E-bike Simulator – a virtual reality application that evaluates user interfaces in an urban traffic environment

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DIVISION OF ERGONOMICS AND AEROSOL TECHNOLOGY | DEPARTMENT OF DESIGN SCIENCES | FACULTY OF ENGINEERING LTH | LUND UNIVERSITY | 2019

MASTER'S THESIS

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LUND
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Abstract

When developing a User Interface (UI), testing the design in a designated area of use is of the utmost importance. However, Testing a UI for a bike in a traffic environment can be both difficult and risky. This thesis aims to solve this problem by developing a VR application in which UIs can be compared and evaluated in a controlled environment. This was completed by following the principals of a user centered design, resulting in a VR simulator of a bike ride in a city environment. Users could hop on a stationed bike while using both controllers to steer and accelerate to ride around in the city. Motion sickness was reported to be an issue that needed solving. It proved to be an obstacle that hindered some users even after proposed solutions were applied.

Keywords: Virtual Reality, Simulation, User Interface, E-bike, motion sickness

Sammanfattning

När man utvecklar ett användargränssnitt (UI), är det viktigt att kunna testa designen i det eftersökta användningsområdet. Att Testa UI i trafikmiljöer kan vara både svårt och riskabelt. Avhandlingen syftar till att lösa problemet genom att utveckla en VR-applikation där användargränssnitt kan jämföras och utvärderas i en kontrollerad miljö. Detta utfördes genom att följa principerna för en användarcentrerad design, vilket resulterade i en VR-simulator av en cykeltur i en stadsmiljö. Användare kan hoppa på en stationerad cykel och med hjälp av två kontroller åka runt i staden. Åksjuka har rapporterats vara ett tröskel som man försökt lösa i avhandlingen. Problemet kvarstod bland en del av användarna även efter att lösningsförslag var applicerade.

Keywords: Virtual Reality, Simulation, User Interface, E-bike, motion sickness

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Abbreviations

The following list contains some often used abbreviations, with a quick explanation.

VR - Virtual Reality, a computer system which can generate a man-made world, in which the user can immerse, roam, and operate objects.

HMD - Head Mounted Display, a display worn on the head, allowing for free head motion, and in some cases full body mobility.

FOV - Field of View, how much of the observable world a person sees at a given time. Often used to indicate restriction, when wearing goggles etc.

FPS - Frames Per Second, is the frequency at which consecutive images appear on the display.

UI - User Interface, the means with which a person controls a software application or hardware device.

NASA-TLX - NASA Task Load Index, a subjective assessment tool that can be used to measure an estimate of the workload of a task or a system.

SUS - System Usability Scale, a tool for quickly measuring reliability of a system.

UCD - User-Centered Design, is an iterative design process in which designers focus on the users and their needs in each phase of the design process.

Chapter 1

Introduction

This chapter will cover the background, purpose and goals as well as the research questions that will be the core focus of the thesis. It will include a small segment about Bosch R&D in Lund and what they are developing related to this work. A few previous related works will be introduced as a measure of comparison to this thesis as well as a list of both hardware and software tools required to perform the tasks at hand.

1.1 Background

With the increase of population in cities more effective methods of transportation and infrastructural changes are needed [23]. These new changes have given public transportation a more sustainable and environmentally friendly approach to utilize and create a healthy city. Nowadays more and more people are using the bike as their preferred means of transportation. This has led to an increased investment into sustainable urban planning and the building of larger and more secure bicycle paths. The technology also tries to keep up with the development and today there are already a number of apps that help the users navigate around the city. Some examples of apps are Google Maps, Sygic and MapQuest. However, there are some risks associated with riding a bike and looking at a display, such as staring at the display for too long and forgetting about the road. Therefore it is of grave importance taking these risks into account when creating a bike application. This project aims to develop a tool that can take these risks into account when developing similar applications for bicycles. With the help of Virtual Reality as a prototyping tool, a simulation of a bike-ride can be created to study specific use cases. An UI designer would have the possibility to control attention time of the application, thus minimizing the risks of a bike accidents.

1.2 Robert Bosch AB

Bosch is a major multinational electronics and engineering company. The unit that resides in Lund, Sweden work primarily with software development related to the automotive, e-bikes and internet of things. Recently Bosch started exploring new ways of testing and improving their user interfaces for their E-bikes resulting in this thesis [18].

1.3 Purpose and project goals

The purpose of this thesis is to investigate if VR can be used to study human interactions with a mobile device mounted on an e-bike during operation. This is done by using the game engine Unity in combination with VR to develop a tool for analyzing user interactions with both the environment and the device.

Following are the project objectives:

- Create a VR environment in which a bike user interface can be tested and evaluated.
- Create physical interaction inputs that can maneuver the bike in VR.
- The simulator should have the ability to perform unusual test cases in VR that otherwise cannot be tested in real life.
- The simulator should have the ability to easily upload HTML-application prototypes into the bike's virtual processing unit in order to test and evaluate different application in a cost-efficient manner.

1.4 Research questions

- How well does the interaction in VR correspond to real-life interaction?
- Is it possible to simulate a bike ride in VR with a sufficient level of immersion?
- Will the motion sickness be overwhelming and ruin the overall user experience?
- Will the resolution be sufficient so that the details in the bike's interface are visible enough?
- Will the user be deceived by the stimuli in the VR and lose balance in real life? If so, can this be mitigated?

1.5 Project limitations and delimitations

Since this project acts as a proof of concept, only the main functionality will be implemented. Hence, no unusual test scenarios will be tested. However, the capability to implement unusual test scenarios will be discussed in the report. Due to the imposed time limitation of 20 week and the limited availability of the VR eye tracking headset HTC Vive Pro eye; machine learning and eye tracking will only be discussed. Another major limitation is the fact that Bosch has blacklisted a lot of websites, software and hardware

components due to security reasons. Since this project will be carried out at the Bosch office a lot of alternative solutions needed to be considered in the design process.

1.6 Related work

This section summarizes a couple of similar projects that have been carried out within the same field, and it describes how they differentiate from this project.

1.6.1 ZouSim Bicycle Simulator

Sun and Quing (2017) studied different design solutions when creating their own virtual bike simulator, which. They constructed a bike simulator based on what they considered to be the best design choices. Their simulator will have some similarities to the one developed in this thesis. For example, they will use game engine and graphics programs. A bike stand similar to the one in Figure 1.1 will be used to lift the bike's rear wheel and a inertia motor will be used to apply resistance when peddling. However, other techniques will be used to track the movement speed and the rotation of the steering wheel. Also, a head mounted display will be used for the graphics instead of a centralized LCD-screen. The two projects still differentiate from each other since the scope of the projects are completely different. The ZouSim simulator was developed to evaluate bicycle traffic control and facilities design, while the aim of this project is to evaluate user interfaces of bike computers [27].

Figure 1.1: A bike setup on a trainer stand that can apply steering and resistance on forward pedaling.

1.6.2 Cycle Spaces

Cycle spaces was a project that was carried out at the Breda University of applied sciences. They developed a bike simulator that could evaluate the interaction between cyclists and design spaces. The aim was to give city planners, politicians and other designers a fully immersive experience while also gaining insights into cyclists' behaviours, preferences and experiences [7]. The outcome of their project can be seen in Figure 1.2.

Figure 1.2: The virtual environment in the cycle spaces simulator from a users point of view.

1.6.3 Spatial Track Cycling Simulator

In a joined collaboration between different universities in Malaysia Yap et al. (2018) developed a mechanical cycling rig that could move with six degree of freedom. The rig could emulate real forces and spatial positions based on interaction with the virtual reality environment. It had six motor, one for every degree of freedom . The simulator also used a Wiimote to track the angular speed, and a Arduino board to handle the connection between the platform motors and the computer. The structure of the rig can be seen in Figure 1.3. Unity was used as their game engine and Oculus rift HMD was used to project the graphics. Their simulator will differ from this one, since the focus of this thesis is to simulate a bike ride in an open urban environment instead of a limited velodrome. This simulator will also have both a steering and a peddling input, instead of just the peddling. This will make the simulator much more interactive and create a completely different experience. However, no mechanical devices will be used to apply forces to the rig, except for the inertia motor that will apply resistance to the backwheel of the bike [26].

1.6.4 Future Cities Laboratory and Institute of 4D Technologies

The institute of 4D technologies and the future cities laboratory made a project in which they developed their version of a bike simulator. The simulator used a bike stand and

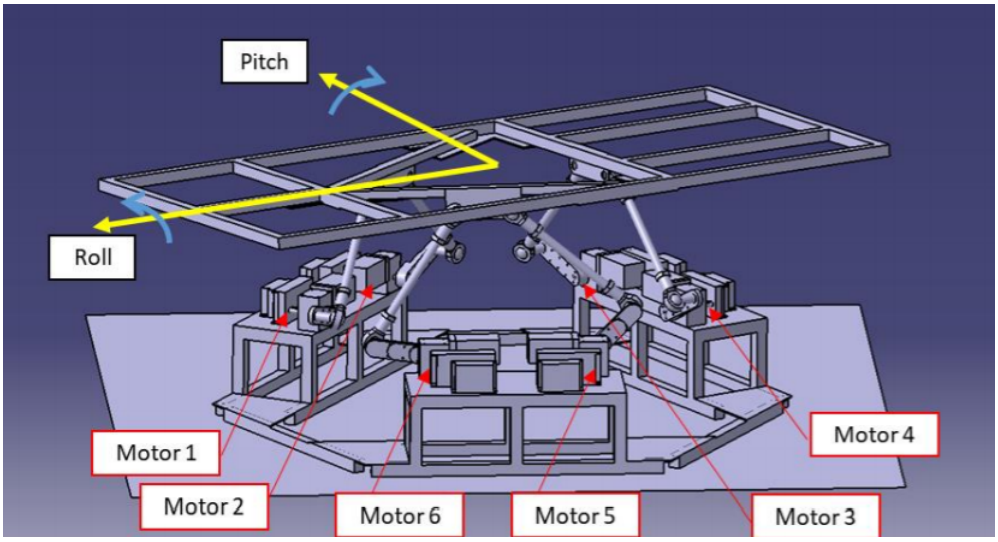

Figure 1.3: An illustration image that shows the structure of the simulator platform.

a resistance motor, much like the ones that will be used in this thesis. They also used MPU6050 digital motion processors which had a built-in accelerometer and gyroscopes. The sensors were used for tracking the roll angle of the bike and the rotations of the pedal and the back wheel. The signal from the sensors was sent via the inter-integrated circuit bus protocol to a Arduino microprocessor which in turn sent the data to computer via a Bluetooth low energy wireless module [20]. The whole setup can be seen in Figure 1.4. The outcomes of the project are just briefly discussed in the article. Although there are a lot of the similarities between these two projects, there is a lot more to be explored when it comes to bike simulators. This project aims to focus more on the software aspects, while their project focused more on the performance of the hardware components. The simulator in this project will use other hardware components to implement the steering and the peddling input.

Figure 1.4: Shows the virtual environment of the simulator and the bike setup.

1.7 Resources

This section contains a description of all hardware equipment and software programs utilized in the thesis.

1.7.1 Hardware

- HTC Vive Pro - a virtual reality headset developed by HTC and Valve Corporation. It uses "Room scale" tracking technology which allows a user to move around freely in a 3D space and use motion tracked hand held controllers to interact with the environment [3].
- Performance computer - VR requires powerful hardware to perform well. Thus, a computer with sufficient graphics and possessing power capacity is needed to run the simulation smoothly.
- Bike - a bike was used as the station to further create a sense of presence in the environment.
- Tacx bike station - a bike station was used to hold up the bike and to apply resistance back wheel so that the users could feel resistance when peddling.

1.7.2 Software

- Unity - a real-time engine and a platform for game development created using C++ and C#.
- 3d studio max - 3D vector-based animation and modeling program made by the company Autodesk.
- Microsoft Visual Studio - is an advanced program development environment created by Microsoft using C++ and C#.
- Node.js - a program system designed to create scalable internet applications, especially web servers.

Chapter 2
Theoretical background

In order to better understand the thesis, this chapter gives some important context and background information on terminology and key concepts.

2.1 Virtual Reality

Most people think of Virtual Reality (VR) as a modern technology created by recent technical advancements. However, the concept or the idea of it originated from Panoramic paintings as early as the nineteenth century [15]. Panoramic paintings are 360-degree murals intended to fill the viewers entire field of view to create a sense of presence at a historic event or scene.

Although VR has no clear or common definition, one could define it as: "A high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell and taste" [2].

In functionality, VR itself is a tool where computer graphics is utilized to render a semi-realistic looking world. A world that is interactive to users (inputs, sounds, movement, etc.) to create a captivating immersive experience.

