Developing a set up for monitoring cycling performance of patients with CVA with an electric tricycle

Lotte Lukassen

July, 2020

UNIVERSITY OF TWENTE.

BSc Creative Technology

Faculty of Electrical Engineering, Mathematics, and Computer Science (EEMCS)

Supervisor: Monique Tabak

Critical observer: Roos Bulthuis

Abstract

Physical activity is very important for both physical and mental health. For people with a chronic illness disability or other condition, it is harder to exercise because they are limited in doing so. People who had a Cerebrovascular accident (CVA) form a large group for whom physical activity is challenging. CVA (also called stroke) is a limited brain dysfunction that is suddenly caused by an inadequate blood flow. There are more and more technologies that make physical activity of patients with CVA easier, such as adapted bicycles with three wheels and electrical support. The Easy rider from Van Raam can contribute to rehabilitation because it offers the opportunity for patients with CVA to be physically active in daily life, outside the clinical setting. However, the challenge here was that the patient does not have enough insight into his cycling behaviour and therefore does not know whether it contributes to his health and improvement of the condition. This study aims to develop a set up for monitoring cycling performance of a patient with CVA with the use of an electric tricycle. The focus of this study was on the motor consequence of CVA, specifically the steering and braking behaviour of patients with CVA while cycling. The sensors used and tested for this were a hall effect sensor, a load cell sensor, and a pressure sensor. With the sensor system created during this study, it is possible to monitor cycling performance of patients with CVA. Still the system can and need to be further developed in order to be used by real patients with CVA in daily life.

Acknowledgement

First of all, I would like to thank my supervisor Monique Tabak for her supervision of this project. Secondly, I would like to thank my critical observer and client from Roessingh Research and Development Roos Bulthuis for her guidance during this project. Furthermore, I would like to thank the experts for sharing their feedback during the evaluation phase. Lastly, I also want to thank all the participants who filled in the online user test questionnaire as part of the evaluation.

Table of contents

List of figures

1 Introduction

1.1 Background

Physical activity is very important for physical and mental health. It can reduce the risk of developing several diseases such as diabetes type 2, cancer and cardiovascular disease (conditions affecting the heart or blood vessels) [1]. Regular activity can improve your quality of life. This applies to young and old people with or without chronic illness or disability [2]. Further investigation [3] [4] shows that for people with chronic illness, disability or other conditions, it is harder to exercise because they are limited in doing so.

People who had a Cerebrovascular accident (CVA), form a large group for whom physical activity is challenging. In 2018, there were an estimated of almost 500,000 people with a CVA in the Netherlands only [5], so it is a common condition. For people who have a CVA, rehabilitation and improvement in their health conditions are very valuable and important. This is because common consequences such as motor problems, balance or cognitive consequences can be the reason that they have difficulty with daily activities. Rehabilitation can help patients with CVA to improve their health condition and therefore can help them to perform daily activities more easily. Physical activity is a key concept for rehabilitation but challenging for patients with CVA because of the limitations.

There are more and more technologies that make physical activity of patients with CVA easier, such as adapted bicycles with three wheels and electrical support. This is a solution for people with CVA because they can perform physical activity despite their limitations as a consequence of CVA. For example, if a patient with CVA does not have enough strength in one leg, the patient can still be physical active because the adapted tricycle has electric pedal support. An example is a smart electric tricycle from the company Van Raam [6]. This bicycle is also known as the Easy rider (see Figure 1). This bicycle has a smart engine, provides pedal support, and collects some data about the cycling behaviour such as pedal force, cadence, support level, speed, distance, and location (GPS).

Figure 1: Easy rider from Van Raam

1.2 Problem statement

As described in the previous section, rehabilitation is crucial for the best possible recovery for patients with CVA. The Easy rider from Van Raam can contribute to rehabilitation because it offers the opportunity for patients with CVA to be physically active in daily life, outside the clinical setting. But the challenge here is that the patient does not have enough insight into his cycling behaviour and therefore does not know whether it contributes to his health and improvement of the condition. Therefore, the aim of this graduation project is to develop a measurement set up that enables patients with CVA to monitor progress/improvements in their health condition by extending the sensing part of the smart electric tricycle.

1.3 Research questions

The main research question can be defined as follows:

> *How can the smart electric tricycle monitor the cycling performance of patients with CVA?*

In order to answer the main research question, the following sub questions needed to be answered first:

> *What are the consequences of CVA?*

> *How can progress be measured in patients with CVA?*

What are the needs and demands from stakeholders for a monitoring system that measures the cycling performance of a patient with CVA?

Which sensor(s) can be added to the e-trike to measure those improvements?

What information will be fed back to the cyclist to indicate the improvements?

1.4 Report outline

In this paper, first some literature and background information about CVA and its rehabilitation will be discussed in chapter 2. The state of the art will consist of a literature review and some research in related work. Thereafter, in chapter 3, the method with its different phases used for this research project will be described. Chapter 4 till 7 will elaborate on the different phases of the process of this project. These phases in order are ideation, specification, realisation and evaluation. In the ideation phase first a context analysis will be conducted to eventually come up with ideas. In the specification phase the product requirements and thereafter the final product idea will be described. In the realisation the explanation on how the prototype if this project will be built can be found. When this is done, evaluations can be performed to check the product. Here some functional testing and user testing will be done. Eventually, to conclude the thesis, chapter 8 will give answers to the research questions and will determine some future work.

2 State of the art

This section consists of the state of the art. First a literature review will be executed to gain an understanding of the existing research and relevant studies on the topic of CVA. Thereafter some related work will be stated. This part of the thesis will answer the two following sub questions of this graduation project:

1. *What are the consequences of CVA?*
2. *How can progress be measured in patients with CVA?*

2.1 Literature review

2.1.1 Cerebrovascular accident

There are different perspectives in defining Cerebrovascular accident (CVA). There is not one common definition, since available information to define CVA events differ according to trail design [7]. Ji et al. [8] define CVA as a "limited brain dysfunction that is suddenly caused by cerebral vascular disease" [5, p. 213] and can last more than 24 hours. Due to inadequate blood flow, brain cells can suddenly be dead [9]. A more common name for a CVA is a stroke. Hicks et al. outlines CVA as "marker of potentially disabling vascular brain injury" [4, p. 967]. To summarize, CVA, also known as stroke, is related to brain dysfunction due to inadequate blood flow.

There are three main categories of consequences of CVA. Pothiban and Srirat [10] point out that people who have suffered from a CVA might remain (partly) disabled. Elaborating on this, Mirza-Babaei et al. [9] describe that the consequences of CVA can be divided into three main categories, namely visual, cognitive and motor losses. Some examples of these consequences are loss of vision and/or memory, speech difficulties, confusion, paralysis and difficulty with swallowing as Mirza-Babaei et al. [6] and Pothiban and Srirat [10] list. However, Smith et al. [11] state that visual deteriorations are not as evident as motor or cognitive impairments.

The main consequences of visual losses due to CVA are low vision, eye movement problems, visual field abnormalities and perceptual issues [11]. Smith et al. [11] state that up to two thirds of CVA patients have some problems related to the visual domain which results in disability. All these visual impairments can affect the patient's daily living. To elaborate on this, Smith et al. [11] observe that there are three sub themes of visual concerns. This includes eye movement problems (such as double vision or difficulty with focusing the eyes), perceptual issues (such as distinguishing colors or loss of depth perception), and consequences of these visual problems (such as reading or impaired balance).

Next is cognitive losses which are frequently occurring consequences such as attention or language problems and have a large impact on patients' lives. The study of Tatemichi et al. [12] observe that 78% of the participating CVA patients have cognitive problems as a consequence of CVA. In addition Lesniak et al. [13] also state that in the post-acute stage 78% CVA patients were affected by one or more cognitive disabilities. Attention, language, short-term memory and executive functions are the most frequently impaired cognitive abilities [13]. As a result, people with cognitive consequences can have considerable functional problems [14]. As a supplement, Lesniak et al. [13] state that patients affected by these consequences are often incompetent to live independently or to return to their work and social activities.

Finally, many patients of CVA are facing motor consequences where hemiparesis is the most common disability. Hemiparesis is defined as a weakness or paralysis on one side of the body (upper and lower limbs) on the side opposite to the brain injury and is one of the most common disabilities related to motor losses [9] . [15]. According to Mirza-Babaei et al. [9], up to 85% of CVA patients suffer from hemiparesis. In addition, Caby et al. [15] point out that especially patients suffering from a CVA that involved part of the brain projection devoted to motor control led to hemiparesis. Caby et al. [15] describe that typical consequences of hemiparesis are loss of fine finger movement's control and deterioration in daily use of upper limb'. Additionally, Lee et al. [16] note that the common shortfall as a consequence of CVA are lower limb impairment and postural imbalance. These can notably impact physical ability. Motor losses are thus a major concern but need and can be addressed in the graduation project.

The above mentioned consequences can make cycling more challenging. With visual losses it is harder and more dangerous to cycle because you need good vision in order to be part of traffic. Furthermore, cognitive consequences can also affect the cycling performance. You need to pay attention to traffic while cycling. In addition, motor consequences also clearly have an effect on the capability to cycle. Because patients can have a weakness or paralysis on one side of the body, it is harder to cycle. Fortunately, for CVA patients there are solutions like an electric tricycle (such as the Easy rider developed by Van Raam) making cycling easier and safer. However, insights in cycling performance is also important and relevant.

Table 1: Summary table of consequence of CVA

Category of consequences	Symptoms
Visual losses	Low vision, eye movement problems and perceptual issues
Cognitive losses	Attention, language, short-term memory and executive functions
Motor losses	Hemiparesis most common consequence which is defined as a weakness or paralysis on one side of the body

2.1.2 Measuring improvement in patients with CVA during rehabilitation

Rehabilitation is crucial for best possible recovery for patients with CVA. The goal of rehabilitation is to help the patient relearn skills that were lost. Rehabilitation can help a CVA patient in improving their quality of life [17]. Especially improvements in motor function can enable patients with CVA to perform daily life tasks such as cycling. Further investigation shows that improvement in the motor conditions of a CVA patient comes down to movements of the limbs. When improving the movements other conditions, such as balance for example, are also improving [16].

There are different ways to check if movements of a CVA patient have been improved during rehabilitation compared to previous times, but coordination is the most common. The coordination of the movement is the most frequent occurring way to check improvement of movements within the literature [15][16][18][19]. Coordination is about the ability to accurately perform a movement using a close collaboration between your senses, nervous system and muscles. Caby et al. [15] also point out smoothness of a movement as a measurement for improvement next to coordination. Furthermore, Pohl and Winstein [19] highlight the speed of a movement and Pollock et al. [18] observe reaction times as characteristics of improvement in health condition of CVA patients. Both Caby et al. [15] and Pohl and Winstein [19] point out that to measure the speed of the movement, for example, the variables total movement time can be used. Additionally, Lee et al. also note reflexes as a way to determine improvements. Moreover, Sakurada et al. [20] state that cognitive factors such as attention direction and motor imagery ability also can affect motor performance. To summarize, motor improvements in the health condition of patients with CVA can be measured with the following indicators: coordination, speed of movement, smoothness, reaction times, balance and strength.

2.2 Related work

This section will give an overview of existing commercial products and projects that are related to sensors used for monitoring the health condition and/or progress of CVA patients and sensors used for cycling in general. Useful information on the highlighted work that is done by others in this area can be extracted and are taken to the next phase.

2.2.1 INTERACTION System

The INTERACTION System [21] is a PhD project from the University of Twente. This new suit (see Figure 2), which can be worn under patients' clothes, is fitted with 41 sensors. In addition, it also includes the infrastructure that is needed to transmit, store and process all the data collected. It is designed to accurately monitor and analyze how CVA patients move during everyday life. The goal of this suit is to make it possible to improve the rehabilitation process and cut healthcare costs. There are different sensors on the suit. It consists of sensors on a large number of body segments such as sensors that measure muscle strength, stretch sensors on the back and the hands, and force sensors in the soles of the shoes. This for accurately measuring and modelling these patients' movement quality, and for transmitting the relevant information to the therapist.

Figure 2: Full body sensing suit

2.2.2 CVA recovery with Microsoft Kinect

This CVA recovery with Kinect [22] is a collaborative project between Microsoft Research and Asia and Seoul National University. This system, which can be seen in Figure 3, helps CVA patients to improve their upper-limb motor functioning at home with the use of the Kinect. It uses the Kinect sensor's three dimensional camera, this to capture the movements of skeletal points on the patient. The system can therefore measure and evaluate the patient's movements. The system evaluates patients' coordination, gross manual dexterity and motor skills. The level of the game will be adjusted using the scores from previous sessions.

Figure 3: Stroke recovery with Microsoft Kinect

2.2.3 Sensors embedded in pair of shoes

This pair of shoes [23] (see Figure 4A) is embedded with a wearable sensor system. A flexible pressure-sensitive insole incorporated with 5 force sensitive resistors. The goal of this pair of shoes is to accurately identify different postures. The positioning of the sensors can be seen in Figure 4B. This positioning allows them to differentiate aspects of the walking cycle. Positioned on the back of the shoe, a 3-dimensional accelerometer is placed to detect the orientation of the foot. The sensor system does not create observable interference with the movement patterns of the user and is very lightweight.

Figure 4: Pair of shoes with embedded sensors

2.2.4 Vector™ 3

The Vector 3 [24] is a pedal (see **Fout! Verwijzingsbron niet gevonden.**) that measures dual-sensing power. This pedal measures total power, left/right balance, cadence and cycling dynamics. This system can give valuable ability to see right and left leg power independently. This product from the company is mainly used in cycling sports which can provide insights into the weaknesses and strengths of an athlete to improve himself. It can track seating/standing position to determine when and how long you were in each. All this information will be shown in a mobile app, as can be seen in figure 6.

Figure 5: The Vector 3 pedal

Figure 6:The Garmin mobile app

2.2.5 Zwift Mountain Biking & Steering

The company Zwift made a game wherein the user can steer the bicycle [25]. In order to track the handlebar movement, Zwift will require either the companion app, or supported 3rd party hardware. When using the companion app, a mobile phone should be connected to the handlebars. Because of the possibility to steer in the game, the user can choose their own cycle line.

Figure 7: Zwift Cycle game with steering

2.2.6 Wireless sensing system for cycling

The system in Figure 8 is a wireless sensing system for cycling [26]. This system is composed of several body area wireless inertial sensor nodes. The microcontroller is dedicated for sampling the inertial sensors and running specific data processing algorithms. As shown in Figure 8 below, three sensor nodes are used and placed along the left leg of the cyclist. One on the thigh, one on the shank and one on the foot. The orientation of each node will be computed. By combining the orientation of each node, it is possible to obtain the joint motions of the three segments of the lower limb.

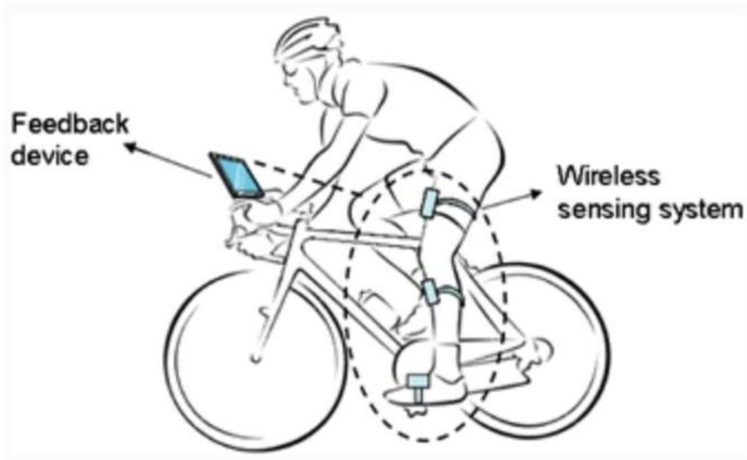


Figure 8: Wireless sensing system for cycling

2.3 Conclusion

In conclusion, a cerebrovascular accident (CVA) is a medical term for stroke and is defined as a limited brain dysfunction which is caused by an inadequate blood flow. There are three categories of consequences: visual, cognitive, and motor consequences. The motor consequences have the biggest impact on the cycling behaviour. Further investigation into the motor consequences showed that there are multiple indicators of movement to measure improvement/progress in health condition of patients with CVA. Those indicators are: coordination, speed of movement, smoothness, reaction times, balance and strength.

However, to get a complete overview of ways to improve health conditions during rehabilitation it is useful to also get some insights in this topic from experts such as an occupational therapist or a physiotherapist who is in contact with patients with CVA for rehabilitation day in day out. In order to have a complete overview for the graduation project, insights from experts will be gathered.

3 Methods and techniques

This section will give an overview of the general structure of this graduation project. The Creative Technology design process will be used during this project, which can be divided into four phases. The methods and techniques used during the process will be explained.

3.1 Creative Technology design process

The process used for this graduation project is the Creative Technology design process [27] and is depicted in Figure 9. This design process is widely used in the bachelor program Creative Technology. On the highest level, the Creative Technology design process consists of four phases as can be seen in Figure 9. This process is an iterative process. The four phases are ideation, specification, realisation and evaluation. Every phase starts and ends with a defined set of (intermediate) results. In the next paragraph the different phases of the process will be clarified.

