UNIVERSITY OF TWENTE.
Faculty of Electrical Engineering,
Mathematics & Computer Science

"Keep Your Eyes on the Road, Kid!"

Exploring the Potential of Virtual Reality Environments to Teach Children to Keep Their Attention While Biking

Paulius Gagelas

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Supervisor:
Dr. M. Cabrita

Critical Observer:
Dr. A.M. Schaafstal

Module Coordinator:
Ir.ing. R.G.A. Bults

Abstract

In this research project, a connection between a bike and a game engine was developed and implemented in Virtual Reality. This was done with the use of a game developed by both the researcher and an external 3D modeler to let a user pedal in a visual environment, namely the Unity game engine. The main focus was to develop a system that could be used to track pedaling and steering of a non-stationary bicycle. The idea came from a request from therapists for this project to develop a simulated training environment for helping individuals who have problems with biking.

The report started with understanding a real-world problem and followed on by making background research and analysis of related work. Then the main methods of the study were described. After that, ideas were created for the prototype and requirements were stated. Using the specifications, a system was realized and 2 evaluations, with 12 testers each, were conducted. The report ended with a conclusion of the study and ideas for future research.

The final prototype contained 2 input devices: pedaling and steering. The pedaling was tracked to measure the speed of the user and steering was sensed to check how much the user rotated the steering wheel. In addition, the view of the user was displayed by using a Virtual Reality headset. The results of the evaluations were positive and a foundation was built for future projects in the domain of biking in Virtual Environments.

Acknowledgments

First and foremost, I would like to thank my principal supervisor Miriam Cabrita for her input and valuable feedback throughout the project. Her supervision was an incredible experience that let me make important choices during my research. Second, I would like to express my very great appreciation to Albert Hoekstra for his technical expertise and help during the project. Third, I would like to thank Admir for the well designed 3D assets in the game and Randy for helping with the programming of the developed game.

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Chapter 1 Introduction

This project is about the development of a system used in Virtual Reality that improves the focus of children with attention-deficit hyperactivity disorder (ADHD) while biking.

1.1 Motivation

The motivation for this project comes from a passion for developing systems for rehabilitation. In the following research report, the process of developing and testing with the intent to help in the rehabilitation of children with Attention-Deficit Hyperactivity Disorder (ADHD) will be discussed.

1.2 Problem Statement

Attention-Deficit Hyperactivity Disorder (ADHD) is a neuro-developmental disorder that is characterized by an impairment of inattention and impulsivity. At this moment, the worldwide prevalence of ADHD is estimated between 5.29% [1] and 7.1% [2] in children and adolescents and at 3.4% in adults [3]. One of the main symptoms of ADHD is having trouble functioning in an active environment; people affected by ADHD have problems focusing and they cannot be attentive.

To help children with ADHD coping with their disorder, they are helped by professionals to perform daily activities, of which one is biking. However, in regard to biking, according to the CDC Department of Motor Vehicle Safety [4], bicycle injuries are common among children overall, where around half of the bicycle accidents are accounted by children under the age of 14. Children with ADHD are especially at risk of making bicycle accidents, as they easily get distracted. Therefore, it is unsafe to let them bike alone. This causes a big problem because bicycle trips are the most frequent modes of transport in Northern European countries, such as the Netherlands, Denmark, and Sweden [5].

To increase the safety of the children whilst biking, it would be ideal to have the children taught how to stay attentive and to not lose their focus. To accomplish that task, attention must be paid to the multiple factors that affect the attention of the children. Most relevantly is the stress factor, that is evoked when the children need to bike through a busy street that captures their attention. The latter is foremost worrying for the children, but as well for the other people surrounding them.

1.3 Project Background

Roessingh Research & Development

This research project is carried out at Roessingh Research & Development (RRD), one of largest Dutch scientific research center for rehabilitation technology which is situated in Enschede, the Netherlands. It contains a wide range of disciplines such as physiotherapy, rehabilitation medicine, movement sciences, etc. It is an independent organization linked to the Roessingh Center for Rehabilitation. RRD closely cooperates with the University of Twente and Saxion, University of Applied Sciences, and occupies a unique position between research and healthcare practice.

This research project will be based on their proposal for developing an interactive game. The game is intended to train the skills needed for bike riding for children with ADHD using Virtual Reality glasses and a non-stationary bike. Additionally, it is expected that learning to bike correctly in difficult situations will improve the child's attention and focus.

Twinsense 360

Twinsense 360 is a software company that develops virtual and augmented reality experiences, applications, and training. With their help, software for the realization of the reports prototype (discussed in the Realization chapter) will be constructed.

1.4 Project Diagram

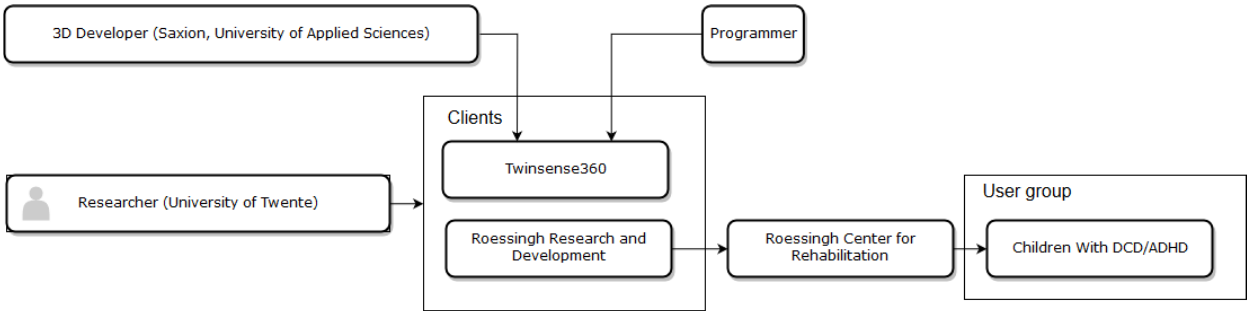


Figure 1 Project diagram

1.5 Definitions

Attention - Deficit Hyperactivity Disorder (ADHD)

ADHD is a neuro-developmental disorder that is characterized by an impairment of inattention and impulsivity [6]. Children with this disorder become distracted and have problems functioning in active environments. This disorder often begins in childhood and frequently persists into adulthood. Due to the project proposal, children with ADHD will be the user group for which this research is developed. Therefore, in the literature review, more information about the difficulties with living with ADHD and the rehabilitation techniques used to help with this disorder will be analyzed.

Developmental Coordination Disorder (DCD)

DCD is a motor skill deficiency. Frequently described as "clumsy" by their teachers and parents, children diagnosed with DCD have problems with simple motor activities, such as tricycle or bike riding [7]. DCD is often associated with other developmental conditions, such as ADHD, learning disabilities (LD), etc. Around half of the children, diagnosed with DCD are also diagnosed with ADHD, hence the child has both attention and motor skill deficiencies. In RCR, multiple children with DCD are in rehabilitation to help them improve their skills, therefore the later discussed therapists that will help in this project are currently training them but need a new, safe, and interesting way to train to ride bikes.

1.6 Research Questions

After researching, the problem and understanding the project background, research questions are constructed and stated hereafter:

Literature Review

Main literature review research question:

How to develop an active game for children with ADHD?

Sub-questions:

Challenges of ADHD:

1. What cognitive challenges do children with ADHD have?
2. What factors influence the attention of children while biking?

Serious games:

3. What is the definition of a serious game?
4. What criteria should be contained in a game for children?

Active games:

5. What is the potential of active games in the treatment of ADHD among children?

Usability and User Experience

1. Does tire resistance influence the experience when biking in a Virtual Environment?
2. What is the experience of pedaling, steering and stopping inside of a virtual environment with a real bike?
3. How immersive is the experience for biking in a virtual environment with a real bike?

Chapter 2 State of the Art

The following chapter contains the goal of the thesis, a literature review on ADHD, serious and active games, Virtual Reality, related projects and a conclusion on the current gaps in technology.

2.1 Project Goal

Attention is a necessity for all people in everyday life to function safely in society. The lack of focus when biking can cause problems, such as injuries or accidents. Individuals with attention deficit disorders are more prone to dangerous situations in daily life, for example, biking is very challenging for them. To help the child focus on the road, a game environment that puts the user in real-life situations to train them is used. The goal of this project is to develop a system for biking in Virtual Reality (VR) that will help children suffering from ADHD increase focus. In addition, ideally, let them bike in the real world safely.

This is a *problem-driven* project that fills the current gap in rehabilitation care for children at Roessingh Center for Rehabilitation (RCR). This project will provide a training environment for transitioning from riding alone indoors to the real world that contains traffic and other bikers.

2.2 Challenges of ADHD

People who have ADHD must live with multiple cognitive challenges. These difficulties make their lives harder than for the general population of children who are not affected by this disorder. Notably, these children have problems with keeping still and trying to focus on one task. This leads to the child becoming distracted and losing his train of thought. A first challenge, according to Davey [8], is that in an academic setting, the attention of the child is elsewhere. This leads to not taking in the information said by a teacher and therefore does not result in a correct response to given instructions. Additionally, they tend to go from one task to another without finishing the former. Davey [8] states that the loss of focus is caused by stimuli and unrelated ideas. In relation to biking, the children might find it difficult to stay on one task, like focusing on the road. Also reading static text that is displayed with instructions can be a hassle.

Another cognitive challenge is derived from the guidelines of the National Institute of Mental Health (NIHM) [9], it can be understood that it is challenging to control impulsive behaviors for children with ADHD, which can result in being restless and constantly active. As an additional challenge, Merrill et al. [10] observe that children with ADHD are likely inattentive and become distracted easily. In addition, they cannot foresee the consequences of some behaviors, unlike children without ADHD. To sum up, the main cognitive challenges these children face negatively affect their everyday life and cause a loss of attention. The reviewed literature gives a good starting point for continuing with what ADHD challenges affect children.

2.3 Current Rehabilitation for ADHD

Multiple treatments of ADHD are analyzed to understand what current practices exist to help children rehabilitate that have this disorder. As of today, there is no cure for ADHD, but currently available treatments may aid in improving the functioning of the children and reducing the symptoms of ADHD. Firstly, the main treatment for ADHD is medication therapy, where pills are used to aid such problems as short attention span, impulsive behavior, and hyperactivity [11]. Although this treatment is effective, problems may occur with optimizing the treatment, such as adjusting the dosing, which can lead to drug abuse [12].

Secondly, Cognitive behavioral therapy (CBT) has shown to improve ADHD symptoms [13]. CBT is a form of psychotherapy used to treat problems by modifying behaviors and thoughts. CBT focuses on solutions, which encourage the patient to change patterns in their behavior. However, this treatment has several limitations concerning its effect on users that have lower cognitive skills.

Another treatment is neurofeedback, which is a type of therapy that uses electroencephalography (EEG) to regulate and improve the patient's brain activity. Neurofeedback is a therapy that aims to tackle the problem of patients with ADHD not having sufficient communication among the neurons in their brains. EEG readings of ADHD patients show brain activity with increased theta and decreased alpha/beta frequencies [15]. In this therapy, the patient is trained to enhance the desired EEG frequencies and suppress the unwanted ones. Lastly, behavioral parent training (BPT) can be used in the treatment of children with ADHD by using effective methods that help handle the child's behavior. The aim is to teach parents new ways of disciplining their child. In this treatment, parents are trained in how to handle different situations with their children: monitor problematic behaviors, reward positive actions with attention or prizes, giving effective commands, etc. [16].

To conclude, multiple different treatments are discussed, many of which have shown clinical benefits for this population. Although none of the treatments specifically targeted the action of biking, different ideas such as EEG monitoring (Using neurofeedback) and learning to give rewards or stimuli to keep patients attentive (Using behavioral parent training) can possibly be used in developing the game for rehabilitation.

2.4 Serious Games

There is no clear definition of serious games due to multiple interpretations. For instance, serious games are defined as games that have an extra purpose that contains goals that do not entertain [17], [18]. Baranowski et al. [17] state that a subset of serious games is designed with an additional purpose next to entertainment and that these types of games are used to increase a person's health. Additionally, even though games contain non-entertaining goals, they must focus on learning or training a specific skill of the trainee, declares Drummond et al. [18]. In addition, the lessons learned in serious games should be used in real-life environments such as everyday life.

One thing serious games can take advantage of is 3D gaming, as proposed by Navarro et al. [19]. Furthermore, 3D gaming can improve the experience of realism from the users. Useful characteristics of 3D gaming are that these types of games combine concepts from computer games and for training specialized personnel. To summarize, the definition in this literature review for serious games will be as follows: *a game that has an additional purpose to entertainment, which will be* *educational*. The game that will be developed should be fun for the children to play and learn how to bike in a correct fashion.

2.5 Potential of Active Games

The potential of active games is immense because it helps users with multiple problems. One of which is the need for more applications of active games that promote physical well-being, as the majority of children and youth around the globe do not meet current physical guidelines and, therefore are considered to be inactive [18]. A variety of games were developed for children for both general health and rehabilitation purposes. Some of which use specific hardware: Wii [20], Kinect [21] and the PlayStation 2 [22]. Also, non-digital games that were tested with children with no electronic devices [23]. All of these involved and promoted physical movement.

Moreover, an additional potential is that participation in active games that require physical activity is suggested to have psychosocial benefits that enhance game-related concepts such as rule compliance [20]. Children who engage in the task in games are motivated to reach intrinsic rewards that help them experience self-efficacy more than usual. The 8-week intervention period resulted in physical improvements such as upper-limb coordination, increased postural stability, etc. Although the research conducted by Berg et al. [20] was with children that have Down syndrome, the reasons why active games are used are also applicable for children with ADHD.

Another potential was recognized in a study done by Chang et al. [21], a couple of young adults, aging from 16 to 17, tested an exercise system using the Kinect that they had developed. The game increased the motivation of the testers to participate in physical activity. Notably, the author suggests letting multiple users engage in the active game, such that peer encouragement and more enjoyment could be achieved with rehabilitation. In a similar study, which was a randomized controlled trial, conducted with children that have ADHD, displayed that active games are one of the most popular leisure activities because they provide a space for engagement, learning and forming emotional bonds with peers [24]. In a physical treatment program, O'Connor et al. [25] showed a significant improvement after sports outcomes were measured. Also, the knowledge of the given tasks, the game, and the performance significantly increased.

The potential of active games for rehabilitation of children with ADHD was analyzed in multiple scientific studies. A variety of concepts such as rule compliance, motivation, engagement increase while taking part in active games. To summarize, active games are truly important for the health of a child, as they have social, physical and emotional benefits.

2.6 Virtual Reality

As discussed in the project proposal the clients have asked to incorporate the bike training in Virtual Reality (VR). Therefore, a virtual environment will be developed as part of the prototype due to all the advantages discussed below.

1. The environment is safe and prevents injuries [26].
2. The environment updated to become more complex: additional audial, graphical elements.
3. The environment can be patient specific and made specifically for the user's needs.
4. The environment can give the user feedback on his task progress.
5. The behavior of the user can be recorded in the system.
6. Scenarios that the users have problems with can resemble in virtual space at a low cost.
7. VR can be made entertaining to motivate the user to continue with the test.

2.7 Related Work

This sub-chapter will describe different previous projects on multiple aspects of the product that will be made. Comparisons of projects will help as an indication of what is possible and what are the pros and cons of the system design.

The conclusions made in this part will be used in the Realisation (Chapter 6) part of the development of a prototype. Firstly, an analysis of projects with Speed-Sensing is discussed. This is split into simple projects and companies. Following that will be the ways to capture the steering of the wheel. Lastly, the different choices for a virtual headset will be compared.