2.1.1 Head mounted display

Head mounted displays (HMD) have been around for a long time. They were initially mostly used in the military aviation industry, but as the quality of the LCD panels evolved, the HMDs became much more popular. Today they are used in variaty of fields, such as sports, engineering, medicine and reserach. The HMD is in its simplicity a screen that is placed in a container on top of a pair of convex lenses. The convex lenses are used to enlarge the content of the screen so that the screen covers as much field of view as possible. High screen resolution and a high field of view are two important parameters that need to be considered when creating an immersive VR application. Low resolutions

will give the user a pixelated non-realistic experience, while it also introduces the screen door effect which will be described in **section 2.1.3**. A low field of view will leave the user with an unnatural and limiting feeling since we humans are use to having a 190 degree horizontal field of view [21]. By comparison, the HTC Vive has a, self proclaimed, 110 degree horizontal field of view [25].

The two mention factors discussed earlier are determined by the hardware and are out the user's control. One parameter that is usually in the user's control is the ability to adjust the interpupillary distance (IPD) of the lenses. IPD is a measurement of the distance between the center-points of our pupils and it is used to set the distance between the lenses in our glasses, or in this case the goggles. If the wrong distance is set, the center of the lenses will not be aligned with the center of our pupils and perceived image will be blurry [25].

2.1.2 Field of view

Field of View (FoV) is the open observable area a person can see through their eyes or via an optical device. For a device, FOV describes the angle through which electromagnetic radiation is picked up, and allows for the coverage of the entire area instead of just a focused point. This essentially means that for VR to improve immersion a large Field of View is required. In this context immersion refers to the technical aspects of deceiving the senses in order to create a sense of belief that one is present in an other place.

For humans, our FOV system is composed of two stitched together monoculars creating one binocular FOV as shown in 2.1.

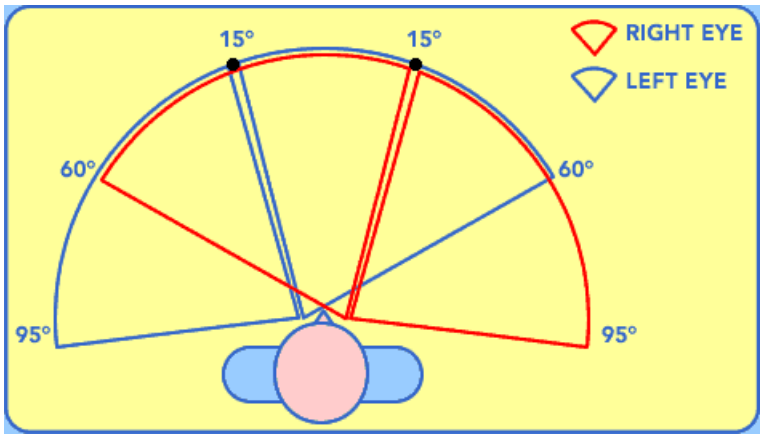

Figure 2.1: The field of view of Humans.

2.1.3 Screen Door Effect

The screen door effect is a mesh-like visual artifact that makes the small gap between pixels visible on an electronic display. This effect is further increased while being in close proximity of the screen or if the objects viewed are magnified. An example of the mesh-like effect can be seen in Figure 2.2 .

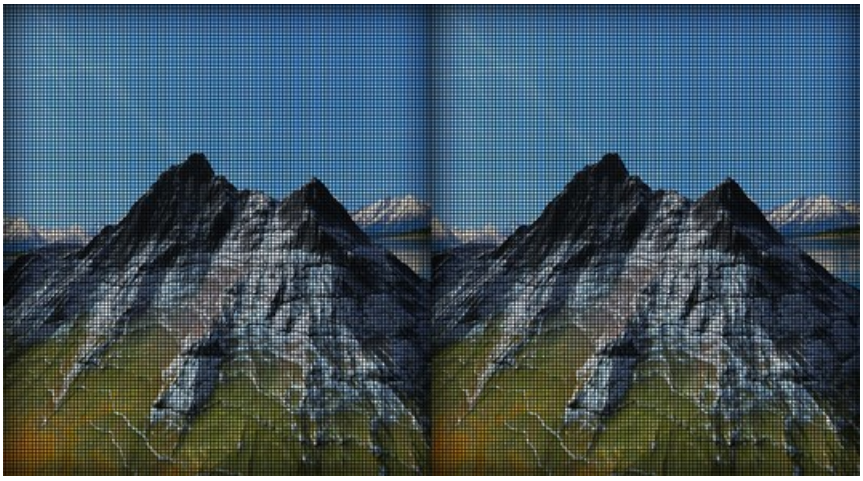

Figure 2.2: Screen door effect on a side by side 3D image.

The Screen door effect can be a major setback in regards to immersion, resulting in a lower quality of use experience. For some users this effect would cause headaches, eyestrain and a distraction. However, this effect can be lowered to a bearable level by having a screen with higher dots per inch (DPI) or by using lenses with lower magnification [11].

2.1.4 Degrees of freedom

Degrees of Freedom (DOF) refer to the number of basic ways a rigid body object can move through a 3D space. In total, there are six degrees of freedom. Three of which determine the transitional movements, and the other three determine rotational movements around the x, y and z axis. Figure 2.3 introduces the set of three rotational movements that represent the simplest form of user tracking for a VR headset. Roll is where the head pivots side to side (i.e. when peeking around a corner). Pitch is where the head tilts along a vertical axis (i.e. when looking up or down). Yaw is where the head swivels along a horizontal axis (i.e. when looking left or right). The HTC Vive headset relies on the inbuilt sensors such as magnetometers, accelerometers and gyroscopes to track rotations, just like the smart phones [13].

Figure 2.3 also introduce the remaining three transitional movements, namely elevation, strafe and surge, creating a total of six degrees of freedom (6DoF). Elevation is where a person moves up or down (i.e. when sitting down or standing up). Strafe is where a person moves left or right (i.e. when sidestepping). Surge is where a person moves forwards or backwards (i.e. when walking). Positional tracking is especially useful in whole-room VR experiences and gives the user more room to explore. To capture these movements, positional sensors are utilized to constantly relay their position to the computer. For the HTC Vive this is done by sending infrared signals to the controllers and the headset, to track their position relative to the lighthouses [13].

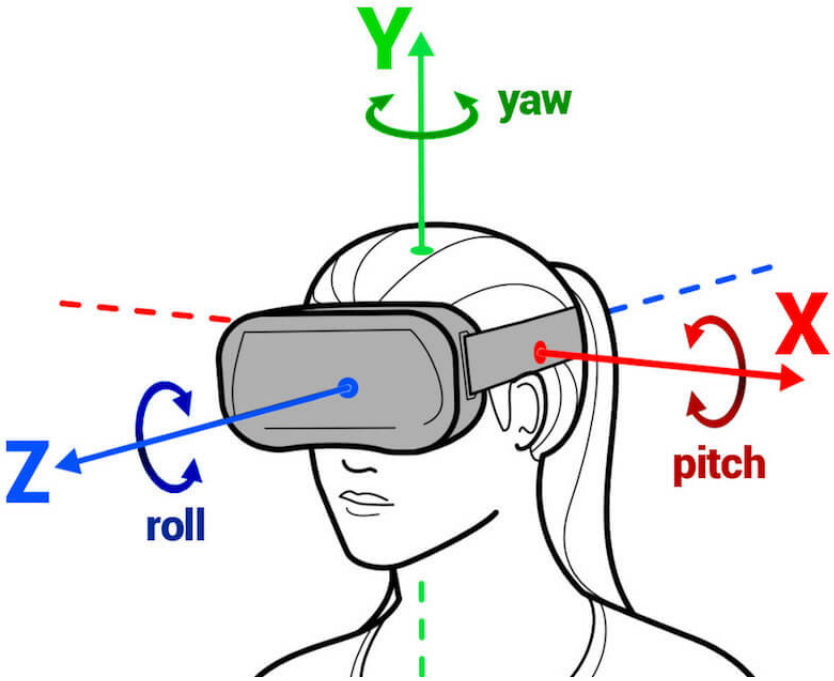

Figure 2.3: 6doF Roll, Pitch and Yaw for rotational movement and elevation, strafe and surge for positional movement.

2.1.5 Latency

The definition of latency depends on the context in which it is being used. In general, one could define it as: "the period of delay when one component of a hardware system is waiting for an action to be executed by another component" [4] . In other words, the time required to produce a desired action. In terms of VR it can be used to reference the time delay in between which two frames are being rendered, or the time it takes the simulator engine to perform an update. In unity, the default fixed update frequency is set to 50Hz. If the frame rate of the application is at 100Hz, then two frames are being rendered for every fixed update [24].

2.1.6 Motion sickness

Motion sickness is a nauseating feeling that most people get when riding a roller coaster or other amusement park rides. It is commonly a problem for people travelling by airplanes, cars, trains etc. Mostly among children, pregnant women and people with certain medical problems [5]. Motion sickness is caused by conflicting signals between the inner ear, the eyes and the sensory receptors. Which are some of the bodies ways of sensing motion alongside the tissue of the body surface. For example it can be a nausea caused by motion seen yet not felt such as in VR or motion felt but not seen [14]. For VR the feeling of motion sickness can be caused by parameters such as FOV, lens distortion, latency (head movement not matching visual feedback), limited general movement in the Virtual environment as well as deficient performance [25].

2.1.7 Drop-outs

A drop-out is a loss of signal between a transmitter and a receiver. The reason why drop-outs occur is closely related to the type of signal or channel that is being used. HTC Vive uses infrared radiation (IR) that is transmitted by air. IR signals can be blocked by any electrically conductive material like e.g. glass, plastics, metals, wood or even skin [19]. If a system, like e.g. a HTC Vive headset, depends on input from several sensors to determine a correct output, then a drop-out to some of sensors might cause the system to behave unexpectedly [16].

2.2 Perception

Perception describes the process of how the human brain perceives, interprets and uses sensory information in order to interact with the environment [25]. This is fundamental to VR, since the whole purpose of VR is to trick the human senses in order to create a realistic user experience. A user experience that in actuality is merely an illusion. In order to understand perception, one has to first understand how the human senses work.

2.2.1 Senses

The human sensory system can be divided into six groups:

- Visual system - responsible for the sight, the most important sense for observing the surroundings. The cells in the eye retina catch electromagnetic rays within a wavelength interval of 400-780 nm and convert them to electrical impulses. The impulses are sent via the optic nerve to the brain, where they are processed to images [1].
- Auditory system - responsible for the sense of hearing, that stretches across the interval of 20-20000 Hz, and is in general the second most import source of sensory data [25].
- Olfactory system - responsible for the smell. Chemo-receptors in the nose detect different molecules structures and convert them to neural signals.
- Gustatory system - responsible for the taste. Similarly to the olfactory system, it uses chemo-receptors, located on the tongue. Since the position of the receptors on the tongue are less exposed than the ones in the nose, it is much easier to control the stimuli.
- Somatosensory system - Sensory receptors that send information about pressure, pain, temperature, sensation of muscle movement and joint position. The sensors are located all over the body, including skin, muscles, bones, joints, cardiovascular system and the internal organs.
- Vestibular system - responsible for the sense of balance and spatial orientation. It is the human body's equivalent of gyroscope and accelerator sensors. It is located in

the ear and uses three semi-circular canals the interpret rotational movements and two otolith organs to interpret accelerations.

2.2.2 Multi-modality

According to Gibson (1986), perception is often a result of multi-modal co-ordination between different senses [8]. The interplay between the senses occur both on a unconscious neural level and on a conscious level. We can therefore train the coordination between our senses to a certain degree. This can be illustrated through a simple demonstration: try to balance on one leg for 20 seconds. Then try to repeat the same task but with your eyes blindfolded. The results are usually that it is much harder to keep the balance while blindfolded. This is because the vestibular system adjusts the body's movement in relation to the external world. But without the information from the eyes, the brain has to rely on the somatosensory system the get an impression of the external world. But a little practice the brain can adjust and learn to rely on sources of information, such as the positioning and self-movement information from the calf muscles, and the tactile pressure feedback from the soles of the feet [17].

2.3 User-centered design

User-centered design (UCD) is an iterative design process where the user is the main focus in each phase of the process. The user is involved throughout the design process to create a suitable product for them. UCD involves a few main iterations. The first one is planning, which involves both understanding the context of use and specifying user requirements e.g. identifying the needs. Second is designing, which involves creating a rough concept or designing a complete solution. After that, developing, creating the product based on what has been learned from previous phases. Lastly, evaluating the product resulting in either a system satisfies or returning to design and development phases.

2.4 Usability

Usability is an subelement of the broader term user experience, and it is lousily referred to as the "ease of use". The official definition according to the ISO 9241-11:2018 standard is: "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". The metrics are defined as [12]:

- **Effectiveness**- "Accuracy and completeness with which users achieve specified goals."
- **Efficiency** - "Resources used in relation to the results achieved". E.g. time, human effort, costs and materials
- **Satisfaction** - "Extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations."