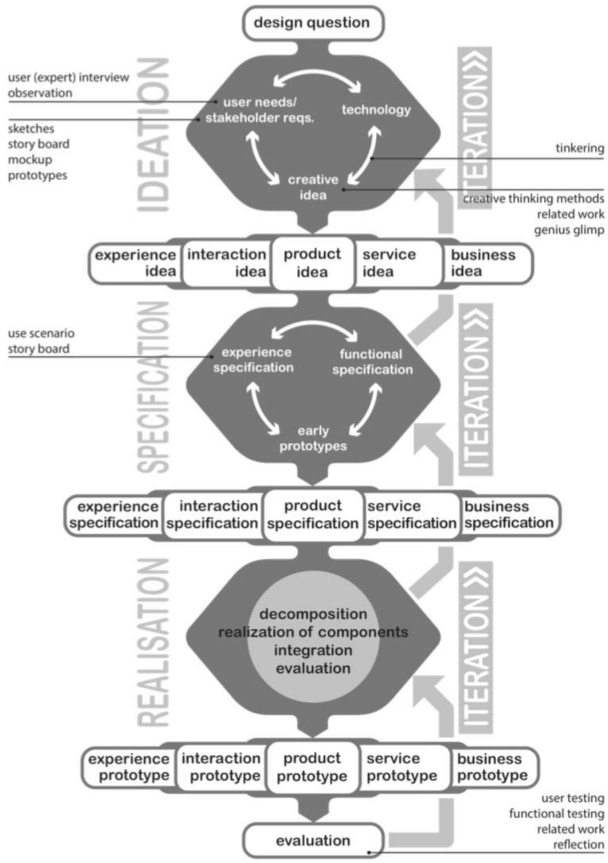


Figure 9: Overview of the Creative Technology Design Process

3.2 Phases of the process

As described above, different phases of the Creative Technology design process for this graduation project will be described in this section.

3.2.1 Ideation phase

The starting point of the Creative Technology design process is the ideation phase. Looking at stakeholders and their needs is a key element is this phase. For this stakeholder analysis, some insights from interviews with experts and a questionnaire with customers were collected and analysed. The interviews and questionnaire were conducted by Roos Bulthuis. In addition, the company of the client Van Raam was visited. Thereafter a future use scenario was written with the use of the template by Van der Voort and Van der Bijl-Brouwer [28]. In addition, some project demands were described based on chapter 2: state of the art and interviews with experts. The final step of this phase is the brainstorm, which consisted of a divergence phase where ideas were generated and thereafter the convergence phase where from the list of ideas a few were picked for the product idea. The elaborate ideation phase of this project can be found in chapter 4.

3.2.2 Specification phase

The specification phase is the second phase. During the specification phase further evaluation on the project idea was performed by defining requirements. The requirements are arranged according to the MoSCoW-method [29]. With this method it is possible to arrange the requirements with different priority. Some requirements are a ‘must have’ for a project while others are a ‘could have’. Based on the product requirements, the final product design was described as outcome of this phase of the process.

3.2.3 Realisation phase

After the product specification was formulated, the next phase is the realisation phase. Here different aspects of the prototype were described. In this phase the first step was to explore the necessary components for the prototype of the final product idea. Thereafter a system overview was given, where all the connections of the system and the program which is used for controlling the system were stated. Finally, the components were implemented on the electric tricycle and were described at the end of this phase.

3.2.4 Evaluation phase

In the last phase of the Creative Technology design process, evaluations on the final prototype were performed. Evaluation may address several aspects of which functional testing is one of them. During this phase, the prototype sensor(s) was functionally tested and evaluated whether all the original requirements identified in the ideation phase are met. Thereafter some feedback from experts with different points of view were gathered with the use of digital interviews. User testing was also executed where users get the chance to share their opinions about the final prototype. Although because of the corona virus and their accompanied measurements of the Dutch government [30], the evaluation phase will be harder than normal. Therefore, the interviews will be performed online, as well as the user testing. The user testing was an online questionnaire. The aim of this questionnaire was to evaluate whether or not the data that is measured with the sensors and the representation of feedback makes sense.

4 Ideation

This chapter describes the process and eventually the result of the ideation. In this chapter the third sub-question will be answered. This question is: *What are the needs and demands from stakeholders for a monitoring system that measure the cycling performance of a patient with CVA?* The ideation phase consists first of a stakeholder analysis to get a deeper understanding of the people and organizations involved in this project. It consists, among other things, of interviews with experts and a questionnaire with customers. Furthermore, a brainstorm was executed to explore the possible ideas. This is the divergence phase of the ideation. In the last section of the ideation, the possible ideas created in the brainstorm were brought back to one final idea in the converging phase.

4.1 Stakeholder analysis

In this section a stakeholder analysis was executed. According to Brugha and Varvasovszky [31], a stakeholder analysis aims to evaluate and understand stakeholders and to determine their relevance to a project. Through collecting and analysing data on stakeholders, one can identify opportunities and develop an understanding of how decisions are taken in a particular context [31]. A stakeholder is any person, group of persons or organization that can influence or can be affected by a new product or project. For the stakeholder analysis, the following sources were used:

- Company visit at Van Raam
- Customer questionnaire and interviews
- Interviews with a physiotherapist and an occupational therapist

The company visit at Van Raam was executed by myself. The customer questionnaire and interviews and the interviews with the experts were performed by Roos Bulthuis. These sources were analyzed. Below a summary of each source is given.

4.1.1 Company visit at Van Raam

On February 25, 2020 we visited the company Van Raam. Van Raam is the company that produces and sells the smart electric tricycles. On the day of the visit, we had an appointment with a sales representative, and a software developer to get some information about the users of the smart electric tricycle, about the cycle itself, and about the data that is collected at the moment in combination with the mobile app of Van Raam. A complete elaboration of the company visit at Van Raam can be found in Appendix A.

A large target group for smart electric tricycles of Van Raam are patients with CVA, of which most are in the age group from 40 to 60 years old. Lack of balance, coordination, strength, and condition are the most common ailments according to a sales employee of Van Raam. He also stated that patients with CVA find improvement very important. Evidence of this change plays a major role here. In addition, the sales employee mentioned that patients with CVA are the most grateful target group, because they really want to improve themselves. The Easy rider is the most sold bicycle of Van Raam for this target group, because the sense of balance is great and it offers more support in, for example, the back and bottom.

During a conversation with a software developer of Van Raam, it also emerged that right now the data collected of the smart electric bicycles is largely used for the company itself. The reason therefore is that Van Raam can monitor the state of the bicycle components, for example the state of the battery of the bicycle. Furthermore, there is also collected data beneficial for customers such as the travelled distance. Customers can get access to such data via a mobile application (see Figure 10).

Figure 10: Mobile application of Van Raam

4.1.2 Customer questionnaire and interviews

As described in the method, a questionnaire and a few interviews were conducted with customers from Van Raam who are using the mobile application of Van Raam. The questionnaire with customers was performed in November 2019 and the interviews with customers were executed in January 2019. These customers are not all patients with CVA and therefore not all part of the target group for this project. Nevertheless, these customers can give insights on the cycling behaviour of people using an adapted bicycle. There were 24 customers who answered the full questionnaire and 4 of them were also interviewed. From the questionnaire and interviews a few insights can be emerged. The main applications for the customers to use the adapted bicycles of Van Raam are for recreation, for visiting family or friends, for doing groceries and for therapy. The adapted bicycle provides them mostly more mobility, more independence of things and more physical activity. The current app is now in particular used for checking distance of their bike ride. From the interviews it became visible that information about their cycling behaviour is always welcome. But things like heartrate sensors were not always seen as something with a longer-term perspective because the sensors should be attached to the body.

4.1.3 Interview physiotherapist

Besides a questionnaire and interview with customers, an interview with a physiotherapist from Roessingh Center for Rehabilitation was analysed as well. This interview was executed by Roos Bulthuis in April 2020. The physiotherapist is involved in the rehabilitation process of patients with CVA. After patients with CVA can perform activities of daily living (ADL), the physiotherapist can help the patient with the motor and technical side of cycling. During a cycling session, the physiotherapist pays special attention to balance, getting on and off the bike, acute braking, (tight) bends, and looking over your shoulder and having no visual control on the road.

Insights into a patient's cycling behaviour can help a patient to improve their health condition or prevent deterioration, according to the physiotherapist. Especially, if a patient has a (personal) goal. According to the physiotherapist, improvement of a patient with CVA is particularly focused on function and activity level. The interviewee examines this with functional movement research such as the 6-minute walk test, motricity index (maximum force test for arm and leg), mini BEST-test (test on balance during different tasks), and tests for hand. The physiotherapist mentioned that strength/force is one of the elements of functional movement but not the only one. Sensibility, spasticity, selectivity, and coordination are elements as well.

The interview with the physiotherapist also showed that for a patient with CVA it is needed to monitor their health condition from the start and during the process of rehabilitation. In addition, the physiotherapist stated that when monitoring the health condition of a patient with CVA there also should be an option for the patient to give a reason if there is a decline in health condition. For example, if the patient was ill or if it was a few weeks very cold outside.

4.1.4 Interview occupational therapist

An interview with an occupational therapist from Roessingh Center for Rehabilitation was performed in May 2020 as well. As mentioned before, an occupational therapist is someone who focuses on the implementation of cycling in daily life. An occupational therapist concentrates on the safety of a patient with CVA to cycle in traffic in terms of cognition. They accomplish this step-by-step. A session starts with cycling laps on the parking lot. Thereafter the patients cycle on a quiet bicycle path and through a residential area. The occupational therapist tries to gradually build up the cycling to increasingly busier traffic situations. The interview also emerged that patients are very motivated in the beginning of the rehabilitation process because of the different therapies. But when this end, the motivation can subside. Therefore, it is important to motivate someone in some way to stay at the same level or improve in health condition.

According to the occupational therapist, the biggest problems for patients with CVA in traffic are cognition and fatigue. As also indicated in literature, cognition is one of three categories of consequences of CVA. In this case, CVA patients can sometimes have less attention on one side. This may, for example, result in them not being able to see the sidewalk of the road when cycling.

4.1.5 Identification stakeholders

For this project multiple stakeholders can be identified. Those stakeholders are patients with CVA, the company Van Raam, physiotherapist, occupational therapist, family and friends, and caregiver. In Table 2 an overview of the stakeholders involved in this project is given with a short explanation.

Table 2: Stakeholder analysis

Stakeholder group	Explanation
Patients with CVA	Patients with CVA are the target group of this project. They are one group of users of the smart electric tricycle. The patients with CVA will be the users of the sensor system of this project.
Van Raam	Van Raam is the Dutch company who produces and sells adapted cycles such as the smart electric tricycle (also called Easy rider). This company is the client of this project. This company will be the organization that could offer adapted cycles

Stakeholder group	Explanation
	with the end product (sensor system) of this project.
Physiotherapist	Physiotherapists are involved in the rehabilitation process of patients with CVA. They focus on the motor side and the cycling skills of a patient with CVA. In this project it is important to take the physiotherapists into account because they are checking in person whether the patient with CVA made improvement. They have a lot of knowledge and experience with patients with CVA and their rehabilitation. With the end product of this project, physiotherapists can possibly use the measured data about improvements in their therapy sessions with the patients in the future.
Occupational therapist	Occupational therapists are also involved in the rehabilitation process of patients with CVA. Occupational therapists focus on the practice side of cycling, so the ability of a patient with CVA to cycle in traffic. Because they have a lot of knowledge about patients with CVA cycling in traffic, they are of added value in this project.
Family and/or friends	Family and friends are the people closest to the patient with CVA and therefore have an emotional connection with the patients. This group is not really part of this project but are considered in this stakeholder analysis because of their emotional connection with the patient with CVA.
Caregiver	If the patient with CVA has a family member that looks after the patient with CVA (a caregiver) this person is also a stakeholder. The caregivers are responsible for physical care and emotional support. This group is, the same as the family and friends group considered in this stakeholder analysis because of their emotional connection with the patient with CVA.

4.1.6 Conclusion: product demands

To choose a good idea after the brainstorm, we need to have the product demands from stakeholders clear. From the stakeholder analysis described above, the following demands and needs were concluded. To fit the project goal of monitoring improvement the sensor system must measure cycling performance of patients with CVA. In order to accomplish this, insights from interviews with the therapists made clear that the sensor system must tackle multiple indicators of improvement in order to better monitor improvement. In addition, the sensor system should be integrated on the bicycle instead of (partly) be attached to the body of the user. This is the demand from customers emerged from interviews.

4.2 Future use scenario and persona

In this section, a user scenario and a persona will be described, to get a better understanding of future use of the product idea. According to Van der Voort and Van der Bijl-Brouwer [28] a user scenario is “an explicit description of the hypothetical use of a product or service”. This shows the interaction between a specific user and a specific product in a specific context of use. The added value is that future user scenarios can help to get a better view of the different situations the product of this project will be used for from a user’s point of view. Van der Voort and Van der Bijl-Brouwer [28] stated that scenarios consist of several elements. The first element is the ‘starting state’ which includes an actor with a certain goal regarding a certain product setting. Thereafter the actor starts to perform activities that are aimed to achieving the user’s goal. To conclude, a scenario should have a description of use issues. In Figure 11: Stock photo of persona a stock photo of the persona can be found.

Figure 11: Stock photo of persona

In Table 3 the elaboration of the use scenario can be seen.

Table 3: User scenario

User scenario	
Starting state	**Actor**: The actor of this user scenario is a 59 years old man named James. James is a patient with CVA. He got CVA 6 months ago. Fortunately, James can already perform activities of daily living (ADL) because of rehabilitation so he can take care of himself. Before the accident, James had a lot of hobbies such as exercising outdoor, visiting his family and friends, etc. James also wants to improve his health condition with the use of the smart electric tricycle, because he is very motivated to rehabilitate as well as possible. **Setting**: James has an adapted electric tricycle from Van Raam to perform his hobbies again and for exercising to rehabilitate as well as possible. He wants to have an active lifestyle and he wants to be more mobile to get groceries by bike, visit his family and friends by bike and maybe cycle to therapies. **Goal**: The goal is that James would like to be able to see whether he improved his health condition compared to previous times with the use of the smart electric tricycle.
Actions	**Steps:** 1. James wants to cycle, so he takes his smart electric tricycle out of his garage. 2. James sits down on the tricycle. 3. He can turn on the sensors that can monitor his health condition attached to the bicycle if he wants to start the measurements. If James wants to only measure part of his bike ride, he can turn them on whenever he wants. 4. James has ended the bike ride, so he turns the sensors off, and the measurement of the sensors stops. 5. After his bike ride, he can look at the mobile app of Van Raam, to see how the bike ride went and if he improved his health condition.
Use issues	**Possible use issues can be encountered at the following action steps:** 3. The user can forget to turn on the sensors. In this case nothing is being measured. 5. The user can not understand the data being presented in the mobile application of Van Raam.

4.3 Brainstorm

In this section, the process of the brainstorm to come up with possible ideas for this project will be described. First an evaluation is performed about what data the smart electric tricycle already can collect. Thereafter some project boundaries are defined. Subsequently possible ideas were created of which eventually a final product idea was emerged.

4.3.1 Current situation

The smart electric tricycle can already collect some data. But all these measurements are not intended to monitor improvements in health condition related to movements of patients with CVA and most of them cannot be used to monitor improvements. In Table 4 below, an overview of the existing collected data can be found.

Table 4: Current data collection smart electric tricycle

Data collecting category	Measurement variable
Battery data	Actual current, actual voltage, support mode and remaining capacity.
Cycle behaviour	Actual cycling speed, driven distance, pedal force, cadence and cycling quantity
Location (GPS) data	Longitude and latitude

When looking at the different types of data that currently can be collected by the smart electric tricycle, pedal force can be used to monitor improvement in strength of the legs, but this is only on one side of the bottom bracket. This is not enough. The reason for this is that literature [12] [19] and interviews have shown that it is important to measure on both sides, because patients with CVA have a reduced functioning on one side of the body. To measure the difference between the functioning and reduced functioning side of the body, it is needed to measure on both sides. In addition, the company does not know yet how to determine the pedalling power from the pedal force sensor. Furthermore, cadence can be used to determine the speed of the movement which is one of the indicators of monitoring improvements of movements.

4.3.2 Defining project boundaries

As described in section 2.1 Literature review, there are 3 categories of consequences of CVA, namely visual consequences, cognitive consequences and motor consequences. For this project it was decided to focus only on the motor consequences of patients with CVA. The reason for that is that visual and cognitive consequences are aspects that cannot meet the goal of this project since monitoring improvement in these categories of consequences with sensors while cycling on the smart electric tricycle is not competent. The state of the cognitive consequences of a patient with CVA can be monitored much more effectively with questionnaires and practical assignments [32] [33]. Furthermore, improvement of the visual problems is not always possible. The missing area of vision can not be restored, but you can get help to make the most of your vision [34]. So, for this project the focus will be on monitoring improvements in motor consequence.

4.3.3 Divergence phase

Based on the insights gained from literature and stakeholder analysis, a brainstorm about how to monitor cycling performance of patients with CVA. The categories of improvement of the motor consequences obtained from literature and interviews with stakeholders are a starting point for the divergent phase of the brainstorm. The categories are coordination, speed of movement, smoothness, reaction times, balance, condition/fatigue, and strength. Thereafter for every category of improvement, ideas for monitoring this improvement of the specific category were created as can be seen in the mind map in the figure below.

