W
User studies	Technical requirements	The addition of new functions should cost as little as possible	Lowering cost	User studies	W
Literature studies	Technical requirements	There should be as few design requirements as possible with the product	Less restricted design	User studies	W
Literature studies	Technical requirements	The joystick should have a high level of robustness/low level of complexity	Simplicity	User studies	W
Literature studies	Technical requirements	The joystick should keep its functionality when used in the actual environment	Reality	User studies	R

Figure A.1: Requirements specification

B

Transcripts from the user studies

	Hur tänkte du kring möjligheten att hitta rätt aktiveringsplats?	Hur tänkte du kring möjligheten att aktivera rätt funktion	Hur lätt var det att avgöra att en funktion aktiverades/deaktiverades?	Hur lätt var det att avgöra om en funktion var aktiverad/deaktiverad?	Vad var ditt intryck överlag?	Övriga kommentarer
	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer
Touch, bas						
visuell			man har vant sig att kolla lamporna lite mer nu, men det är ju lite lurigt när det inte ör nån slags återkoppling liksom förutom att det finns lampor.	att se att den är aktiverad då är det ju i stort sett liksom 10 liksom, om lamporna ska vara vid lamporna hade inte spleat så stor roll om jag bara vill kolla om den är aktiverad så därför vill jag ändå säga typ 10, man kan kan ju inte ha nåt annat, man kan ju inte ha en siren liksom.	Jag gillade den förra mer, om denvar 5-6 så skulle jag säga 4, det är lite lurigt att amn inte får nån återkoppling att man måste kolla hela tiden.	
visuell & haptisk			10 alltså, vibration, vilken grej, det är nice!	nu när man körde en gång till, att lamporna sitter häruppe när knapparna sitter här och det finns plats runt knapparna så hade det varit bättre om det hade lyst vid knapparna så man inte behöver titta, man behöver a koll där(på skärmen), där (vart man ska trycka) och där (på dioderna), har man kört mycket så vet man såklart, men att det är två olika ställen det kanske inte fungerar toppen så kanske en 6a	jag tänkte på det nu mer när man hade vant sig att det var 2 olika ställen, nu funkade knapparna bättre, men jag tror att så här eftersom att de ligger här precis under så är det inte så ergonomiskt, man vill antingen göra så(använda vänsterhanden) och då blir det en konstig rörelse eller så måste man släppa spaken så kanske had evarit bättre att ha dem på sidan här om man vill ha allt i en box. Det blir lite konstig rörelse att behöva korsa armarna i stort sett.	
visuell & auditiv			Samma som nedan			
visuell, haptisk & auditiv	lätt att hitta vilken som var rätt, att klicka var desto svårare. Visste inte att det var touch.	samma	man fattade att led skulle lysa så det var lätt	samma	vet inte om jag gillar touch på såna grejer just. Känns som att det kan bli blött, det krånglar ju på mobilen bara det	