2.5 NASA-TLX

The NASA-Task Load Indexer is a multidimensional assessment tool used to rate perceived workload in order to evaluate a systems performance. There are two main parts of the NASA-TLX, the first of which measures total workload by analyzing the following sub-scales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration. For the second part, an individual weighting of the sub-scales is created by comparing the subjects pairwise based on their perceived importance. Using the second part of the NASA-TLX might lead to unreliable test results according to Hart [9]. Thus, only the first part was used in this thesis.

2.6 System usability scale

System usability scale (SUS) is a measurement tool that measures different cognitive attributes. It has been used in over 13000 publications and is considered to be a well-proven and reliable tool for evaluating usability of products, systems and services. The tool itself is just a simple questionnaire that consists of 10 questions that are graded on a five point Likert scale. The questionnarie can be found in Appendix F [22].

Chapter 3

Method

This chapter describes the methodology used in this thesis. An overview in presented in Figure 3.1 and all of its integral parts are discussed under their respective phase.

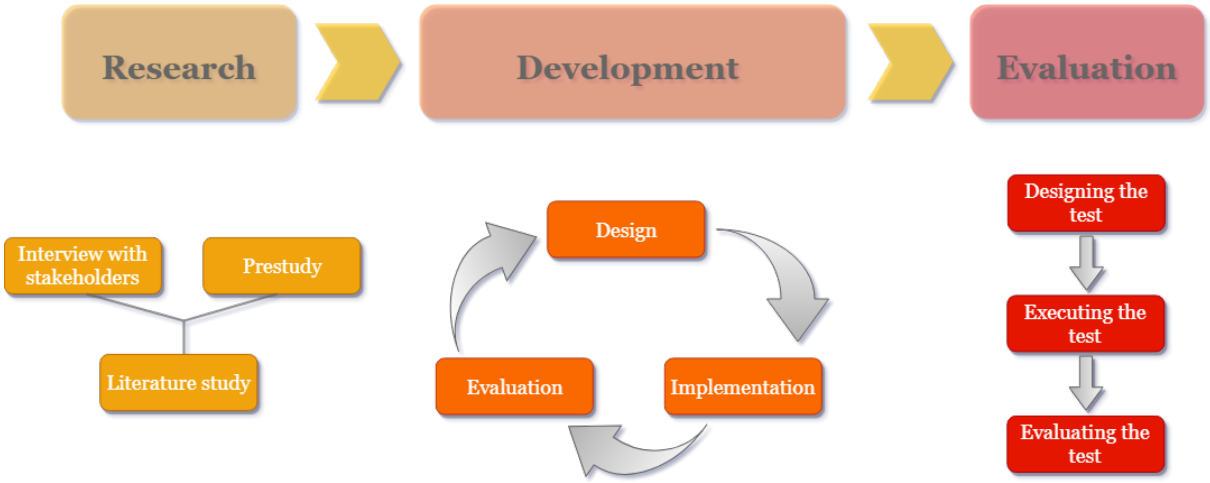

Figure 3.1: Overview of the thesis process.

3.1 Research

This section will contain an overview of the methods used to conduct the research. Three different methods were used to triangulate the research data, and each method is described in detail below.

3.1.1 Interview with stakeholders

The research started out with mapping out who the stakeholders of this thesis were. Stakeholders can be defined as the individuals and groups that are affected, or that have the power to affect decision or activity.Since this thesis was carried out at a company, the entire organisation could be seen as a stakeholder. In such a large organisation it is impossible to toke all parties into consideration, thus only the key stakeholders were considered. Key stakeholders are those individuals or groups that must be satisfied, since they are the ones that determine weather the project is successful or not.The key stakeholders in this thesis consisted of supervisors, a resource manager and end users.

After determining who the key stakeholders were, an interview was conducted to better understand the business goals, constraints and the end users of the project. The interview started out with a brief presentation of the company's background and visions. It was followed by a discussion about the context, purpose and the scope of the thesis. The technological, financial and the organisational constraints were also discussed. The outcomes of the discussions were summarized into a goal document and signed by both parties.

3.1.2 Literature study

To gather an idea of how a simulation of this sort can be created, research into multiple areas was conducted as noted earlier in **Section 1.6**. Among the early concerns was reducing motion sickness. However, each time this issue needed to be solved the problems became multifaceted and required different measures. Within motion sickness, performance needed a second look and required continuous development throughout the thesis. Since the HTC Vive has a refresh rate of 90Hz, to feel less of a lag the system needed to deliver 90 or more frames per second. Each time the frame dips below that ratio the sense of presence reduces and motion sickness increases. For an untrained user this could lead into immediate stoppage of the test. For performance enhancements the documentation on Unity profiler was of great use [10]. It introduced the possibility for narrowing down where optimization was required. In turn optimization was enforced for example on objects level of detail, background physics, code sections and a few other minor details. Furthermore, a paper on reducing motion sickness introduced a different concept by creating an adaptive FOV [6]. This meant depending on how fast the bike inside the simulator was the FOV would get reduced for higher speeds and increase for lower speeds. For constructing the code, the main source of information was based on general guides on the internet concerning C# and Unity.

3.1.3 Prestudy

To complement the literature study, a pre-study was performed to further investigate other areas of conflict. This was done by actually playing other VR games in the steam library. Immediately the lack of sharpness in the images resulted into some areas of text losing detail at certain distances. If the performance of the computer was not sufficient, lag spikes would occur regularly. As for motion sickness, it was little to non existent if player movements were limited to the room. However, if the camera rig was moving like in a roller

coster or a car game the feeling would increase and lead to discomfort. Other minor details related to Screen door effect, latency or drop-outs were also noticed and taken into account. In effect the focus of this section was to answer the following set of questions:

Will the user be deceived by the stimuli in the VR and lose balance in real life? This was tested using car-games to get an idea of how disorienting it could get and if it resulted in a loss of balance. In theory the lack of force-feedback would be enough to disorient a user. However, using a bike mounted on a station might decrease this effect.

Will the resolution be sufficient so that the details in the bike's interface are visible enough? This was tested by creating a small demo to measure the detail level needed for texts and icon sizes in the UI.

Will the motion sickness be overwhelming and ruin the overall user experience? This question depends mainly on how well executed the implementation is.

Even though some of the previous questions were answered by the testing made, still there remained uncertainties revolving how well a system like this would function for studying UIs. This leaves us to the final question.

3.2 Development process

After conducting all the research required, the development process was initiated. The process was iterative where each iteration consisted of three main stages. First stage included a clear **design** that needed to be thought out to cover the minimum requirements set by the stakeholders. In other words, a study into the issues was made to plan out a methodology to solve them. Second is the **implementation** stage of the design which resulted in a functioning prototype. Last but not least an **evaluation** was made based on previous steps leading to one of three outcomes:

- Prototype satisfactory, meaning the design and implementation resulted in an acceptable result so that usability testing can begin.
- Prototype needs to be redesigned resulting in a complete restructure of the implementation.
- Minor improvements needs be made to the implementation to enhance functionality. In other words, the design remains however implementation should be done differently.

Each iteration utilizing the concept presented in this section will be further discussed later in **Chapter 4**.

3.3 Testing

This section covers the last phase of the thesis and describes how the final tests were constructed, executed and evaluated.

3.3.1 Designing the test

To design the test, the most natural approach was to divide it into three stages: the pre-test, test and the post-test. In the pre-test, users were briefed about the project and informed about how the testing would be carried out. An orientation script was written so that every user would be given the same information. Additionally, an informed consent form was written to inform the users about the purpose of the test and its associated risks. The form had to be signed before the test could start. Lastly, a pre-test survey had to be created, since it is always interesting to analyze the correlation between the end results and the demographic factors. In addition to the the demographic factors, a couple of other parameters that were closely related to this project were also included in the pre-test questionnaire see Table 3.1. The orientation script, informed consent and the pre-test survey can be found in Appendix B-D.

Table 3.1: Pre-test questionnaire.

Age
Gender
Technical background
Ability ride a bike
Previous experience with bike navigation apps
Motion sickness sensitivity
Prior experience with VR
Prior working experience with Bosch's E-bike devices?

To perform the test users had to navigate along a predefined route using a virtual GPS. Each user had to navigate the same route twice using two different UIs. The UIs served only as mock-ups and had the bare essential content and functionality needed to perform the tests. The purpose was to analyze the interaction between a user and a generic UI, not to evaluate contents of the UIs. To evaluate the interaction, a couple of questions were asked in between each session to gather the users' thoughts and to see if they payed attention to the interfaces. In addition to the short interview, observations of behaviour and quotes were also noted. To capture the quantitative performance data the following three metrics were observed: time elapsed, number of missed turns and the number of additional directions given. This data would later be used to assess the efficiency and the effectiveness of the simulator.

After the test was completed the users need to be debriefed. The most straight-forward solution was to simply conduct an interview. A semi-structured type of interview was chosen since it assured that all users would answer the same questions, while the users were still able to steer the conversation in any desired direction. To capture the quantitative data three different standardized questionnaire forms were used: NASA-TLX, SUS and word association. NASA-TLX and SUS measured the satisfaction level of tasks performed, while the word association form gathered the overall impressions of the test experience. All three forms can be found in Appendix F-H and an overview of how the data was captured can be seen in Figure 3.1. The reason why NASA-TLX and SUS were chosen was because they are well-proven, research based metrics that have stood their ground during more the three decades. The reason why the word association was included is because there is not

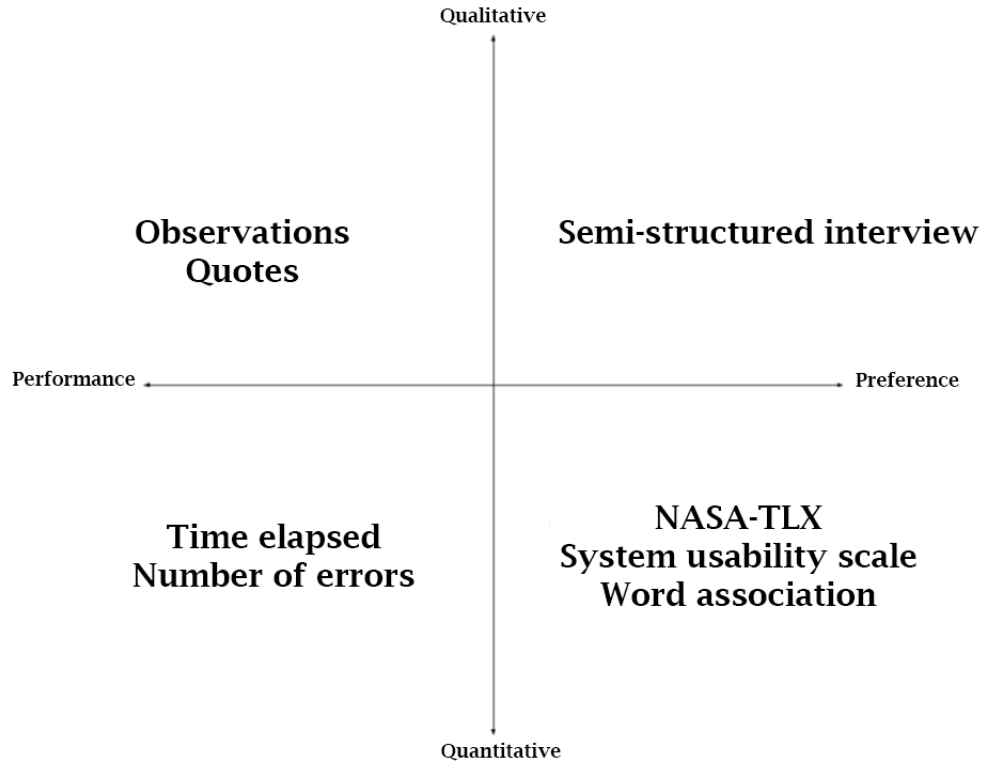

Figure 3.2: Show how the different types of data were captured.

any single metric that can measure the usability of a system. Therefore, combining several metrics and triangulating the data is considered to be good practice.

3.3.2 Executing the test

The responsibility of the test was split into two roles: test leader, and test assistant. The test leader was responsible for the pre-test process which is illustrated at the top in Figure 3.3. The test assistant was responsible for getting the simulator ready, helping the user put on the equipment, recording the computer screen and navigating the user using the wizard-of-oz technique. The test leader was responsible for taking notes of the users' behaviour and writing down the comments that they made while thinking out loud. Since the test leader had to keep his attention on the test subject, the assistant who was faced against the computer was responsible for observing the number of missed turns, the number of additional directions giving and the elapsed time. After the test of each interface, the test leader asked the users a couple of questions. Once the test was over, the test leader continued with a more in-depth interview and handed out three questionnaires that are presented in the bottom of Figure 3.3.

3.3.3 Evaluating the test

This section contains an explanation of the metrics that were used in the evaluation phase.