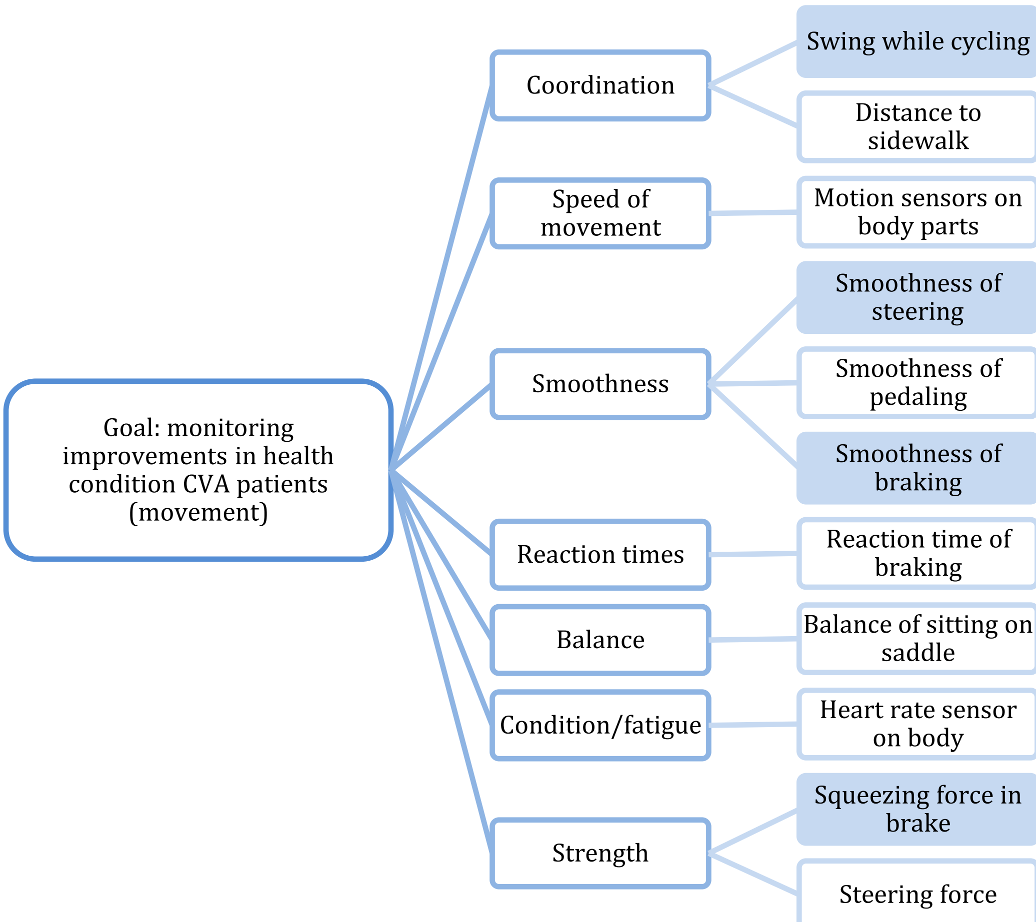


Figure 12: Brainstorm mind map

4.3.4 Convergence phase

Now that different ideas are created in the divergence phase, the convergence phase can start. The ideas that are in the blue filled rectangles in the figure above are the ideas that were chosen for the final product idea. A more explicit explanation of the final product idea can be found in the next chapter. The reason that those ideas were chosen, is mainly because with a few sensors multiple categories/indicators of improvement can be tackled. This is important because from the insights gained from literature and interviews with stakeholders it was emerged that for improvement it is not enough to, for example, just tackle strength but a combination of multiple indicators is needed. Furthermore, the smart electric bicycle already has a bit of sensing at the pedals for the pedalling movement of the legs. Therefore, in this project the focus will be on the steering and braking. Steering and braking are two important aspects of cycling and both deal with the handlebars of the bicycle. The main focus will thus be on the arms and hands of the patients with CVA. The ideas related to steering are measuring the swing while cycling and sensing the smoothness of steering. The ideas sensing the smoothness of braking and measuring the squeezing force in the brakes are related to braking.

4.4 Conclusion

To summarize, the following stakeholders are involved in the development of a sensor system to monitor cycling performance of patients with CVA: patients with CVA, the company Van Raam, physiotherapists, occupational therapists, family and/or friends and caregivers. Currently, the electric tricycle of Van Raam can measure cycling performance by measuring the actual cycling speed, driven distance, pedal force, cadence and cycling quantity. However, this information is not enough. Therefore, other methods to measure cycling performance of a patient with CVA was explored. After performing a brainstorm with its divergence and convergence phase, it was found that the steering behaviour (by measuring the coordination and smoothness of steering) and the braking behaviour (by measuring the squeezing force and the smoothness of braking) were measures of cycling performance where this project focuses on.

5 Specification

To develop a prototype of a sensor system to measure cycling performance in patients with CVA, it is needed to set some product requirements. Sources that will be used to define the requirements are literature interviews with experts, brainstorm, future use scenario, Van Raam company visit and the project goal. All this information can be found in previous chapter. The product requirements are stated and arranged according to the MoSCoW-method. Thereafter, the final product idea will be described. With this information, sub-question four was answered which was: *Which sensor(s) can be added to the electric tricycle to measure those improvements?*

5.1 System requirements

In this section the system requirements will be listed, as can be seen in Table 5. All these requirements will be prioritized with the MoSCoW-method [29]. The MoSCoW method prioritizes the requirements based on the following criteria:

- **Must have**; this defines the requirements that are not negotiable.
- **Should have**, these requirements are features that would be nice to have if possible
- **Could have**; these are the same as should have, but slightly less advantageous
- **Will not have**; these requirements are not unimportant, but they will definitely not be implemented in this project

Table 5: System requirements

Requirement #1	
Requirement explanation	The sensor system measures steering behaviour.
Source	Brainstorm and literature + interviews with experts
Justification	To measure improvement in health condition of patients with CVA it was chosen that it should measure steering behaviour. This because with steering you can measure coordination and smoothness which are multiple indicators if improvements which eventually can give a better picture of improvements.
Priority	Must have

Requirement #2	
Requirement explanation	The sensor system measures braking behaviour.
Source	Brainstorm and literature + interviews with experts
Justification	To measure improvement in health condition of patients with CVA it was chosen that it should measure steering behaviour. This because with steering you can measure strength and smoothness which are multiple indicators if improvements which eventually can give a better picture of improvements.
Priority	Must have

Requirement #3	
Requirement explanation	The sensor system must convert raw sensor data into understandable data for the user.
Source	Interviews, future use scenario and project goal
Justification	In order to meet the project goal, it is important to feed the measured data back to the patients with CVA. It is necessary to convert the raw data in understandable output data for the user.
Priority	Must have

Requirement #4	
Requirement explanation	The sensor system should have a start and end button for the measurements
Source	Further use scenario
Justification	When defining the future actions, the user needs to perform to use the system, it was clear that the sensor system should have a start and end button for the measurements. In this case the user can decide when and if he/she wants to measure the bike ride.
Priority	Should have

Requirement #5	
Requirement explanation	The sensor system should not get in the way of normal cycling execution.
Source	Interview with experts and future use scenario
Justification	You do not want to get in the way of normal cycling performance of the users of the smart electric tricycle. Therefore, the sensor should not be placed on a position which cause impact on their cycling execution. In addition, the sensor should not be too big and too heavy so that it does not interrupts the cycling performance.
Priority	Should have

Requirement #6	
Requirement explanation	The sensor system gives a signal so that the user does not forget to start the measurement if the user wants to measure his ride.
Source	Future use scenario
Justification	To make sure the user does not forget to start the measurement, the user can be notified.
Priority	Could have

Requirement #7	
Requirement explanation	The sensor system saves the data into a database and sends them to the official Van Raam app
Source	Van Raam company visit
Justification	Although it is important to save all data into a database and send it to the official mobile app of Van Raam, this is beyond the scope of this project. When this product will be implemented, this needs to be done.
Priority	Won’t have

5.2 Final product idea

From the brainstorm described in previous chapter, it was decided not to include the other ideas in the final product idea based on the requirements. The motion sensor on body parts and heart rate sensor on body were not chosen because of the fact that those sensors are on body sensors which was not desired by customers of Van Raam which emerged from the interviews with the customers. Measuring the distance to the sidewalk, smoothness of pedalling, reaction time of braking and balance of sitting on the saddle are not chosen ideas because of feasibility.

The prototype must measure multiple indicators of movements in patients with CVA. This will be accomplished by two sensors in total. First, there should be one sensor for measuring the smoothness of steering and the swinging of cycling. The idea is that this sensor should measure whether the cyclist cycles straight on or whether the cyclist is swinging. The idea is to use a hall effect sensor that can measure magnetism. A sketch of the idea can be found in figure 13. The sensor should be placed on the stationary part of the steer, while a magnet should be placed on the rotational/moving part of the steer. Whenever the cyclist steers, the strength of the magnetism field changes. It was chosen to use this idea, because it is a small and cheap sensor. This sensor should be able to accurately monitor the steering behaviour. Another possibility was using a phone as was done in one of the state-of-the-art projects. However, this was not chosen because one of the requirements is that it should not be in the way of normal cycling. A phone on your steer can distract you from cycling. In addition, by using a phone you need to demand from every user that they have a smartphone with the functionality on it to measure their steering behaviour.

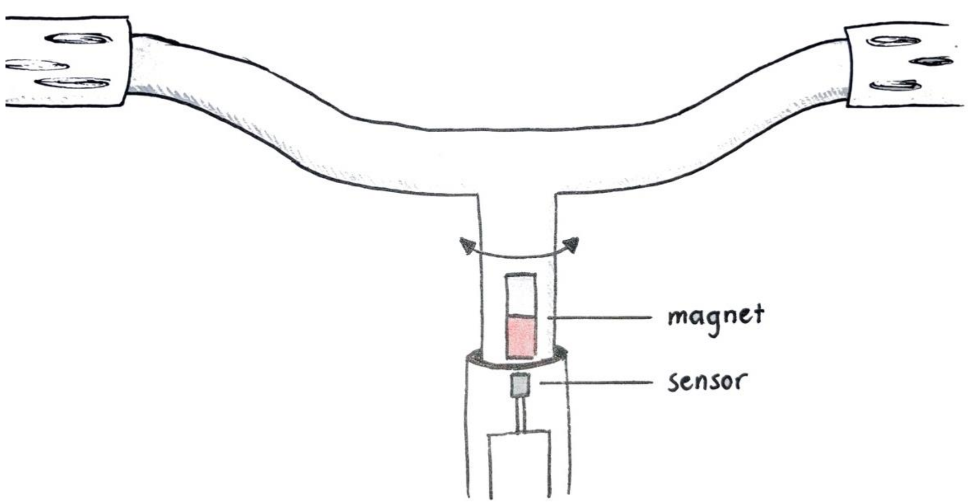


Figure 13: Steering sensor idea

Second, there should be another sensor for measuring the squeezing force in the brake and the smoothness of braking. This could be accomplished with a sensor in the braking system of brake cable itself, but those sensors are expensive and complicated to use especially for prototyping. So, the sensor should be placed at the handbrake of the bicycle and should be able to measure the force of braking by the cyclist. After some research two sensors are both an option. Both should be able to measure force in this situation, but in different ways. In addition, the implementation of both is different, but both possible for the prototype. The two sensors were also not too expensive. Because they both seem to be a good candidate for the prototype, both will be implemented and tested to be able to conclude which one is better afterwards.

One idea is to use a load cell sensor which can measure the force with the use of resistance. A sketch of the idea can be found in Figure 14. Here the brake handle should be adapted in order to let the sensor function well. Because it works a bit with mechanics, it should work accurate.

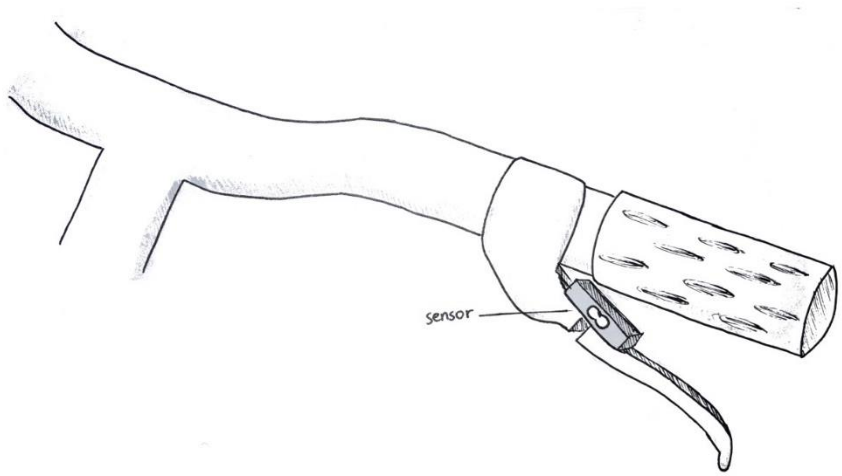


Figure 14: Braking sensor idea: load cell

Another idea is to use a Pressure sensor. This sensor can be easily attached to the back of the handbrake without any complicated adaptions. But it only has a small pick-up area.

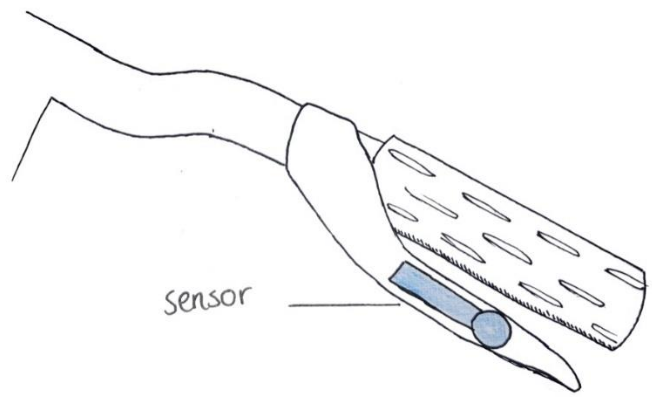


Figure 15: Braking sensor idea: pressure sensor

6 Realisation

In this section of the report the realisation phase of this project will be described. Here, among others, the fifth sub-question will be answered which is: *What information will be fed back to the cyclist to indicate improvements?* Sensors and components that will be used are listed and described. Thereafter a system overview will be given to show how all the components are connected with each other and how the components are controlled with a code in the Arduino software. Finally, the implementation of all the components on the smart electric tricycle will be stated.

6.1 Components

In order to create a prototype of the final product idea as described in section 5.2, three sensors will be used to be able to monitor the steering and braking behaviour of a patient with CVA while cycling. Two sensors should measure the same braking behaviour and it will be tested which one is better. In addition, a button to control the system, a LED ring for at-a-glance feedback and a SD module for data collection will be used.

6.1.1 Components sensor system

Below in the table all the components used in the realisation of the prototype and their functionality will be listed and described.

Table 6: Components realisation

Component	Explanation
Hall effect sensor	This sensor will be used to measure the steering behaviour, which tackles requirement 1. The Hall effect sensor can be used to detect the presence of nearby magnetic fields, such as magnets. Besides the digital output, the module also has an analog output to determine the strength of a magnetic field or the distance to an object. The polarity of the magnetic field influences the switching action. The front of the sensor needs the opposite polarity as the back of the sensor before turning on.
Load cell	One way to measure the braking behaviour of a patients with CVA is to use a load cell. With this sensor requirement 2 is met. A load cell is a type of transducer. To be more specific, it is a force transducer. This sensor can convert a force into an

	electrical signal which can be measured. When a force (such as tension or pressure) is applied and increases, the measured electrical signal changes proportionally. The type of load cell that will be used is a strain gauge. With the load cell that will be used, up to 1kg of weight can be measured. It was measured how much force is performed with squeezing the handbrake with the use of a spring scale. Here is was found that around 1 kg was performed to squeeze the handbrake. If it turns out in the end that this is too less, the load cell is also available in other ranges, for example up to 2 kg.
Load cell amplifier – HX711	The signals from this load cell can not be read with an Arduino. This requires an additional module, namely the Load Cell Amplifier - HX711. This small module is needed to read the load cell correctly by amplifying the signal.
Pressure sensor	Another sensor for the braking behaviour that was implemented and tested is the Taiwan Alpha Membrane Pressure Sensor. This sensor is able to measure pressure using the membranes incorporated in the sensor. The resistance of the sensor changes based on the pressure on the membrane. With a simple voltage divider, it is possible to easily read the sensor on an analog input pin.
LED-ring	Providing the user feedback of the status of the system and possibly the data that is measured is important, because with feedback it is possible to give patients insights in their progress which is part of the project goal. At-a-glance feedback will be accomplished with the 12 LED RGBW NeoPixel Ring in Cool White. Each LED is addressable as the driver chip is inside the LED. It is possible to set the brightness and colour of each LED. This is a simple way of giving feedback while cycling.
Button	The button was used to control the system by turning the measurements on and off. It is a basic component and widely used in Arduino projects. For this project it will be used in a pull-down configuration. With this component, requirement 4 was met.
SD card module	To be able to collect data during testing, a SD module was needed. It is possible to insert a SD card in this module on which the data will be stored and saved.

	This module interfaces in the SPI protocol. The SD card module allows to communicate with the memory card and write or read the information on them.
Power bank	To provide the whole sensor system with electricity a power bank was used.

6.1.2 Controller: Arduino uno

The Arduino Uno will be used to connect and control all the sensors. The platform Arduino is widely used as a platform to create prototypes with electronics. To be able to control all the components with the Arduino and collect data, it is needed to use the Arduino Software (IDE). The Arduino Software allows you to write programs and upload them to the Arduino board [35]. Mainly, the code consists of a setup and a loop function. In the setup function the system with all the components will start up and some components will calibrate. Here variables, pin modes and libraries will be initialized. This function will only run once. After the setup function, the loop function will run. This function, as its name suggest, loops consecutively. This is used to actively control the Arduino board. A flow chart of how the Arduino software works can be found in Figure 16 below.

