How to design a wearable for coaching in rowing

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TABLE OF CONTENTS

1. SUMMARY OF THESIS

This report is about the development of a prototype of an electronic wearable for rowing: a product that is able to give feedback on the performance of the athlete in a live feedback system. The purpose is that it is able to measure a key factor of the rower's performance and give effective feedback to the athlete but also the coach. The resulting prototype is a system which uses force sensors at the feet and the hands which can measure accurately when the rower starts the stroke. The difference in time between the feet and hands is called the 'catch-factor', which is the factor that determines the accuracy of the body engagement and therefor the efficiency of the rower. This time in seconds is then given to the rower and coach in different feedback formats which suite them best to give an optimal experience. The assignment was crafted by Angelika Mader and Reint Dijkstra together as an bachelor thesis in the study study Creative Technology on the University of Twente.

2.1 INTRODUCTION

Rowing is a sport where success is achieved by covering a set distance in the shortest time. This time influenced by many factors, of which most can be physically explained. These factors influence the average boat speed and thus should form the basis for feedback to the rower. One of the big factors in rowing is the propulsion, which is created by the rower. This impulse creation needs to be as efficient as possible to create the most drive during the stroke. As stated by Kleshnev [21] the key to a powerful drive in rowing is an accurate application of power generated by the legs, trunk and arms. However, the optimal application of power may vary between athletes due to differences in there biomechanical features. To access the power application the coaches have varying tools to get feedback from, like rowing machines (RP3 [18], Concept 2 [23]) and pressure sensors for the oarpin (NK Empower[22]).

FIGURE 1 RP3 ROWING MACHINE

2.1.1 ROWING INTRO

Rowing is a sport where the athlete sits in the boat facing toward the stern, and uses the oars which are held in place by the oarlocks to propel the boat forward (towards the bow). This may be done on a canal, river, lake, sea, or other large bodies of water. The sport requires strong core balance, physical strength, flexibility, and cardiovascular endurance.

Whilst the action of rowing and equipment used remains fairly consistent throughout the world, there are many different types of competition. These include endurance races, time trials, stake racing, bumps racing, and the side-by-side format used in the Olympic games. The standard distance for rowing is 2000 meters.

There are two forms of rowing:

- In ***sweep*** or *sweep-oar* rowing, each rower has one oar, held with both hands. This is generally done in pairs, fours, and eights. The rower is rowing on port or starboard, depending on which side of the boat the rower's oar extends to. Port is where the rower extends its oar to the rowers right and starboard is where the rower is extending its oar to the left.

- In ***sculling*** each rower has two oars (or *sculls*), one in each hand. Sculling is usually done without a coxswain, in quads, doubles or singles. The oar in the sculler's right hand extends to port, and the oar in the left hand extends to starboard.

FIGURE 2 SWEEP ROWING

FIGURE 3 SCULLING

Rowing is mostly done on the water, however they do use rowing machines on land for cardio training and power testing.

Rowing machines

Rowing machines can be divided into two categories: static and dynamic rowing machines.

Static rowing machines, as the Concept2 [23] ergometer, are machines where only the seat of the athlete moves up and down. This means that their feet are fixed to the device. This is not representative of rowing on water, while the feet are attached to the boat. The boat, and there for the feet, can move independent from the seat , which on the static rowing machine is not possible. This creates more strain on the athlete, because every time they start the drive they first have to catch their weight on the feet and redirect this energy.

Dynamic rowing machines, like the RP3 [18] are machines where the feet and the seat can move independent from each other, which therefor recreates the movement on the water more effectively.

Key factors

Key factors of rowing are: oar angle, stroke rate, power and efficiency. Oar angle is the factor which determines the drive and length of the stroke. A longer stroke length means more time to accelerate the boat which leads to a higher average boat speed. This however does not mean that a heavier/oar angle lever on the oar means a faster boat. This all depends on what is optimal for the crew. Power derives from the fitness of the athletes. Factors like the athletes height and lung capacity determine how much power it can produce for how long. Efficiency is determined by the precision of the rower. A higher level of precision means the boat is slowed down less which leads to a higher average boat speed. The boat is slowed down when the rower catches to slow, rushes on the recovery and when he/ she washes the blades out of the water.

Benefits

Rowing is one of the few non-weight bearing sports that uses all the major muscle groups, including quads, biceps, triceps, lats, glutes and abdominal muscles. The sport also improves cardiovascular endurance and muscular strength.

Terms

Some of the used terms in rowing are:

- Catch: the catch is the moment where the rower places the blade in the water and applies power to create propulsion.
- Drive: part of the stroke where the blades are under water and the rower is applying power to the water.
- Oarlock: Part of the rowing boat which keeps the oar in place. See figure 8.
- Slip: This reverse to the effective angles of the blade which moves in the water, as stated by Concept2[11]
- Wash: This is the term used when a rower lets the blade come out of the water while still driving. This means that the power which is generated is not being used effectively.