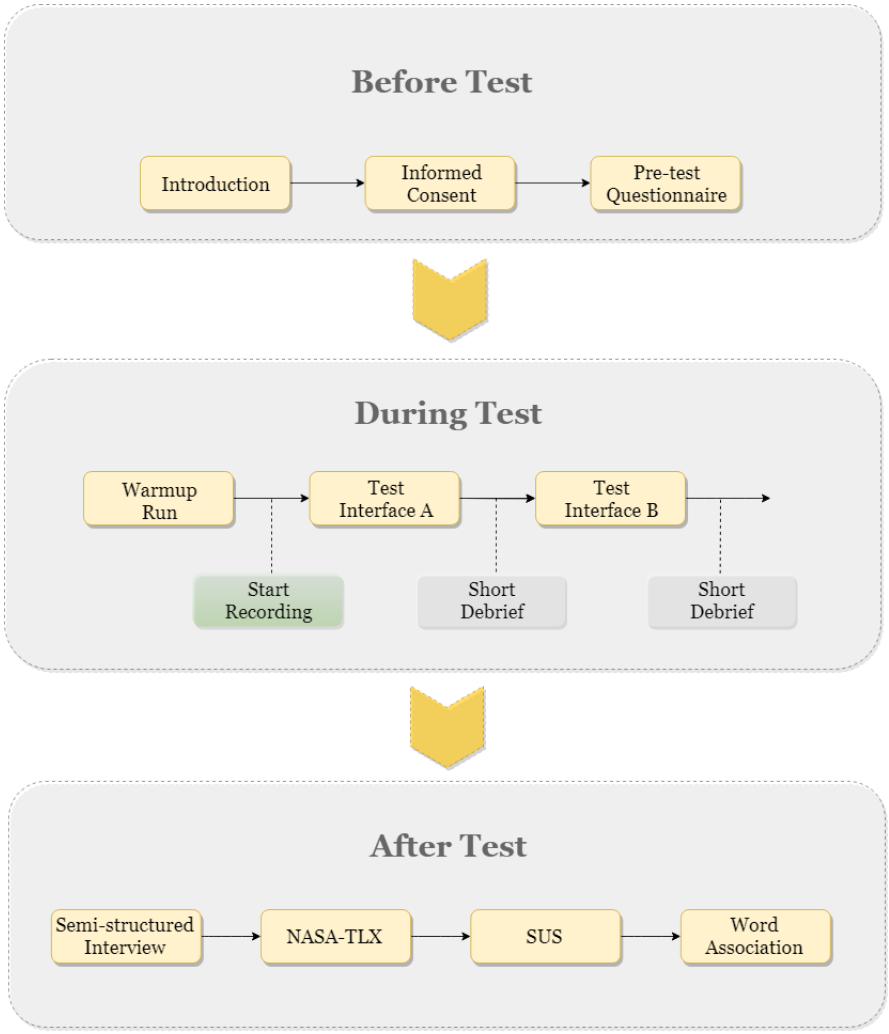

Figure 3.3

Effectiveness

$$Competition\ Rate = \frac{Number\ of\ tasks\ completed\ successfully}{Total\ number\ of\ tasks\ undertaken} \times 100\%$$

$$Number\ Of\ Errors = (observed)$$

Efficiency

$$Elapsed\ time\ per\ task = End\ time - Start\ time$$

$$Overall\ Relative\ Efficiency = \frac{\sum_{j=1}^{R}\sum_{i=1}^{N} n_{ij}t_{ij}}{\sum_{j=1}^{R}\sum_{i=1}^{N} t_{ij}} \times 100\%$$

Where,

N = The total numver of tasks
R = The number of users
n_{ij} = The result of task i by user j; if the user successfully completes the task, then n_{ij}=1, if not then n_{ij}=0
t_{ij} = The time spent by user j to complete task i. If the task is not successfully completed, then time is measured till the moment the user quits the task

Satisfaction

$$NASA - TLX\ score = 5 \times x_i$$

Where,
x_i represents the order-number of the selected square of sub-scale i

$$SUS\ score = \left(\sum_{i=1}^{5} a_i - 1 + \sum_{i=1}^{5} 5 - b_i\right) \times 2.5$$

Where,
a_i = The scores of the odd-numbered questions
b_i = The scores of the even-numbered questions

Word Association

To generate a word cloud, all the words are simply put into an online word generator and png image was created. This represent the spectrum of words that were chosen. Since some test subjects chose more words than others, they were all asked to encircle 5 words that represented their experience the most. To normalize the word cloud, the 5 encircled words from every user were put in the word generator.

Chapter 4

Development process

*In this chapter each iteration will be presented as described in **Chapter 3.2**. This chapter includes details within each iteration such as why changes were made and what they achieved.*

4.1 Iteration 1

This section includes the first thought process of development retaining the interview questions.

4.1.1 Design

The first design revolved around creating a city environment with people walking around and cars driving according to basic traffic rules. In this phase a bike would be created with simple keyboard controls to maneuver around a city. The main idea is to maintain a simple template of minimum requirements to create a living city.

4.1.2 Implementation

After the city map was implemented as seen in Figure 4.1, an implementation of both people and cars were created and run by simple scripts, which is illustrated in Figures 4.2 and 4.3. The cars themselves would stop and not collide into objects in front of them.

As a final step in the implementation phase a bike model with simple keyboard controls was implemented. Included with the bike was the display centered in the middle as shown in Figure 4.4. However, new issues appeared around this implementation and will be further discussed in the next segment.

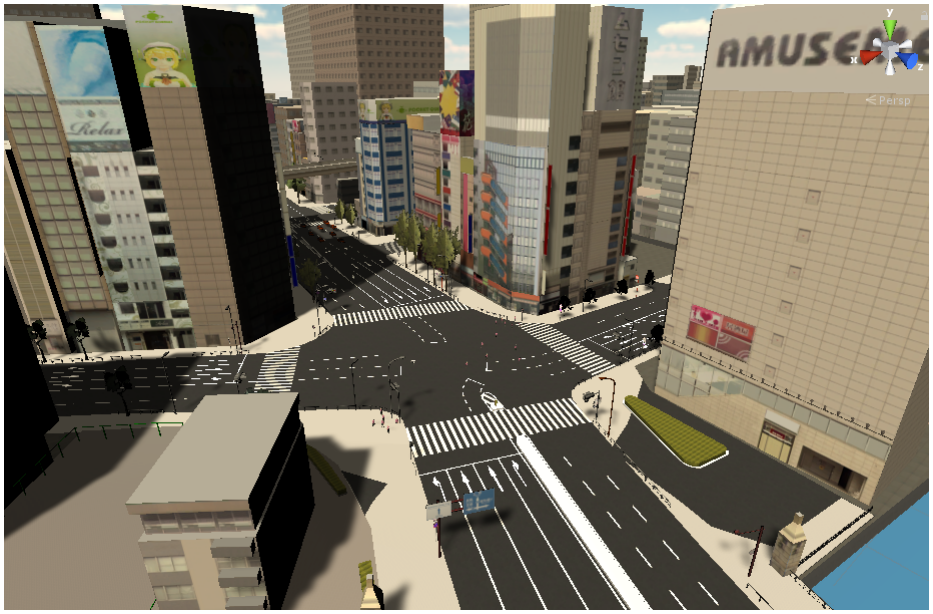

Figure 4.1: Image over the first simple implementation of the city environment.

Figure 4.2: Overview of pixelated render details of objects further away.

4.1.3 Evaluation

Based on comments from pilot studies revolving around the environment in general it was decided to make some changes. Some testers commented that the city model had some uneven ground areas, which affected the physics of the bike and the cars. The bike would spin uncontrollably in those areas. Also, the bike was not fully balanced and lost traction in most turns which resulted in it spinning around. The effect is clearly visible on Figure

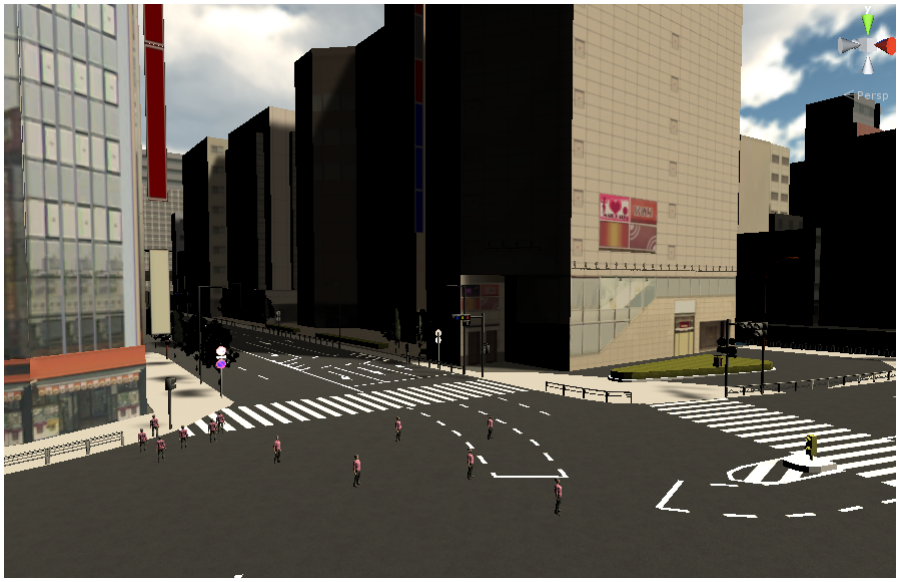

Figure 4.3: Simple script for creating moving people.

Figure 4.4: First person view of riding a bike with a display in center.

4.5. For the cars, the effect of uneven ground surface resulted in a bumpy drive throughout the road.

Having the city implemented with all these issues resulted in throwing away the old city model and look for a new one. With that in mind, it was decided to also give an uplift to the graphics of the simulator and make it more realistic. On an other note the control-ability of the bike needed improvements by using the VR controllers instead of the keyboard. Also the bike needed to lose the tilt on turn because that motion would not be emulated well with reality. In turn this meant a total redesign of the bike construction within Unity.

Figure 4.5: Issue of bike tilting when turning left or right.

4.2 Iteration 2

4.2.1 Design

Based on the evaluation from the previous iteration, it was clear that the model of the old city was not sufficient, so that a new model was required. The functionality including the models of the cars and the people could still be reused from the previous iteration. However, the bike itself required improved physics. Among those, was improving stability for it not to spin out, as well as balancing it to a point where it cannot tilt. In other words, it should act similar to a three wheeler.

Included in this design was the setup for controlling the bike using the VR controllers. This meant that one controller would manage steering and breaking and the other managing acceleration.

4.2.2 Implementation

A new city model was found and all of the previous models and scripts needed to be integrated. Images of the new city can be seen in Figures 4.6, 4.7, 4.8.

The implementation so far worked as designed with minor improvements to the functionality of the cars. A honking mechanism was added as well. The cars would honk if they detected a bike in front of them. Cars would also break before colliding with objects and regulate their speed according to the set rules implemented.

So far the simulation contained all necessary parts to be used for the last testing phase.

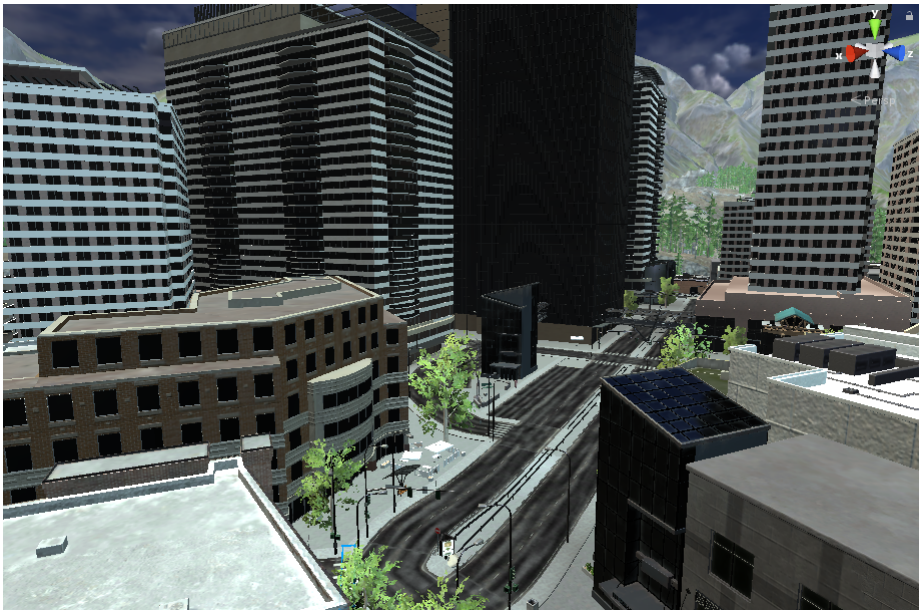

Figure 4.6: Image of the new city to be used as a replacement for the older version.

Figure 4.7: Image showcasing new reflections and shadows.