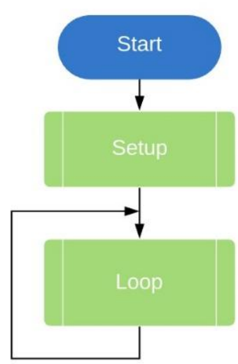


Figure 16: Flow chart of basics of Arduino software

6.2 System overview

In this section an overview of the system will be given. In Figure 17 all the hardware connections of the different components needed for this project can be found. As mentioned before, all the components will be connected to and controlled with the use of the Arduino Uno. This because Arduino as platform/system is great and very useful for prototyping electronics such as sensors.

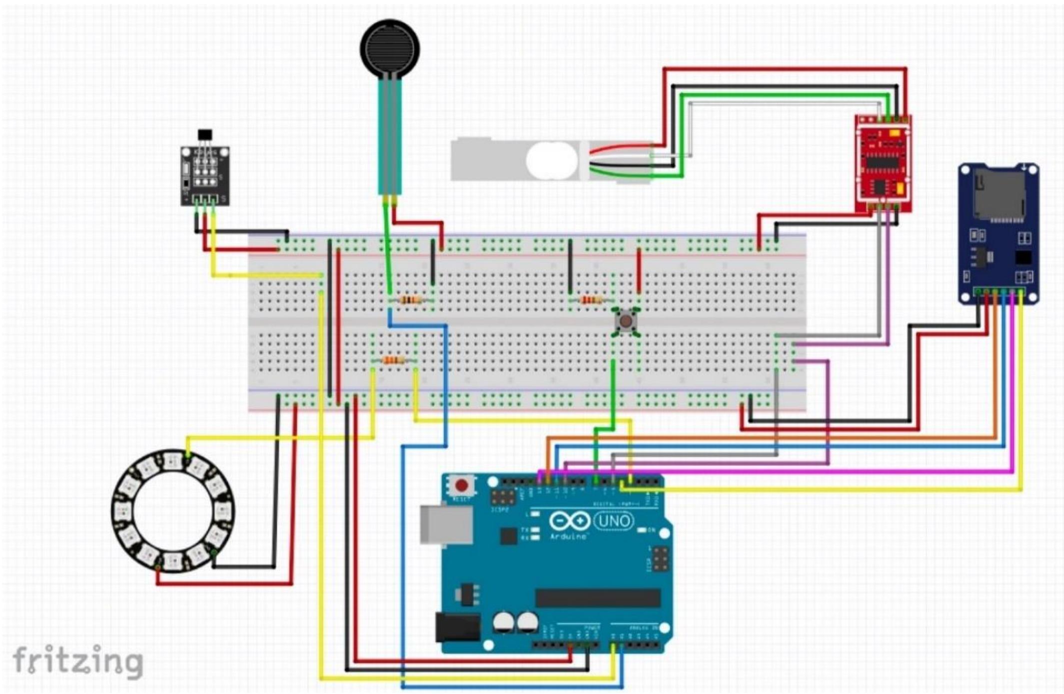


Figure 17: System overview

The code that is written for this project can be found in *Appendix B. Arduino code*. To give some explanation of the structure of the code, some flow charts will be discussed. First the setup of the code will be described. As mentioned before, the setup only runs once as can be seen in the flow chart in the figure below. Here the baud rate (the speed for serial communication) was set, the LED-ring was coloured, and all the components were set up and ready for usage.

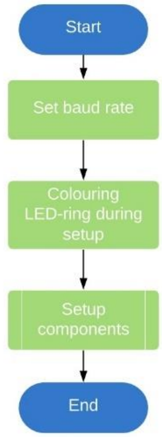


Figure 18: Flow chart setup

The loop function (see Figure 20) will be executed a lot of times. The blue part of the flow chart is meant for controlling the system with the button. Whenever the button will be pressed, the system starts or stops with taking measurements. The green part is for executing the measurements and giving feedback to the user of the tricycle. The green rectangle represents the all the measurements of the different sensors, providing feedback with the use of the LED-ring and save the data that has been measured on a SD card. These functions will only be executed whenever the button is pressed to start the measurements.

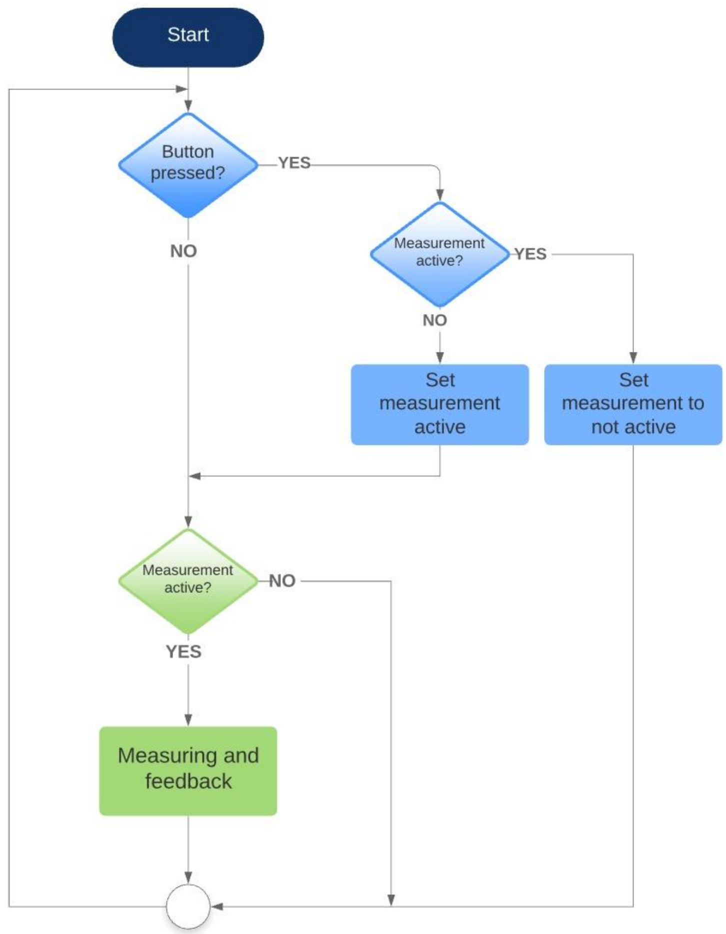


Figure 19: Flow chart loop function

6.3 Implementation

Now that all the components and the system overview are known, the implementation of all the components on the smart electric tricycle will be described. Roessingh Research and development has an Easy Rider from Van Raam on which the components will be placed temporarily. In the figure below, a complete overview of tricycle with all the sensors and other components on it can be seen. The Arduino was placed on the front of the bicycle to keep the length of the wires from the Arduino to the sensors as small as possible and to have a fixed and stationary location that did not interfere with normal cycling movements.

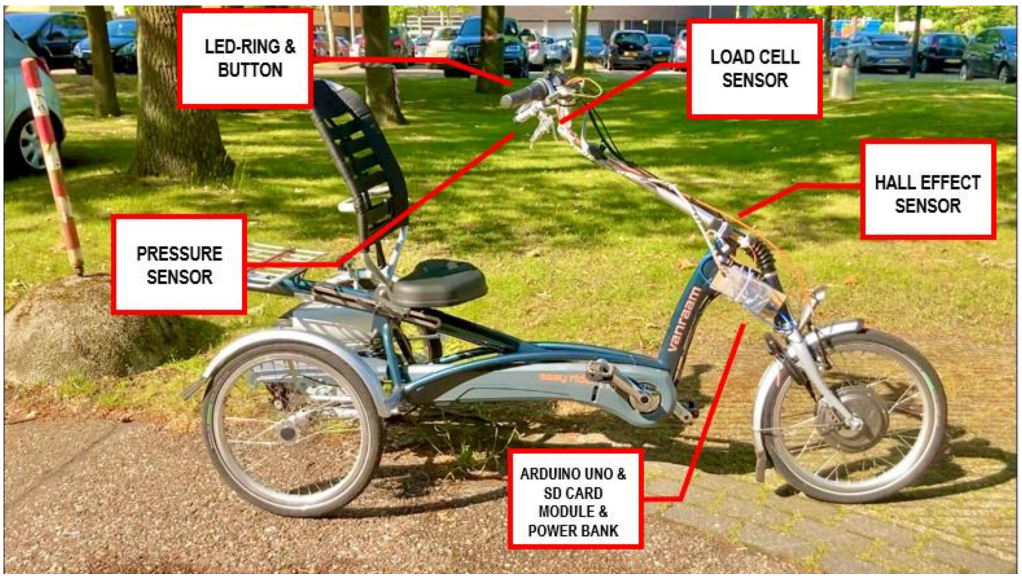


Figure 20: Overview components implemented on tricycle

6.2.1 Implementation steering behaviour

First, the hall effect sensor was attached to the smart electric tricycle (see Figure 22). The hall effect sensor was placed on the stationary part of the steering axle because then the wires of the sensor do not interfere with the turning of the steer. A magnet was placed on the moving part of the steering axle such that when the cyclist cycles straight forward the magnet is right below the hall effect sensor. When the cyclist steers, the magnet moves away from the hall effect sensor. When the magnet is not near the sensor, no magnetic field will be measured. Therefore, the sensor can measure if the cyclist cycles straight or not.

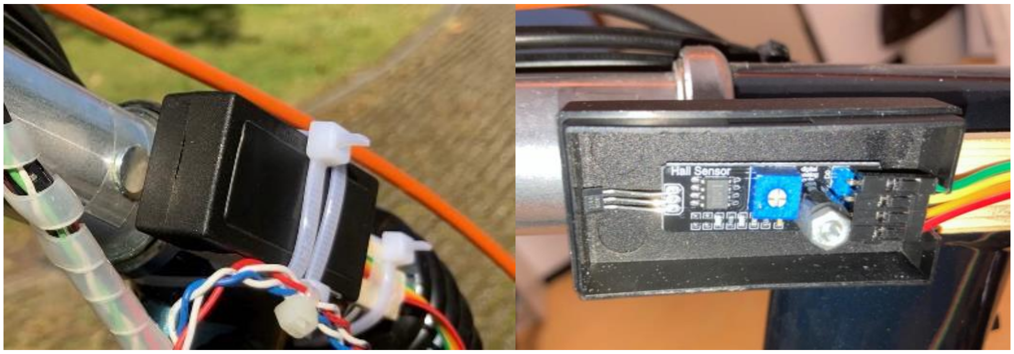


Figure 21: Hall effect sensor attached to tricycle

6.2.2 Implementation braking behaviour

As mentioned before, for measuring the braking behaviour, two sensors will be implemented and tested to compare which sensor is the best option to choose. First, the implementation of the load cell sensor will be described. Before the load cell can be implemented on the tricycle, first a test setup was made as can be seen in Figure 23. This to make sure it was working. A force will be applied on the left side (see force), the right side will be static. The force can then be measured area above the hole in the sensor will be bend a very tiny bit which results in some resistance that will be measured.

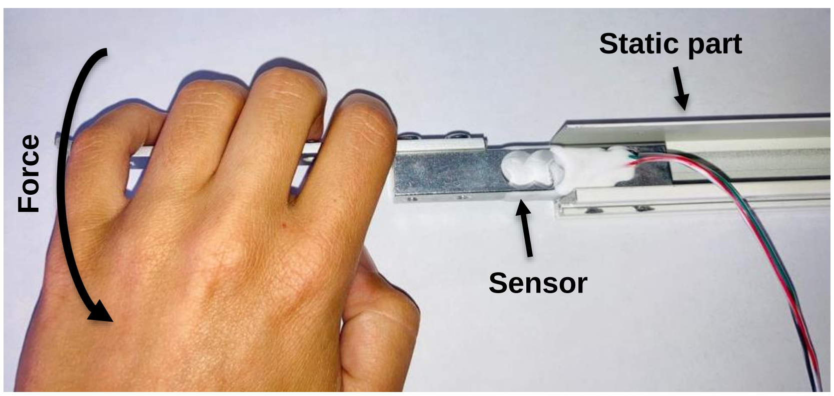


Figure 22: First prototype of load cell

After the test setup (described earlier) was working, the load cell could be implemented on a real handbrake. To be able to accomplish this, some adjustments on the handbrake had to be made. Adjustments are needed in order to let the load cell sensor work as it should work because above the 8-form hole some space should be open. Therefore, a separate handbrake was bought to be able to make those adjustments. In Figure 24 the final result can be seen. When the separate/external handbrake was attached to the smart electric tricycle, the brake cable was inserted in the separate brake handle as well. This to ensure that the measurement with the load cell sensor is as accurate as possible.

Figure 23: Final prototype load cell

The other sensor that will be implemented and tested for the braking behaviour is the pressure sensor. As can be seen in Figure 25, for this prototype the pressure sensor was placed on the back of the handle brake.

Figure 24: Pressure sensor attached to tricycle

6.2.3 Implementation providing feedback

To be able to give some feedback on the system status and possibly on some measurements, a LED-ring will be implemented. In addition, also a button was placed within this LED-ring to be able to start and stop the measurements. This LED-ring together with the button were placed on the steer so that both are clearly visible. Both the LED-ring and button were attached to the steer within a 3D-printed case. A model of this 3D-printed case from the website Thingiverse [36]. When the system is busy with the setup and calibration, the measurements cannot be turned on. This is indicated with a red circle on the LED-ring. Whenever the system is done with the setup and ready for measuring, the LED-ring will turn blue. This can be seen in Figure 26.

Figure 25: System status feedback

To provide some at the glance feedback, the LED-ring can also be used. For example, it can be used to give at-a-glance feedback about the braking behaviour data that is being measured with the pressure sensor. The force of the braking can be showed with the number of LEDs of the LED-ring turned on. The colour of those LEDs can be used to provide feedback on the smoothness of braking. This can be done in terms of categories. Whenever a patient with CVA brakes very smoothly, the LEDs can be green to indicate that he or she is doing great. Orange can indicate that someone is almost braking smoothly. Red can be used to indicate that someone is braking jerky and should try to brake a bit more smoothly. In Figure 27 below, the concept of providing at-a-glance feedback is shown.

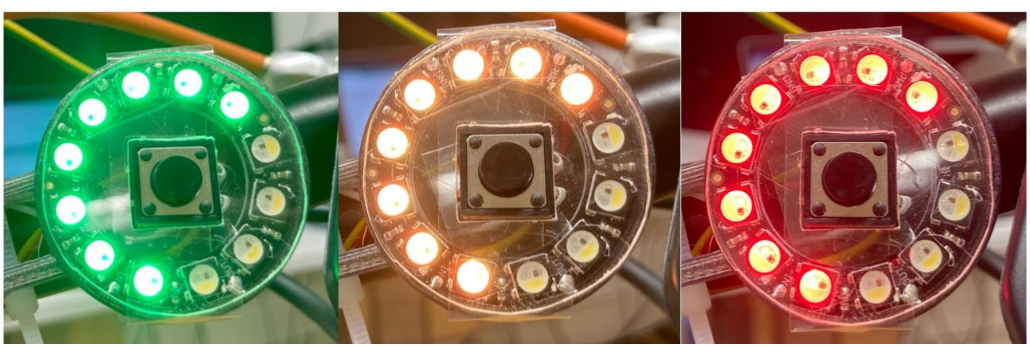


Figure 26: Feedback of smoothness of braking

6.2.4 Implementation wires

All the components are controlled with an Arduino Uno, as mentioned before. To avoid loose wires on a breadboard, all the wires were soldered on an Arduino shield as shown in Figure 28. This shield can be easily put on the Arduino Uno.

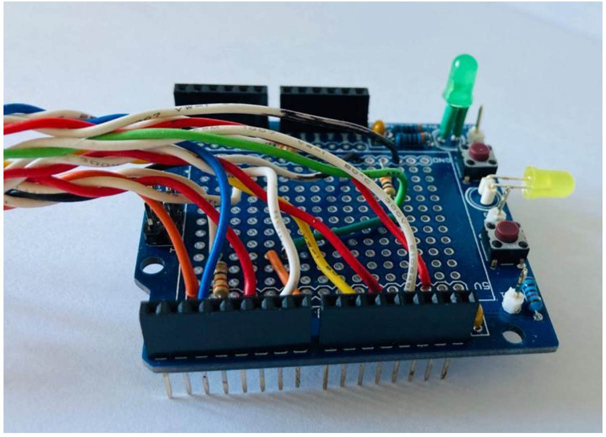


Figure 27: Arduino shield with soldered wires and components

Where possible all the sensors and wires were shielded. The wires had a cable binder around them which ensures that the cables stay together and do not interfere with the signal. Other components that could have a shield were also shielded, such as the hall effect sensor, the LED-ring with the button (described above) and the Arduino with shield.

7 Evaluation

Before being able to answer the main research question, in this section the evaluation of realised prototype will be described. The evaluation will consist of three parts. First a functional testing will be described to evaluate if the sensors function as they should be. Thereafter some interview with experts will be described to evaluate and get feedback from experts with knowledge of the working field. The experts that are interviewed are an occupational therapist, a lab administrator/biomedical engineer from Roessingh Research and Development and a software developer at Van Raam. At last, for user testing a questionnaire was made to evaluate whether or not the setup, the data that is measured with the sensors and the representation of feedback is clear and make sense.