Knappar, bas						
visuell	enkelt, att hitta vart man skulle klicka var lika enkelt som förut, eller nä, en lite konstigare grej är att knapparna inte sitter i samma ordning som dioderna sitter, man vill ju ha a och d däruppe, man tänker att man ska kolla, man had evelat haft q uppe till vänster, svårt att hitta då man vant sig vid den andra, men 6 typ.				det som är lite lurigt, nu måste man inte tänka på att trycka, det är krånglgare med touch, men nu hade man vant sig vid den förra setupen innan, placeringen av knappanra blir lite konstigt. hade fått 9 om man hade placerat om knapparna, 10 är att lamporna är jämte knapparna.	
visuell & haptisk			8-9 om förra var med ljud, kände att det var vibration men det var lite svårt att känna det tycker jag, jag kände det inte utan bara antog att det var vibration så samma intryck som på den första(bara visuell)			
visuell & auditiv			samma som nedan			
visuell, haptisk & auditiv			alltså 10, men om man kan kolla på verkligheten om man är ute på havet så kan det nog blåsa lite, och ljudgrejer på en båt kanske inte fungerar, om man inte är inomhus då.	dte fungerar bra liksom, det är en lampa som lyser, hade varit bättre att ha den vid knappen.	ingen stor skillad från förra, det var enklare men inte så stor skillnad, den förra kanske skulle varit en 7 istället	
Touchskärm, bas						
visuell			Alltså guld, 10 av 10. bra att det lyser på knappen.		fortfarande inte så bra, det som saknades var att den satt på höger sida, hade hellre haft den på andra sidan.man vill inte släppa spaken och ska man använda vänsterhanden så blir det en obekväm rörelse. om du ska jämföra en touchskärm med fysiska knappar, vad tänker du där?- jag gillade fysiska knappar mer, förutom att skärmen hade bättre visuell feedback. Fysiska knappar är mer tillförlitliga, man vet att de alltid funkar. Touchskärm funkar inte om den blir blöt eller om man har handskar på sig. jag gillar inte touch då jag inte litar på att tekniken kommer fungera.	Vad tänkte du om positioneringen?-den här var bättre iaf, sen hade man velat haft den här(till vänster) kanske.
Knappar, handtag						
visuell			När jag testat den med all feedback så var inte denna så imponerande			
visuell & haptisk			Samma som ovan			
visuell & auditiv			Samma som ovan			
visuell, haptisk & auditiv	Applåd! när man väl bara öärde sig vilken ordning de låg i så var det jätteenkelt, det här är som en playstationkontroll, man vill ju inte kolla på kontrollen när man spelar fifa liksom.		Den låter ju så kanon.	man kan ju inte ha det på spaken, där är det ju bra men kanske hade varit ännu bättre att ha det framför sig så man inte behövde kolla ner men det är bra ändå.	Det här var bäst	kändes det som att du skulle kunna trycka in knappar av misstag? Ja det är man väl lite rädd för ändå, den nedre framförallt, man använder långfingret för att röra joysticken.