4.2.3 Evaluation

In this iteration functionality was improved marginally compared to previous iteration according to our pilot testers. However, they commented on there still remained some hiccups revolving performance that had to be addressed to reach the sweet-spot of 90 frames or above. Figure 4.9 shows the average frames prior to the performance improvement phase. Based on these comments and observations made on the recorded performance, a performance overhaul needed to be made.

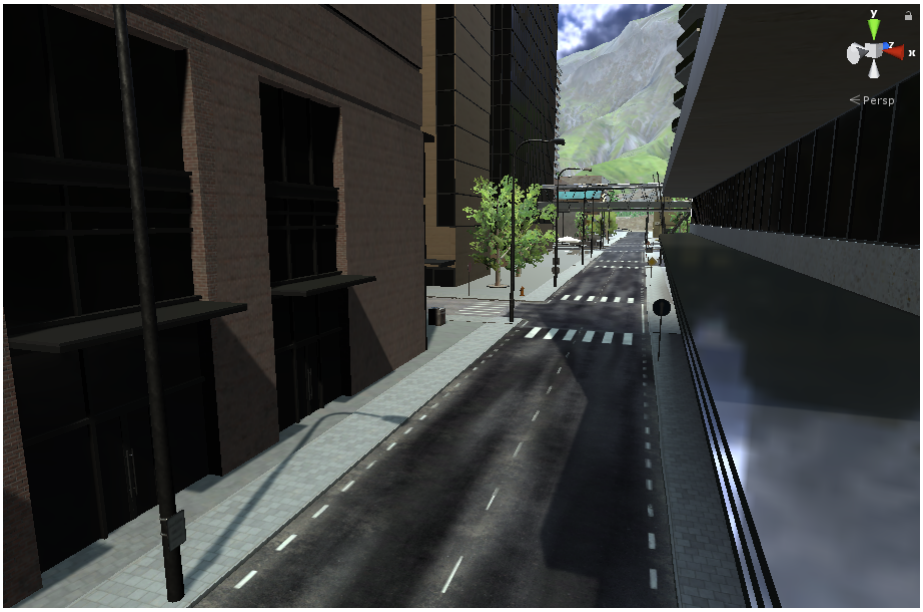

Figure 4.8: Image containing recalculated reflections on building surfaces.

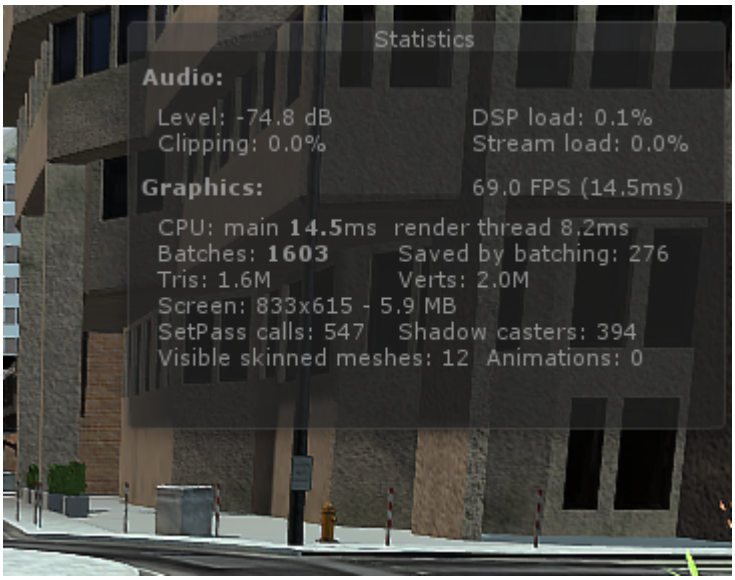

Figure 4.9: Average frames of 70 fps before improvements.

4.3 Iteration 3

4.3.1 Design

To implement a virtual GPS four components were required. First, a browser that could operate HTML files was needed. Second, a connection between the internal browser and an external server needed to be implemented. Third, an actual server needed to be created so that it could communicate and send the HTML files to the browser. Finally, a HTML UI needed to be created for testing purposes.

The design in this iteration did not go through major changes however new methods of performance improvements have been added. GPU instancing, batching objects in one single batch and sending them all in one go to GPU to render. Tunneling effect for VR camera lowering the FOV for lower motion sickness also improving performance. The tunneling effect is the same effect described in paper about improving motion sickness [6]. Furthermore it was decided that all static objects have pre-calculated shadows and reflections. This in turn meant if objects was stationary such as buildings, city lamps benches, etc. they would have static shadows and reflections. Thus minimizing the cost of real-time rendering marginally.

4.3.2 Implementation

An asset that could run a browser was found in unity's asset store. The asset used a chromium browser and was applied to a plane surface object. A separate asset was found that could handle the connection between the browser and the server. Using websocket, it was connected to a NodeJs server running on the local device. Finally, two mockup UIs were created in HTML and javascript, which can be seen in Figures 4.13 and 4.14.

On an other note for enhancing the performance some implementations can clearly be distinguished such as Figures 4.10 and 4.11. These showcase the work of GPU instancing where it removes grass and trees of objects not in view. However, for the objects in view it batches them together and send them as one call from the CPU to be rendered by the GPU later on.

Figure 4.10: Image of grass field pre GPU instancing.

All previous implementations resulted in clear performance improvements as shown in Figure 4.12.

Figure 4.11: Image of grass field after GPU instancing.

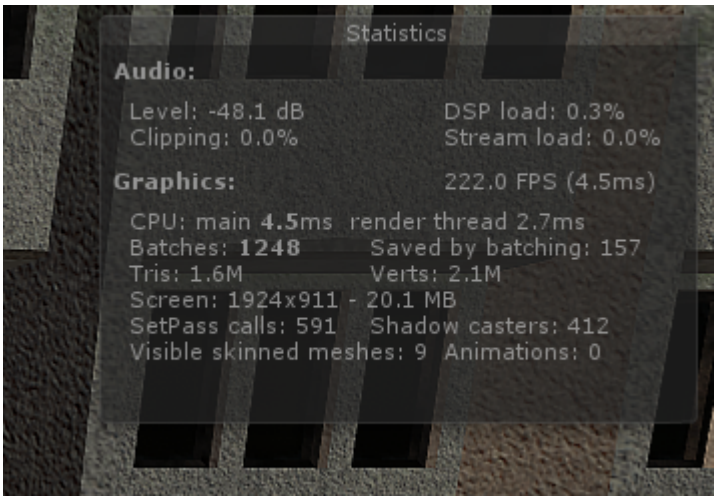

Figure 4.12: After performance improvements resulting in an average increase to 220 fps.

Keep in mind rendering images in VR halves the frame time. This is due to VR actually renders two images simultaneously for two different screens, one for the right eye and another for the left. This in turn means the observed performance while in VR would have improved from about 40 fps to 110 fps give or take, based on location in the simulator.

4.3.3 Evaluation

All improvements have resulted in a product that is ready for testing with real users. The pilot testers were happy with the results so far and testing could begin. This conducts the implementation of the simulator resulting in a final product of the bike and the UIs as seen in Figures 4.13, 4.14 and 4.15.

Figure 4.13: Image of bike and display showing signposts and message count.

Figure 4.13 shows the layout of the first UI. As can be seen there are 3 messages popping up at the bottom and signposts telling the user what roundabout exit to follow. In Figure 4.14 is the second UI showing a message from the top with content inside barely visible. Furthermore in Figure 4.15 the messages completely cover the signpost. To be able to progress the user was given the option to remove each massage if wanted to do so by a button press.

Figure 4.14: Image of bike and display showing signposts and message on top almost covering the sign.

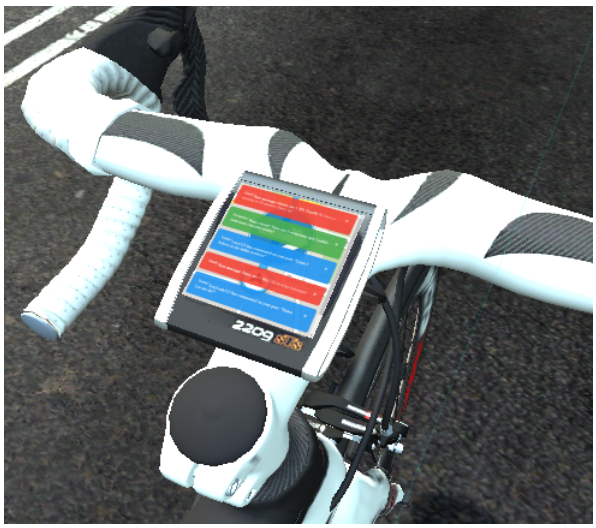

Figure 4.15: Image of bike and display showing signposts and message on top completely covering the signpost behind it.

Chapter 5
Final test results

*In this chapter a compilation of all results related to **Section 3.3** (Testing Phase) will be presented. This includes, Participants pre-questionnaire, scores of both NASA-TLX as well as SUS survey and finally a word association representation related to the simulator experience.*

5.1 Participants

This section contains a collection of answers of the pre-questionnaires.

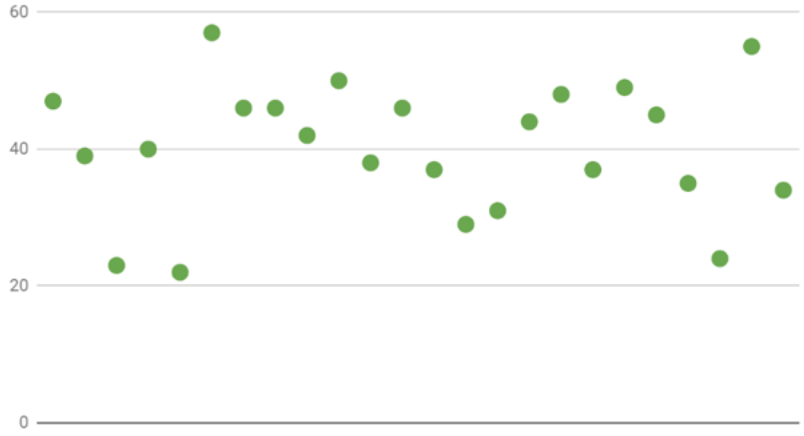

Figure 5.1: Scatter plot of the participants' age

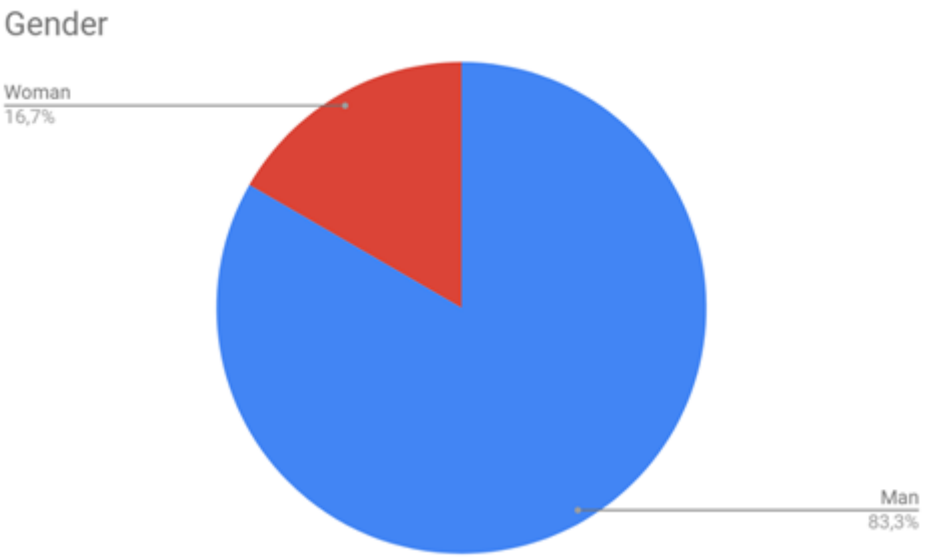

Figure 5.2: Pie charts of gender representation.

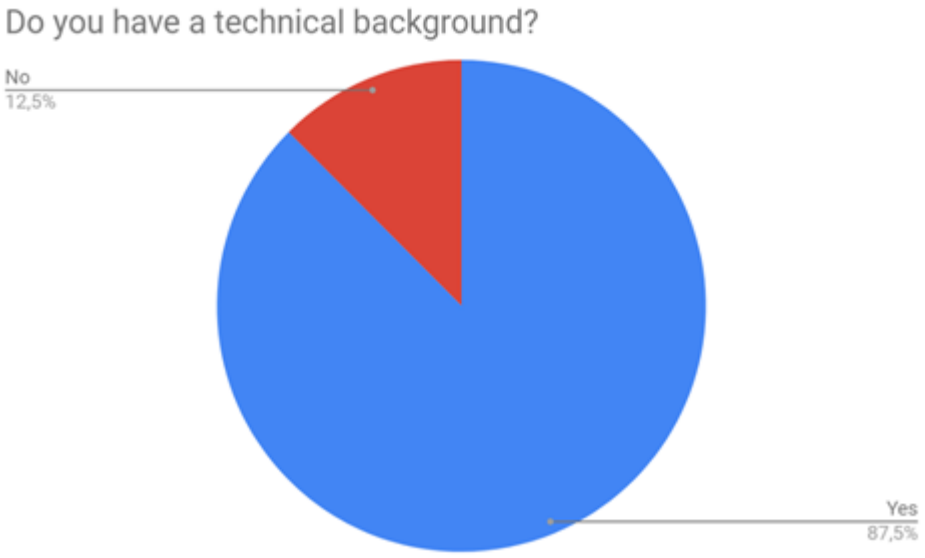

Figure 5.3: Participants with technical background.