7.1 Functional testing

In this section all three sensors that were applied in the prototype will be tested and evaluated.

7.1.1 Hall effect sensor

First the hall effect sensor will be tested. For the test, the analog output was used, because it should give analog values (between 0 and 255). The sensor was connected correctly as described in 6.2 System overview and tested. A graph from the test can be seen in Figure 29. The data gathered on the SD card was copied into excel by which this graph was made. For the test some swinging movements were created. Whenever the signal is 0, the magnet is right under the sensor. If the signal is high (around a value of 230), the magnet is not under the sensor which means the cyclist is steering either to the right or to the left, this distinction can not be made with this sensor. The height of the signal value in this case does not matter (explained later).

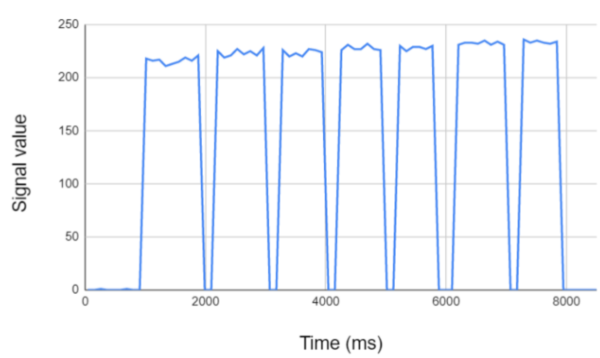


Figure 28: Graph of testing results hall effect sensor

By evaluating the results, it is possible to conclude this sensor can measure well if the magnet is right under the hall effect sensor which results in a signal value (around) 0 or if the magnet is not underneath the sensor which results in a signal value around 220/240. With this information it is possible to monitor whether a patient cycles straight on or cycles swinging, because when the graph quickly switches between the highest and lowest value, it means the cyclist cycles very swinging. The sensor reacts very quick, which results in accurate measurement.

Another indicator that was aimed to be able to monitor with this sensor was the smoothness of steering. This sensor was not able to accomplish this. It was stated that the sensor should be able to determine the strength of a magnetic field or the distance to an object because of his analog output. However, this is was not possible to achieve this. The analog value only was 0 whenever the magnet was underneath it and (around) 230 whenever the magnet was not underneath the sensor.

7.1.2 Load cell sensor

The load cell sensor is one of the two sensor options for measuring the braking behaviour. The load cell needed to be attached to a separate brake handle but could be attached to the real braking system of the bike by attaching the brake cable to the handle. This to make the testing results more reliable. The results of the testing can be found in the graph in Figure 30. First one “long” brake was performed (1), thereafter two middle long brakes where performed (2). At last, multiple (5 to be exact) short brakes were performed quick after each other (3).

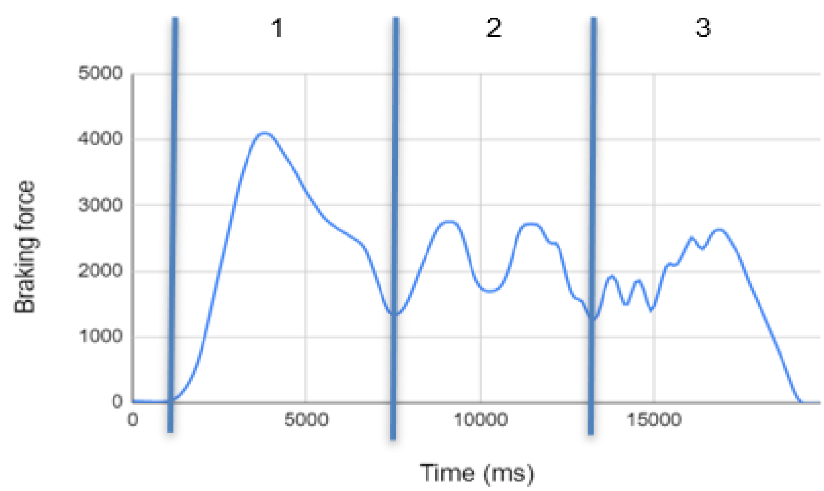


Figure 29: Results load cell testing

From the results it is possible to conclude that the sensor has a high accuracy of the force, because of his large range. However, the output data from the sensor has a sort delay and needs some time to go back to a value of 0 again once you released the brake. This results in a low accuracy for determining the smoothness of braking. As can be seen in the graph (3), once multiple brakes are performed quick after each other, the sensor does not recognize every brake.

7.1.3 Pressure sensor

Lastly, the functionality of the pressure sensor will be evaluated. For this test, a force was applied when braking 4 times quickly after each other. The results of the test of the pressure sensor can be found in the graph of Figure 31.

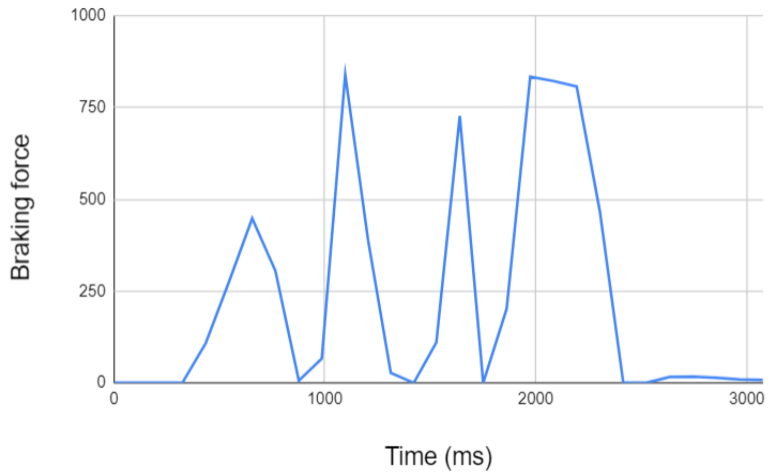


Figure 30: Results test pressure sensor

As can be seen from the results, the braking force has a smaller range than the load cell sensor (namely 0-850 instead of 0-4200), which results in a slight less accuracy of the braking force. However, the pressure sensor reacts quickly. Every brake squeeze was measured correctly. So, in contrast to the load cell sensor, this sensor can monitor both the indicator force and smoothness as planned but with a slightly less accurate force value.

7.1.3 Conclusion functional testing

The half effect sensor measures the swinging behaviour very well, however the coordination of steering was not achieved with this sensor because it was not able to determine the strength of the magnetic field. For the braking behaviour, the pressure sensor would be the best option for now, because it measures both the force and the smoothness well. Still, some signal processing needs to be further developed so that the system works better. The platform Arduino is not that suitable for signal processing.

7.2 Feedback experts

As described above, three experts were interviewed to get feedback from their point of view. In this section their feedback gained from the interviews will be described. The full typed elaboration of the interviews can be found in Appendix D, Appendix E and Appendix F at the end of this report.

7.2.1 Recruitment

To form a complete picture of feedback, multiple different experts were approached. The experts that were approached and interviewed are an occupational therapist from Roessingh Rehabilitation Center, a lab administrator/biomedical engineer from Roessingh Research and Development and a software developer/project leader of the EMBIPRO project at Van Raam. It was chosen to approach and interview them to receive feedback from different perspectives. From the therapist, the technical and the client point of view. The contact details of those experts were obtained from Roos Bulthuis.

7.2.2 Method

To gather some feedback from experts, formative and in-depth interviews were conducted. Some information about how to organize and conduct an interview [37] was gained beforehand. When the interviews started, first some consent was asked about recording, voluntary participation, and privacy. The consent form used for the interviews can be found in Appendix C. Informed consent form. This form was delivered to the ethical committee of the faculty EEMCS, together with some project information and an ethical checklist. This request was approved. The interviews were performed over phone and Skype. All three interviews were recorded, with permission from the concerning persons, so that all the attention went to the interviews and the interviews could be fully typed out.

The interviews were semi structured. This means that there were some questions prepared but, if necessary, there was also space to allow new questions or ideas to be brought up during the interview as a result of what the interviewee said. The type of questions that were asked during the interview were all open questions, which invites interviewees to provide longer responses instead of just yes or no answers. The questions for the experts were not the same because of their different field of expertise. However, some questions did overlap.

7.2.3 Results

In this section, a summary of the results from the interviews with the different experts will be described.

7.2.3.1 Product idea in general

After explaining what the idea of the sensor system is and how the prototype was realized, the experts said they thought the idea of the sensor system is interesting and made them curious. The employee of Van Raam said that it would be very nice if Van Raam could offer such a system on the adapted bikes to customers. But if the system has potential, is hard to say right now. The occupational therapist thinks it probably has potential because she often notices that when people get tired, both physical and mental fatigue, they start to swing more. Monitoring more indicators is not needed according her. Stability of cycling with measuring the steering behaviour and whether or not continuous abrupt braking is good. She pays particular attention to the steering behaviour during a session with a patient, especially when a patient makes a turn, to see if he/she ends up on the right side of the road. Swinging can then be an effect.

7.2.3.2 Target group

The employee of Van Raam thinks that if you want to apply this within the time that patients with CVA also have rehabilitation sessions with therapists, most of the time they do not have their own adapted bicycle from Van Raam. This can result in a small target group. In addition, the occupational therapist said that once a patient with CVA is cycling independently, occupational therapists do not pay that much attention to it anymore. What she could imagine is that the sensor system would be attached to the cycle in the practice sessions to give patients with CVA some insights because a lot of people are not aware of how much they swing during cycling for example.

7.2.3.3 Further development

Looking at future development of the sensor system, the lab administrator of Roessingh Research and Development mentioned that the pressure sensor that is used for the prototype can be improved by using a pressure strip instead of a circle shape. This to increase the pick-up area of the measurements. Furthermore, the lab administrator of RRD stated that when such a sensor system is being further developed and it is wanted to include them on other adapted bicycles of Van Raam, you have to found out if there are different braking systems. Because if that is true, you need to refine your system to be compatible for multiple braking systems.

There were only two things the occupational therapist could think of that could be of added value. It would be helpful to relate the braking behaviour with the speed someone has. Some people have a lot of speed and then stop pedalling and let the bike reduce speed by itself. In addition, the occupational therapist stated that it would be beneficial to also be able to measure the angle of steering and therefore monitor if they make a small or large turn. According to the lab administrator of Roessingh Research and Development, a gyroscope, accelerometer, or an encoder could be solutions to achieve this measuring of the angle of steering.

7.2.3.4 Implementation in future

If the system will be further developed and applied to the adapted bicycle, Van Raam could integrate the sensor system into their own electro-system when they manufacture the bicycles themselves as mentioned by the Van Raam employee. This will as result also simplify the process of sending the data to the mobile application of Van Raam which, according to the employee of Van Raam, is probably the easiest way to communicate the measured data to the users. Other options would be via e-mail addresses (every once in a while an update) or via a web-portal. But because nowadays people are often on the mobile phones and it is the main means of communication of Van Raam (other data that is already been measuring is also made visible), the mobile app would be the best solution.

7.3 User testing questionnaire

In this section the user testing part of the evaluation will be discussed. For the user testing, an online questionnaire was created. The questionnaire was made to evaluate whether or not the setup, the data that is measured with the sensors and the representation of feedback is clear and make sense.

7.3.1 Recruitment

For the questionnaire people were recruited by asking if they wanted to participate in this research by filling in a questionnaire. Some fellow students were asked, and some acquaintances of my parents were asked. The reason therefore was to make sure that there is some variety in age and education.

7.3.2 Method

For the questionnaire, the online questionnaire tool Google forms was used. The questions asked in the questionnaire can be found in Appendix G. Questionnaire user testing. In the questionnaire both open and closed questions are asked. The open questions are aimed to invite participants to give longer responses that demonstrate their reasoning and explanation. The closed questions are a mix of multiple-choice questions and rating scale questions where a question was asked, and the participants had to give a rate between 1 and 5 (very unclear to very clear). For some questions, a small video needs to be watched before a participant can answer the question.

7.3.3 Results

In this section, the results of the questionnaire will be described. First some results on the demographic questions will be mentioned. Thereafter the results of the questions about the braking behaviour, steering behaviour and providing feedback will be described.

7.3.3.1 Demographic questions

In total 23 people (n=23) filled in my questionnaire. 73.9% of the total amount of people was female, the rest was male. A variety of different ages and education level filled in the survey. The average age was 27.70 years old (median 21 years old) with a standard deviation of 13.00. Most participants completed a high school degree as highest level if education (43.5%). Besides this, 21.7% completed a WO bachelor and 17.4% a WO master. The remaining part completed a HBO master or a MBO degree as highest degree.

7.3.3.2 Braking behaviour

First some questions were asked about measuring the braking behaviour. First a video of two situations of braking was shown. One where the braking went smooth and one where the braking went jerky. A graph of the braking force was shown during both situations. When asked if the difference is graphs was clear, the majority said it was very clear, as can be seen in the graph below.

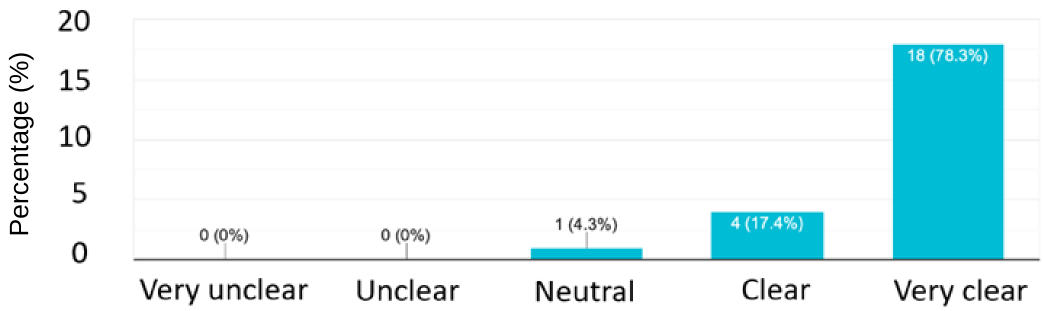


Figure 31: Results clarity graphs of braking behavior

Most of the people give as argument that it was clear that with smooth braking, a clear constant force was seen, but for the jerky braking multiple peaks in force was seen which corresponds to the multiple breaking actions. Adding a clear name on the x-axis would be something that can be improved.

In addition, all 23 participants (100%) said that they think that this information about the braking behaviour provides insights in the cycling performance of patients with CVA. As main reasons the participants mentioned that braking is an important part of cycling, it can be an indicator of progress for patients with CVA and it can measure how stable and self-confident a patient is.

7.3.3.3 Steering behaviour

For the steering behaviour, the principle was the same as for the braking behaviour. First a video with two situations was shown. One situation where the cyclist goes straight on and one where the cyclist is swinging. Again, graphs during both situations were shown. Thereafter the participants were asked if the graphs of both situations were clear to them. The results of this question can be seen in the graph below. It can be concluded that the graphs were very clear for the majority of the participants.

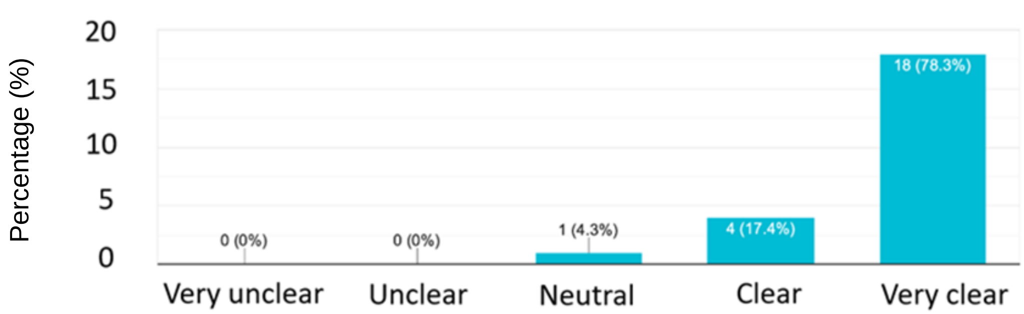


Figure 32:Results clarity graphs steering behavior

As explanation the participants said that it was clear that when the cyclist cycled straight on, nothing happened, but when the cyclist starts cycling swinging, peaks were seen. However, some people said that it would clearer if the signal was flipped. So that it is clear that if you are cycling straight, something is still being measured.

From the participants group, 95.7% said that this information about the steering behaviour provides insights in cycling performance. This because steering is also an important part of cycling and it provides information about the control of motoric functions of the patient: their stability with steering.

7.3.3.4 Feedback on system status and cycling behaviour

There were also questions about the feedback that can be provided with the use of the LED-ring. First the feedback of the system status will be discussed. The participants watched a video of the system setup. When the LED-ring is red, the system is not ready for measurements. Only if the LED-ring turns blue, the system is ready, and the button can be pressed to start the measurements. For every participant, this setup visualization was clear or very clear, as can be seen in the graph below.