Speed-Sensing Projects

Arduino Bike Speedometer [27]

In this project, a magnetic (reed) switch is used to check when the wheel has made a complete revolution. When a magnet is in close vicinity of the sensor, a digital read value spikes, and then a mathematical calculation, seen in Equation (3), is done to save the miles per hour of the bike. Both the bike wheel diameter and the time is taken (incremented each loop cycle) must be known for completing the calculation. The Equations are included below.

$$miles\ per\ hour = mph = \frac{milliseconds\ per\ hr}{inches\ per\ mile} \cdot \frac{circumference}{timer} \tag{1}$$

There are 63360 inches in a mile and $1000 \cdot 60\ (minutes) \cdot 60(seconds) = 3{,}600{,}000\ ms$ in an hour.

$$mph = \frac{3{,}600{,}000}{63360} \cdot \frac{circumference}{timer}$$
$$mph \approx 56.8\ \cdot \frac{circumference}{timer} \tag{2}$$

The type of $timer$ is a double so we must cast both to a float and then divide them.

$$mph \approx 56.8\ \cdot \frac{float(circumference)}{float(timer)} \tag{3}$$

Equation (3) can now be used to convert from mph to kilometers per hour (kph).

A VR Cycling Experience [28]

In this project, an infrared (IR) light is used to check when the wheel has made a complete revolution. A piece of white paper is placed on the wheel of the bike that helps detect when the bike has made a complete turn.

The technique used here is to set an infrared pin to high and then check if the sensor pin becomes low because then the sensors are pointing towards the paper. After that, a digital value of HIGH is sent to the serial port, which is read in a Unity sketch and the time difference between values are sent is recorded. Bluetooth low energy (BLE) is used to connect to the sketch and open a serial port for data from the sensor.

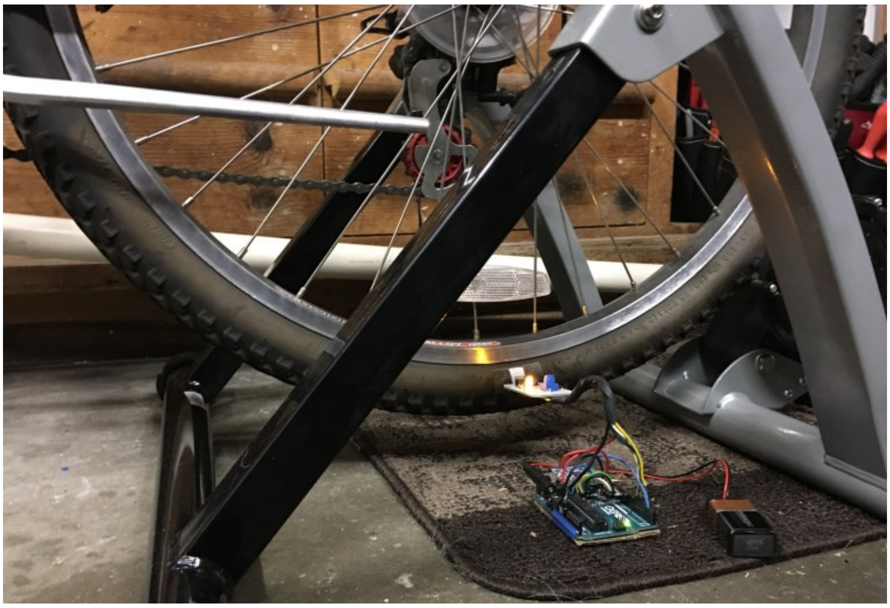


Figure 2 Infrared light sensor

Exercise Bike Racing with a Wireless Wearable [29]

A wireless sensor was used to send over data using Serial Communication wirelessly. Although this has a goal of measuring speed and subsequently using it as input to software, this project is regarding measuring the movement of the foot while pedaling. This movement is captured with an accelerometer that is placed on the user's foot, as can be seen in Figure 3. This project involves transmitter and receiver modules for communication with a computer. When the user constantly follows a pedaling motion, this data is converted into a click of a button on a keyboard.

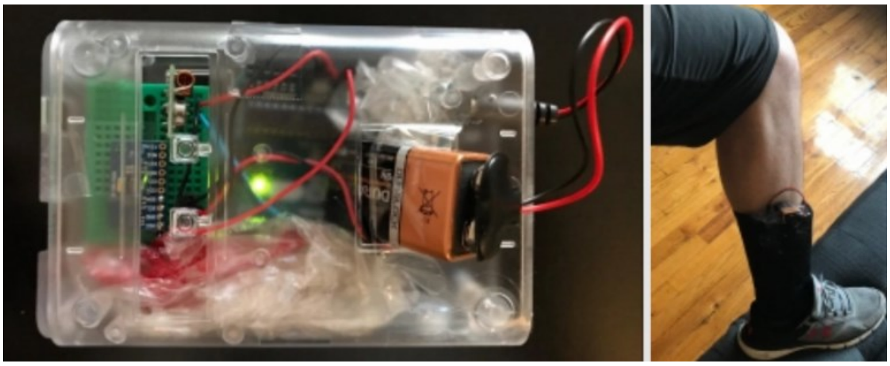


Figure 3 Sensor mounted on the leg

DIY Speedometer on Arduino [30]

In this project, a hall sensor is used to check when the wheel has made a complete revolution. The project is very similar to the one mentioned before [27], such that both of these projects involve magnetism and capture the moment when a magnet is sensed in close proximity of the sensing device.

Similar Systems

VirtuPro [31]

A company that is involved in the development and sales of stationary bikes used with self-made software to travel in a virtual environment. The user pedals and then these movements are transferred to virtual space. A user can choose to cycle in multiple different locations. There is a very important limitation in this product, there is no virtual headset involved, and therefore a screen is used to display what the user sees in front of him.

Figure 4 Stationary bike from VirtuPro

Bike Trainer by Widerun [32]

A company based in Italy have made a bike trainer that works with the Oculus Rift. Their system helps make a fitness session more engaging and interesting. Their aim is to increase motivation for fitness indoors. That is done by tracking speed and adding resistance depending on the difficulty of biking at a specific virtual place, such as going uphill in their application has more resistance. An addition here is that because of how the system is designed (Figure 5), any bike can be used with it, this makes it accessible for more people.

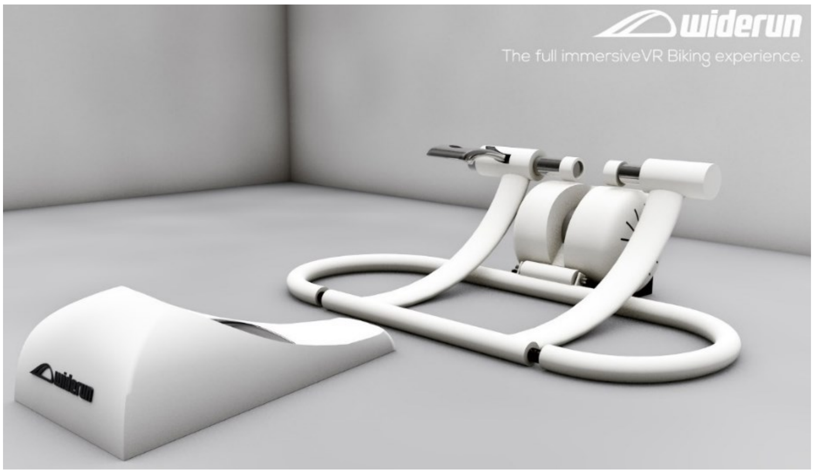


Figure 5 Exercise machine made by Widerun

Additionally, Widerun has a selection of different Virtual Environments, which the user can choose to bike in (Figure 6). Therefore, Widerun does not solely work on hardware, these different scenes show how they try to incorporate game engines and their main product, the exercise machine.

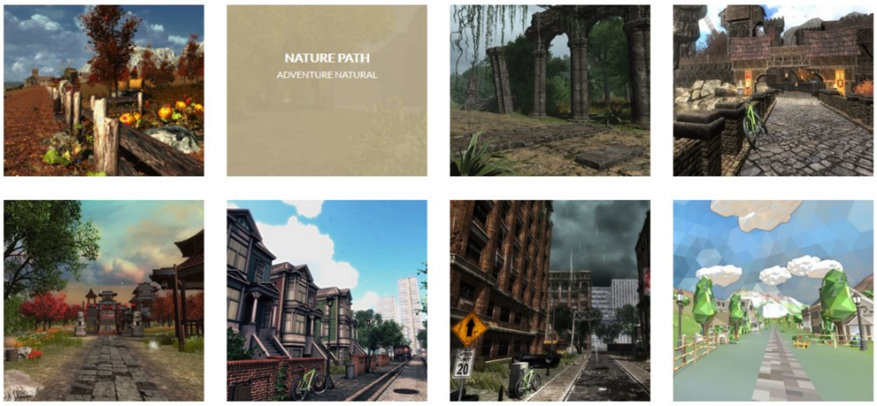


Figure 6 Map choices in the software of Widerun

Another addition to this project is the User Interface (UI) that displays statistics of the user: distance traveled, completion percentage, average speed and total time exercising. Also, it incorporates other people by showing them in the video with their name and their score.

Virzoom [33]

Virzoom develops software and hardware for biking in Virtual Reality. “Play VR. Get FIT” is the motto for their product. It works with multiple Head Mounted Displays (HMDs) and contains a variety of different games (Figure 7). Surprisingly, most of the games do not involve biking, they contain a car, tank, horseback, etc. driving that makes the game less monotonous. This lets the user imagine that he is controller some other type of vehicle.

Figure 7 Map choices in the software of VirZoom

Speed-Sensing summary

Table 1 Summary of projects with Speed-Sensing

<table>
<tr><th>Project</th><th>Sensor technology</th><th>Pros</th><th>Cons</th></tr>
<tr><td>Arduino Bike Speedometer [27]</td><td rowspan="2">Electromagnetism</td><td rowspan="3">• Easy to build
• Easy to attach sensors
• Cheap sensors
• Accurate sensing
• Needs a non-stationary bike to work
• Wheel rotation tracked</td><td>• Needs to attach a magnet</td></tr>
<tr><td>DIY Speedometer on Arduino [30]</td><td>• Magnet needed as a tracking point
• Fragile glass sensor</td></tr>
<tr><td>A VR Cycling Experience [28]</td><td>Infrared light</td><td>• Light colored surface needed as a tracking point
• Can have a negative influence depending on light intensity
• Will not work with a light-colored wheel</td></tr>
<tr><td>Exercise bike racing with a wireless wearable [29]</td><td>Accelerometer</td><td>• Foot rotation is tracked</td><td>• The user must wear a sensor on their body</td></tr>
<tr><td>VirtuPro [31]</td><td rowspan="3">Undefined (Company secret)</td><td>• Integrated/Covered sensors</td><td>• Uses a stationary bike
• Uses a screen and not a VR HMD</td></tr>
<tr><td>Bike trainer by Widerun [32]</td><td rowspan="2">• Integrated/Covered sensors
• Works with VR glasses
• Works with multiple HMDs</td><td>• Bulky design</td></tr>
<tr><td>Virzoom [33]</td><td>• Uses a stationary bike</td></tr>
</table>

Steering-Sensing Projects

Steering Project with MPU6050 [34]

This project uses an MPU6050 which contains a 3-axis compass, accelerometer, and a gyroscope to measure the rotation of an object in real space. It is an IMU (Inertia Measurement Unit) sensor. It communicates using the Inter-Integrated Circuit (I^2C) Bus Protocol because it allows multiple sensors, called “slaves”, communicate with one or more “master” chips. Therefore, using Visuino, a visual program for programming in Arduino, the values of the sensors by default are acceleration forces but are converted into 3 angles: X, Y, Z corresponding to each dimension in space. Then the angles are visualized.

HTC Vive Tracker

A tracker developed and sold by HTC that brings any real-world object into a virtual world. It a wireless add-on to the HTC Vive software (Steam VR). It calculates its position and orientation based on infrared signals emitted by HTC Vive base stations. It is very similar to normal HTC Vive controller but contain no buttons and are not ergonomically made for being held in a hand.

Figure 8 HTC Trackers

Virtual Reality Headsets

Multiple Virtual Reality (VR) head-mounted displays (HMD), headsets, are available for consumer use. Some of them will be explained and compared below.

Mobile/ Handheld Headsets

The Samsung Gear VR was the most commonly sold Virtual Reality HMD in 2016 [35]. The crucial difference between the other technologies that will be discussed is that a smartphone is needed to render and display images. There are numerous similar products such as the Google Daydream View 2, etc. There are differences between HMDs: price, supported smartphones, lens calibration, the field of view.

PC/ Console Connected Headsets

These are more high-end systems that usually contain proximity sensors that need to be set up for position tracking of the user. These HMDs must be connected to a high-end computer or a VR compatible. The most popular HMDs are the HTC Vive, Oculus Rift, and PlayStation VR.

Figure 9 Different HMDs

Summary

There are many Head Mounted Displays used for Virtual Reality headsets but only the best VR headsets of 2018 [36] will be included in the comparison table below.

Table 2 Comparison table of VR headsets

Name	Resolution (per eye)	Field of View	Wired
Samsung Gear VR	Depends on smartphone	96°	No
Google Daydream View 2	Depends on smartphone	110°	No
HTC Vive	1080x1200	110°	Yes
Oculus Rift	1080x1200	110°	Yes
PlayStation VR	960x1080	100°	Yes

From the comparison, it can be seen that there are multiple differences between the headsets. A requirement will be specified such that the developed system must support multiple Mobile/ Handheld and PC/ Console immersive Virtual Reality headsets.

2.8 Gaps in Technology

After the analysis of similar projects, it is apparent that technology for biking has not been combined for the realization of a system with both steering and pedaling of a real bike in the context of rehabilitation, education more than entertainment or solely exercising. The hardware choices are done in conjunction with the opinions mentioned in the websites in 2.7 Related Work.

Chapter 3 Methods and Techniques

The following chapter contains the methods used in this thesis and the hardware, software used for developing the system.

3.1 Design Methods

"A Design Process For Creative Technology" [37] will be used as a guideline for the execution of the design project. This paper discusses a specific iterative design process used for projects in Creative Technology. This process is described as a flow diagram below in Figure 10. The central theme of developing in this process is the idea of iteration. This involves thinking of different techniques to complete a task and then testing them with users. This makes the design non-linear and the chapters more intertwined and relevant to each other.

The report will be split into multiple chapters where the design, development, testing will be explained. The first design process is described in the Ideation Phase (Chapter 4 Ideation). The Specification Phase will be done inside of the Ideation chapter which will contain end system requirements. The Realization Phase (Chapter 5 Realization) will decompose the product specifications and the implementation choices made for the end product.

Between each of the chapters, evaluations of the developed system will be done to improve the quality of the end product. This involves either short non-structured user tests or the developer tweaking and polishing the functionality of the system. The report will be ended with an Evaluation Phase (Chapter 6 Evaluation) in which an evaluation plan and form for evaluating the system will be discussed.