Figure B.1: Transcript from test user 1

	Hur tänkte du kring möjligheten att hitta rätt aktiveringsplats?	Hur tänkte du kring möjligheten att aktivera rätt funktion	Hur var det att avgöra att en funktion aktiverades/deaktiverades?	Hur lätt var det att avgöra om en funktion var aktiverad/deaktiverad?	Vad var ditt intryck överlag?	Övriga kommentarer
	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer
Touch, bas						
visuell			mycket mycket bättre, det kändes mycket mer flytande nu för att det funkade bättre(lättare att trycka), största skillnaden(mmärkte inte att det var vibration i den tidigare). jag lärde mig att okej H ligger där osv, jag behövde ändå tita på den för att se att den är på och att jag vill försäkra mig själv om att det är rätt knapp jag klickar på. Märkte ingen skillnad på feedbacken från de två tidigare men det krävdes bara att jag la tummen på för att funktionen skulle aktiveras.		Märkte ingen skillnad från de tidigare angående feedbacken, så länge den aktiveras bara jag lägger tummen på , att jag bara behöver göra det en gång snarare än att jag behöver trycka flera gånger så kanske inte jag behöver lika mycket feedback. Jag hade mycket mer förtroende för att knapparna fungerade.	
visuell & haptisk			återigen, jag har bara lamporna att gå på(märkte inte vibrationen), nu har man vant sig, nu blir det mer som en inlärd rörelse, att man trycker här, min blick går ner mot knappen, klickar och sen så väntar jag med blicken här på tills den aktiveras.		nu pep den ju inte, men det märkte jag ju inte förra gången heller satt, eller jag tänkte inte på det snarare, det är fortfarande som tidigare, överlag så är det en bra lösning men kommunikationen av vilka funktioner som är aktiverade och inte aktiverade kanske behöver förbättras.	Märkte inte att han fick haptisk feedback
visuell & auditiv						
visuell, haptisk & auditiv	hörde inte ljudet, tänkte inte på det, förväntade sig inte feedback. "väldigt komplicerat alltså", dels en faktor att jag inte gjort det innan så jag vet ju inte. jag associerar det med att sätta mig i en manuell bil att om det var olika sätt att lägga i växeln på olika bilar, man måste ju lära sig det först har dom ligger innan man kan börja navigera själva den. och det vr krångligt at trycka när det var touch, jag tänker att jag har ju ögonen framåt och då vill jag nästan känna det på automatik för att slippa ta blicken från skärmen, typ som blinkersen på bilen, man vet att den sitter där, den spaken istället för en knapp typ, och man vet sin gas och broms. Om 1 gör jobbet väldigt bra, 0 fungerar inte och 5 fungerar men det är ingen surprise så 3 för det var svårt att aktivera dem(touchknapparna funkade dåligt)	samma	det var väldigt otydligt, det enda var ju de här liksom(lysdioderna), jag vet ju inte vad de olika knapparna gör så det var lite svårt att få, jag fick ju feedbacken mendet är ju inte där jag kollar när jag kör liksom, för joysticken är ju väldigt intuitiv men då vill jag ju ha den informationen på ett annat sätt.	jag hade inte velat släppa blicken ifrån vad som är framför mig, så jag hade velat ha den informationen som är här(på dioderna) på något sätt i det fältet jag kllar när jag styr båten så det jag direkt hoppar till är att man hade velat haft nån laser... Fick väldigt bra intryck av själva joysticken, men knapparna sänkte den.		blev chockad över att han kunde snurra joysticken.
Knappar, bas						
visuell	de sitter ju inte på samma plats längre så mitt muskelminne från tidigare blev lite rubbat, men jag skulle säga att den låg i linje, touchen fungerade väl och det här fungerade också väl men jag tror att om jag haft mitt musjelminne kvar så hade jag inte behövt kolla lika mycket på dom. då hade det varit enklare.		den var mycket tydligare nu, jag kollade fortfarande ner men jag fick mer feedback när jag tryckte in nånting, jag fick knapprespons.		mycket bra	kan du se några fördelar med att ha en touchyta: Som användare så ser jag inga fördelar med det men de positiva sakerna jag ser är som utvecklare, om du inte har d-funktionen till exempel så har du inte en tom knapp utan det kan vara nåt annat där eller så, men inte som användare nej. vad tycker du om det visuella intrycket: Slät yta är finare men det känns som de här fina silverbesticken man har på jul, de är fina att kolla på men de går inte att skära i kött med. Det ser snyggt ut men funktionen tar stryk.