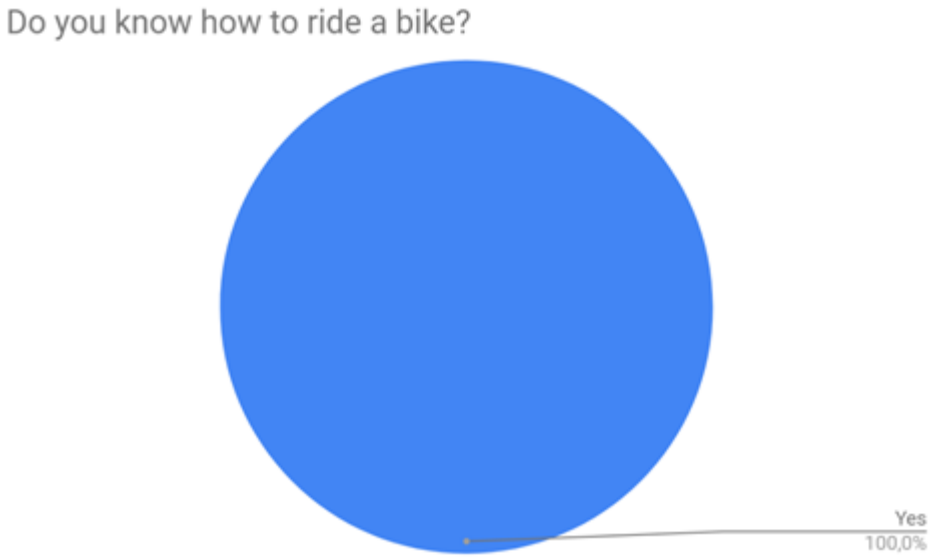

Figure 5.4: Participants that know how to ride a bike.

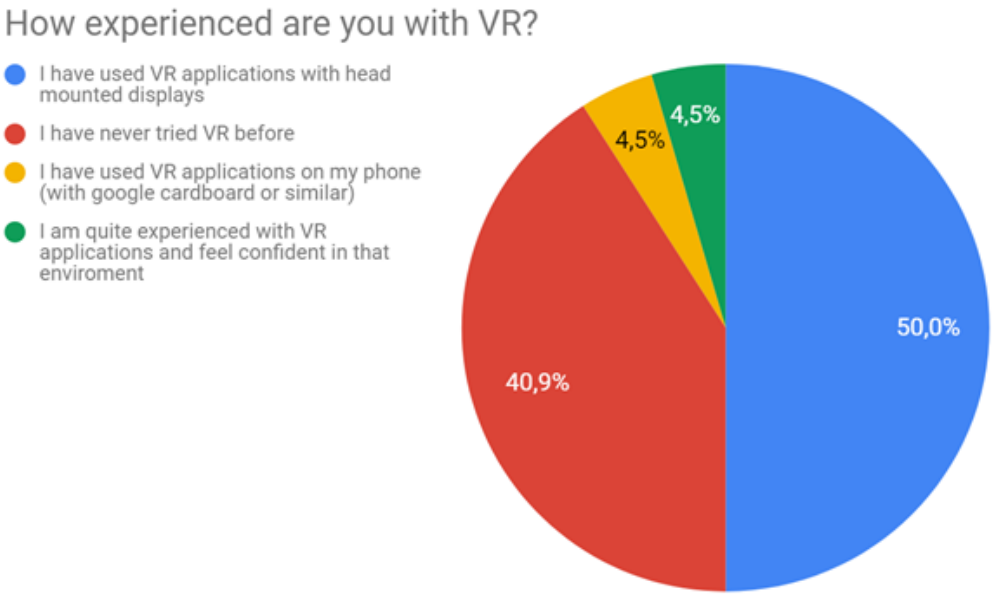

Figure 5.5: Participants experienced with VR.

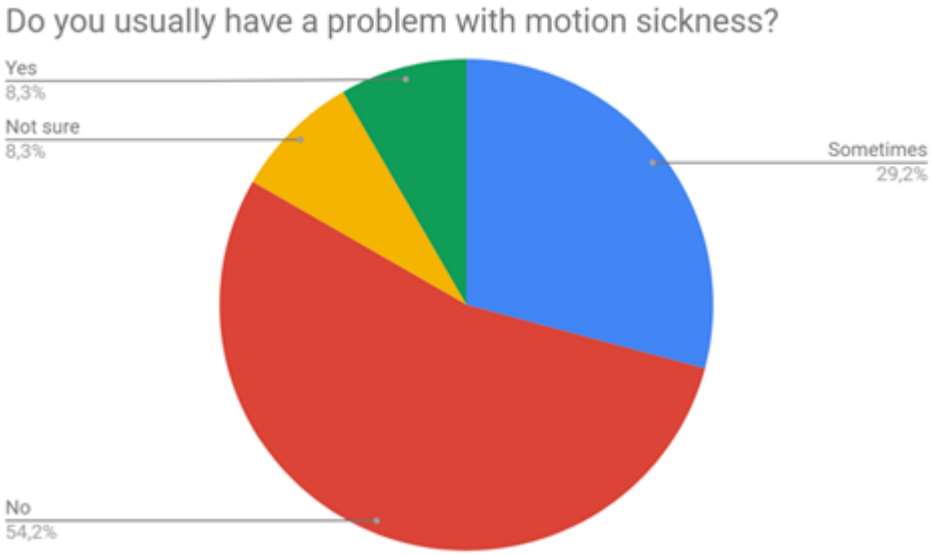

Figure 5.6: Participants having issues with motion sickness.

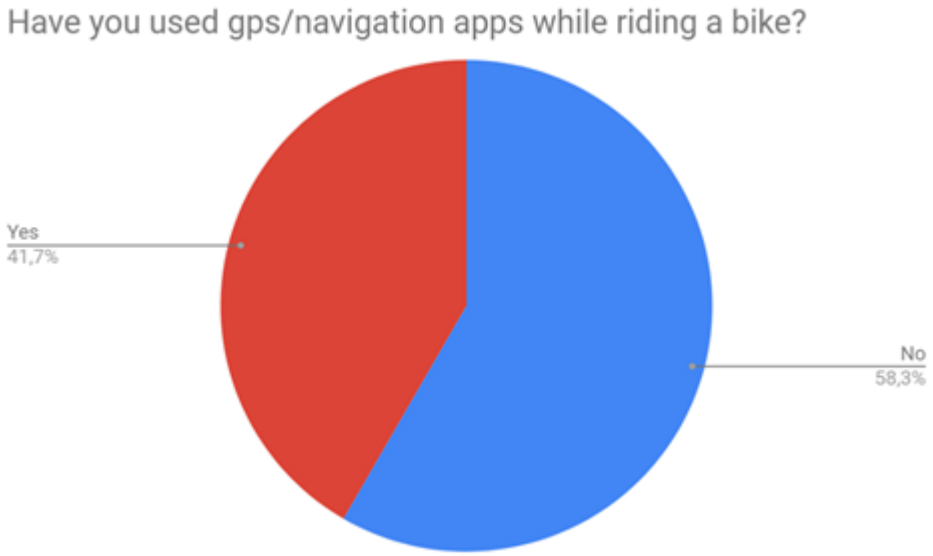

Figure 5.7: Participants that used GPS apps while riding a bike.

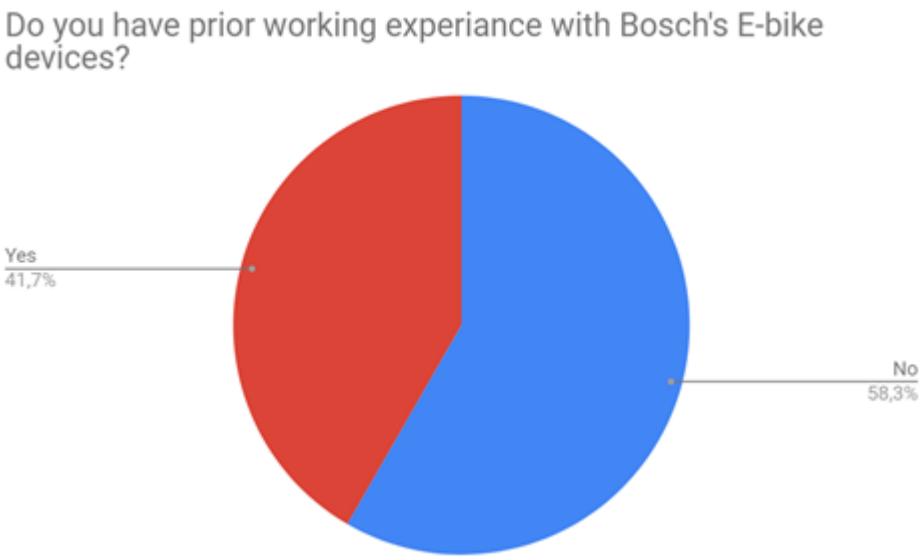

Figure 5.8: Participants experienced with e-bikes.

5.2 Results

5.2.1 Effectiveness

Effectiveness describes metric describes the "accuracy and completeness with which users achieve specified goals".

$$Number\ of\ errors\ per\ run = \frac{7\ Errors}{28\ Runs} = 0.25$$

Table 5.1: Test completion rate

15/25	Completed the whole test
7/25	Dropped out before the test
3/25	Dropped out during the test

Table 5.2: Reason for drop out

3/25	Balance problems
7/25	Motion sickness

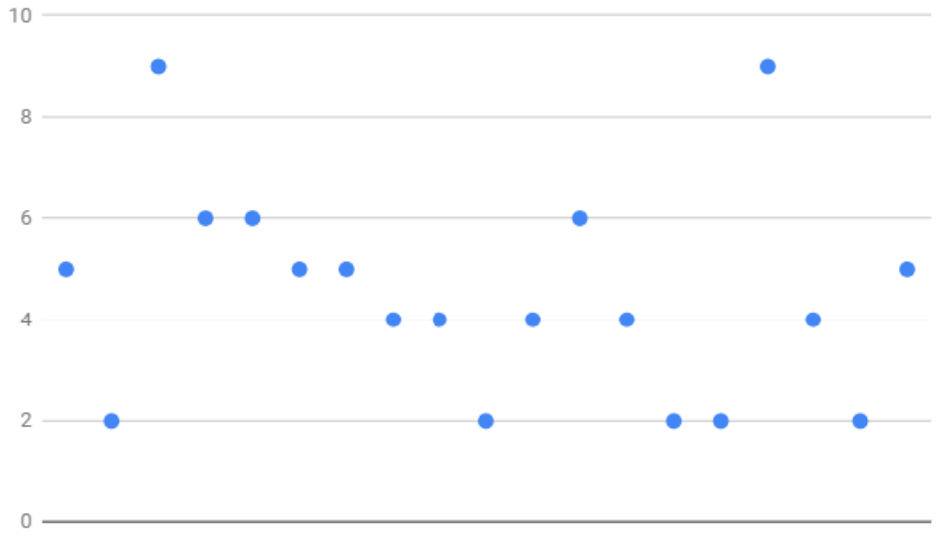

Figure 5.9: Scatter plot of the post-test motion sickness rating.

5.2.2 Efficiency

Efficiency describes the "resources used in relation to the results achieved". E.g. time, human effort, costs and materials.

Mean time to complete run 1 : 1*min* 48*s*

Mean time to complete run 2 : 1*min* 39*s*

Overall relative efficiency = 0.918

5.2.3 Satisfaction

Satisfaction describes the "extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations".