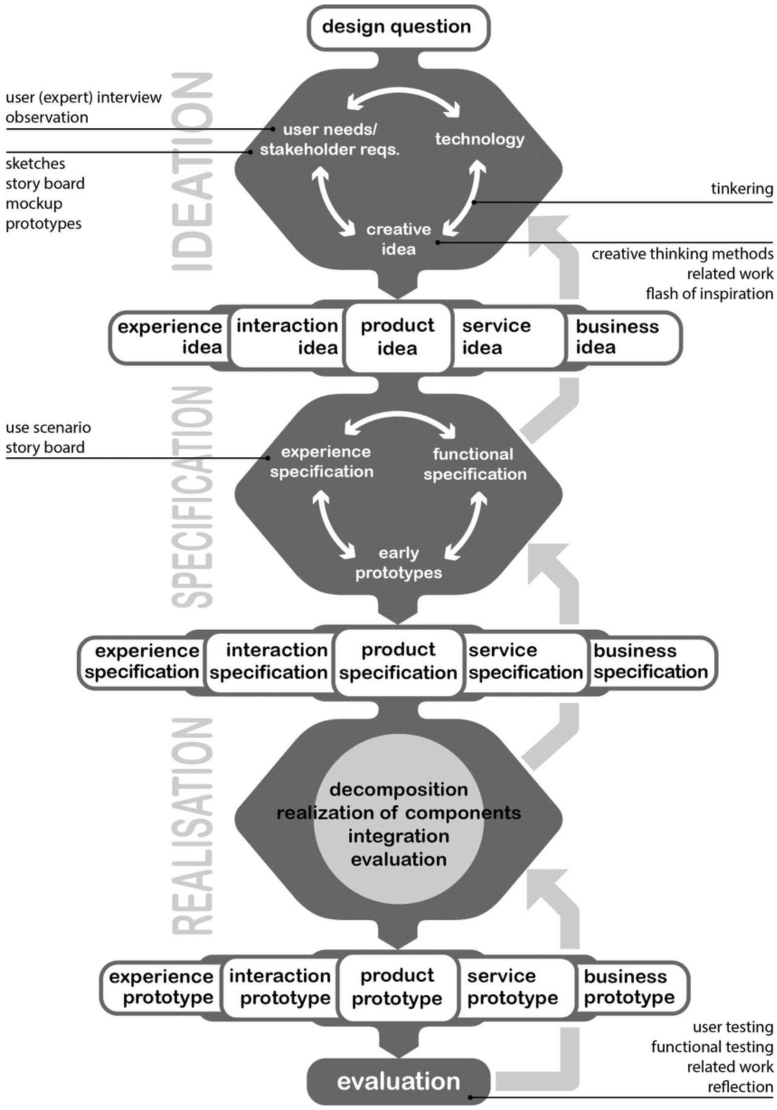


Figure 10 Creative Technology Design process (Source: [37])

3.2 HTC Vive

The Virtual Reality headset that will be used for development and testing the end product is the HTC Vive. It was mentioned in subchapter 2.7 Summary, that one of the best headsets currently available is this specific model. Additionally, the research is being conducted at RRD where an HTC Vive is available on hand for testing.

3.3 Unity

Unity is a cross-platform game engine; it is popular among game developers. The whole developed game will be rendered using this engine due to multiple advantages. Firstly, it contains an asset for handling input from the HTC Vive. Secondly, while being a game engine, it can be used for research and simulation. Therefore, an environment will be simulated for pleasure and for academic research reasons. Lastly, the researcher has experience with the Unity development environment. The version in this project was Unity 2018.1.0f2 64bit Personal Edition.

3.4 Microprocessor

Currently, there are multiple microprocessors that could be used in this project. Nevertheless, a choice was made to use an Arduino because of prior knowledge and its open source software [38]. An Arduino Uno is available at hand and contains multiple digital and analog pins that can be used for connecting input devices.

3.5 Indoor Bicycle

For this project, the researcher has received access to a full-size 28-inch city bike and indoor fitness exerciser so that pedaling in place would be possible. Additionally, a small 18inch bike will be used for evaluating the system with children. A while ago it was also used for connecting parts of it to software, so currently it still has magnets on it from the previous sensing.

3.6 IPQ Questionnaire

For the evaluation of the system, the Igroup presence questionnaire (IPQ) [39] will be used in combination with general quantitative questions for system evaluation. The IPQ form is used to understand the sense of the presence of the users in the virtual space. This questionnaire was used in multiple studies, one of which was done with a large sample size (N = 296). A reliability analysis revealed that different components had either Acceptable or Good internal consistency. The questionnaire contained 4 different subscales, their Cronbach's Alpha values were calculated. The subscales were Spatial Presence, Involvement, Realism and the complete questionnaire with values: $\alpha = .77$, $\alpha = .76$, $\alpha = .70$, $\alpha = .87$ respectively.

Chapter 4 Ideation

The following chapter contains the brainstorming process and thinking of different ways to capture the needed data and transferring that information to Unity. Also, the initial iterations of the technical part are described. In addition, a couple of scenarios are described for how and why the product might be used.

4.1 Brainstorming

A brainstorm session was realized to diverge in the number of ideas for different components of the end product. This can be seen in Figure 11. The main idea for having a brainstorming session was to visualize the different techniques and problems that may occur in the development of the small subsystems.

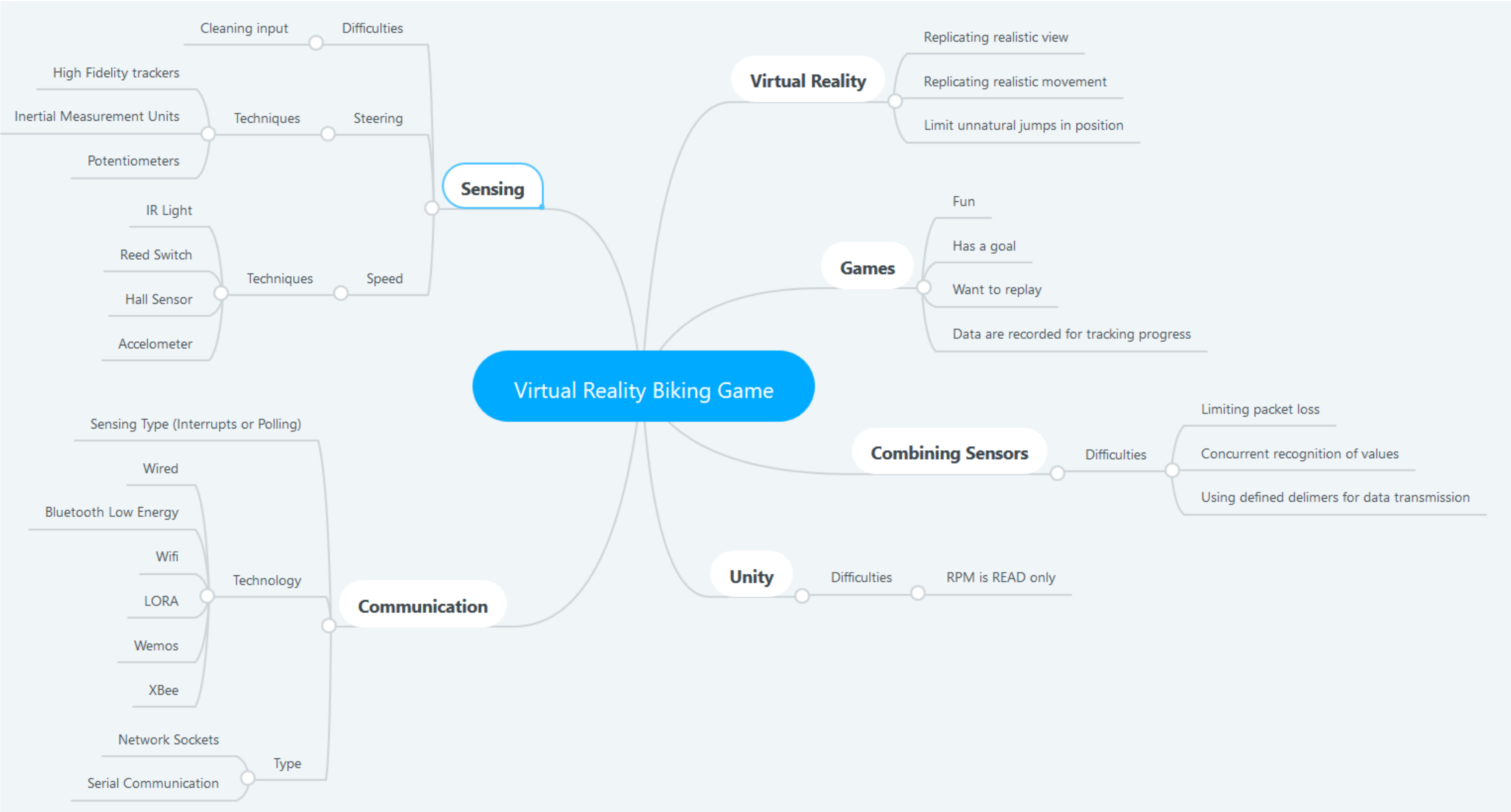


Figure 11 Brainstorm diagram

4.2 Scenarios

To have a better understanding of how the system, that will be developed, will function, a couple of detailed scenarios are described.

Rehabilitation Center Scenario

Tom, aged 8, has problems with focusing while biking, therefore several therapists are helping him rehabilitate. He trains indoors how to correctly use a bike, i.e.: keep upright, steer correctly. Unfortunately, this does not represent reality accurately and he cannot test different situations that may occur in the real world, such as turning with active traffic.

Tom visits the rehabilitation center, enters the training room, where he is asked to sit on a bike. This bike is on an indoor bike holder to let the bike tire rotate in place. After he sits down and adjusts the seat to his liking, he is handed a Virtual Reality headset, after putting it on, the therapist turns on the first level of the game, in which Tom gets acquainted with the controls and the sensitivity of the steering. He is told in-game that he needs to reach some point straight ahead, so he starts pedaling towards there. He is surrounded by peace and quiet until the end.

Now that he knows how to pedal in the game, the second level is started. Now he sees multiple cars driving next to him, he starts pedaling and, in a few meters, he sees a traffic light, it is red and therefore he waits. After it becomes green he continues pedaling forwards but then another biker from his right comes out and Tom hits him with the bike, Tom becomes scared because he was only looking in the forward direction and not around. The therapist turns on the camera and asks him what happened and why did he not look around. While looking at the therapist's video stream, he explains himself and then the level is restarted, now he completes the intersection correctly and does not cause any accidents. He gets greeted with a prize in the game for completing the first 2 levels. Then he continues with the third level.

At-home Scenario

Anne is 10 years old and she bikes to school each day alone. She drives according to the rules and is focused and attentive whilst biking. Although she has problems with intersections with cars of bikes. She starts to maneuver but loses her focus when multiple other people are surrounding her. She freezes and sometimes just stops in the middle of the road. After some seconds she restarts pedaling and leaves the intersection.

She wants to train in these specific circumstances but does not want to try in the real world. Therefore, she purchases the system, connect it to her own bike at home and puts on a virtual headset. She chooses the thing she would like to try, such as a level where crossing the road and interactions are included. She tries those levels and after some practice, she gets the hang of it and completes them flawlessly. The following day she is faced with a similar situation in the real world. She does not panic or get stressed, she just remembers what she had done and learned in the virtual world which helps her cross the road correctly.

4.3 Requirements

The following subchapter contains a subset of the requirements for the system. Functional and non-functional requirements are differentiated to distinguish between *what* the system should do and *how* the system will do it, respectively. For each listed requirement, the MoSCoW [40] method will be used to prioritize the requirements. An additional list of the requirements that were not implemented due to time constraints are added as an idea for improving the product in the future; they can be seen in Appendix F: Extra Requirements. The requirements that were asked to be included by the therapists were added containing the source: the expert interview. The requirements were created on the 9th of April, 2018.

Functional Requirements: Hardware

Requirement ID#: 1	Requirement Category: Functions and Events
Requirement: The system measures the rotational speed of the back tire.	
Rationale: The ability to pedal will affect the visuals of the game, which will make the experience of biking real and the virtual environment will simulate the actual world.	
Source: Clients (RRD & Twinsense 360)	Priority: High (Must)

Requirement ID#: 2	Requirement Category: Functions and Events
Requirement: The system measures the rotation of the steering wheel.	
Rationale: Steering will increase the degrees of freedom of the experience and will let the user become more in control of the game.	
Source: Clients (RRD & Twinsense 360), Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 3	Requirement Category: Interaction and usability issues
Requirement: The system is stable; the sensors measure as intended.	
Rationale: The sensors must stay in place and not shift over time. Might be problems with sensor placement.	
Source: Personal preference	Priority: High (Must)

Requirement ID#: 4	Requirement Category: Functions and Events
Requirement: The system works with a Virtual Reality (VR) headset.	
Rationale: Using a VR headset, the head movements of the user are tracked live to make the user believe that he is in a virtual environment.	
Source: Clients (RRD & Twinsense 360)	Priority: High (Must)

Requirement ID#: 5	Requirement Category: Functions and Events
Requirement: The system works with *different* Virtual Reality (VR) headsets.	
Rationale: Users may have different headsets available at their home or rehabilitation center, therefore the system should be VR device independent.	
Source: Clients (RRD & Twinsense 360)	Priority: Medium (Should)

Functional Requirements: Software

Requirement ID#: 6	Requirement Category: Interaction and usability issues
Requirement: The software contains a trigger to pause it and/or restart it (i.e. a keyboard button).	
Rationale: It is important to pause the game to let the user think about what went wrong. Restarting the game is important to practice the same situation again.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 7	Requirement Category: Interaction and usability issues
Requirement: The system allows the therapist to see what the user is seeing.	
Rationale: The therapist wants to see alongside the patient to check if the game is progressing correctly and the user is playing in a right fashion.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 8	Requirement Category: Interaction and usability issues
Requirement: The game shows the therapist in-game.	
Rationale: The ability to talk to the therapist while in a virtual environment decreases the hassle of taking off and putting back on the VR headset.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 9	Requirement Category: Interaction and usability issues
Requirement: The system is easy (1min max, low technical skills) to calibrate.	
Rationale: The process of calibrating the steering wheels location and alignment is very important for smooth gameplay.	
Source: Clients (RRD & Twinsense 360)	Priority: High (Must)

Requirement ID#: 10	Requirement Category: Interaction and usability issues
Requirement: The game can be played without assistance from a therapist.	
Rationale: The use of professional assistance should not be necessary, hence making this program low-cost for the end-user.	

Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 11	Requirement Category: Interaction and usability issues
Requirement: The game contains multiple traffic conditions.	
Rationale: Different traffic conditions will help the patients learn and train how to correctly maneuver in such situations.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)

Requirement ID#: 12	Requirement Category: Interaction and usability issues
Requirement: The system gives textual and audial feedback to the user.	
Rationale: The user needs to be informed about his progress while playing a game, this way will give either positive or negative feedback live.	
Source: A Literature review (Baranowski et al. Games for Health for Children)	Priority: High (Must)

Non-functional Requirements

Requirement ID#: 13	Requirement Category: Interaction and usability issues
Requirement: The system features clear documentation of all subsystems and source code.	
Rationale: Documentation is useful for understanding how/why something works which helps in adding new elements to the code.	
Source: Client(RRD)	Priority: High (Must)

Requirement ID#: 14	Requirement Category: Interaction and usability issues
Requirement: The system is relatively (Up to 50 EUR) cheap to produce.	
Rationale: The system should be affordable for people without investing a large amount of money.	
Source: Personal preference	Priority: Medium (Should)

Requirement ID#: 15	Requirement Category: Interaction and usability issues
Requirement: The system is lightweight and compact.	
Rationale: All of the sensors are of a compact size and low weight.	
Source: Personal preference	Priority: Medium (Should)

Requirement ID#: 16	Requirement Category: Interaction and usability issues
Requirement: The system works with different sized bikes.	
Rationale: Users may have different sized bicycles tires.	
Source: Clients (RRD & Twinsense 360)	Priority: Medium (Should/Could)

Requirement ID#: 17	Requirement Category: Interaction and usability issues
Requirement: The system must work with different types of bikes.	
Rationale: Users may have different types of bicycles.	
Source: Clients (RRD & Twinsense 360)	Priority: Low (Could)

4.4 System Design

To successfully construct a system that can both sense steering and pedaling of a bike a clear system design is included in Figure 12. All of the additional modules will have to be an addition to this design. For increased immersion headphones will be used during gameplay. The idea is to connect a module that senses the steering of the bike and another one that measures the rotational speed of the back wheel.