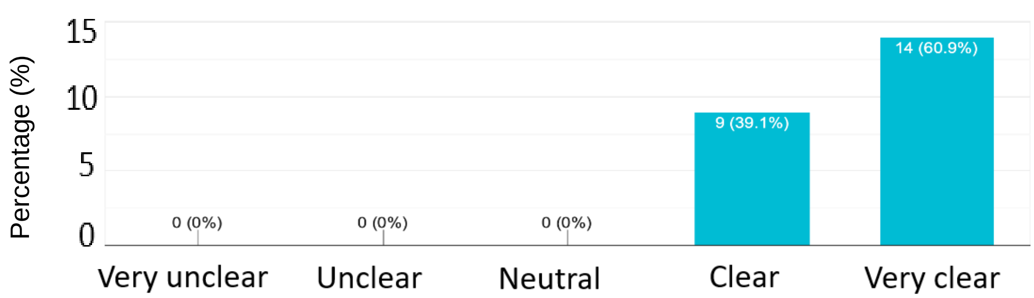


Figure 33: Results of clarity of setup visualization

As reasoning, a lot of the participants stated that the colour red is a good indication that you have to wait. In addition, the colour change indicated clearly that the system is ready for measurements. Finally, the colours are bright, good visible and contrasting. Some people mentioned that once you have an explanation about the colours, it is clear and easy to use.

It is also a possibility to provide at the glance feedback. In the questionnaire a video about the feedback of the braking force which is indicated with the number of LEDs was shown the participants. Majority of the people filled in that they think this way of feedback is clear and easily to be seen. The results can be found in the graph below.

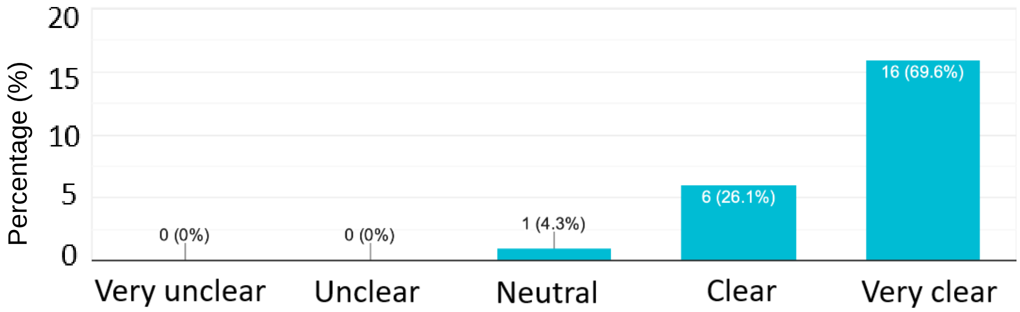


Figure 34: Results clarity of braking force feedback with amount of LEDs

Participants mentioned that this is an easy way to see what the braking force is, the more LEDs, the more braking force is applied. They say it is a very obvious and intuitive way of feedback, no explanation required.

Thereafter also categorization of the indicator smoothness of braking was applied with different colours. A lot of participants filled in that they thought this is a clear/very clear way to provide feedback. The results can be found in the graph below.

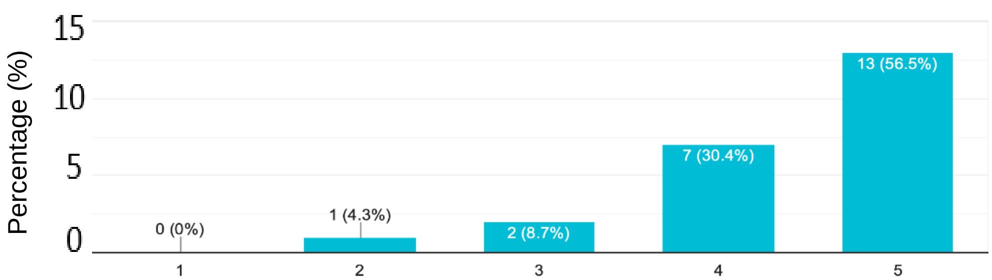


Figure 35: Results of coloring LEDs for feedback smoothness braking

Most people say that the colour choose is easy to understand, because they are used in daily life very often (for example a traffic light). It also indicated good and bad very well. However, some said that orange was too close to the red, so it was a bit hard to see the difference especially when someone is colour-blind. One participant thought that with this addition it is too many usages of one led device.

After the bike ride, the user should be able to see how they performed. In the questionnaire the participants were asked in which way they prefer to give feedback in the mobile application of Van Raam. A large majority preferred the option with the categories, as can be seen in the graph below.

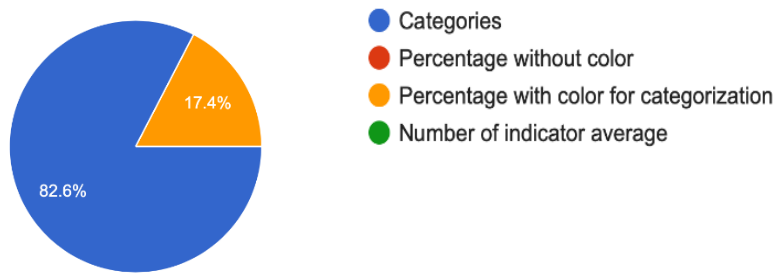


Figure 36: Results different ways to provide feedback afterwards in the app

As explanation most of the people said that different colours/categories are simple and easy to understand. They also mentioned that for the other options, you first have to give an explanation on what the numbers mean, without them the meaning is not clear. Furthermore, categorization also motivates more.

7.4 Conclusion

The sensors used for this project work well overall. However, they can be improved, which will one of the possible goals for future work. The signal processing can be improved since there was not much time for during this project. Furthermore, interviews with experts made clear that a sensor that can measure the angle of steering would be useful. Increasing the pick-up area can also be an improvement. It was also mentioned in interviews that it is of added value to relate the braking behaviour to the speed of the cycle to even get a better view of the behaviour. Lastly, it has been proven that for most of the people that filled in the questionnaire, the system status and data feedback of the measurements were clear to very clear and does provide information on the cycling behaviour.

8 Conclusion & Discussion

The goal of this graduation project was to answer the main research question of this project. This question is *How can the smart electric tricycle monitor the cycling performance of patients with CVA?* To be able to answer this question, four sub-questions were formulated at the beginning of this project. Those question are: *What are the consequences of CVA? How can progress be measured in patients with CVA? What are the needs and demands from stakeholders for a monitoring system that measures the cycling performance of a patient with CVA? Which sensor(s) can be added to the e-trike to measure those improvements? What information will be fed back to the cyclist to indicate the improvements?*

In order to answer the first sub-question, a literature research was performed in chapter two of this report. There it was found that there are three main categories of consequences, namely visual, cognitive, and motor consequences. Along the way it was chosen to only focus on the motor consequences for this project. This because visual and cognitive consequences are aspects that cannot meet the goal of this project since monitoring improvement in these categories of consequences with sensors while cycling on the smart electric tricycle is not competent. Further research into the motor consequences showed that there are multiple indicators of movements to measure progress in health condition of patients with CVA. Those indicators are the following: coordination, speed of movement, smoothness, reaction times, balance, condition/fatigue, and strength. This answers the second sub-question. In chapter 4 of this report, the ideation phase was performed. Here the third sub-question was answered. After performing a stakeholder analysis, defining a possible use scenario and a brainstorm, it was chosen to focus on monitoring the following indicators of improvement: smoothness and coordination of steering and the smoothness and force of braking.

After defining the product requirements in chapter 5, the product idea was described. It was chosen to use the hall effect sensor for the steering behaviour. For the braking behaviour two sensors, a load cell sensor and pressure sensor, were chosen to be able to evaluate which one fits better. With this, sub-question four was answered as well. Some other components were added to achieve a functional sensor system, which can for example been turn on and off and can possibly give some at the glance feedback. The information that will be fed back to the patient, can be done in categories of good, almost good, or bad. This answers the fifth and last sub-question of this graduation project.

Finally, the sensor system was evaluated on a few aspects. First functional tests were performed to evaluate if the sensors function correctly. The hall effect sensor did measure the smoothness (swinging behaviour) very well, however it was not able to monitor the coordination of the steering. The load cell sensor had a high accuracy of the braking force, but to monitor the smoothness of braking, it had too much delay. The pressure sensor had a slight less accuracy of the braking force but could monitor the smoothness very well. Therefore, the pressure sensor would in this case be the best option to choose for now. Besides the functional testing, some feedback from experts were gathered with the use of interviews. The experts were very interested in the concept. Maybe the target group is a bit too small to develop the system really further but if it is not, some points still need some attention and can be developed further. For example, it would be of added value to also be able to measure the angle of the steering movements to determine the smoothness. Some other sensors can be used for this purpose. Lastly, an online questionnaire was made to evaluate whether or not the data that is measured with the sensors and the representation of feedback makes sense. The overall conclusion was positive. The majority understood what was meant with the data and the feedback.

To summarize, with the sensor system that was described in this graduation thesis, it has been proven that it is possible to monitor the cycling performance of patients with CVA with the focus on steering and braking behaviour. However, further development needs to be done to make this prototype into a real product. With this system it is accomplished to make the electric tricycle smart and provide information to the patient that they need about their cycling performance.

9 Future work

As described before, it has been proven that with this sensor system it is possible to monitor the cycling performance of patients with CVA. However, further development of the sensor system is needed to build a real product of this prototype. The sensors and their signals can be improved. Some signal processing is needed for further developing. In addition, some recommendations made in the evaluation phase can also be applied to improve the system. Some further research on this topic can be done. Second, user testing with real patients with CVA can be advised. This to evaluate if this system works for patients with CVA. The test could, for example, measure the differences of both sides of CVA when braking. This because often patients with CVA have one side that has less functionality. For the steering behaviour, a parcourse could be created where patients should follow the route. Here some different exercise can be monitored such as cycling straight on or taking small turns. Lastly, some research into other (brain dysfunction) diseases or other purposes can be performed to evaluate if such a sensor system can be used for more target groups and in other situations with, if needed, some small changes. Because it was mentioned in the evaluation interviews with experts that the target group of this project could be too small to really produce such systems, it might be an idea to broaden the target group and the purpose/situation.

Appendix A. Company visit at Van Raam

A1. Conversation with sales representative

The target group of the adapted bicycles uses the bicycles for general usage. In addition, these people like to set goals. People with different disorders or limitations come to Van Raam to get an adapted bicycle. However, people suffering from CVA is the largest target group. This target group is mostly aged in the range from 40-60 years old. Improvement is very important for them. In the first year after they had a CVA, improvement is large, thereafter they improve themselves with smaller steps. The sales representative also stated that for patients with CVA it is important to have proof of improvement, to respond to how the user changes. Patients with CVA are group of people that are very grateful. According to the sales representative of Van Raam, lack of balance, coordination, strength, and endurance are the most common difficulties of patients with CVA.

The smart electric tricycle of this project (the Easy rider) is the most sold bicycle of Van Raam. Mainly because the sense of balance is the best, more support (in the back, on the seat, etc.), and steering takes a little less strength. The sales representative also believes that the current mobile app of Van Raam has not that much of an added value, make sure that it helps the user.

A2. Conversation with software developer

From the conversation with the software developer a few things emerged. The current mobile application is more of a means for the company to collect their own data. For example, to get information about the state of the battery. The company is also thinking about to add a sensor to collect data about the tire pressure. In the mobile application users can also see information about travelled distance and current speed for example.

Appendix B. Arduino code

```
//Including liberies
#include <LiquidCrystal.h>
#include <HX711_ADC.h>
#include <EEPROM.h>
#include <Adafruit_NeoPixel.h>
#include <SPI.h>
#include <SD.h>
int baudRate = 9600;

//pinbezetting
#define inputHall_Sensor A0
#define HX711_dout 10 //mcu > HX711 dout pin
#define HX711_sck 5 //mcu > HX711 sck pin
#define forcePin A1
#define LEDpin 3
#define knopPin 7
const int chipSelect = 4;

int outputHallSensor; // om de output ergens naar toe te lijden
misschien niet nodig
int valueHallSensorAnalog;
const int calVal_eepromAdress = 0;
long t;
int i = 0;
int adc_key_in;
#define LED_COUNT 12
int knopStatus = 0; // Een variabele voor de status van de
schakelaar of knop.
int meetingAan = 0;
int forceValue; //save analog value
int vlaggetjeForce = 0;
int ikBenErBoven = 0;
int forceSmoothnessRating;
unsigned long tijd = 0;
unsigned long tijdForce = 0;
unsigned long lastMillis = 0;
float loadcellValue;
int ikBenErBovenHallSensor = 0;
int vlaggetjeHall = 0;
int hallSmoothnessRating;


//Constructors
HX711_ADC LoadCell(HX711_dout, HX711_sck);
Adafruit_NeoPixel strip(LED_COUNT, LEDpin, NEO_RGBW + NEO_KHZ800);


//-----------------------------------------------------------------
-
```

```
void setup() {
  // put your setup code here, to run once:
  Serial.begin(baudRate);
  setupHallSensor();
  setupLedRing();
  setupKnopje();
  calibrationLoadCell();
  setupData();
  ledRingDuringSetup(strip.Color(0, 255, 0), 50); // Red
  ledRingDuringSetup(strip.Color(0, 0, 255), 50); // Green
}

//-----------------------------------------------------------------

void loop() {
  knopStatus = digitalRead(knopPin); // Lees de status van de
shakelaar of knop.

  if (knopStatus == HIGH) { // Als de ingang hoog is ( knop
ingedrukt ):
    //    digitalWrite(ledPin, HIGH); // Zet de LED aan.
    if (meetingAan == 0) {
      meetingAan = 1;
      ledRingDuringSetup(strip.Color(0, 0, 0), 50); // bxlue
      tijd = millis();
      tijdForce = millis();
    }
    else {
      meetingAan = 0;
      ledRingDuringSetup(strip.Color(0, 255, 0), 50); // Green
    }
  }
  if (meetingAan == 1) {
    Serial.print(millis());
    Serial.print("\t");
    hallSensorAnalog();
    loadCell();
    flexiForce();
    writeData();
  }
}

//-----------------------------------------------------------------
------

void hallSensorDigital() {
  if (digitalRead(inputHall_Sensor) == HIGH) {
    digitalWrite(13, HIGH);
  }
  else {
    digitalWrite(13, LOW);
  }
}
```

```
int hallSensorAnalog() {
  valueHallSensorAnalog = analogRead(inputHall_Sensor);
  if ((tijd + 5000) > millis()) {
    if (ikBenErBovenHallSensor == 0) {
      if (valueHallSensorAnalog >= 150) {
        vlaggetjeHall = vlaggetjeHall + 1;
        ikBenErBovenHallSensor = 1;
      }
    }
    else {
      if (valueHallSensorAnalog < 150) {
        ikBenErBovenHallSensor = 0;
      }
    }
  }
  else   {
    hallSmoothnessRating = vlaggetjeHall;
    vlaggetjeHall = 0;
    tijd = millis();
    Serial.print("Indicator smoothness steering:        ");
    Serial.println(hallSmoothnessRating);
  }
}
void loadCell() {
  static boolean newDataReady = 0;
  const int serialPrintInterval = 0; //increase value to slow down
serial print activity

  // check for new data/start next conversion:
  if (LoadCell.update()) newDataReady = true;

  // get smoothed value from the dataset:
  if (newDataReady) {
    if (millis() > t + serialPrintInterval) {
      float loadcellValue = LoadCell.getData();
      Serial.print("Load_cell output val: ");
      Serial.print(loadcellValue);
      Serial.println("                ");
      newDataReady = 0;
      t = millis();
    }
    else {
      Serial.print("Load_cell output val: ");
      Serial.print("none" );
      Serial.print("                ");
    }
  }

  // receive command from serial terminal, send 't' to initiate
tare operation:
  if (Serial.available() > 0) {
    float i;
```

```
    char inByte = Serial.read();
    if (inByte == 't') LoadCell.tareNoDelay();
  }

  // check if last tare operation is complete:
  if (LoadCell.getTareStatus() == true) {
    Serial.println("Tare complete");
  }
}

void ledRingDuringSetup(uint32_t c, uint8_t wait) {
  for (uint16_t i = 0; i < strip.numPixels(); i++) {
    strip.setPixelColor(i, c);
    strip.show();
    delay(wait);
  }
}
void ledRingForce(uint32_t c, uint8_t wait) {
  for (uint16_t i = 0; i < forceValue / 100 + 1; i++) {
    Serial.println("forceValue:     ");
    Serial.println(forceValue);
    strip.setPixelColor(i, c);
    strip.show();
    delay(wait);
  }
  for (uint16_t i = forceValue / 100 + 1; i < strip.numPixels();
i++) {
    strip.setPixelColor(i, 0, 0, 0);
  }
}

void flexiForce () {
  forceValue = analogRead(forcePin);       //Was forcePin!!!! Read
and save analog value from potentiometer
  if ((tijdForce + 3000) > millis()) {
    if (ikBenErBoven == 0) {
      if (forceValue >= 500) {
        vlaggetjeForce = vlaggetjeForce + 1;
        ikBenErBoven = 1;
      }
    }
    else {
      if (forceValue < 500) {
        ikBenErBoven = 0;
      }
    }
  }
  else   {
    forceSmoothnessRating = vlaggetjeForce;
    vlaggetjeForce = 0;
    tijdForce = millis();
    Serial.print("Indicator smoothness braking (flexi):        ");
    Serial.println(forceSmoothnessRating);
```

```
  }
  ledRingForce(strip.Color(200, 255, 0), 50); // Green
}

void writeData() {
  // make a string for assembling the data to log:
  String dataString = "";

  // read three sensors and append to the string:
  for (int analogPin = 0; analogPin < 2; analogPin++) {
    int sensor = analogRead(analogPin);
    dataString += String(sensor);
    if (analogPin < 2) {
      dataString += ",";
    }
  }
  int brakeSensorIndicator = forceSmoothnessRating;
  Serial.println(forceSmoothnessRating);
  dataString += String(brakeSensorIndicator);
  dataString += ",";
  int steeringSensorIndicator = hallSmoothnessRating;
  dataString += String(steeringSensorIndicator);

  // open the file. note that only one file can be open at a time,
  // so you have to close this one before opening another.
  File dataFile = SD.open("test0925.txt", FILE_WRITE);

  // if the file is available, write to it:
  if (dataFile) {
    dataFile.println(dataString);
    dataFile.close();
    // print to the serial port too:
    Serial.println(dataString);
  }
  // if the file isn't open, pop up an error:
  else {
    Serial.println("error opening datalog.txt");
  }
}

//-----------------------------------------------------------------
------

void setupHallSensor() {
  pinMode(outputHallSensor, OUTPUT); //TODO: Even kijken of dit
nodig is
  pinMode(inputHall_Sensor, INPUT);
}

void calibrationLoadCell() {
  LoadCell.begin();
  float calibrationValue; // calibration value (see example file
"Calibration.ino")
```

```
  calibrationValue = 696.0; // uncomment this if you want to set
the calibration value in the sketch

  long stabilizingtime = 2000; // preciscion right after power-up
can be improved by adding a few seconds of stabilizing time
  boolean _tare = true; //set this to false if you don't want tare
to be performed in the next step
  LoadCell.start(stabilizingtime, _tare);
  if (LoadCell.getTareTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 wiring and pin
designations");
    while (1);
  }
  else {
    LoadCell.setCalFactor(calibrationValue); // set calibration
value (float)
  }
}

void setupLedRing() {
  strip.begin();           // INITIALIZE NeoPixel strip object
(REQUIRED)
  strip.show();            // Turn OFF all pixels ASAP
  strip.setBrightness(50); // Set BRIGHTNESS to about 1/5 (max =
255)

}

void setupKnopje() {
  //  pinMode(ledPin, OUTPUT); // De LED Pin is een uitgang.
  pinMode(knopPin, INPUT); // De knop Pin is een ingang.

}

void setupData() {
  // Open serial communications and wait for port to open:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB
port only
  }


  Serial.print("Initializing SD card...");

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    while (1);
  }
  Serial.println("card initialized.");
}
```

Appendix C. Informed consent form

Ptcpt no.