[1] http://www.concept2.com/oars/how-made-and-tested/blade-path

2.2 PROBLEM STATEMENT

Although rowing uses technology to its benefit, there are few technical solutions for giving feedback to the rower or the coach when it comes to body coordination of the rower during the rowing cycle. This coordination is still only accessed by visual inspection by the coach when on the water, or on land by camera systems [11]. This means that the rowing performance is still depended on the skill of the coach and is hard to make tangible or backup with data about this performance. This is why the goal of this project is to design and develop an electronic wearable which can be used for coaching in rowing.

2.2.1 THE RESEARCH QUESTIONS

The main research question that will be answered is:

'How to design a wearable for coaching in rowing? '

To answer this question, the following sub-questions will also be answered:

- *What are the technological standards for sport wearables?*
- *What are parameters for rowing?*
- *How to measure rowing activities?*
- *What are the requirements for a rowing wearable?*

To materialize the research questions a concept wearable system will be made.

3 ANALYSIS

3.1 RELATED WORK

Related work was studied in order to get a good view on the existing possibilities for rowing wearables and what has already been done.

3.1.1ROWING WEARABLES

Sport wearables that are interesting for this research can be divided in five parts. The first part is about rowing wearables.
Rowing wearables come in some variations, the first which will be discussed are heartrate monitors.

HEART-RATE MONITORS
The Polar [24] or Garmin [25] are 2 of the most used heart-rate monitors today. These devices are used to measure the heart-rate during training and are usually plotted against other variables like speed or time. These devices use various sensors, but mostly ECG sensors to pick up the heart rate. This data is interesting for rowers because it gives insight into their hear behaviour. Heartrate behaviour is different for every individual and shows the athlete at what intensity they are training. Athletes and coach want to know this data to determine if the athlete is training at the right intensity. This data also correlates to overtraining syndrome, according to Foster C. [31]. the data which the device measures is given to the athlete in a quantitative way and only on demand. This means that the wearable is not intended to be used to actively change the behaviour of the athlete during the performance. Though athletes sometimes do change they performance based on the information that the device gives. But because the device does not state if the performance of the athlete is good or bad it means that the change in behaviour is voluntarily.

FIGURE 4 POLAR M400 HEARTRATE WATCH WITH HEARTRATE SENSORS STRAP

Sensing leotard

The sensing leotard of Tesconi et al. [1] is one of only a few wearables which was created as a rowing wearable. It measures the angles of the knee and pelvis with the use of a custom designed stretch sensor. This sensor was woven into the garment so the wearable would be as ergonomic as possible. This wearable was designed as a part of a study, which means that it was made as a measuring device. This meant that the feedback that the rower, and the researchers, was given very minimalistic, namely as pure numbers. This means that the device is not yet implemented in a feedback system.
The data that this system provides is interesting because this data helps with understanding if the rower is using his body effectively or not. As stated by Kleshnev [21] and Biorow [17], for an efficient power application it is necessary that the rower is connected to the water. This can be derived from the body angles threw the drive phase, hence Tesconi et all [1] developed the system. However, it cannot measure other interesting data, like the how fast the connection is to the water.

FIGURE 5 SENSING LEOTARD FROM TESCONI ET AL[1]

Cosmed K5

The wearable metabolic system COSMED [12] is a wearable designed for measuring the oxygen intake of athletes in the environment in which they perform their matches. Usually these tests are done in a controlled environment like a lab, however this systems gives the opportunity to do them in their normal setting. The Cosmed K5 measures gas exchange either with micro- dynamic mixing chamber or breath by breath techniques. This gas exchange is interesting because it shows how fit the athlete is and can give an indication of how fast they could row. This device is interesting for this research because it revolves around getting insight into the training and the behaviour of the athlete and giving him/her live feedback about that insight.

FIGURE 6 COSMED K5 VO2 METER

3.1.3 Sport wearables

The second part is about sport wearables, where in there are many different varieties of wearables. These wearables are examined to look at how wearables are implemented and used in different sports. There will be looked at the form of the wearable, what data they are producing and how the data is used and what sensors they use.

Besides the before mentioned heartrate monitoring systems there are smart wearables which give athletes insight in their performance.

GPSports halfshirt

The GPSports half shirt [13] monitors athlete's performance and give real-time data to coaches. This data consists of the distance, speed, heartrate and impact load (measured in G-force). The data which is acquired is send to a computer on which the coach can analyse it and coach the athlete on the basis of this data. The device itself therefor does not give any feedback to the athlete directly.

FIGURE 7 GPSPORTS HALFSHIRT[13]

Samsung Smartsuit

The Smartsuit by Samsung [3] gives real-time data about body angles using accelerometers and gyroscopes. The gyroscopes determine the body angles of the athlete. When the athlete has bad posture it gives the athlete haptic feedback whilst the coach can also see the data on an app. This wearable is there for different because it has two types of feedback it can give.

FIGURE 8 SAMSUNG SMARTSUIT[3]

The Sensoglove [14] monitors the golf swing and corrects the athlete on their grip via audio and haptic feedback. The system works with pressure sensors which monitors the grip of the athlete. In golf it is important to have a loose grip because this results in an optimal swing and maximum shot distance.