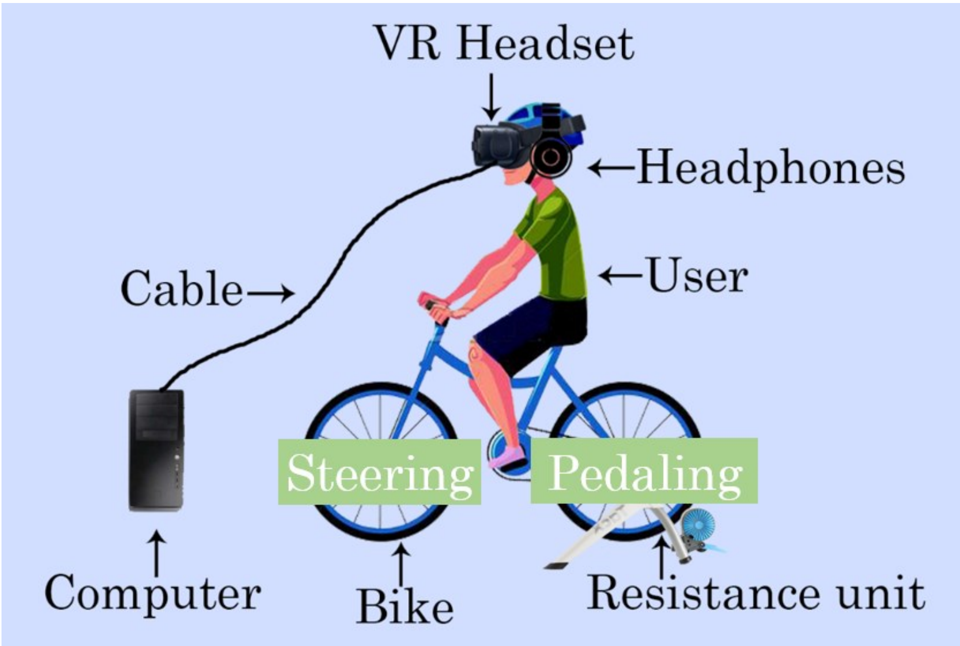


Figure 12 System design of the product

Chapter 5 Realization

The following chapter contains the development of the pedaling and the steering systems, also the additions made to the Unity project and a system sustainability and manual of how to use it.

5.1 Speed-Sensing

Theory

The goal of this subchapter is to find the most reliable way to sense the pedaling of a bike. There are multiple ways to measure speed by using electrical components as sensors. One of the ways would be to use infrared light, this technique was used in [28]. Another way would be by using a reed switch [27]. After noticing that infrared light sensors are affected by the amount of light in the room and need to be adjusted accordingly, a choice is made to use magnetic waves. Therefore, a simple reed switch (seen in Figure 13) will be used to detect when magnets are in close vicinity of the sensor. This will make a closed loop and the wires will conduct electricity.

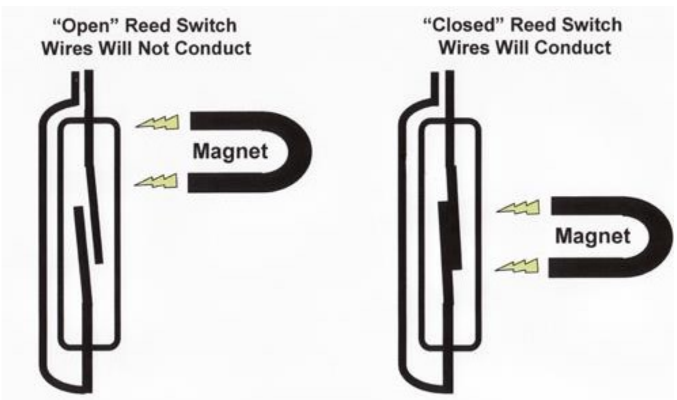


Figure 13 Reed Switch

After choosing the sensor it was time to think about what will be sent to the Unity game engine. For sure, the back wheels position is constant and its rotation is around its central axis. If a point of reference is made on the wheel, then a reed switch can be used as an optical tachometer to measure the Revolutions per Minute (RPM). To complete this goal, an interrupt was called each time the magnet was sensed by the sensor. To minimize the amount of noise and interference, an input pull-up resistor was used, therefore the interrupt could be run each time the signal on a chosen digital pin would fall from HIGH to LOW.

Practice

The bike used for testing already had magnets on it, so those were counted and then added as a constant value. After that, a variable was used to count how many magnets were passed, if this amount was greater or equal to the magnet count on the bike, the RPM was calculated. This was done by the following set of steps:

1. Calculating the milliseconds that it took the tire to rotate a complete rotation of magnets.
2. Multiplying this value by 60,000 because: $1\,min = 60\,seconds = 60 * 1000\,milliseconds = 60{,}000$
3. Then the value is divided into the number of magnets on the bike.
4. The value is printed in the Serial monitor for Unity to read and use.

To program these steps, a class was made in Arduino that contained all the variables and methods connected to its functionality. The class diagram can be seen in Figure 14.

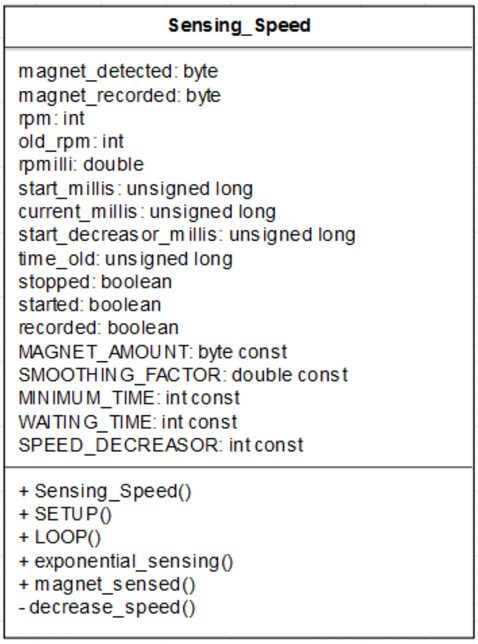


Figure 14 Speed-Sensing class diagram

Additionally, the sensor was firmly strapped to the bike to not move or rotate. Then the hardware was finished and functioning properly, therefore, the software was written to calculate RPM values. The technique discussed at the start of this subchapter was programmed, tested and worked fine, although the RPM was very volatile and constantly changing. Therefore, an improvement was needed for the end product. The filtering of the input is described in Chapter 5 Realization.

5.2 Pedaling Prototype Optimization

The primary prototype for the pedaling detection and RPM calculations are done using a reed switch (discussed in subchapter 5.1 Speed-Sensing). After pedaling in a relatively constant speed, the RPM changes rapidly because small changes in time largely affect the resulting value. To smoothen the data an exponential smoothing [41] was used. This involves having a value that exponentially decreases weights over time and past observations are not weighted equally as in a moving average. The Equations needed for this technique are included below.

$$s_0 = x_0 \tag{4}$$

$$s_t = \alpha x_t + (1-\alpha)s_{t-1}, t > 0 \tag{5}$$

where α is the smoothing factor, and $0 < \alpha < 1$.

The raw data sequence is $\{x_t\}$ and the output from the smoothing algorithm is $\{s_t\}$. Equation (4) states that the first output of the smoothing algorithm is the raw data at time $t = 0$. Equation (5) states that the output value at t is the raw data multiplied with the smoothing factor added to the $(1-\alpha)$ multiplied with the previous output of the previous iteration. After understanding the theory behind the smoothing, the algorithm was implemented in Arduino software. Then multiple tests were done for checking the best smoothing factor, each time the wheel made a full rotation, its RPM was sent to Unity and then saved in an Excel sheet.

Data were measured by pedaling at a similar RPM to check how well the signal converges towards a specific RPM value. At first 3 sets of data were recorded for sensing without smoothing, after that recording was done with different values for the smoothing factor: (0.1, 0.15, 0.2, 0.3, 0.5, 0.7) which are all inside of the range $\alpha \in (0,1)$. After comparing the different plots for the RPM value, an R^2 the statistic was used to check which value minimizes the distance between the fitted line and all of the data points. The best value for this task was when the smoothing factor was set to 0.15, therefore that value was used.

To compare the difference, in Figure 15 the normal and the smoothened RPM values are plotted. The figure contains the Revolutions per minute on the Y-axis and the input number that was received by Unity from the Serial port. It is important to note that the recordings might have included false changes in RPM because the data saved were from different pedaling sessions which might have had different speed values. Nevertheless, data became more convergent to a value and stopped actively fluctuating.

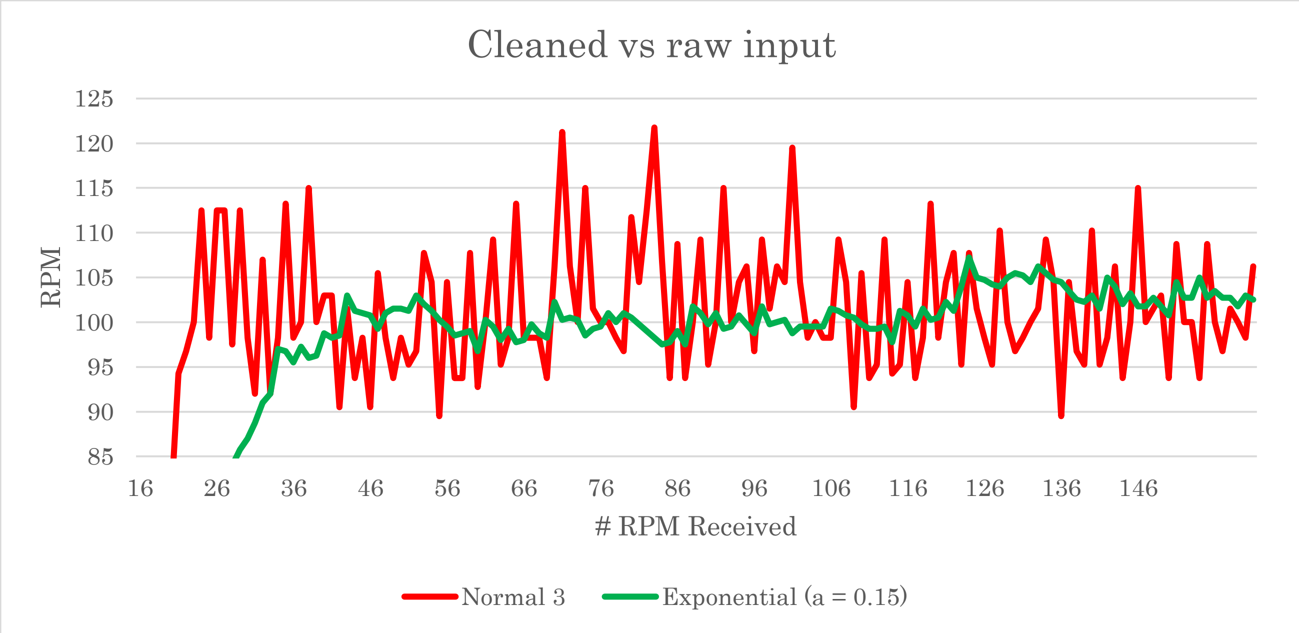


Figure 15 Comparison of normal and smoothened output

The optimization decreased the amount of volatility in the signal and helped make the video output in the game look more fluent. Another addition that was added to better optimize and track the current RPM is that in the final version, the RPM is calculated 3 times per frame (every 3 magnets).

5.3 Steering-Sensing

Theory

The goal of this subchapter is to find the most reliable way to sense the rotation of the steering wheel. From the brainstorm session (Figure 11) it can be seen that the steering was split into 3 techniques. The best technical way that would have the least amount of interference and mathematical computation is to use a linear potentiometer. To check how the steering module would function, an initial idea was to put the bike wheel on top of some surface which is connected to the potentiometer. Unfortunately, that would be impossible, due to the fact that the potentiometer might break from all of the weight. Therefore, after more ideating and consulting an expert, the idea to stabilize the surface on wheels to handle the mass was made.

A 3D model was created in Autodesk Maya 2018 Student edition to understand how the final product would look like. In Figure 17 the first layer of the steering module is displayed. It contains 4 mounted wheels that rotate on one axis. In the middle is the potentiometer with a bit of heightening to reach the plate in the second layer.

Figure 16 First layer of the Steering-Sensing prototype

On top of the first layer, the surface to put the bike on needed to be added, it can be seen in Figure 17. It contains 2 small pieces of wood with a distance of the tire thickness between them, this was done to hold the tire in place so that the plate turns with the same angle as the steering wheel.

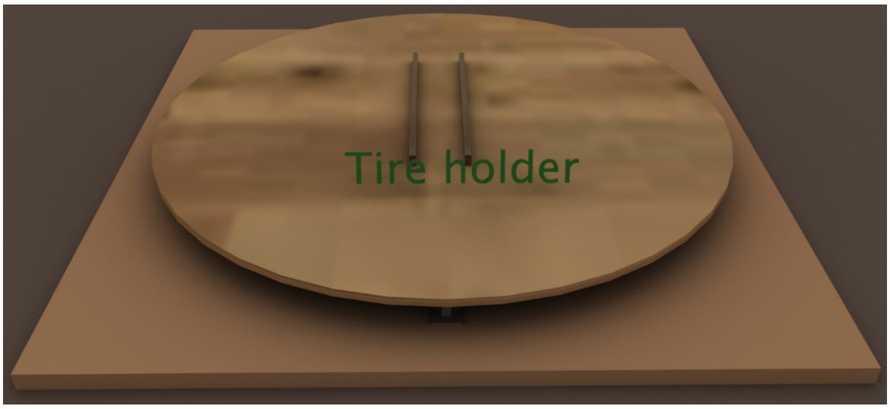


Figure 17 Second layer of the Steering-Sensing prototype

The last additional part added to the modeling software was the bike model that will be used in testing. Figure 18 was included to check the look and feel of the prototype. After the modeling phase was complete, it was time to design with what dimensions and what size will the woodcut pieces be.

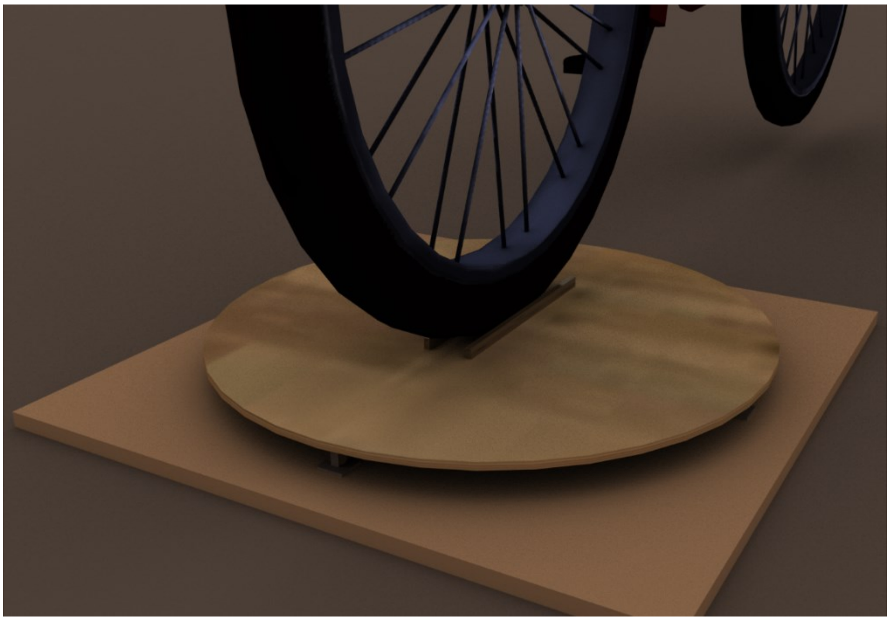


Figure 18 Visualization of the Steering-Sensing module

Practice: First prototype

After creating a file on CorelDRAW X5 and designing the first layer, it was laser cut on 6mm poplar plate. Then it was time for gluing and hammering everything together. The final result of the first prototype is displayed in Figure 19. It contains 2 6mm poplar plates on the bottom, wheels connected to the base with nails. Also, the rotational surface is held on the potentiometer. As mentioned previously it contains a holder (made out of Styrofoam) for the bike wheel to keep the rotation of the steering wheel and of the sensor the same.