visuell & haptisk					jag hade velat haft knapparna vid vänsterhanden istället, som en separat konsol. Hade varit gött att slippa gör allt med en hand. obekväm rörelse om jag skulle trycka på knappen amed vänsterhanden, som att växla i en bil med vänsterhanden, det gör man ju inte, kan inte släppa ratten för att växla.	Märkte ingen skillnad från de två tidigare koncepten, släppte joysticken varje gång han skulle aktivera en funktion så då kände han inte vibrationerna.
visuell & auditiv			Märkte inte ljudet			
visuell, haptisk & auditiv			väldigt snarlik innan, ingen upplevd skillnad så, det är fortfarande tydligt med själva knapparna. Jag tänkte inte på ljudet, förrän nu när du sa det, inte när jag tryckte. räknar du in tt det hörs när knappen trycks ner eller bara att man känner att den trycks ner- Oh, det är nog båda alltås, man hörde ju plast liksom, jag tänkte på det innan att den har ju ett visst ljud den ger ifrån sig.		Ingen skillnad från den tidigare, det ger väldigt mycket att man trycker på en fysisk knapp.	
Touchskärm, bas						
visuell			Väldigt tydligt alltså, en kombination av att där jag klickar, där får jag feedback. Det jag har mina ögon på, det ger både feedback och det är även där jag interagerar med själva produkten, det skulle jag säga är en väldigt stor anledning till att den var bra.	helt omöjligt att missta så länge man inte är färgblind.	Angående positioneringen av touchskärmen: Den kändes lite mer klänkig, men jag gillade att jag kunde vila handen, rent ergonomiskt så är det bättre att ha stöd än att ha handen i luften som med den tidigare. Den här kändes dock inte lika stabil(mer prototypens fel). Om jag behöver använda vänsterhanden så är det bättre att ha den framför för att jag kan fortfarande röra joysticken som jag vill, jag blickar inte den med den andra armen, om man har den där fram så blir det att man måste ha en handledsrörelse bara istället för en armrörelse som man nog hellre har. Hur skulle du jämföra en tuchskärm mot fysiska knappar?- rent att trycka på så gillar jag touch mer förutset att den kan ge både informationen på den knapp jag klickar på, annars är det inte att föredra. vidare, om jag inte har h-funktionen så är det lättare för en utvecklare att bara ta bort den knappen på en touchskärm, det ger bättre intryck som användar eom det inte är en tom knapp. lättare för en utvecklare att ändra mjukvara än hårdvara. Litar du mest på att en touchskärm ska fungera eller en fysisk knapp?:- förutsett att jag kan få visuell feedback i samma skärm, då vet jag att skärmen fungerar och att funktionen aktiveras, gentemot om jag bara haft knappar utan feedback. vad skulle du tyckt om ifall knappen stannar intryckt?:-förtroendet för mig ligger inte i att knappen stannar inne eller att den går ut igen utan att jag faktiskt trycker ner den, och då spelar det ingen roll om den stannar intryckt om jag på nåt sätt kan få information om att den har aktiverats när den gått tillbaks. Hade hellre haft en intryckt variant framför en diod, mest enligt magkänsla, om den stannar inne så är den fysiskt aktiverad så tänker man att man kan lita på det.	
Knappar, handtag						
visuell						
visuell & haptisk						
visuell & auditiv						
visuell, haptisk & auditiv	Jättebra, inget negativt med det över huvud taget. Vi snackar 10.	utan handbok, när man först sätter sig vid den kan det vara lite frågetecken,vad som är vad, sen så tar det några knapptryck och då har man lärt sig det. Jag vet inte hur ofta man aktiverar de olika funktionerna, men om man aktiverar dem väldigt sällan då tänker jag att det är lätt att glömma bort det, om det är den övre eller nedre, eller ovanpå för den delen, att den hjälper snarare än stjälper i de lägena	Väldigt lätt, klickljud, solklar, märkte inte vibrationsfeedbacken.Ljudet var hundra procent, faktumet att det var både en fysisk klickknapp och pipjud, det säljer väldigt bra alltså och som kombination, väldigt elegant löst.	Den enda feedbacken man fick var dioderna så jag tror jag tittade ner någong gång för att se om jag verkligen hade aktiverat en funktion eller inte. Men typ assisted var ju väldigt tydlig för om man inte hr den aktiverad så styr ju inte båten så det märker man ju även om man inte får feedback	Jag tycker inte knapparna var i vägen för de var väldigt små, som de är nu så är de inte alls intrusive och jag tror att om det är ännu mer ergonomiskt utformat, som de gamla microsoft flygjoystickarna där knapparna är integrerade i designen det kommer ta dem den sista vägen men att ha dem såhär, det hjälper jättemycket tycker jag.	"I loved this shit" utbrast han direkt efteråt.