INFORMED CONSENT

Research
This research is for a bachelor thesis of the study Creative Technology at the University of Twente. This research focuses on monitoring improvement in health condition of patients with CVA with the use of a smart electric tricycle.

Hoofdonderzoekers:
Lotte Lukassen, Roos Bulthuis and Monique Tabak

Contact information
For questions about the research you can contact Lotte Lukassen (c.m.a.lukassen@student.utwente.nl). If you have other questions you can contact the Ethical Committee (ethics-comm-ewi@utwente.nl) . This committee consists of independent experts of the university and is available for questions and complaints.

Research:

☐ I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

☐ I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

☐ I give permission for gathering anonymous data that I provide via this questionnaire for this research and understand that my anonymous data can be used for publication.

Date:

Name: Signature:

………………………………………………………………………….…….
…………………………………………………………………………

The extra copy of this consent form is for you to keep.

Appendix D. Interview Occupational therapist

Denkt u dat dit sensor systeem potentie heeft?
Ik zal er wel heel nieuwsgierig naar zijn moet ik je heel eerlijk zeggen. Ik vind het wel lastig om te zeggen of het ook daadwerkelijk potentie heeft, ik denk het haast wel. Omdat je natuurlijk inderdaad vaak merkt als mensen vermoeid raken, zowel fysiek als mentale vermoeidheid, dat ze dan meer gaan slingeren, met name bij het nemen van bochtjes (afslag nemen en weer terug vinden van positie op de weg bij links of rechts afslaan). En waar ik zelf, naar aanleiding van jouw uitnodiging, aan zat te denken en wat ik zelf ook merk is dat als mensen het heel spannend vinden om te fietsen dat ze steeds harder in te handvatten gaan knijpen. En als je dat doet, krijg je natuurlijk een hele vaste/gesloten cirkel tussen handen, fiets romp en dergelijke waarddoor het sturen veel moeilijker en krampachtiger wordt en waardoor mensen ook minder de mogelijkheid hebben het hoofd te draaien en dus verkeersdeelname lastiger wordt. Dus druk in het handvat zou wellicht ook een indicator kunnen zijn: zit ik op het zadel of hang ik meer op het stuur.

Voor mijn project heb ik door verschillende redenen gekozen om een paar indicatoren te pakken en te meten. Als dit sensor systeem verder ontwikkelt zou worden, zouden er dan meer indicatoren gemeten moeten worden?
Ik denk niet dat meer indicatoren beter is. Ik denk dat inderdaad van stabiliteit van het fietsen wat je met het sturen doet en het al dan niet voortdurend of kortdurend snel en abrupt remmen goed is. Iets wat me nu te binnen schiet, zou je het remgedrag wat je nu meet in relatie kunnen brengen met de snelheid die mensen maken. Sommige mensen maken heel veel snelheid en laten zich dan meer uitrijden. Sommige mensen die moe worden of als het te druk wordt in het verkeer, vergeten ze te trappen omdat alle aandacht naar het verkeer gaat. Maar dat is meer mijn nieuwsgierigheid dat ik door jouw vragen denk, hoe zal dat werken en geeft dat misschien meer informatie?

Als u kijkt naar het rem- en stuurgedrag, waar let u op tijdens een therapeutische sessie met CVA patiënten?
Ik let vooral op het stuurgedrag. En dan vooral blijven de CVA patiënten recht rijden op de weg en vooral ook als ze rechts afgeslagen zijn dan is het relatief makkelijk om rechts weer op te weg te komen, maar bij links afslaan is het voor sommige mensen lastiger op weer de juiste positie op de weg te vinden. Zeker met de driewieler merk je dat vaak dat ze dan eerder in het midden van de weg blijven rijden. Het slingeren kan dan een effect zijn. En, wat wel altijd lastig te meten is, hoeveel prikkels er voor mensen opkomen en hoe ze dus al die informatie uit het verkeer kunnen opnemen. Daar merk je ook altijd iets in terug met aandacht hebben voor de positie op de weg, aandacht voor het slingeren. Dat is dus meestal een oorzaak gevolg. Maar cognitieve vermoeidheid is wel heel moeilijk te meten.

De informatie die nu wordt gemeten is vooral bedoeld voor de CVA patiënt zelf. Zou u tijdens sessie ook wat kunnen hebben aan deze informatie?
Dat zou kunnen. Op dit moment zijn we vanuit de ergotherapie als iemand zelfstandig fietst, dan hebben we daar eigenlijk niet zo veel aandacht meer voor. Dan hebben we vrij gegeven dat iemand zelfstandig kan fietsen in het verkeer. Dus dan hebben wij er niet zo veel aandacht meer voor. Ik zou me wel kunnen voorstellen dat dat misschien in oefensessie gebruikt kunnen worden, omdat heel veel mensen zich helemaal niet bewust zijn van hoeveel ze slingeren of heeft dat effect op als ze langer fietsen en dus vermoeider raken dat ze dan meer of minder gaan slingeren of positie op de weg minder wordt. Het kan mensen inderdaad inzicht geven, daar kan ik me wel iets bij voorstellen. Maar als het cognitief goed gaat dan geven wij het vrij en dan hebben we er eigenlijk niet zoveel aandacht meer op. Maar dat zijn altijd dingen als je niet weet dat het er is of je het wel of niet gaat gebruiken.

Voor het stuurgedrag meet ik nu vooral of iemand rechtdoor fietst of dat iemand slingert. Zou het een goede toevoeging zijn om ook te kunnen meten hoe of klein groot iemand een bocht maakt, met andere woorden hoe groot is de uitslag van de hoek van het sturen?
Ja dat denk ik wel. Dan kan je zeggen hoever wijkt iemand af van de normale positie van de weg. Iemand kan een hele brede bocht maken, maar heel snel terug zijn op de rechterkant de weg. Iemand kan ook een hele ruime bocht maken maar aan de verkeerde kant van de weg blijven rijden. Dat is wel mooi als je dat visueel kan maken, zodat de mensen kunnen zien wat ze doen. Omdat mensen het vaak niet in de gaten hebben dat ze het doen. In onze fase als we hier met een driewieler leren fietsen dan moeten ze ook echt gaan wennen aan het rijgedrag van zo’n driewieler in vergelijking met een tweewieler.

Mijn focus is nu vooral op CVA patiënten. Heeft u ook te maken met andere doelgroepen waar dit systeem ook zal kunnen toegepast worden?
Ik werk zelf eigenlijk ook alleen met CVA patiënten of mensen met een andere vorm van hersenletsel dus daar zit ook mijn denk trend in. Maar ja waarom niet. Tuurlijk kan het voor iedereen zichtbaarheid in hun rijgedrag is helpen denk ik. Alleen de vraag is soms is dat zinvol. Als je die tellertjes hebt op de fiets, vraag ik me altijd af hoe zinvol is het? Meestal gebruiken ze alleen de snelheid of de afstand. En al de andere dingen die erop zitten worden vaak niet gebruikt. Dus wat kan de toegevoegde waarde zijn. En ik denk zeker als iemand kan fietsen, denk ik dat ze dat niet zo belangrijk vinden. Het gaat mensen om dat ze weer kunnen fietsen en dan zijn ze tevreden. Hoeveel moet er extra bij komen wat mensen gaan gebruiken of niet. Er zullen altijd mensen zijn die dat hartstikke leuk vinden, maar ja leuk is dat genoeg om dat verder te ontwikkelen en verder te implementeren.

Appendix E. Interview Lab administrator and biomedical engineer

Wie bent u en wat doet u bij Roessingh Research and Development?
Ik heb een achtergrond in de elektrotechniek en ben momenteel laboratorium beheerder en biomedisch engineer bij RRD. Dat betekent dat ik deels laboratorium beheerder ben en deels aan projecten werk. Als laboratorium beheerder ben ik vooral verantwoordelijk voor de veiligheid en inzetbaarheid van meetapparatuur en de meetruimtes en dergelijke.

Ik heb voor mijn prototype Arduino als systeem gebruikt. Heeft u daar ervaring mee en wordt dat vaker gebruikt bij RRD?
Ja wel, ik heb er wat ervaring mee. En er zijn ook wel wat andere projecten waarbij Arduino was gebruikt.

Als dit systeem verder ontwikkelt zou worden wat voor platform/systeem zou u aanraden te gebruiken?
Dan zou ik eerst een stap terug nemen, is de sensor oplossing die ik nu heb is dat de oplossing of zou je naar een andere configuratie gaan. Ik zou sowieso voor een embedded oplossing gaan. Maar het hangt ervan af wat je verder met de data wil. Wil je de data gaan presenteren? Wil je het op een gegeven moment doorsturen naar elders? Wil je het nog combineren met andere data? Dat heeft behoorlijk wat consequenties op wat voor platform je wil gebruiken. Je moet ook rekening houden met wat denk je dat de markt is (hoeveelheid devices).

Kijkend naar het remgedrag heb ik 2 sensors getest. Wat zijn volgens u verbeterpunten op deze sensors?
Het hangt af van hoeveel aanpassingen je moet doen aan de fiets om sensoren er tegen aan te zetten. Voor de load cell sensor moest inderdaad wel wat aanpassingen gedaan worden aan de rem. De pressure sensor is wat makkelijker, die plak je ergens aan en dan meet je wel wat. Die heeft weer als nadeel dat die soms niet altijd lineair is. Die je nu had, heeft een wat kleine pick-up area, maar dat zou makkelijke vergroot kunnen worden door een strip.

En een sensor in de remkabel of remsysteem zelf, wat denkt u daarvan als doorontwikkeling van dit idee?
Meestal zijn zulke sensors duurder. En als je kijkt naar veiligheid moeten ze de kracht die door de remkabel gaat wel aan kunnen. Dan is ook de vraag hoe groot moet dat ding uitgevoerd worden en wat voor problemen ga je dan tegenaan lopen. Dus hier zitten ook nog wel haken en ogen aan. Want dan zou je waarschijnlijk dichter bij de rem zelf meten in plaats van bij het stuur en dan krijg je te maken met andere dingen.

Nog meer dan dat je bij andere sensoren krijgt. Een andere methode zou wellicht nog kunnen zijn om rekstroken direct op de remhendel te plaatsen. Misschien dat je daar ook goede informatie zou kunnen halen. Maar ook die hebben weer allerlei nadelen. Waar je ook naar moet kijken is, is dit de enige remoptie die op dit soort fietsen beschikbaar is? Van Raam heeft natuurlijk meerdere aangepaste fietsen. Zijn die allemaal met handremmen of zijn er nog andere opties? Misschien hebben ze ook nog andere systemen.

Kunt u dat verder uitleggen?
Misschien hebben ze niet de standaard remhendels maar dat je naar andere reconstructies kijkt waarbij iemand wel kracht kan uitoefenen, maar niet per se op de normale manier. Misschien zou er ook wel een remkracht versterker kunnen worden aangebracht om CVA patiënten te helpen met remmen.

Verder heb ik ook een stuursensor op basis van magnetisme. Deze kon goed meten of iemand rechtdoor fietste of dat iemand aan het slingeren was. Eigenlijk had ik ook gewild dat het kon meten hoe groot de uitslag hoek was van het stuur. Heeft u hier nog suggesties of tips voor?
Misschien is een gyroscoop of accelerometer een optie. Een gyroscoop is een hoeksnelheidsmeter. Hiermee zou je de verandering in stuurhoek kunnen bepalen. Door hem te integreren zou je tijdelijk de stuurstand kunnen afmeten. Andere optie is misschien ook een encoder. Stel je wilt ook de hele oriëntatie van de hele fiets, maar dat wordt lastiger. De optie waarmee je dat zou kunnen meten op lange termijn met GPS of op korte termijn met een magneet hoekmeter. Maar ook daar zitten nadelen aan.

Wilt u verder nog iets kwijt over het project?
Als je dit verder in ontwikkeling wil brengen, moet je kijken naar hoe verzend ik de data? Hoeveel kabels moet ik gebruiken? Hoe robuust is het systeem? Kijk naar het groter plaatjes dan alleen functionaliteit.

Appendix F. Interview software engineer at Van Raam

Wie bent u en wat doet u bij Van Raam?
Ik werk bij Van Raam als programmeur en ik ben projectleider van het EMBIPRO project.

Ziet u vanuit Van Raam gezien potentie in dit systeem?
Dat is lastig om te zeggen. We zijn met Roessingh al een tijdje bezig om te kijken wat kan je met de onze fiets in de revalidatie doen. En daar krijg je vaak te horen dat het erg moeilijk is omdat mensen niet een Van Raam fiets zelf hebben. Dus misschien wordt de doelgroep van het systeem wat klein als iemand CVA patiënt moet zijn in revalidatie moet zijn en een Van Raam fiets moet hebben. Persoonlijk vind ik het wel heel interessant en heel mooi als we zoiets op de Van Raam fietsen zouden kunnen aanbieden aan klanten. We hebben het er ook wel vaker over gehad, het zou erg mooi zijn als je feedback kan geven zoals pas op je gaat nu te veel doen. Of in dit geval, we zien dat je goed bezig bent met herstellen, blijf zo doorgaan. Dat zou mooi zijn.

De data die ik verzamel met mijn sensors zouden uiteindelijk moeten worden doorgestuurd naar de Van Raam app. Zodat patiënten in de Van Raam app gegevens over hun vooruitgang kunnen zien. Is dit handig voor de patiënt om dat in de Van Raam app te doen?
De Van Raam app is wel het communicatiemiddel naar de klant toe. We hebben ook e-mail adressen. Dus via die adressen zou je ook een rapport kunnen sturen om te zoveel tijd. En je zou ook nog een stap verder kunnen gaan door een web portaal te ontwikkelen. Maar dan is de vraag of dat gebruikt gaat worden. Tegenwoordig zijn mensen veelal op hun mobiel bezig dus dan is het net zo makkelijk of via de app de gegevens te laten zien. Zeker omdat er ook andere gegevens die nu al worden gemeten ook in de app worden weergegeven.

Als het een optie is om tijdens het fietsen al een beetje feedback te geven, is dat iets wat interessant is of extra waarde heeft?
Ik merk zelf als ik met Strava fiets of iets van een app gebruik tijdens het sporten, dat je dan toch wat meer bezig bent met haal ik wel het optimale eruit zeg maar. Ik heb nu een paar keer naar het werk gefietst en dan vooral op de terugweg probeer ik toch een bepaald gemiddelde snelheid te halen. Er zijn ook van de opties waarbij je medailles kunt winnen als je sneller bent dan de vorige keer, dat zijn ook leuke dingen om te stimuleren om toch even extra aan te zetten. En ik denk dat het bij mij werkt, dat het bij andere mensen ook wel werkt.

Stel dit systeem zouden worden door ontwikkelt, zou Van Raam dit zelf in de fiets verwerken tijdens de productie?
Ja we hebben een eigen elektro-systeem, dus daar zouden we de sensoren gewoon op aan kunnen sluiten dat je ook makkelijk de date naar de app kan verzenden en ook van de app naar de Van Raam cloud kan zenden.

Kijkend naar hoe welke sensoren ik nu voor het prototype gebruik heb, heeft u daar nog suggesties voor?
We hebben zelf in ons systeem een accelerometer die het een en ander zou kunnen detecteren, maar ik weet niet hoe nauwkeurig die is. Daar zijn we ook nog mee bezig. Maar daarmee is het de bedoeling om ooit iets mee te doen. Daar zou je stuurgedrag mee kunnen meten. Je kan bijvoorbeeld zien of iemand links of rechts stuurt maar of je ook kan zien hoe groot de hoek/slingering is, weet ik niet. Maar als je dat zou kunnen gebruiken voor het stuurgedrag, zou dat een mooie integratie zijn.