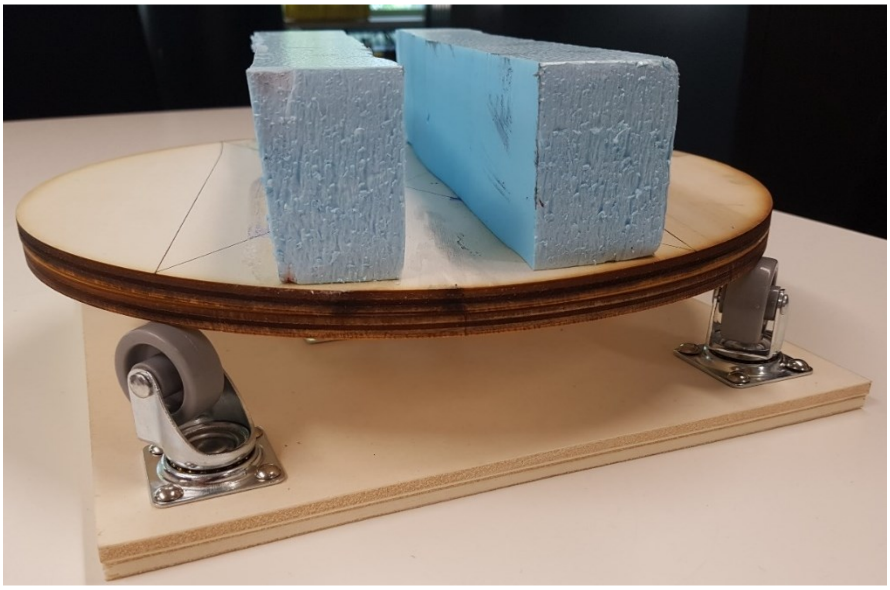


Figure 19 First Steering-Sensing prototype

Unfortunately, this prototype was not fully functional due to some problems. Firstly, the wheels were secured to the bottom plate but could rotate on both where the rubber wheel is connected and also where it is connected to the board. This problem is mandatory to fix, due to the fact that if the wheel rotates out of the bounds of the circular board, the wheel cannot reach and support the board anymore. Hence, the board would fall inside and not stay perpendicular to the sensor. Secondly, the potentiometer was too high and a part of it needed to be cut. This lead to direct contact with the rotating plate with no place for the sensor to move vertically. This also needs to be fixed in such a way that the sensor could move on the vertical axis but still be connected to the rotational plate.

Thirdly, the holding of the bike did not work correctly, everything fit perfectly but there were unaccounted physical limitations. This problem led to the removal of the Styrofoam from the circular surface. This was caused by the bikes steering wheel tilt axis. As can be seen in Figure 20 the wheel does not only rotate around the steering axis, it also tilts towards the side the bike is steering. For example: When the user steers to the left, the steering wheel tilts at an angle which tilts the tire itself. While the tire is being tilted, it pushes on the material that is holding it, therefore after turning the wheel to a high angle, the holder of that side would be removed.

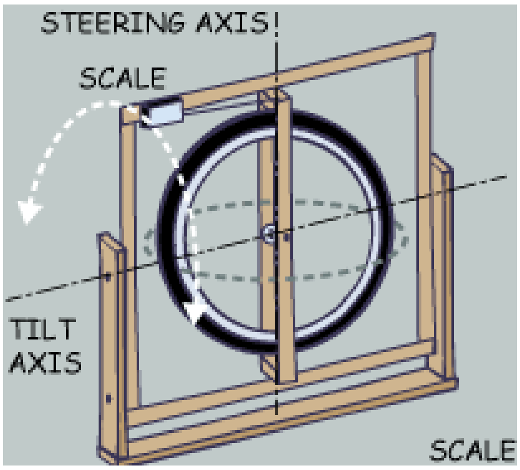


Figure 20 Steering bike

Practice: Second prototype

For the second iteration of the Steering-Sensing sub-system, the goal was to fix all of the problems that occurred with the predecessor. As discussed in the previous subchapter the main problems were:

1. Wheels rotating around 2 different axes.

To fix this problem woodcutting a holder for the wheels was made. It contains 6 identical pieces of glued wood with a top layer that turns the wheel towards the middle of the rotating surface. This helped immensely and the problem was eradicated. This addition can be seen in Figure 21.

Figure 21 Second steering prototype's wheel holders

2. The sensor receiving too much pressure and cannot move vertically.

This problem was fixed by putting the sensor into a small woodcut box in which it could move up and down. This was made possible because a hole was made inside the rotating surface in which a knob was placed. Hence, the potentiometer could stick into the knob and depend on the amount of weight spring up or down inside of the box. Additionally, a hole was made in the bottom of the box to get wires which will be connected to the microprocessor as an input pin. This can be seen in the figure below.

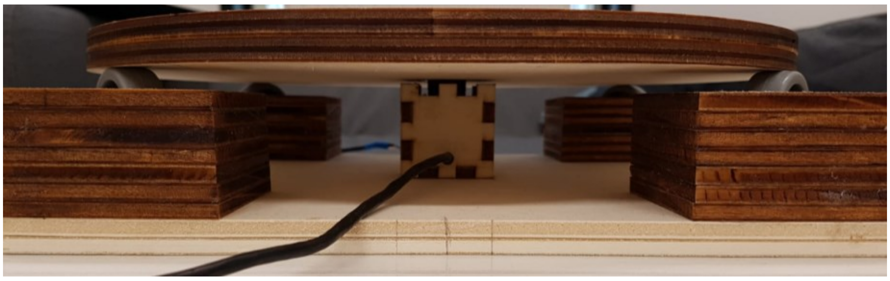


Figure 22 Second steering prototype's potentiometer holder

3. Bike wheel tilts towards the places that hold it.

The holders of the wheel were too high last time and therefore they were reduced in height. This fix was an improvement but, unfortunately, it was not good enough for the end product. Sometimes after rotating the steering wheel, the tire would come on top of the holders. Then the steering could not be detected because the rotating plate would not move with it. This problem could not be fixed because the tire would go on top of the reference points that help to stabilize the center of rotation in place. The top view of the second prototype can be seen below.

Figure 23 Second steering prototype

In Arduino, this and the first prototype initially sensed the potentiometer value, which became the starting value in the sketch. The sketch then interpreted the starting value as 0, an increase in the angle resulted in positive values, decrease with negative. From then on, the angle was cast into an integer to only change with whole numbers. Resulting from these translations and rounding, the angle was in the range of -180° to 180°. Hence, this value was sent over the serial port and then read in Unity.

Practice: Last prototype

Due to a lack of time, the steering angle detection was done with an HTC Vive controller that was put inside a case on the steering wheel. This choice was made because it was a fix for the aforementioned problem that could not get fixed in the Second prototype.

This way of sensing did not need the Arduino anymore because it was tracked by one of the base stations of the HTC Vive setup. These headsets track both the position and orientation of the headset and the controllers. Therefore, a script was added to the controller so that it could be used to sense steering. This was done in a similar way like in the prior prototypes but the main difference is that the controller points to some angle in 3D space, therefore has a rotation that contains X, Y and Z rotational components. To rotate on one axis, a projection with the Y axis was made. As can be seen in Figure 24, 2 Vectors need to be defined to complete this calculation. Vector 1 was the controller's rotation in Euler angles and Vector 2 was the Y plane. This resulted in a Vector that contained zeros for the X and Z components and the rotation on the Y axis in the Y component.

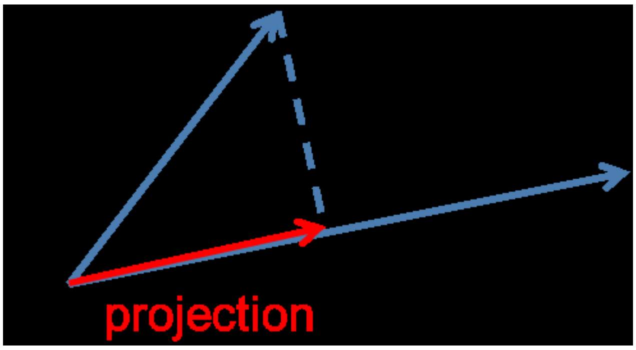


Figure 24 Vector projection in theory

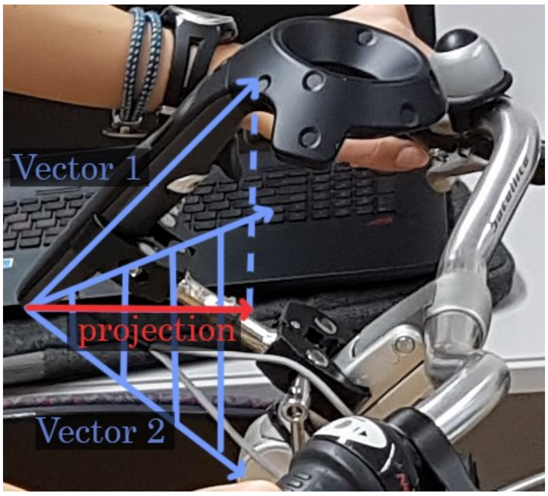


Figure 25 Vector projection in practice

5.4 Unity Connection

Speed

The following subchapter contains the connection of the speed sensor peaks to the Unity game engine. Arduino software will send the Revolutions per Minute (RPM) which will be used to calculate torque that will be added to wheel colliders for moving the bike in the game. Unfortunately, the RPM of the wheel is a read-only value and therefore it cannot be assigned by the researcher. Therefore, some way of reaching the speed had to be found. Luckily, it is possible to calculate the torque of the wheel by using the following formulation. It contains a constant value for horsepower. The resulting formula that will be used in Unity can be seen in Equation (6).

$$HP = Horse\ Power = Constant$$
$$RPM = Input\ from\ Arduino$$
$$HP = TORQUE\ x\ RPM\ /\ 5252$$
$$TORQUE = HP\ x\ 5252\ /\ RPM \qquad (6)$$

The result from Equation (6) was then assigned to the wheel colliders attribute called motor torque in the game engine. This, in turn, changed the RPM of the bike in Unity. The wheels RPM value was used to rotate the mesh of the bike wheel to make the tires seem like they are rotating while the bike is moving.

Steering

The idea for connecting steering can be generalized to any input device that could be used for tracking the steering wheel rotation. This involves simple steps that, firstly, read the input, then translate it depending on the starting angle and then assign it in the game engine. For testing the first and second prototypes, the input had a heading of a character that was used to differentiate between steering and pedaling. After the char was checked, the substring without the first index was parsed into an integer. This input value is then assigned as the steering angle attribute on the wheel collider, which turns the steering wheel and the wheel rotates towards the steered angle. This gives feedback to the user that makes it seem that the bike steering wheel changes in both reality and the game which the user is playing.

After connecting the angle to Unity new problems came up. The most important one was the replication of a kinematic model of a bike in software. After noticing problems with calculating the orientation of the back tire, the choice was made for the bike to contain a single wheel collider. This would mean that the collider would both rotate depending on the angle and have a motor for which torque can be chosen. After testing with one collider it was simpler to turn and the turning contained less friction due to a missing back-wheel.

The rotation of the bike in virtual space works in such a way that at all times, the user can turn the steering wheel from -60° to 60°, if it is smaller or larger then it is clamped to that extremum. I.e. rotating the wheel by 80° would keep the rotation of the bike at 60°. This clamping technique was used to replicate the real world because rotating more would be unsafe. The rotation is added to both the steering wheel and then the parent game object if the bike is in motion. The latter mentioned fact is needed so that the user could not rotate in place and could only change the direction where he/she is heading when the bike has a non-zero velocity.

5.5 Unity Game

Additionally, next to designing and improving the system, multiple additions were made to the game that will be used for testing. Some of the completed tasks were given by the therapists as requirements that should be contained in the game, others were helping the 3D modeler connect the objects and make them more dynamic and interactive.

Bike

Firstly, the main component that is connected to the built system is the Bike game object. This game object is the main thing connected to all of the system inputs. That means that the steering wheel rotation value is used to turn the mesh of the wheel and the RPM input adds torque to the wheels to make the bike move. It must be mentioned that the bike needs to be calibrated to be aligned with the bike in real space. This is done first by turning on the controller mesh and aligning the rotation and position to the correct place on the bike and then slightly translating to perfect the transition between the virtual environment and reality.

Figure 26 In-game view of user's perspective

Position Calibration

Each time the game is run, the real bike has a chance to move out of its initial position because the indoor fitness exerciser slides on the ground. This influences the position of the bike in VR because it is set to a constant value and must be shifted each time the game is played. To fix this problem an addition was implemented that helps calibrate the position of the bike inside of the game depending on the position of the controller in the real world. Therefore, each time a scene is started, its position is saved relative to the controller's orientation.

Microprocessor Port

The microprocessor port is not hardcoded so that it could work as a plug and play controller with different computer ports. Each time the microprocessor is connected to a different USB port, the port number changes, therefore it would be best to check which the Arduino is connected to. This is done by checking the registry for the right registry key, which results in the correct port to which the microprocessor is connected.

Webcam

One of the requests from the therapists was that they could pause and talk to the children while they are playing the game. That goal was implemented in such a way that the child does not have to leave virtual space, it becomes possible to see the therapist live on a webcam displayed in front of the bike. Also, while the therapist is talking with the child, pedaling and steering are not tracked so that they cannot move and distract themselves from listening. After conversing, the therapist chooses to either reset their position to the start of the level or let them continue from where they were before the webcam conversation.

Car Spawner

A car spawner was coded that adds cars (modeled by the 3D developer of the project) driving in a specific direction towards a goal location. The goal, in this case, is a tagged box collider with a trigger which destroys the car game object. Additionally, if something happens such that the car cannot reach the collider, it is removed after a given lifetime or if it collides with another car.

Intersection

One of the additions from the other programmer of the project was a functioning traffic intersection. It contains traffic lights from both sides of the main road. They are always green but turn yellow, then red after some delay when the user comes close inside of a trigger. Then a car is spawned in the spawner perpendicular to the traffic light. After some time passes, the light becomes green again. This changing of states was set to reset itself, hence it was possible to trigger the lights multiple times. The figure below shows a situation where the traffic light is triggered and a car crosses the intersection.