Word Association

Figure 5.10: Word cloud representing the participants' overall impressions of the simulator

NASA-TLX

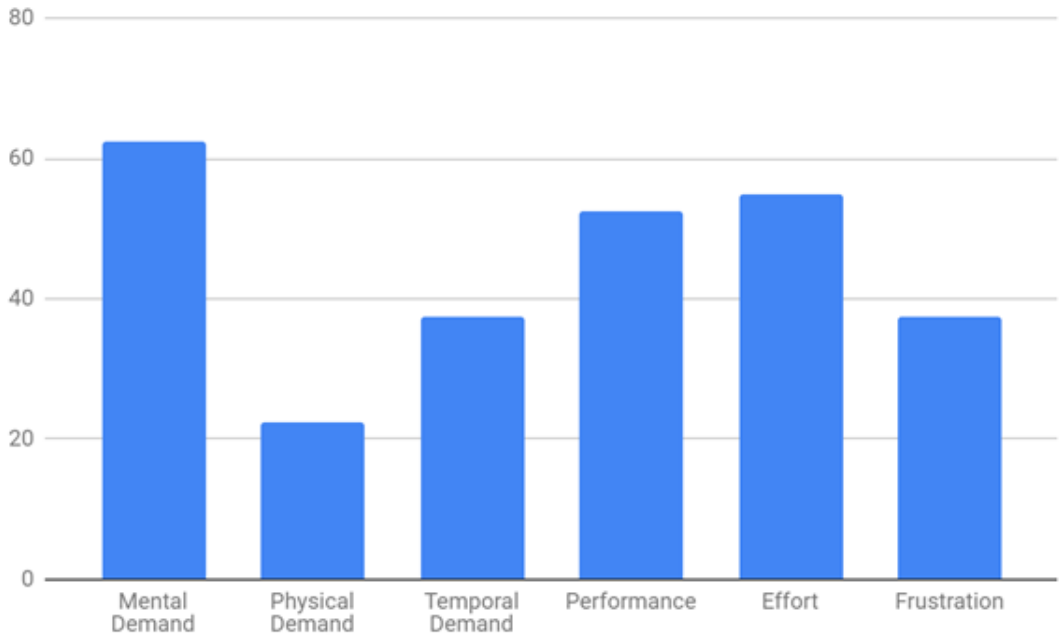

Figure 5.11: This graph shows the measured workload according to the different metrics.

SUS

Table 5.3: Evaluation of the SUS scoring system.

SUS score	Adjective rating
>80.3	Excellent
68-80.3	Good
68	Okay
51-68	Poor
<51	Awful

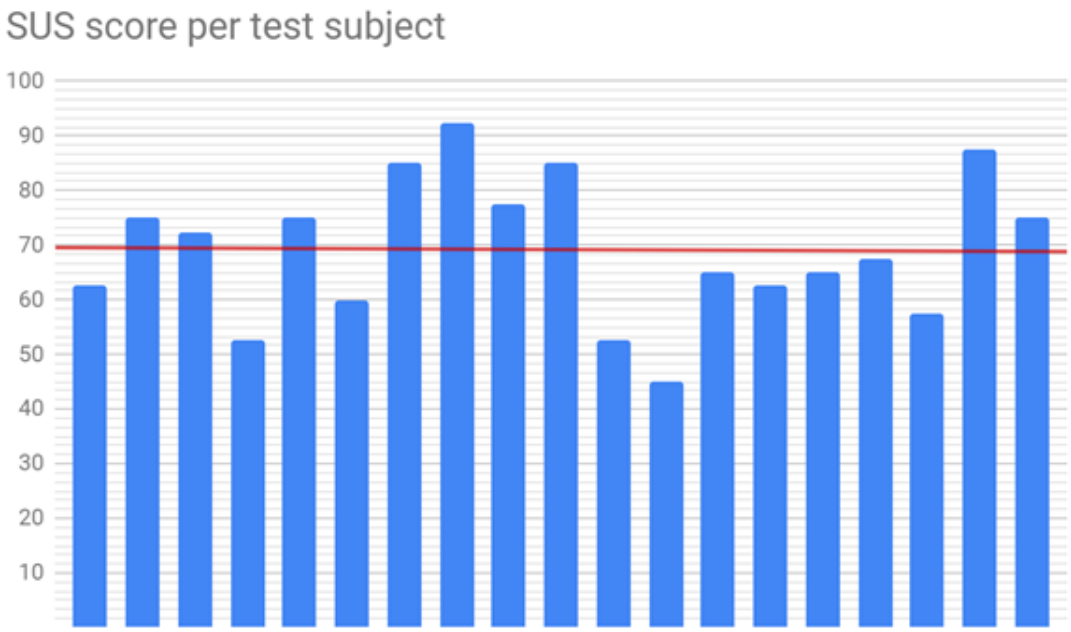

Figure 5.12: The blue bars represent the test subjects' SUS score and the red line illustrates the median score value.

Chapter 6
Discussion

This chapter contains discussions and reflections concerning the results presented in previous Chapter. It will include a few remarks on some previously untouched areas such as, if previous VR experiences matters or if age differences result into actual test differences. Each phase of the design will be discussed as well as future work revolving this thesis.

Before we begin let us briefly re-emphasize the aim of the thesis:

- Create a virtual reality environment in which an bike user interface can be tested and evaluated.
- Implement physical interaction inputs that can control the bike in virtual reality.
- The simulator should have the ability to perform unusual test cases in VR, that otherwise cannot be tested in real life.
- The simulator should have the ability to easily upload HTML-application prototypes into the bike's virtual processing unit in order to test and evaluate different applications or UIs in a cost-efficient manner.

After the interviews with the stakeholders was conducted it became clear that the target group was the developers at the company. Thus, functionality of the simulator was prioritized over aesthetics of the UIs. The main idea was to construct a proof of concept by creating a tool that could test out UIs on a virtual bike display. The questions previously introduced in **Section 3.1.3** carry a different understanding now compared to before so let us go through them again one by one:

Will the motion sickness be overwhelming and ruin the overall user experience?

Right from the beginning of the project we understood that motion sickness would be a huge obstacle and that it would need to be addressed. However, we were not certain of how big of a part it would play until we got the feedback from the users in the second iteration.

Motions sickness was a significant factor in project, since it caused tests to be stopped prematurely. As seen in **Section 5.2.1** that 10 of 25 participants dropped out in total, 7 of which dropped out because of motion sickness. The remaining 3 dropped out because of lack of balance as we will further discuss later on. Out of the 7 test subjects that dropped out, 6 of them reported having previous issues with motion sickness. A couple of participants felt motion sick for several hours after the test ended and one of the participants felt so sick that he could not continue to work for the rest of the day.

Moreover, a few observations were noted after all tests were conducted. For example, it was noted that the participants who tried the application several times got a better controllability with each consecutive try and became more resistant to motion sickness. These consecutive tests were not taken into account and were not included in the test results. However, this behaviondur was still interesting to note because a similar thing occurred with some of our pilot testers. In fact during the actual test, one participant in particular mentioned feeling an improvement regarding motion sickness on the second run where the second UI was tested. Which in turn raises the question: is there a learning curve when it comes to getting used to the VR simulator? This question in particular was only discussed and not thoroughly tested. but it's worth noting that 3/4 of the participants that tried the application again did not feel as motion sick as they felt the first time around. This can open the possibility for a further study in VR, testing if motion sickness can be lowered or eliminated through VR practise.

Will the user be deceived by the stimuli in the VR and lose balance in real life?

To begin with the testing was conducted on a real bike, stationed on a bike stand. This meant tilting left or right was not possible during a simulated bike ride. Only steering right or left with the handlebar and paddling forward was allowed. Keep in mind there are two controllers. One of which controls forward momentum and is bound to the right leg. Meaning, if the leg starts paddling a motion will be felt and the bike inside the simulator will move forward. The other controller was responsible for the steering. It was bound to the handlebar, resulting in rotational changes being applied to the steering inside the simulator.

After the user conducted testing, it was clear that the first instinct many users had was to find balance while riding the bike. In other words, they tried regulating the handlebar by applying small twitch movements to keep their bodies centered on the bike. For many it was not an easy task and almost resulted into some users falling off during the initial bike ride in the simulator. This effect was magnified during turns and roundabouts. However, driving straight was not an issue for most users. In comparison to the car game experience mentioned earlier in **Section 3.1.3** a bike turns by tilting left or right, yet a car only applies centripetal acceleration during turns. Thus, the lack of force feedback resulted in participants focused less on the road and more on relearning how to ride a bike in VR.

Will the resolution be sufficient so that the details in the bike's interface are visible enough?

To test this, we created a virtual bike display that that had a size similar to real ones that are currently available on the market. We also made the messages on the second interface deliberately small, so that they resembled the small sized content that are found in real bike

navigation displays. Our own internal testing showed right from the beginning that it was impossible to see the small content of the second UI in the HMD display. However, it was fully viable on the computer screen despite it having, approximately, the same resolution as the HMD screen. The reason for this is that we view the computer screen's 1600X1200 pixels from a ~ 45 degree field of view, while we view the HMD display's 1440x1600 pixels from a 110 degree field of view. The pixels in the HMD are spread out across 110 degrees, which means that the HTC vive has to represent the same content but with less than half the amount of pixels. To meet the demand we would need a HMD display with, at least, two times better resolution than the HTC vive. There are already several HMD displays with a higher pixel density than that of HTC vive, but we have not tried these yet so we can not draw any conclusions about their capacity. What we can conclude is that an increase in pixel density will put higher demands for a better CPU and GPU. And this is something that we have struggled with already with the lower resolution of the HTC Vive.

How well does the interaction in virtual reality correspond to real-life interaction?

This question is a bit more general and requires user input to determine how well the simulator was executed. In other words, user's comments will be taken into account to discuss this further. Previously we have discussed how balance was an issue in the matter of feeling immersed with the environment. We mentioned, steering with the handlebar did not feel accurate enough, it was considered to be problematic if users required larger movements to turn left or right. This particular issue does not correspond well to the real world and was pointed out by the users that it felt unrealistic to steer with the handlebar. Because of the sense of presence users felt, allowing larger movements would result into them falling with the bike as previously mentioned. Thus a decision needed to be made between dangerous biking or unrealistic biking.

Other users commented on the fact that breaking and pedaling felt unusual at times. Sometimes it felt like the bike was speeding up at start until it reached a certain point, one user said. This also meant that the bike speed in the simulator did not match the speed applied in reality. This effect was felt due to velocity tracking of the controller was not always accurate. Resulting into having limited top speed, so users do not accelerate into infinity. Also on some occasions the right leg controller would lose tracking depending on user movements, so velocity spikes would occur rendering speed limit a must.

One user in particular felt more of a sense of presence when trying to stop the bike using his legs. He mentioned that he felt as if his feet were scraping along the surface of the ground as the bike was moving. Yet, the same user mentioned that riding the bike over obstacles felt odd due to lack of force feedback. This effect is harder to be simulated with the setup used. One would perhaps need a vibration system to be able to emulate that feeling.

On a different note some users mentioned feeling motion sick when performing a quick look up or down. However if head motion was steady the sickness would feel way less. This effect can be related to the fact that quick motions in VR requires more rendering power thus introducing more lag. This in combination with the limited refresh rate of the monitor would result into an odd feeling.

All users were in agreement that the environment and the navigation felt realistic. However, the physics needed to be improved to reflect that of the real world.

6.1 Future work

At the beginning of the thesis, eye tracking was considered to be the main objective. However, due to the limited availability of the device it was decided to conduct the user tests with the regular HTC Vive. Moreover, with the limited time available we were able to create a proof of concept as illustrated in Figure 6.1. The idea is to showcase the capabilities of the eye tracker and what benefits it could bring to the simulator.

This means that eye tracking data can be stored in a data system for later analysis. It would improve the study of user behaviour during a test. For example, if an UI designer would like the application to require less gaze time on the internal bike display, this would be one way to study it. Since the eye tracking data consist of 3D coordinates in a larger room it will be easy to identify the objects at which a user was looking.

Figure 6.1: Green dots in the image represent gaze direction.

An other benefit to storing eye tracker data is to perform a test for risk analysis. This could involve the use of machine-learning to further automate the process of analyzing the data. And based on gaze time on the bike display, a bike ride can be deemed safe or dangerous.

Chapter 7
Conclusion

In the previous chapter a discussion was initiated to analyze the project questions. However, there was no clear conclusion outlined previously. This chapter will give a short and clear idea of our conclusions revolving each question, based on what we have learned so far working on the thesis.

Will the motion sickness be overwhelming and ruin the overall user experience?

If motion sickness is something that has bothered you before, there is a high probability that it becomes an overbearing factor in this simulator. However, for users with no issues with motion sickness the feeling is much less in comparison.

Will the user be deceived by the stimuli in the VR and lose balance in real life?

Due to a high sense of presence in the virtual world, a first time user would most definitely struggle to keep balance. There is a small learning curve to get used to the balancing when riding the simulator bike for the first time. The feeling is quite similar to the feeling when you learn how to ride a three wheeled bike. That is why allowing the user to freely ride around in the simulator can be good to get used to the feeling.

Will the resolution be sufficient so that the details in the bikes interface are visible enough?

No, the resolution of the HTC Vive HMD is far from sufficient to emulate the content of the Bosch e-bike displays. It is uncertain if even the HMD displays with the highest resolution, as of today, would be sufficient. However, the resolution of the HMDs will most certainly continue to improve, and if they continue to improving at the same pace as of today one can expect them to reach a satisfactory level within the next decade.

How well does the interaction in virtual reality correspond to real-life interaction?