Zijn jullie toevallig ook al bezig of ooit naar gekeken voor sensors die het remgedrag kunnen meten?
Niet echt. Ik weet dat we in het verleden ooit bezig zijn met sensors die als remdetector werken. Dus als je de rem indrukt dat meteen de ondersteuning stopte. Maar dat was meer een aan/uit schakelaar. Maar dan zijn we ook snel van afgestapt omdat er veel vocht problemen waren. Dus nu kijken we naar als je stopt met trappen, dan stopt de ondersteuning. Wat ook vrij logisch is. Maar de optie die jij geeft zoals die druk strook, zouden goed weg te kunnen werken in de rem zelf.
Misschien zou je een accelerometer kunnen gebruiken, maar dan heb je niet echt het remgedrag van de hand zelf. Bijvoorbeeld als je tegen een stoep aan botst, dan heb je ook een hakkelig remgedrag.

Appendix G. Questionnaire user testing

Graduation project Lotte Lukassen

Vragenlijst voor de evaluatie fase voor de afstudeeropdracht van Lotte Lukassen
Questionnaire for the evaluation phase of the graduation project of Lotte Lukassen
* Required

Graduation project

Beste deelnemer,

Van Raam en Roessingh Research & Development (RRD) werken samen aan het EMBIPRO-project. Binnen het EMBIPRO-project willen RRD en Van Raam een slimme elektrische driewieler (e-trike) ontwikkelen. De slimme elektrische driewieler kan bijdragen aan revalidatie omdat het CVA-patiënten de mogelijkheid biedt om thuis fysiek actief te zijn. Maar de uitdaging hier is dat het met de sensoren die op dit moment op de fiets zijn, moeilijk is om een volledig beeld te geven van het fietsgedrag van de patiënt en om te meten en te controleren of de CVA patiënt (beroerte) zichzelf heeft verbeterd in tijdens of na revalidatie. Daarom is het doel van dit onderzoek om te controleren of de CVA-patiënt zijn gezondheidstoestand heeft verbeterd in vergelijking met voorgaande keren door het sensor gedeelte van de slimme elektrische driewieler uit te breiden.

Als onderdeel van de evaluatiefase van dit onderzoek wil ik evalueren of de data die worden gemeten met de sensoren en de weergave van feedback zinvol is. Ik vraag u vriendelijk om mij hierbij te helpen door de vragenlijst in te vullen. Dit duurt maximaal 10/15 minuten. Bij voorbaat dank!

Voor vragen over dit onderzoek kun je contact opnemen met Lotte Lukassen, derdejaars bachelor student Creative Technology aan de Universiteit Twente via Voor overige vragen kunt u contact opnemen met de Ethische Commissie (ethics-comm-ewi@utwente.nl). Deze commissie bestaat uit onafhankelijke experts van de universiteit en is beschikbaar voor vragen en klachten. Deze vragenlijst is verder in het Engels, mocht u hier probleem mee ondervinden, neem dan ook contact op met Lotte Lukassen.

Dear participant,

Van Raam and Roessingh Research & Development (RRD) are working together on the EMBIPRO project. Within the EMBIPRO project, RRD and Van Raam aim to develop a smart electric tricycle (e-trike). The smart electric tricycle can contribute to rehabilitation because it offers the opportunity for CVA patients to be physically active at home. But the challenge here is that with the sensors that are on the cycle at this moment, it is hard to give a complete picture of the patients' cycling behavior and to sense and check whether the stroke patient has improved himself compared to previous times during or after rehabilitation. Therefore, the aim of this thesis is to monitor whether the CVA patient has improved his health condition compared to previous times by extending the sensing part of the smart electric tricycle.

As part of the evaluation phase of this research, I want to evaluate whether or not the data that is measured with the sensors and the representation of feedback makes sense. I kindly ask you to help me with this by filling in the questionnaire. This takes a maximum of 10/15 minutes of your time. Thanks in advance!

If you have any questions about this research, please contact Lotte Lukassen, third year student of the bachelor program Creative Technology at the University of Twente at
If you have other questions you can contact the Ethical Committee (ethics-comm-ewi@utwente.nl) . This committee consists of independent experts of the university and is available for questions and complaints.

1. Consent form *

   In order to fill in the questionnaire you need to give consent to the following statement:

   Check all that apply.

   - [ ] I have read and understood the study information. I have been able to ask questions about the study and my questions have been answered to my satisfaction.
   - [ ] I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.
   - [ ] I give permission for gathering anonymous data that I provide via this questionnaire for this research and understand that my anonymous data can be used for publication.

Demographic questions

2. What is your age? *

   ____

3. What is your gender? *

   Mark only one oval.

   - ( ) Female
   - ( ) Male
   - ( ) Prefer not to say
   - ( ) Other: ________________

4. What is the highest level of education that you completed? *

   Mark only one oval.

   - ( ) Less than high school degree
   - ( ) High school degree
   - ( ) MBO
   - ( ) HBO bachelor
   - ( ) HBO master
   - ( ) WO bachelor
   - ( ) WO master
   - ( ) Other: ________________

System startup

For this project a prototype was made which consist of two sensor which measure braking and steering behavior. The sensor system first needs to setup and calibrate. This is visualized with a red LED ring. Ones the system is ready with the setup, the LED ring will turn blue and the measurements can turned on by pressing the button.

Video system startup


http://youtube.com/watch?v=YlsglHa_6QE

5. Is the setup visualization clear? *

Mark only one oval.

	1	2	3	4	5	
Very unclear	◯	◯	◯	◯	◯	Very clear

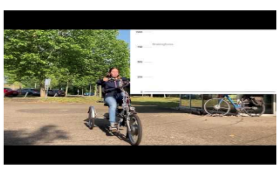
6. Why do you think so? *

____
____
____
____
____

Measurement braking

One sensor can measure the braking behavior. With this sensor it is possible to measure the braking force and determine the smoothness of braking. These data will be send to the mobile app of Van Raam. The measured data can be visualized in graphs such that CVA patients easily can see how the bike ride went. In the video below you see two situations with their corresponding data of the braking force. One where the braking went smooth and one where the braking went jerky.

Video measuring braking


http://youtube.com/watch?v=HWKL6GqZ8lk

7. Was it clear what the differences in graphs were and why? *

Mark only one oval.

	1	2	3	4	5	
Very unclear	◯	◯	◯	◯	◯	Very clear

8. Explanation: *

____
____
____
____
____

9. Do you think that this information about the braking behavior provides insight in cycling performance? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Other: ______________________

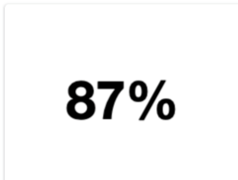
10. Why do you think so? *

____

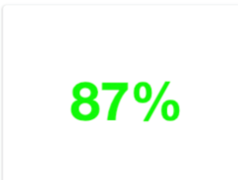
11. If the smoothness of braking of a bike ride will be fed back to the CVA patients in the mobile app afterwards, which way do you prefer to give feedback? *

Mark only one oval.

( ) Categories



( ) Percentage without color



( ) Percentage with color for categorization

( ) Number of indicator average

12. Why do you think so? *

____

Measuring steering

The other sensor can measure the steering behavior. It can determine if someone cycles straight or cycles swinging. In the video below two situations are presented with their data. The height of the graph does not matter in this case. The first situation is where the cyclist cycles straight ahead, which results in a signal constantly zero. Situation 2 is where the cyclist cycles swinging.

Video measuring steering behavior

http://youtube.com/watch?v=PVylP3ZDMHM

13. Was it clear what the differences in graphs were and why? *

Mark only one oval.

	1	2	3	4	5	
Very unclear	◯	◯	◯	◯	◯	Very clear

14. Why do you think so? *

15. Do you think that this information about steering behavior provides insight in cycling performance? *

Mark only one oval.

◯ Yes
◯ No
◯ Other:

References

[1] Australian Government, "Physical activity - it's important," 2018. https://www.betterhealth.vic.gov.au/health/healthyliving/physical-activity-its-important (accessed Mar. 12, 2020).

[2] Rijksinstituut voor Volksgezondheid en Milieu (RIVM), "Aanbod bevorderen van sport en bewegen," 2019. https://www.volksgezondheidenzorg.info/onderwerp/bewegen/preventie-zorg/preventie#node-aanbod-bevorderen-van-sport-en-bewegen (accessed Mar. 12, 2020).

[3] D. H. Saunders *et al.*, "Physical fitness training for stroke patients," *Cochrane database Syst. Rev.*, vol. 3, p. CD003316, 2020, doi: 10.1002/14651858.CD003316.pub7.

[4] A. C. Smith, D. H. Saunders, and G. Mead, "Cardiorespiratory fitness after stroke: A systematic review," *Int. J. Stroke*, vol. 7, no. 6, pp. 499–510, 2012, doi: 10.1111/j.1747-4949.2012.00791.x.

[5] Rijksinstituut voor Volksgezondheid en Milieu (RIVM), "Prevalentie en nieuwe gevallen beroerte in huisartsenpraktijk," 2019. https://www.volksgezondheidenzorg.info/onderwerp/beroerte/cijfers-context/huidige-situatie#node-prevalentie-en-nieuwe-gevallen-beroerte-huisartsenpraktijk %0A%0A (accessed Mar. 29, 2020).

[6] Van Raam, "Easy Rider driewielfiets." https://www.vanraam.com/nl-nl (accessed Apr. 25, 2020).

[7] K. A. Hicks *et al.*, "2017 Cardiovascular and Stroke Endpoint Definitions for Clinical Trials," *Circulation*, vol. 137, no. 9, pp. 961–972, 2018, doi: 10.1161/CIRCULATIONAHA.117.033502.

[8] W. Ji, J. Wang, X. Fang, and S. Gu, "An evaluation model of stroke rehabilitation," *Lect. Notes Electr. Eng.*, vol. 216 LNEE, no. VOL. 1, pp. 213–220, 2013, doi: 10.1007/978-1-4471-4856-2_27.

[9] P. Mirza-Babaei, M. Kamkarhaghighi, F. Da Rocha Tome Filho, and K. Gerling, "Opportunities in game-based stroke rehabilitation," *Conf. Proc. - 2014 IEEE Games, Media, Entertain. Conf. IEEE GEM 2014*, pp. 7–10, 2015, doi: 10.1109/GEM.2014.7118436.

[10] L. Pothiban and C. Srirat, "Association between stroke knowledge, stroke awareness, and preventive behaviors among older people: A cross-sectional study," *Nurs. Heal. Sci.*, vol. 21, no. 3, pp. 399–405, 2019, doi: 10.1111/nhs.12614.

[11] T. M. Smith, M. R. Pappadis, S. Krishnan, and T. A. Reistetter, "Stroke survivor and caregiver perspectives on post-stroke visual concerns and long-term consequences," *Behav. Neurol.*, vol. 2018, 2018, doi: 10.1155/2018/1463429.

[12] T. K. Tatemichi, D. W. Desmond, Y. Stern, M. Paik, M. Sano, and E. Bagiella, "Cognitive impairment after stroke: Frequency, patterns, and relationship to functional abilities," *J. Neurol. Neurosurg. Psychiatry*, vol. 57, no. 2, pp. 202–207, 1994, doi: 10.1136/jnnp.57.2.202.

[13] M. Leśniak, T. Bak, W. Czepiel, J. Seniów, and A. Członkowska, "Frequency and prognostic value of cognitive disorders in stroke patients," *Dement. Geriatr. Cogn. Disord.*, vol. 26, no. 4, pp. 356–363, 2008, doi:

10.1159/000162262.
[14] C. van Heugten, S. Rasquin, I. Winkens, G. Beusmans, and F. Verhey, “Checklist for cognitive and emotional consequences following stroke (CLCE-24): Development, usability and quality of the self-report version,” *Clin. Neurol. Neurosurg.*, vol. 109, no. 3, pp. 257–262, 2007, doi: 10.1016/j.clineuro.2006.10.002.
[15] B. Caby, J. Stamatakis, P. Laloux, B. Macq, and Y. Vandermeeren, “Multi-modal movement reconstruction for stroke rehabilitation and performance assessment,” *J. Multimodal User Interfaces*, vol. 4, no. 3–4, pp. 119–127, 2011, doi: 10.1007/s12193-010-0056-y.
[16] S. Y. Lee, B. R. Kim, and E. Y. Han, “Association between evoked potentials and balance recovery in subacute hemiparetic stroke patients,” *Ann. Rehabil. Med.*, vol. 39, no. 3, pp. 451–461, 2015, doi: 10.5535/arm.2015.39.3.451.
[17] Mayo Clinic, “Stroke rehabilitation: What to expect as you recover,” 2019. https://www.mayoclinic.org/diseases-conditions/stroke/in-depth/stroke-rehabilitation/art-20045172# (accessed Apr. 10, 2020).
[18] C. L. Pollock, L. A. Boyd, M. A. Hunt, and S. J. Garland, “Use of the Challenge Point Framework to Guide Motor Learning of Stepping Reactions for Improved Balance Control in People With Stroke: A Case Series,” *Phys. Ther.*, vol. 94, no. 4, pp. 562–570, 2014, doi: 10.2522/ptj.20130046.
[19] P. S. Pohl and C. J. Winstein, “Practice effects on the less-affected upper extremity after stroke,” *Arch. Phys. Med. Rehabil.*, vol. 80, no. 6, pp. 668–675, 1999, doi: 10.1016/S0003-9993(99)90170-3.
[20] T. Sakurada, T. Nakajima, M. Morita, M. Hirai, and E. Watanabe, “Improved motor performance in patients with acute stroke using the optimal individual attentional strategy,” *Sci. Rep.*, vol. 7, no. January, pp. 1–10, 2017, doi: 10.1038/srep40592.
[21] University of Twente, “At long last - stroke patients can be monitored at home, using a sensor suit,” 2016. https://www.utwente.nl/en/news/2016/11/34208/at-long-last-stroke-patients-can-be-monitored-at-home-using-a-sensor-suit (accessed Apr. 11, 2020).
[22] Microsoft, “Stroke recovery gets a boost from Kinect,” 2014. https://www.microsoft.com/en-us/research/blog/stroke-recovery-gets-a-boost-from-kinect/ (accessed Mar. 12, 2020).
[23] G. D. Fulk and E. Sazonov, “Using sensors to measure activity in people with stroke,” *Top. Stroke Rehabil.*, vol. 18, no. 6, pp. 746–757, 2011, doi: 10.1310/tsr1806-746.
[24] Garmin, “VectorTM 3.” https://buy.garmin.com/en-US/US/p/573589.
[25] D. Rainmaker, “Zwift Demonstrates Mountain Biking & Steering at Eurobike,” 2019. https://www.dcrainmaker.com/2019/09/zwift-demonstrates-mountain-biking-steering-at-eurobike.html %0A.
[26] R. Marin-Perianu *et al.*, “A performance analysis of a wireless body-area network monitoring system for professional cycling,” *Pers. Ubiquitous Comput.*, vol. 17, no. 1, pp. 197–209, 2013, doi: 10.1007/s00779-011-0486-x.
[27] A. Mader and W. Eggink, “A design process for Creative Technology,” *Proc. 16th Int. Conf. Eng. Prod. Des. Educ. Des. Educ. Hum. Technol. Relations, E PDE 2014*, no. September, pp. 568–573, 2014.
[28] M. van der Bijl-Brouwer and M. va der Voort, “Exploring future use: scenario based design,” in *Advanced design methods for succesful innovation*, 2013, pp.

56–77.
[29] P. Achimugu, A. Selamat, R. Ibrahim, and M. N. R. Mahrin, “A systematic literature review of software requirements prioritization research,” *Inf. Softw. Technol.*, vol. 56, no. 6, pp. 568–585, 2014, doi: 10.1016/j.infsof.2014.02.001.
[30] Rijksoverheid, “Nederlandse maatregelen tegen het coronavirus,” 2020. https://www.rijksoverheid.nl/onderwerpen/coronavirus-covid-19/nederlandse-maatregelen-tegen-het-coronavirus (accessed Apr. 27, 2020).
[31] Z. Brugha, R. ; Varvasovszky, “Stakeholder analysis: a review,” *Health Policy Plan.*, vol. 15, no. 3, pp. 239–246, 2000, doi: 10.1093/heapol/15.3.239.
[32] L. Wattel and W. Achterberg, “UNO - COGToolkit - Cognitieve Meetinstrumenten voor de Ouderenzorg - Een practice based benadering.”
[33] E. M. J. Steultjens, E. H. C. Cup, J. Zajec, and S. Van Hees, “Ergotherapierichtlijn CVA,” pp. 66–76, 2013, [Online]. Available: www.reprorecht.nl.
[34] Stroke Association, “Visual problems after stroke,” *Stroke Assoc.*, pp. 1–10, 2010.
[35] Arduino, “Getting Started with Arduino products.” https://www.arduino.cc/en/Guide/HomePage (accessed Jun. 22, 2020).
[36] Nixternal, “Raspberry Pi Camera Case w/ NeoPixel Ring (12 LED),” 2017. https://www.thingiverse.com/thing:2189609 (accessed Jun. 04, 2020).
[37] E. Jansen and M. Magnee, “PowerTools EvaluatieSuite,” 2018.