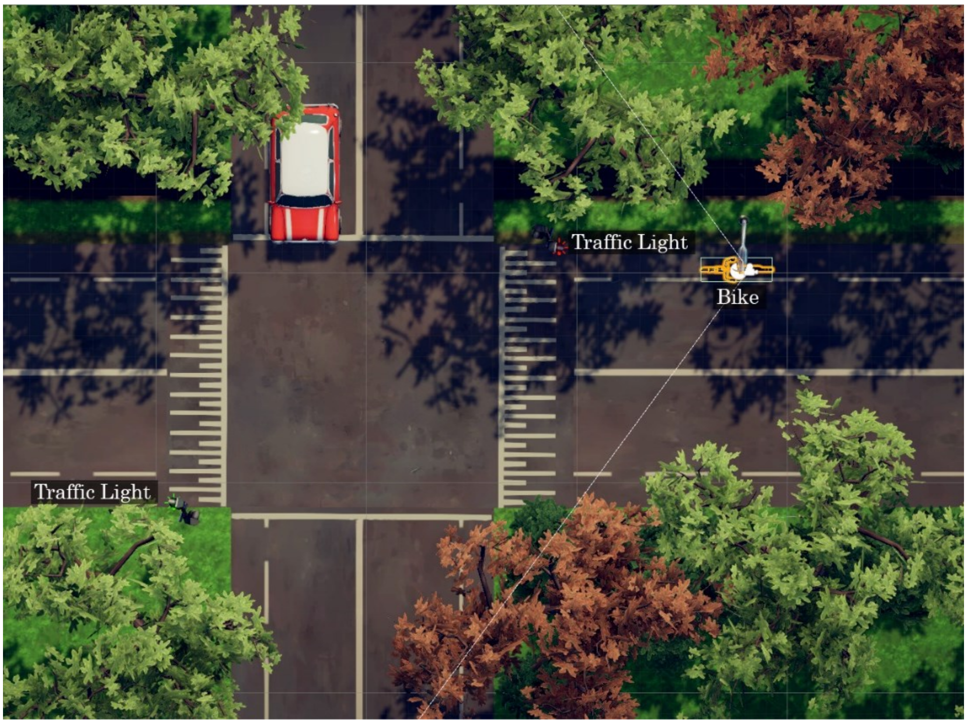


Figure 27 Intersection top view

5.6 Unity Testing Scene

The scene used for evaluation contains multiple visual elements that represent real-life objects. One of these objects is the bike road next to the street, the idea is that the user follows it and does not use the car road for moving forward. In the second evaluation game scene, there were 2 different bicycle prefabs. This was because the users could choose the pedaling mode to be used in the game. The first way was with the resistance unit which dampened the back wheel, the second pedaling mode was without it. This made the wheel rotate and very slowly stop even if the user would not be pedaling, the dampening was very minimal because the tire was not touching any surface and therefore it was much easier to pedal. A top view of the complete map used in the Second Evaluation is given below. The First Evaluation map was a subset of it without additional houses, just an intersection, 3 houses, and 1 chest.

Figure 28 Top view of the level for evaluation

5.7 Requirement Realization

In the table below, all of the requirements and severity ratings are mentioned with their implementation in the final system. Additionally, they contain information if they were realized and if so then How? if not then Why not?

Table 3 Requirement realization

ID #	Type	Requirement	Severity rating	Realized	How?
1	Hardware	The system measures the rotational speed of the back tire.	High (Must)	+	Using a reed switch.
2		The system measures the rotation of the steering wheel.	High (Must)	+	Using an HTC Vive controller.
3		The system is stable; the sensors measure as intended.	High (Must)	+	The sensor is strapped to the bike, magnets are taped to the wheel spokes.
4		The system works with a Virtual Reality (VR) headset.	High (Must)	+	Works with the HTC Vive.
5		The system works with *different* Virtual Reality (VR) headsets.	Medium (Should)	-	Current setup will not work with other headsets because the HTC Vive controller is used.
6	Software	The software contains a trigger to pause it and/or restart it (i.e. a keyboard button).	High (Must)	+	The position of the bike can be restarted, also the bike gets restarted when it hits a car.
7		The system allows the therapist to see what the user is seeing.	High (Must)	+	Unity game view was used to see live gameplay.
8		The game shows the therapist in-game.	High (Must)	+	A webcam is added to a canvas in VR to let the user see the therapist.
9		The system is easy (1min max, low technical skills) to calibrate.	High (Must)	+	The wheel rotation starting value is set when the game starts and also if the trackpad on the controller is pressed.
10		The game can be played without assistance from a therapist.	High (Must)	+	UI in the game guides the user with feedback.
11		The game contains multiple traffic conditions.	High (Must)	+/-	Only an intersection situation was made.

12		The system gives textual and audial feedback to the user.	High (Must)	+/-	Text appears when the user has to start the game and when he hits a car. Background/ ambient music is played in the game.
13	Non-functional	The system features clear documentation of all subsystems and source code.	High (Must)	+	The code is commented and structured in classes.
14		The system is relatively (Up to 50 EUR) cheap to produce.	Medium (Should)	+	It uses already available at hand hardware (HTC Vive controller)
15		The system is lightweight and compact.	Medium (Should)	+	The system for pedaling uses a sensor that is around 5 grams. The steering needs an HTC Vive controller which weights 470 grams.
16		The system works with different sized bikes.	Medium (Should)	+	Works with an adult 28-inch bike and an 18-inch child's bike
17		The system must work with different types of bikes.	Low (Could)	+/-	Tested with 2 different bikes but the system should theoretically work on all bikes.

5.8 Final System Cost

The approximate prices of the final system are included in Table 4 to have an indication of what kind of investments and equipment is needed to realize this specific system, in the next subchapter, sustainability of the project is described.

Table 4 Final system costs

Product	Type	Price
HTC Vive	Hardware	~600 eur
Personal computer		~900 eur
Reed Switch		3 eur
Arduino Uno		27 eur
Bike	Physical	~150 eur
Indoor fitness		~100 eur
Controller holder		~10 eur
Magnets		1 eur
Headphones		~30 eur
Arduino Software	Software	Free
Unity personal edition		Free
TOTAL PRICE:		~1821 eur

5.9 System Sustainability

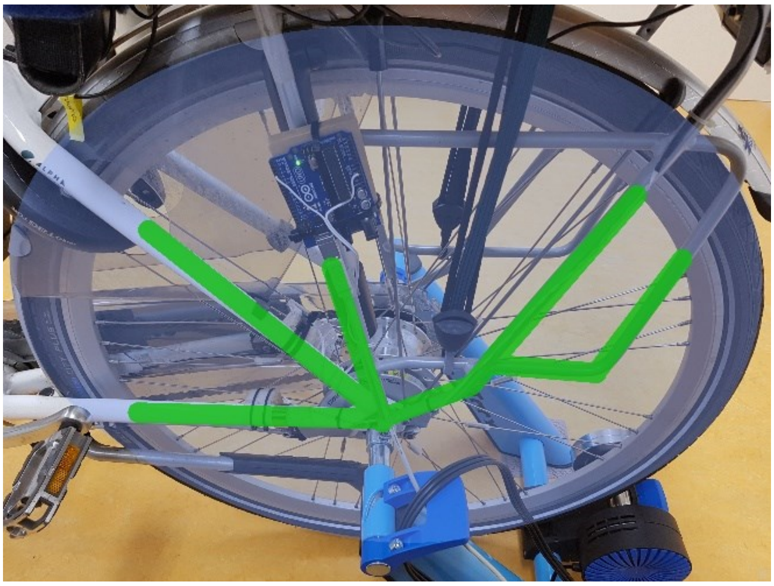
The system sustainability is high for sensing the pedaling because reed switches are simple components that do not change or get updated. On the other hand, the final prototype uses an HTC Vive controller which might not be used for a couple of years. To solve this problem, either a self-built device can be used, one of which was described in Subchapter 5.3 Steering-Sensing in the first and second prototype. Unfortunately, this was not used here because of physical limitations but if that problem would be fixed then some similar device can be used. Additionally, the sensing can be done with IMUs but that would involve algorithms for removing noise and drift over time. The HMD in this product is just for the view, hence any other Virtual Reality headset could be used for a system similar to this one.

5.10 System Manual

To understand how to use the system, a set of steps must be done by connecting the sensors and turning on the game. The following subchapter contains guidelines of how to connect everything properly and then turn on and use the developed system.

Reed Sensor Connection

1. Find a reed switch.
2. Connect the reed switch with one wire going to digital pin 2 and the other to ground (GND).
3. Test the reed switch with magnets.
4. Find a spot on the frame of the bike where it would be pointing towards the wheel. In the figure below the blue zone is the wheel's area and the green lines are metal parts of the bike where the sensor can be placed.



5. Test if the sensor gets triggered when the magnet is put on the wheel in front of the sensor.
6. If it gets triggered, then strap the reed switch at that position. If not, then find some material to fill the gap between the bike frame and the wheel. In the figure below the sensor is fixed on a piece of wood to come closer to the magnet.

7. Choose how many magnets will be put on the bike wheel.

8. Put on the magnets in equidistant spots from each other on the wheel while checking that the sensor gets triggered by each of them.

9. Connect a USB wire to the Arduino.

10. Update and Upload the Arduino software with how many magnets were used.

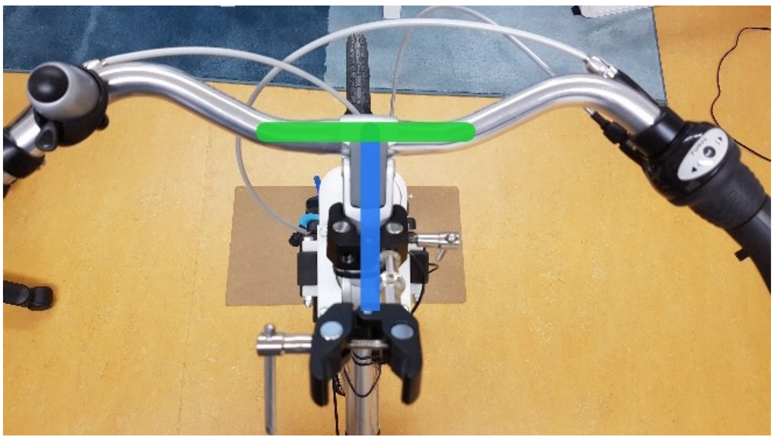
11. Now the RPM should be sent through the Serial of the Arduino Port.

12. Turn on the Serial Monitor and pedal, it should send out values each line in the following format “S” and the RPM value, i.e. “S56”.

Controller Connection

13. Find a controller holster.

14. Clamp it to the steering wheel or the part perpendicular to it.



15. Fasten the controller inside of it.

16. Make sure the controller is approximately perpendicular to the clamp.

Unity Connection

17. Turn the steering wheel in its neutral position so that it points forward.

18. Run the executable file.

19. Now it should be possible to move in the virtual environment when pedaling and rotating when the steering wheel is turned.

Chapter 6 Evaluation

The following chapter contains the evaluation of the system with 2 different user tests one with children and the other with young adults.

The first evaluation took place on June 2nd while the other was done between the 13th and the 19th of June. In the first one, children and a couple of therapists were evaluating the system, in the later evaluation young adults had tested it.

6.1 First Evaluation

Each year Roessingh center for rehabilitation has an open day in which multiple children come to try out different products used for training or rehabilitation. Luckily, the system described in Chapter 5 Realization was tested with children. One of the main differences between this and the Second Evaluation is that a small kids bike was used. The bike tire was 18 inches and therefore was too small to reach the resistance unit, this lead to a very slow damping in speed which made it necessary to use the handbrake more than usual.

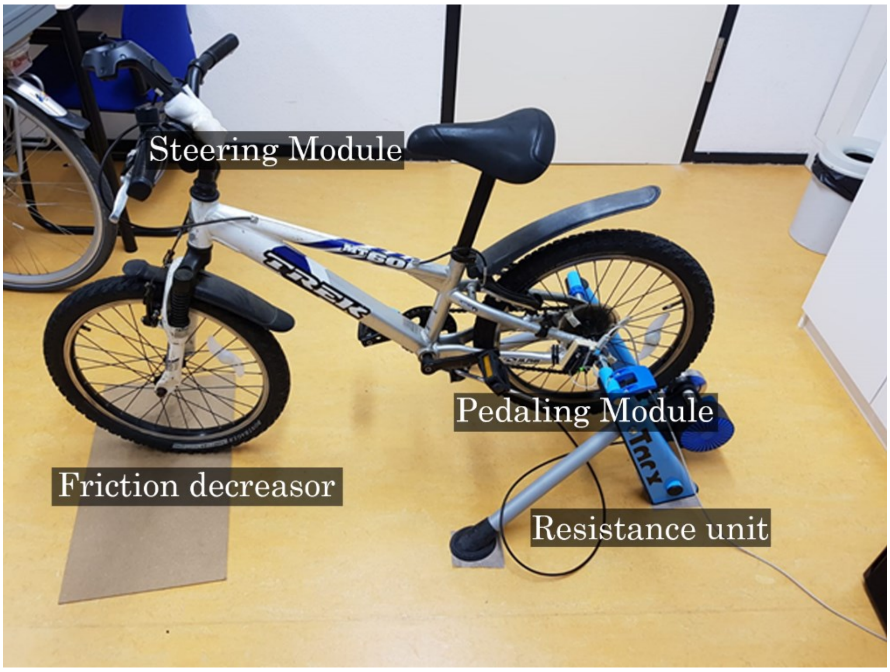


Figure 29 First Evaluation Setup

Questionnaire

A questionnaire was one of the tools used to evaluate the system with children. The question that was posed to the children after riding in the demo level was: How much did you enjoy cycling in the VR environment? (Translated from Dutch, original: Hoe leuk vond je het om te fietsen in de VR omgeving?). The choices were smiley faces, which will be coded on a scale from 0 to 4 in integer values for each of the choices. During the evaluation, the users were asked to test the game in which there was no clear ending and each time the end was reached they were translated to the start of the level. The results of the questionnaire were included in a table below:

Table 5 Evaluation with Children statistics

N	Sex (Male/Female)	Age $\bar{x} \pm s$	Result $\bar{x} \pm s$
12	7/5	8.8 ± 2.0	3.4 ± 0.5

The average choice in the evaluation was a 3.4 which is close to the middle between Really good (Original: Erg leuk) and Brilliant (Original: Geweldig). The results were successful and the children generally liked playing the game.

The questionnaire was made short and simple because the user group was young (age ranged from 5 to 12). Therefore, to get more insight into the experience the children had with the developed system, observations were made of the user activities. The complete questionnaire can be found in
Appendix A: User Testing Questionnaire (With children).

Observations

Multiple children were very happy with the realism in the game, they really felt like they were moving inside of the game environment. Additionally, most of the children complied with the traffic rules in the game: Waiting for the light on the traffic light changed to green. One of the children said that she had felt tiny bumps in the road while pedaling inside of the game. An idea proposed by a user was that including people in the way would make the game more interesting and realistic.

Feedback from Therapists

Additionally, to children testing the game, therapists could also try it and also gave feedback about the system. They were very happy with the amount of realism in the game and were really glad that both the built system and the game worked for both children who have a disability and also, who do not. An interesting tip was given by one of the therapists, they noticed that some of the children had problems with fully experiencing the biking. The front wheel movement felt like it was missing realism, one of the therapists had some surface moving in a circular motion that would turn the tire, this would simulate motion and feeling on the steering wheel that the bike is fully in motion and not only the back tire is rotating. Another idea proposed by one of the therapists was that a system like this could be used for the diagnosis of bike problems. This evaluation would include measuring the reaction times of users in specific situations.

Problems

Problems in the user testing were recorded for future improvement of the system. Multiple problems were found with the prototype, one of which was that when a parent or a therapist was close to the child, the trackers were blocked which seemed to affect the rotational value of the steering wheel, the easy fix for this was to ask them to stand by the other side of the child, where the signal could go through correctly.

Another problem was that the controller was put inside of a small case on the steering wheel but could be rotated by pushing it to the sides. Assumptions were made that the controller will only move with the steering angle but one of the children kicked the controller each time after their knees had made a full revolution, this both moved the controller up and also rotated it to the sides. The last problem that came up was a mechanical one, the brake line had disconnected from the bike and therefore stopping was not possible anymore. This lead to a very slow damping of the speed and the disabled the stopping inside of the game. Fortunately, this problem was fixed by screwing the brake line back into place.