Compared to the real world, simulating a bike ride is more complicated to do. It requires more and better equipment to reach the sufficient level of realism. Accelerating, breaking and turning can further be developed to perform well with minor adjustments to current equipment. Such as extracting the velocity and the steering angle from the bikes internal computer. However, tilting while turning, going up or down hill and feeling bumps in the road requires more advanced equipment.

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Appendices

Appendix A

Test plan

Test objectives

The purpose of this test is to evaluate the usability of the simulator and to see if it can be used to evaluate different navigation user interfaces. The test will consist of a casual bike ride along a predefined route. The user will not be familiar with the route and will solely rely on a virtual navigation device for directions. Three different user interfaces will be used on the navigation device to see how well the interfaces can be evaluated with our simulator.

Research questions

> Is the simulation immersive enough so that the user feels convinced of riding a bike?

> Does the simulation have distracting elements that ruin the overall experience?

> Is the motion sickness overwhelming to such a degree that it ruins the user experience?

> Could the user imagine themselves working in a virtual environment to perform some of their tests?

Screening

The questions below are used to determine if the test subjects are part of our target population. They will also be used to for analysis purposes to determine if there are correlations between test results and population characteristics.

Age
Technical background
Ability to ride a bike?
Previous experience with bike navigation apps
Motion sickness sensitivity
Prior experience with VR
Prior working experience with Bosch's E-bike devices?

Method

Phase	Description	Materials	Time
Pre-questionnaire	Gather demographic information	Computer with Internet access	*1 min*
Briefing	Give the test subject an introduction and gather the subjects informed consent	Paper copies of the informed consent sheet	*3 min*
Perform test	Give the subject test tasks and observe the results according to the observation protocol	See equipment list below	*8 min*
Debriefing	Perform a semi-structured interview, NASA TLX survey, SUS survey and the word association survey.	Computer with an internet access	*7 min*

Test environment and equipment

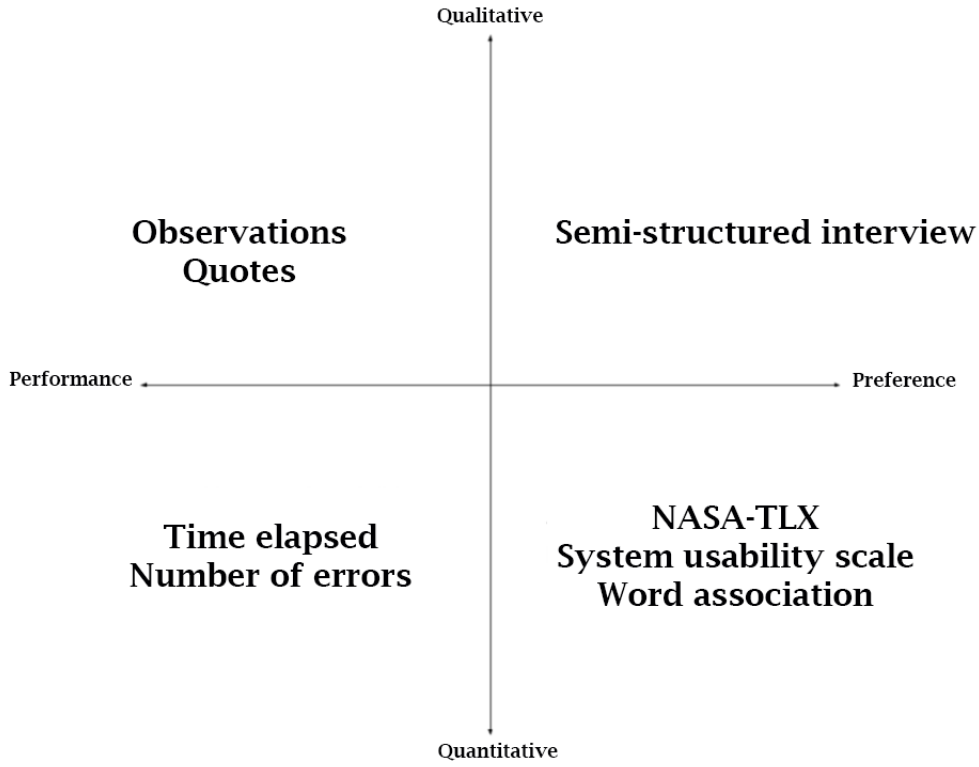
The tests will be performed at the Bosch office in Lund. The following equipment are needed:

- Bike
- Performance computer with Unity, SteamVR and the project installed
- HTC Vive pro kit
- Bike mount for the rear wheel
- Wheel friction machine
- Computer for documenting and conducting surveys

Roles

Test Leader - responsible for the main interaction with the test subjects. His responsibilities are setting up the equipment, briefing, guiding the subject during the test, post-test interview, controlling the simulator and answering questions.
Test assistant - responsible for observing and documenting the outcomes of the test. The assistant will also keep track of max-time for each task and be responsible for gather information from the pre-questionnaire, NASA-TLX, word association and the SUS survey.

Data capture



Documentation

Demographic questions- Google's online questionnaire form will be used and the answers will be stored on google sheets.
Semi-structured interview- The discussion will be briefly summarized by the test leader and stored in a google docs document.
Observation and Quotes- The test leader will write down the observations and quotes in a google docs document.
NASA-TLX- An online html/javascript version will be used to facilitate the documentation process. The scores will be added to a google sheets matrix where the columns represent the measurements and the rows represent the test subjects' scores.
SUS- Google forms will be used for the questionnaire and google sheets for the storage.
Word association- The survey will be conducted on a piece of paper and the answers will be later transferred to a google sheets document.

Appendix B
Pre-questionnaire

1. What's your gender?

- Woman
- Man
- Other

2. What's your age?

3. Do you know how to ride a bike?

- Yes
- No

4. Do you have a technical background?

- Yes
- No

5. How experienced are you with VR?

- I have never tried VR before
- I have used VR applications on my phone (with google cardboard or similar)
- I have used VR applications with head mounted displays
- I am quite experienced with VR applications and feel confident in that environment

6. Do you usually have a problem with motion sickness? (think of previous roller coaster experiences)

- Yes
- No
- Sometimes
- Not sure

7. Do you have prior working experience with Bosch's E-bike devices?

- Yes
- No

8. Have you used gps/navigation apps while riding a bike?

- Yes
- No

Appendix C
Informed consent

Informed consent

This usability test is for research purposes only and all personal information will be kept confidential. The outcomes of these tests will be accessible for the research group only and it will be included in our thesis work that will be published at Lund university's online library.

The test may cause some nausea, and in extreme cases, vomiting and headache. If you are at the end of your sprint or have important deadlines due, we advise you not to participate. The participation is at your own discretion and you have the right to interrupt the test at any given time without any explanation.

By partaking in this test, you agree to being recorded on video. The recorded video will be used for analysis purposes only, and all recorded material will be destroyed once research is over.

I have acknowledged the information above and consent to participate in this usability test.

Name

_____

Signature

_____

Date

_____

Appendix D
Orientation script

Thank you for volunteering to participate in this test. Our names are Sava and Mustafa and we will guide you through this test. The objective here is to evaluate the product, not you or your performance. Behave as you naturally would and do not be afraid to share your thoughts and impressions. We encourage you to "think out loud" (e.g. "this damn button is hard to press", "why is this thing yellow", "now I am going to see what happens if I press this"). You can ask questions during the test, but it is not certain that we will answer.

The session consists of two parts: the test and the evaluation. We are going to start out with the testing where we will give you a destination that you must navigate to using our virtual GPS. You will try three different GPS interfaces and in between each round there be a quick interview. After the testing is done, we will ask you a couple a questions and hand out 3 form that you will fill out. The whole session lasts about 20 minutes, but you may discontinue the participation at any point.

Appendix E
Post-test interview questions

- Which of the user interfaces did you prefer the most? Sort them from best to worst.
- Is the simulation immersive enough so that the user feels convinced of riding a bike?
- Would you use this simulator to perform tests? If yes, what kind of tests would you perform?
- On a scale from 1-10 how motion sick did you get? Which parts were the worst?
- What are your impressions of the virtual bike computer?

Appendix F
SUS Survey

System Usability Scale

© Digital Equipment Corporation, 1986.

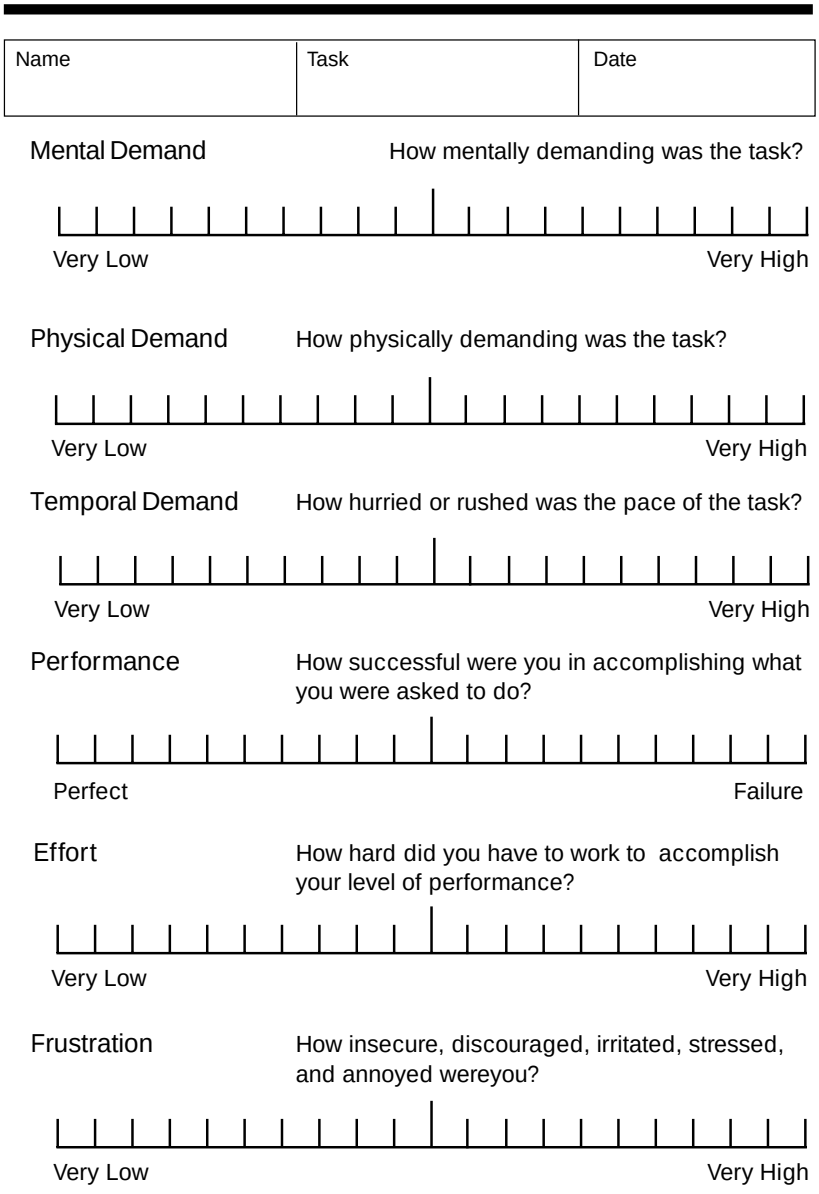
	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Appendix G
NASA TLX

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.



Appendix H

Word assocation

Accessible	Creative	Fast	Meaningful	Slow
Advanced	Customizable	Flexible	Motivating	Sophisticated
Annoying	Cutting edge	Fragile	Not Secure	Stable
Appealing	Dated	Fresh	Not Valuable	Sterile
Approachable	Desirable	Friendly	Novel	Stimulating
Attractive	Difficult	Frustrating	Old	Straight Forward
Boring	Disconnected	Fun	Optimistic	Stressful
Business-like	Disruptive	Gets in the way	Ordinary	Time-consuming
Busy	Distracting	Hard to Use	Organized	Time-Saving
Calm	Dull	Helpful	Overbearing	Too Technical
Clean	Easy to use	High quality	Overwhelming	Trustworthy
Clear	Effective	Impersonal	Patronizing	Unapproachable
Collaborative	Efficient	Impressive	Personal	Unattractive
Comfortable	Effortless	Incomprehensible	Poor quality	Uncontrollable
Compatible	Empowering	Inconsistent	Powerful	Unconventional
Compelling	Energetic	Ineffective	Predictable	Understandable
Complex	Engaging	Innovative	Professional	Undesirable
Comprehensive	Entertaining	Inspiring	Relevant	Unpredictable
Confident	Enthusiastic	Integrated	Reliable	Unrefined
Confusing	Essential	Intimidating	Responsive	Usable
Connected	Exceptional	Intuitive	Rigid	Useful
Consistent	Exciting	Inviting	Satisfying	Valuable
Controllable	Expected	Irrelevant	Secure	
Convenient	Familiar	Low Maintenance	Simplistic	

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