Figure B.2: Transcript from test user 2

	Hur tänkte du kring möjligheten att hitta rätt aktiveringsplats?	Hur tänkte du kring möjligheten att aktivera rätt funktion	Hur var det att avgöra att en funktion aktiverades/deaktiverades?	Hur var det att avgöra om en funktion var aktiverad/deaktiverad?	Vad var ditt intryck överlag?	Övriga kommentarer
	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer	Kommentarer
Touch, bas						
visuell	Inte tydligt vart själva knappen satt, visste inte hur hårt jag behöver trycka	Inga problem	Ganska svårt, bara ledn som gav feedback	Man kunde kolla på ledn men då måste man kolla på dem hela tiden	Sämre knapp då den inte aktiveras hela tiden då man vill. Men bättre än vanlig keypad	Touchplatta känns inte så robust och båtigt, vanliga knappar känns mer båtigt. Känns konstigt med touch om det blir blött typ
visuell & haptisk	Inte tydligt vart själva knappen satt, visste inte hur hårt jag behöver trycka	Inga problem	Ganska svårt, bara ledn som gav feedback	Man kännde att det vibrarade men vibrerade i handtaget istället för i touchytan. Bara vibration är inte nice	Känns som att vibrationen sitter i handtaget inte i touchplattan. Man ska ha vibration där den ska vara	
visuell & auditiv			Finns utrymme för misstolkning när både vibration och auditivt samtidigt	Bästa alternativet av touchyta-varianten	Beroende på vilken situation man kör i kan det vara jobbigt med auditiv feedback, t.ex kör man en båt i storm där hytten inte är helt isolerad kan det bli svårt att höra	
visuell, haptisk & auditiv	Man måste känna sig fram vart aktiveringsytan är, och när man känner vart den är aktiverar man funktionen	Inga problem	Ganska svårt, bara ledn som gav feedback	Vill ha vibration för aktivering och ljud för deaktivering		
Knappar, bas						
visuell	Samma	Samma	Samma	Gillade inte att bara ha visuell feedback, ströde mig på knapparna	"Det ska mycket till att göra en bra knapp om man inte har ljud/vibration!"	
visuell & haptisk				Gillade inte att ha bara vibration		
visuell & auditiv	Samma	Samma	Samma	Jag tycker inte att en vibration passar vid aktivering av funktioner. då jag förknippar det med något negativt		
visuell, haptisk & auditiv	Det var jättelätt att hitta rätt aktiveringsplats. Möjligt att man av misstag skulle kunna tro att man kan trycka på lederna för att aktivera funktion	Man aktiverar inte fel om man tänker efter	Lätt att avgöra genom att kolla på lampan, men enklast om man har ljud och vibration också	Kollar på leder för att avgöra detta	Typ ett gasreglage hade passat i handtaget, typ om man skulle kunna få lite mer kraft när man trycker in en knapp i handtaget	1. Förvirrande att sensorerna i handtaget inte användes i testet. 2. T.ex i tv-spel betyder vibration att något negativt inträffar, typ att man börjar sladda eller åker in i något.
Touchskärm, bas						
visuell	Gillar att trycka på bokstaven för att aktivera funktion vilket man gör på skärmen	Lätt då man ser på knappen ifall den är på eller av, man behöver inte kolla på led för att avgöra	Enkelt om man kollar på skärmen	Man fick direkt feedback från touch-skärmen om vad som aktivers/deaktiveras	Känns framtida/modernt att ha touchskärm. Bättre med touchskärm än touchknapp. Funktionalitetsmässigt kan man lika gärn ha en knapp som lyser	Hade velat ha touchskärmen skiljd från joystcicken, så slipper man använda sin vänsterhand för att aktivera funktioner
Knappar, handtag						
visuell	Inte alls lika nice med ingen feedback.Det är lite otillfredställande utan feedback	Jag aktiverade fel funktion ett par gånger, förestod efter att tag att lamporna var positionerade som aktiveringsplatserna	Jag ville kolla på lampan hela tiden, litatde inte på bara det mekaniska klicket i knappen som feedback	mer förvirrad för fick ingen respons, sämre intryck överlag. förvirrad om det ens hänt nånting.	mycket sämre	Gillade att lederna är positionerade på samma vis som aktiveringsplatserna på joysticken.
visuell & haptisk						
visuell & auditiv						
visuell, haptisk & auditiv	Jag lärde mig snabbt vart de satt då jag behövde hoppa mellan dem mycket.	Det var lätt, kände att jag råkade aktivera funktioner av misstag.		Gillade att man fick audiotiv feedback när funktionen aktiverades. Kollade ner på lederna för att dubbelkolla vilka funktioner som var aktiverade.	Bra men hade velat ha variation i feedbacken, att den surrar när den aktiveras, men låter när den deaktiveras. Att man skiljer dessa åt feedbacksmässigt.	

Figure B.3: Transcript from test user 3