6.2 Second Evaluation

An additional evaluation was conducted with young adults to have more data to work with. The system was evaluated by letting the users play a complete level and then fill in a questionnaire. Additionally, to the questionnaire, observations were done to check for any major or minor problems the user has with the system while playing the game.

Testing Procedure

The testing began with an initial introduction to the research and then the consent form for this user test was signed. The complete form can be found in Appendix D: Informed Consent Form. The initial introduction for each of the users was approximately the following:

"Hello, thank you for helping me with my research, I am working on connecting a real-world object inside of virtual space to be used as a controller to play a game. Firstly, I will ask you to sign a consent sheet so that I could record your gameplay and voice in the game. Secondly, you will be put in Virtual Reality to get used to it and to calibrate the bike position. Also, I will let you try 2 different pedaling modes and you will tell me which you like more. Then you will be put in the real game level".

This was all done without headphones to have no interference between them and me, it was important to correctly calibrate their position to align the bike in reality to the one in the game. Then after the system was calibrated and the user chose the mode he/she would like to pedal in, the real level was started with headphones. They were told:

"The goal of this level is to find and open 3 different chests found in the map. They are all near some path and will open when you come next to it."

Then the user would pedal around the map to find the chests and when they open all of them then the researcher said:

"Congratulations on finding the chests and completing the level".

After that, the headset and headphones were removed and they were asked to fill in a questionnaire which will be explained in the following subchapter.

Each person tested both pedaling with and without the resistance unit and chose which one they liked more. The first mode always alternated between with and without i.e.: tester #1 started with, #2 without, #3 with, etc.

Figure 30 End system architecture

Observations

The users were also observed and recorded using cameras inside a usability lab by screen capture software developed by MSI Afterburner [42]. Additionally, their ideas, tips, criticisms were recorded on paper and then included in Appendix C: User Testing Observations. An interesting thing to see was that users did not solely use bike roads but also used the grass in the scene to go from place to place. Multiple participants had difficulties with overturning to compensate leaning because they slightly rotated the steering wheel towards a side and tried to lean with their body which was not included in the present system. The second participant mentioned that eye tracking would be a cool addition to this prototype. A couple of the participants found the tire stopping too fast with resistance displeasing. One problem that a participant had is that they had to rotate their whole head to look at incoming cars and could not just move their eyes because the quality of the video had become blurry. Participants felt motion sick when the object in the virtual environment was very close to them, such as trees or bushes.

Questionnaire

After the testing was completed, each participant was asked to fill in a questionnaire. It contained multiple parts split with headings for different topics. Some questions were asked about the developed product: Pedaling, Steering and Stopping. Then, the complete Igroup presence questionnaire (IPQ) [39] is asked. Both of the parts mentioned contained quantitate data. Lastly, some general and demographic questions are asked which have more qualitative data. The complete questionnaire can be found in Appendix B: User Testing Questionnaire.

Questionnaire Results

In total 12 people evaluated the test level and then 11 submitted survey results because 1 could not continue and had to stop with the testing due to immense motion sickness. In addition, another 5 participants had problems with motion sickness and had to take a break but then continued and finished the test level. The genders of the testers were approximately equal with 7 males and 5 females. The ages of the participants ranged from 22 to 27 years ($\bar{x} = 23.8, s = 1.72$). Participant were asked the highest degree they had already received, the majority of participants had received a Bachelor degree (63.6%), others finished a Master's degree (18.2%) and 18.2% are high school graduates.

In addition, the testers were asked about their experience with using Immersive Virtual Reality. The question was: *Have you used Immersive Virtual Reality (With Virtual Reality Headsets) before this testing session?* The coding for the answers is displayed below and used in

with all of the quantitate data of each participant. Additionally, Figure 31 shows the distribution of the different prior experiences of people with VR with the majority of the people using it less than 5 times in their life.

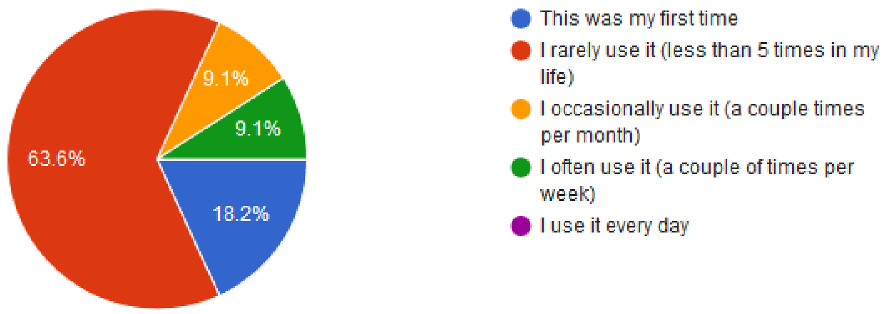


Figure 31 Results of prior experience with Immersive VR

Pedaling, Steering and Stopping results

The following questions were asked by using a Likert scale (Fully disagree – Fully agree) and coded as integer values $[-2\ to\ 2]$.

Table 6 Sub-system questions

Sub-system	Q #	Question	Range	Question $\bar{x} \pm s$	System $\bar{x} \pm s$
Pedaling	1	The movement in virtual reality felt realistic	[-1, 1]	0.55 ± 0.82	0.85 ± 0.76
	2	When pedaling I moved in the game	[1, 2]	1.55 ± 0.52	
	3	The pedaling felt natural	[-1, 2]	0.45 ± 0.935	
Steering	1	The steering felt natural	[-1, 2]	0.45 ± 1.13	0.82 ± 1.00
	2	The steering was tracked correctly inside of the game	[0, 2]	1.18 ± 0.87	
Stopping	1	The stopping was responsive (reacted fast to stopping)	[-2, 2]	0.64 ± 1.29	0.27 ± 1.17
	2	The stopping felt natural	[-2, 1]	-0.09 ± 1.04	

IPQ results

The last amount of data that was analyzed was from the IPQ. The questionnaire was split into multiple components to measure the presence experienced in a virtual environment (VE). These components are:

1. Spatial Presence: it represents the sense of being physically present in the VE.
2. Involvement: measures the attention devoted to the VE.
3. Experienced Realism: measures the subjective experience of a realist in

the VE

4. Global Presence: a global feeling of being present in the VE.

The complete English version of the IPQ can be found in Appendix E: Igroup Presence Questionnaire. All of the 4 different components were calculated by averaging the questions of that specific component and some answers had to be inverted. The complete questionnaire results can be seen below.

Table 7 Second evaluation questionnaire results

PID[1]	Demographics		General		Resistance used[2]		System evaluation[3]							IQP Components[4]			
	Sex	Age	Highest degree[5]	VR[6]	Initial[7]	Chosen[8]	Pedaling			Steering		Stopping		C1[9]	C2[10]	C3[11]	C4[12]
							1	2	3	1	2	1	2				
1	M	24	B	1	+	-	1	2	2	2	2	2	1	6	4	3	5
2	F	22	H	1	-	+	1	2	1	1	0	1	0	5	6	4	5
3	F	26	B	0	+	-	1	1	0	1	0	0	-1	4	3	2	4
4	M	27	M	3	-	-	1	1	-1	1	1	1	1	4	3	3	3
5	F	25	B	1	+	-	0	1	0	0	2	1	0	4	6	3	5
6	M	22	M	1	-	+	1	2	1	2	2	2	0	5	3	4	6
7	M	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
8	M	23	B	1	-	+	1	1	1	0	1	1	1	5	4	4	6
9	F	23	B	1	+	+	1	2	1	-1	2	2	2	4	5	4	4
10	M	22	B	2	-	+	1	2	1	1	2	0	0	6	5	4	6
11	M	25	B	0	+	+	-1	2	0	-1	1	-1	-1	5	5	1	5
12	F	23	B	1	-	+	-1	1	-1	-1	0	-2	-2	4	4	2	4
x̄	M/F (7/5)	23.8	H/B/M (1/8/2)	1	+/- (6/6)	+/- (8/4)	0.55	1.55	0.45	0.45	1.18	0.64	-0.09	4.69	4.32	2.93	4.82
s	-	1.72	-	-	-	-	0.82	0.52	0.93	1.13	0.87	1.29	1.04	0.85	1.05	0.92	0.98

[1] Participant ID
[2] Resistance unit used in testing: W - With resistance, W/O - Without resistance
[3] On a five-point Likert Scale: -2 - Fully disagree and 2 - Fully agree
[4] On a seven-point scale: 0 to 6
[5] Highest gained degree: H - High school, B - Bachelor, M - Master
[6] Experience with immersive VR: 0 - This was my first time, 1 - I rarely use it (less than 5 times in my life), 2 - I occasionally use it (a couple times per month), 3 - I often use it (a couple of times per week)
[7] First pedaling mode shown
[8] Chosen pedaling mode for real level
[9] Spatial Presence
[10] Involvement
[11] Realism
[12] Global Presence

Likes

At the end of the survey, the user could fill in what they liked the most and the least. Some people enjoyed the game environment and found it realistic. Additionally, the sound helped some people get immersed even more into the experience. One participant mentioned that he enjoyed that there was a purpose in the game with some risks (cars) and rewards (chests). Another participant mentioned that he enjoyed that the game was cartoonish and not fully realistic, this made the game feel more interesting. Participant #10 enjoyed the concept and the interaction with the virtual world.

Dislikes

What the users disliked the most was that it caused them motion sickness, therefore some of the users had to take a break from VR. One participant mentioned that motion sickness got worse when they were close to bushes and could move through them in VR. Also, the steering did not work like in the real world, most of the users were trying to lean but that did not work because it was not tracked. Additionally, movement felt peculiar for some, they mentioned that it was not as smooth as in the real world and sometimes when turning drifting is possible.

Recommendations

Each participant was asked if they would recommend the system to others. In total, 9 (81.8%) people would recommend the system to others, 1 would not and 1 chose "I don't know". The participant that had chosen "No" had explicitly mentioned that she thought it was a great idea but needs further development and has good potential. Additionally, some of the participants would not use the system again themselves because of motion sickness.

Tips

Lastly, the testers could fill in any last thoughts or tips. Multiple participants mentioned that for future research it would be important to implement a way to not let the bike automatically stop so fast and that still moving while not braking should be included. In addition, a participant mentioned that she would like to see “freeing”, that is not pedaling constantly but doing it in bursts and then having a delay in between. One of the participants mentioned that the system needs more calibration and value tweaking to make it more real-time.

Chapter 7 Discussion and Conclusion

The following chapter contains the discussion, ideas for future work and the conclusion of the thesis.

The Creative Technology design process [37] is cyclic and ends with the evaluation phase. Therefore, this section concludes the accomplishments of the project. The realized product will be evaluated in the discussion and the choices made will be reviewed.

7.1 Discussion

Research Questions

A few research questions were constructed and their descriptions are included below. The first question was: “Does tire resistance influence the experience when biking in a Virtual Environment?”. To answer and test this question the users were asked if they preferred to have resistance during the Second Evaluation. The results of their choice were logged and the correct setting was turned on and used for real scene. Two-thirds (8/12) preferred the mode with resistance and therefore the addition did affect their experience in the game. Although the sample size was quite small, most of the people mentioned that at least some resistance is better than none, to have a more realistic experience.

The second research question was: “What is the experience of pedaling, steering and stopping inside of a virtual environment with a real bike?”. Well according to the results contained in Table 6, nearly all of the mean values of each question were above “Neutral” and therefore are on the positive side of the scale. Surprisingly, the mean average of the stopping feeling natural was slightly below 0. Multiple testers had mentioned that the stopping was too fast and therefore they would have to constantly pedal to move. Additionally, they could not pedal a bit and then let their wheel slowly dampen. The developed pedaling system could be improved in such a way that the speed of the bike in the game would not try to replicate the real wheel but could slow down at a lower rate and therefore might make the experience more natural. To sum up, users who tested the system knew exactly what to expect because they could relate their gameplay to the real experience they while biking in the real world. This ability to make a comparison affected the results of the questionnaire.

The last research question was: “How immersive is the experience for pedaling in a virtual environment with a real bike?”. This was measured by using the IPQ results which are discussed below and also based on observations of testers. To give an answer to the question, the immersion inside of the level that was developed for the Second Evaluation was 4.32 which signifies that the result was above “Neutral” and therefore the users felt immersed inside of the Virtual Environment. Additionally, some of the participants mentioned that they were immersed in the game while playing it.

IPQ Results

The IPQ results were first translated from an interval from -3 to 3 to 0 to 6 so that calculating a mean average would be possible. Then the values were calculated on a scale from 0 to 6 (3 as a neutral value). As a result, the Involvement, Spatial and Global Presence were scored with an average higher than “Neutral”, with 4.69, 4.32 and 4.82 respectively. The involvement showed that the participants were not aware of the real environment surrounding them and were captured by the virtual world. In addition, the Spatial Presence result signifies that the users were immersed inside the Virtual Environment (VE) and felt present in the game.

Moreover, the Global Presence average was constructed from the results from a question where the participant had to choose how much he/she had a sense of “being there” inside of the computer-generated world. On the other hand, the realism was perceived to be lower than “Neutral”, with a score of 2.93, which made sense due to the fact that the graphics of the game were meant to look like a cartoon and to not replicate reality. Also, the experience while biking might not have seemed consistent with the real-world experience.

Requirements

Most of the requirements of the developed system were incorporated in the final prototype with some exceptions. One of the limitations of the prototype was that it used the HTC Vive controller, this decreases the amount of different device that could potentially run this product. Currently, it is only possible to test the game by using an HTC Vive system due to the fact that the Unity project contains game objects that connect to only HTC Vive headsets. Another element that was not extensively implemented in the game was the number of different traffic conditions and feedback the game gives to the user. This was not done because of lack of time but is feasible and simple to add to the current Unity project. Also, one of the low priority non-functional requirements contained the idea of letting the system work with different types of bicycles. This was tested with only 2 different frames and sizes but should theoretically work on all different bikes, the connection of sensors and turning on the system is described in 5.8 System Manual.

Additionally, most of the functionality discussed in the Realization phase were tested during the Evaluation phase. The bike was used to move around in the Virtual Environment (VE), microprocessor port was found by using the described script and there were multiple car spawners inside of the scene.

System Results

Another point of discussion is the results presented in Subchapter 6.2. They indicate that the prototype works and users rated the system positively than neutral, with the exception of the stopping feeling natural. The most positively answered question was for pedaling in the game, it was asked to make sure that the data was received from the Serial Port and read in unity for moving the bicycle game object. This was purely a technical requirement that was needed for adding movement when pedaling.

Additionally, the stopping was considered unrealistic because the bike kept stopping with resistance and did not damp when there was no resistance causing the tire to rotate for too long this could be seen in both the system questions for stopping and the IPQ questions that talked about the relation of the real experience of biking and the one perceived inside of the game. Moreover, a choice was made to include steering for all of the users which might have influenced the amount of motion sickness perceived. The technical goal of having steering incorporated in the prototype was achieved but might have had negative consequences on the end product due to the fact that users were rotated while steering and moved with pedaling but remained in the same place in the real world. The movement of the participant's game object moved rapidly to replicate pedaling in the real world but this might be one of the sources for motion sickness.

7.1 Conclusion

The goal of this bachelor thesis was to provide a connection between a physical bike and the Unity software game engine to be used in Virtual Reality. This resulted in a functional prototype that was tested with 24 individuals with the ability to pedal and steer while being tracked inside of a Virtual Environment. The developed prototype functioned properly and most of the requirements specified for it were implemented. Therefore, using a real bike and pedaling in Virtual Reality is a feasible idea for training how to properly ride and also how to learn traffic rules. There are many different additions that might improve the experience of the user so it is a topic that should be continued to research.

Chapter 8 Future Work

This subchapter contains my future recommendations. If more time would have been available then multiple things could be added to the system, this is discussed in the requirements in Appendix F: Extra Requirements and below.

Leaning

One of the things worth improving in this type of research would be to obtain more degrees of freedom in the game so that the user feels more immersed, this could involve tracking the lean of the bike (which was not possible here because the back tires rotation is fixed). This would make the steering more realistic, people tend to steer by leaning and not just by rotating the steering wheel.

Resistance

Connecting the resistance unit to the software as an output device could make the game more realistic. If the user would be pedaling upwards, the resistance might become lower and vice versa. Maybe simulating some surface that the bike moves through would make the game more realistic, maybe change the texture of the resistance unit depending on the terrain. Also, make the dampening dependent on the ascension of the bike and friction with the ground. In addition, it would be important to implement a way of not stopping instantly and that the brakes become obsolete with all of the friction of the resistance unit.

Wireless System

Making the system wireless would make the system more portable and contain fewer wires to trip on or disconnect. If this would be realized, then the system would need a power supply and a way for the sensors to communicate. What could be done is to have individual microprocessors to do their own task i.e. track pedaling and all be connected to the device with the Unity scene i.e. a computer or smartphone? If an Arduino would be chosen, then it would need a Wi-Fi shield [43] to connect to wireless networks. Recommendations are given to purchase and use a Geekcreit ESP32 Development Board because it is very compact and already contains Wi-Fi and Bluetooth modules for wireless communication.

Steering Different Implementations

Unfortunately, different iterations of the steering module were discussed in subchapter 5.3 Steering-Sensing but the final version was developed with the use of an HTC controller. This might be fixed by using a similar idea to what was done but it needs to be improved so that steering is always tracked correctly and cannot shift over time. Perhaps it would be possible to secure the tire to some plate with a Velcro strap to keep it in place. Another great improvement with making the steering system independent (without an HTC Vive controller) would help in making the game work on more platforms, such as a smartphone.

Motion Sickness

One of the main problems with the developed system was that many people became motion sick. This problem should be analyzed and at least minimized in relation to the current system. It is unknown what exactly was the main source of the problem. Multiple things could have had an effect on this, namely the idea of moving in virtual space while staying still in the real world. Additionally, the speed of the user was simulated to be similar to the speed obtained by biking. This is fast and might also be one of the problems related to feeling sick. A complete list of tips for another head mount display is described where multiple arguments are made about the rotation of the camera which is not controlled by head movements might make the user nauseous or dizzy [44].

Hand Tracking

If the hands of the user could be tracked, then this would make the user more immersed inside of the Virtual world. Moreover, there would be more input that the user could see inside of the game. Additionally, this would let the future developers trigger things with the hands, for example, the sensor found next to the traffic light. This might contain difficulties, like the fact that if a sensor like the Leap Motion [45] is used, then the hands can only be tracked if they are in the line of view of the user, fortunately, that would not be difficult to fix. One solution would be to trigger a value when the user is holding the steering wheel and then keep their hands on the steering wheel if any of the hands are not sensed.

Eye Tracking

Another great addition that could have multiple uses in the project is the implementation of eye tracking. This would make it possible to know where exactly a user is looking with their eyes during gameplay. Currently, the system supports head tracking, hence adapting the view according to the orientation of the user's head which might be a problem if users would only look around with their eyes.

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Appendices

Appendix A: User Testing Questionnaire (With children)

This is the Questionnaire in Dutch with an added translation in English in parentheses.

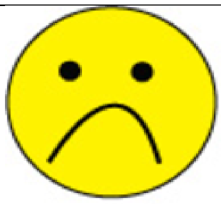
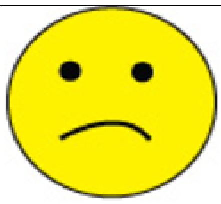
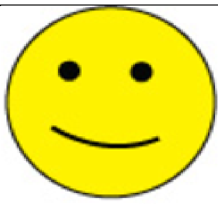
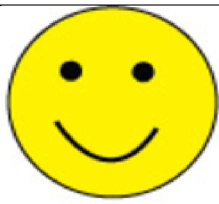
4. Hoe oud ben je? (*How old are you?*)

……………………………………………………………………………………

5. Je bent een… (*You are a...*)

☐ Jongen (Boy)
☐ Meisje (Girl)

6. Hoe leuk vond je het om te fietsen in de VR omgeving? (*How much did you enjoy cycling in the VR environment*)

				
Verschrikkelijk (*Awful*)	Niet zo leuk (*Not very good*)	Leuk (*Good*)	Erg leuk (*Really good*)	Geweldig (*Brilliant*)

Appendix B: User Testing Questionnaire

Virtual Reality biking game

This survey is for evaluating the connection between a bike and the Unity game engine with combination of a Virtual Reality headset (HTC Vive).

I would like to thank you very much for trying out the system and would be very happy if you could fill in the form below.

* Required

Pedaling

The movement in virtual reality felt realistic *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

When pedaling I moved in the game *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

The pedaling felt natural *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

Steering

The steering felt natural *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

The steering was tracked correctly inside of the game *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

Stopping

The stopping was responsive (the game reacted fast to stopping) *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

The stopping felt natural *

	Fully disagree	Disagree	Neutral	Agree	Fully agree
.	○	○	○	○	○

Experience

How much did your experience in the virtual environment seem consistent with your real world experience ? *

	Not consistent -3	-2	-1	Moderately consistent 0	+1	+2	Very consistent +3
.	○	○	○	○	○	○	○

How real did the virtual world seem to you? *

About as real as an imagined world -3	-2	-1	Neutral 0	+1	+2	Indistinguishable from the real world +3
○	○	○	○	○	○	○

How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, etc.)? *

Not aware at all -3	-2	-1	Moderately aware 0	+1	+2	Extremely aware +3
○	○	○	○	○	○	○

I had a sense of acting in the virtual space, rather than operating something from outside. *

Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
○	○	○	○	○	○	○

How unreal did the virtual world seem to you? *

Completely real -3	-2	-1	Neutral 0	+1	+2	Not real at all +3
○	○	○	○	○	○	○

I did not feel present in the virtual space. *

Did not feel present -3	-2	-1	Neutral 0	+1	+2	Felt present +3
○	○	○	○	○	○	○

I was not aware of my real environment. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

In the computer generated world I had a sense of "being there" *

	Not at all -3	-2	-1	Neutral 0	+1	+2	Very much +3
.	○	○	○	○	○	○	○

Somehow I felt that the virtual world surrounded me. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

I felt present in the virtual space. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

I still paid attention to the real environment. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

The virtual world seemed more realistic than the real world. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

I felt like I was just perceiving pictures. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

I was completely captivated (absorbed) by the virtual world. *

	Fully disagree -3	-2	-1	Neutral 0	+1	+2	Fully agree +3
.	○	○	○	○	○	○	○

Demographic and general questions

What is your sex? *

○ Male

○ Female

What is your age? *

Your answer

What is the highest degree or level of school you have completed? If currently enrolled, highest degree received *

○ No schooling completed

○ Some high school, no diploma

○ High school graduate, diploma or the equivalent

○ Bachelor’s degree

○ Master’s degree

○ Doctorate degree

Have you used Immersive Virtual Reality (With Virtual Reality Headsets) before this testing session? *

- ◯ This was my first time
- ◯ I rarely use it (less than 5 times in my life)
- ◯ I occasionally use it (a couple times per month)
- ◯ I often use it (a couple of times per week)
- ◯ I use it every day

What did you like the most? (Optional)

Your answer

What did you like the least? (Optional)

Your answer

Would you recommend this system to someone else? (Optional)

- ◯ Yes
- ◯ No
- ◯ I don't know

Would you use this system again? (Optional)

- ◯ Yes
- ◯ No
- ◯ I don't know

Last thoughts or tips? (Optional)

Your answer

Appendix C: User Testing Observations

Participant 1

The experience felt unnatural because of resistance.

Participant 2

Became motion sick and had to have a break.

Did not use a path to get to a chest (used grass).

When looking at one point she got sick because she did not move.
Stopping was very digital because of the resistance unit, either no speed or full speed.
Would be cool to add eye tracking.

Participant 3

Used hand brakes a lot.
Went on the grass.

Participant 4

Had difficulties with overturning. Speed was too fast. Used grass a lot. Passed red light.
Did not like that stopping was jittery (either fast or no speed).

Participant 5

Tried to counterbalance the bike.
Used grass to get to the chest.
Passed red light.
Hit a house (enjoyed it).
Said Drifting is not very realistic.

Participant 6

Really scary going so fast.
"Funny" because could on the grass.
Makes biking fun.
Pedaled very slowly so tire stopped frequently.
Overturning to compensate leaning.
Looked back for incoming cars.
Passed red light.
"Immersed in the game".
"Felt like it was both realistic and unrealistic at the same time".

Participant 7

Speed too fast.

Went through a red light.

Got motion sick and became very sweaty, therefore stopped and did not finish.

Participant 8

"Speed is too fast".

Asked if there was a map.

Passed Road Closed sign (Original: weg afgesloten).

Passed red light.

"Leaning would be good to add".

Used the car lane often.

Had to say where the last chest was.

Got irritated by getting hit by cars.

Participant 9

"Going really fast".

Did not feel the difference between pedaling (with/without resistance).

Obeyed traffic conditions.

Got motion sick from turning.

Weird that tire stops so fast.

Had to stop from motion sickness but then finished.

Participant 10

Chose to use resistance but wanted less resistance.

Drifting because of steering.

Did not use the path to get to the road.

Tip: More intersections for traffic lights.

More road signs so that they could feel more natural.

More different roads.

Make map busier to simulate an environment.

Participant 11

Overturning is a problem.

Passed red light.

Asked what road sign (Weg afgesloten) means.

Looked at traffic light each time.

Felt dizzy and had to have a break.

Tried to tilt for steering.

The sound is too loud and not realistic.

Suddenly stops because of resistance.

Car hits without stopping or horn.

Add tilting.

The bike did not feel it was moving in the real world.

"Second mode is a flying bike" (without resistance).

Stopping and pedaling change suddenly.

Noticed pedals too far away in VR.

"Have to turn head to check for cars because just with the eye is blurry. Have to look straight at it."

Feels motion sick when something is very close to the user.

Wanted to go in front of the bike to touch the ground.

Participant 12

"Weird to turn".

Liked the rust on the bike model.

Really pedaled a lot because the movement was very slow.

"Brakes react too late".

Noticed that the bike could drift.

Torque was not correct.

Appendix D: Informed Consent Form

Consent Form for “Keep your Eyes on the Road!”

I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time.

If my research results are to be used in scientific publications or made public in any other manner, then they will be anonymized completely. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Paulius Gagelas (p.gagelas@student.utwente.nl).

I agree to allow the experiment to be recorded with the video and audio from the game and also with a microphone. The recordings will be used for evaluating the system developed by the researcher for his Bachelor thesis in Creative Technology. The recorded media will not be published.

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente.

……………………………………………	……………………………………………
Name subject	*Signature*

I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.

……………………………………………	……………………………………………
Name researcher	*Signature*

Roessingh Research and Development

UNIVERSITY OF TWENTE.

Appendix E: Igroup Presence Questionnaire

The English version of the questionnaire.

Number	PQI/II Nr. (internal)	IPQ item name	shortcut	loading on ...	English question	English anchors	Copyright (item source)
1	s62	G1	sense of being there	PRES	In the computer generated world I had a sense of "being there"	not at all--very much	Slater & Usoh (1994)
2	s44	SP1	sense of VE behind	SP	Somehow I felt that the virtual world surrounded me.	fully disagree--fully agree	IPQ
3	s30	SP2	only pictures	SP	I felt like I was just perceiving pictures.	fully disagree--fully agree	IPQ
4	s28	SP3	not sense of being in v. space	SP	I did not feel present in the virtual space.	did not feel--felt present	???
5	s31	SP4	sense of acting in VE	SP	I had a sense of acting in the virtual space, rather than operating something from outside.	fully disagree--fully agree	IPQ
6	s33	SP5	sense of being present in VE	SP	I felt present in the virtual space.	fully disagree--fully agree	IPQ
7	s64	INV1	awareness of real env.	INV	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?	extremely aware-moderately aware-not aware at all	Witmer & Singer (1994)
8	s37	INV2	not aware of real env.	INV	I was not aware of my real environment.	fully disagree--fully agree	IPQ
9	s40	INV3	no attention to real env.	INV	I still paid attention to the real environment.	fully disagree--fully agree	IPQ
10	s38	INV4	attention captivated by VE	INV	I was completely captivated by the virtual world.	fully disagree--fully agree	IPQ
11	s48	REAL1	VE real (real/not real)	REAL	How real did the virtual world seem to you?	completely real--not real at all	Hendrix (1994)
12	s7	REAL2	experience similar to real env.	REAL	How much did your experience in the virtual environment seem consistent with your real world experience ?	not consistent-moderately consistent-very consistent	Witmer & Singer (1994)
13	s59	REAL3	VE real (imagined/real)	REAL	How real did the virtual world seem to you?	about as real as an imagined world--indistinguishable from the real world	Carlin, Hoffman, & Weghorst (1997)
14	s47	REAL4	VE wirklich	REAL	The virtual world seemed more realistic than the real world.	fully disagree--fully agree	IPQ

Appendix F: Extra Requirements

Wireless System

Requirement ID#: 18	Requirement Category: Interaction and usability issues
Requirement: The system is wireless using the Wi-Fi (802.11) protocol.	
Rationale: Cables are hard to manage and may disconnect, using wireless technologies it is possible to omit that struggle.	
Source: Clients (RRD & Twinsense 360)	Priority: Medium (Should)
Conflict(s): none.	
History: Created on April 9th, 2018	

Requirement ID#: 19	Requirement Category: Interaction and usability issues
Requirement: The system is powered by a rechargeable battery/accumulator/power bank.	
Rationale: The system needs a power source for sending data.	
Source: Clients (RRD & Twinsense 360)	Priority: Medium(Should)
Conflict(s): none.	
History: Created on April 9th, 2018	

Requirement ID#: 20	Requirement Category: Interaction and usability issues
Requirement: The system contains a switch to turn it on.	
Rationale: The system should not be constantly running to preserve battery life.	
Source: Clients (RRD & Twinsense 360)	Priority: High (Must)
Conflict(s): none.	
History: Created on April 9th, 2018	

Scoring System

Requirement ID#: 21	Requirement Category: Interaction and usability issues
Requirement: The game gives rewards for playing the game correctly (according to the rules).	
Rationale: Extrinsic rewards will give a sense of achievement to the user.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)
History: Created on April 9th, 2018	

Requirement ID#: 22	Requirement Category: Interaction and usability issues
Requirement: The system gives a score or rating depending on the performance of the user.	
Rationale: The score is an important part of the game that reports to the user how successfully the level was completed.	
Source: A Literature review (Baranowski et al. Games for Health for Children)	Priority: High (Must)
History: Created on April 9th, 2018	

Level Design

Requirement ID#: 23	Requirement Category: Interaction and usability issues
Requirement: The game contains different levels.	
Rationale: A level system will at first teach the user to play the game and then progressively increase in difficulty.	

Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)
History: Created on April 9th, 2018	

Requirement ID#: 24	Requirement Category: Interaction and usability issues
Requirement: The game contains a level selection screen	
Rationale: Level selection is very handy for navigating through what scenes are available in the game.	
Source: Expert Interview with healthcare professionals in March 2018.	Priority: High (Must)
History: Created on April 9th, 2018	

Requirement ID#: 25	Requirement Category: Interaction and usability issues
Requirement: The system is easy (1min max) to set-up.	
Rationale: The process of connecting the sensors correctly must be easy. Might be difficult to place the sensor.	
Source: Clients (RRD & Twinsense 360)	Priority: High (Must)
History: Created on April 9th, 2018	