FIGURE 9 SENSOGLOVE BY SENSOGLOVE

3.1.2 ROWING TECHNOLOGIES

The third part consists of the existing rowing technologies. The technologies which are made for rowing specifically can be divided between land and water technologies. Examples of technologies which are used on land are the ergometers such as the RP3 [18] and the Concept2 [23]. These devices monitor the power output of the rower and are used for conditioning training and performance testing.

NK EMPOWER OARLOCK

Devices which are used on the water come in many shapes and sizes and measure different aspects of rowing. The first example is the NK Empower Oarlock [22]. This device replaces a conventional oarlock and measures the oar angle, slip, wash and power.

The oar angle determines the length of the stroke. This is very useful to know because a longer stroke means a longer period of accelerating the boat and therefor a higher average speed.

The slip and wash determine what the connection of the blade to the water during the stroke. Slip happens at the catch when the blade comes in the water. An effective catch is performed when the compression of the water happens quickly, which result in less slip. A rower has more slip when the blade enters the water too slowly. To prevent this from happening the rower must catch quicker. This is done by having the oar square to the water and more closely.

Wash happens in the middle and the end of the stroke. This occurs when the connection of the blade to the water is lost due to inadequate blade depth. This can be prevented by burying the blade through the whole length of the stroke.

FIGURE 10 NK EMPOWER OARLOCK WITH OAR

FIGURE 11 NK OARLOCK

NK Speedcoach

The unit which is used together with the NK empower Oarlock [22] is the NK Speedcoach [22]. This device can measure the stroke-rate, distance and time. Besides this it can also display the measurements of the Empower oarlock.

The measurements which are done by the NK Speedcoach itself are also done by similar devices, like the Coxmate GPS [32]. These devices are most commonly used by rowers because the stroke-rate and speed are the most basic data a rower wants to have feedback on.

These devices use GPS location to determine the distance they have travelled. To determine the stroke-rate the devices usually use accelerometers. These measure the 'shock' which is created at the catch of the stroke. The interval between these shocks determines the stroke-rate of the rower.

FIGURE 12 NK SPEEDCOACH

NK COXBOX

The next devices which are used on the water are emplification devices like the NK Coxbox [22] or the Coxmate SX 10HZ GPS [32]. These devices are not used by the rowers itself but by the coxswains. These devices are used in conjunction with a microphone worn on the head of the coxswain to make him/her heard in the boat.

FIGURE 13 NK COXBOX

All these devices are used in the sport and are effective in what they are supposed to do. However, they all measure factors of the sport which derive from the actions which are done by the rower. None of the devices measure directly what the rower is doing. No aspect of the physical performance is measured.

3.1.4 SENSORS

The fourth part consists of the sensors used in wearables. We however concentrate on the sensors which are used for rowing wearables. There are three basic categories of sensors which are used for measuring in rowing: Gyroscopes and accelerometers [2], resistance sensors [7], [1] and body sensors like EMG sensors. Every sensor has its own qualities and purposes. Gyroscopes and accelerometers can be used together to make one sensor that when used in a network, like King et al. did [2]. then these sensors can determine each other's position. When these sensor nodes are placed on strategic positions on the body then body angles can be determined. Resistance sensors used by Tesconi et al. [1] or made by Stretchsense [7] and Sparkfun flexible sensor [34] use materials which under varying stretch levels will differ in their resistive capacity. This then can be measured and used to determine angles of different joints. EMG sensors like the MyoWare [15] measures muscle activity by detecting its electric potential.

3.1.5 FEEDBACK

The fifth part concerns feedback; how to give feedback and in what for. There are many ways of giving feedback, as stated by Christopher et all [16], there is a distinct difference between knowledge of performance(KP) and knowledge of result(KR) knowledge of performance is information about the characteristics of the movement, whereas knowledge of results are externally presented information about the outcome of the movement. Both can be presented in different ways, but usually it is presented through a visual medium like video. However, there are systems that use vibration as feedback, like the Samsung Smartsuit [3]. As stated by Wulf et all [27] the benefits of feedback on movement outcome are greater than feedback which focusses solely on the movement. This very relevant for this research, because rowing is a sport where it is all about the outcome, namely moving the boat faster. Wulf and Christopher both talk about giving real time feedback. This is usually done verbally.

HAPTIC FEEDBACK

Haptic / Tactile feedback is a form of feedback which makes use of advanced vibration patterns and waveforms to convey information to a user. This form of feedback can be found in wearables and in other devices such as mobile phones. The use of haptic feedback in wearables is very common and is also researched a lot. Research ass done by Van Breda et all [28] and Igrist R et all [30] suggest that there is no evidence that vibration as feedback system has benefit in improving a motor skill and sport performance. This suggests that the feedback system of this should not include a vibrational feedback system. Igrist R et all [30] and van Erp et all [33] also did some testing with haptic (vibrational) feedback. They made a system where the rower got feedback on the knee and back angles. Although the system worked the results showed no difference between vibrational feedback and visual feedback.

VISUAL FEEDBACK

Visual feedback is one of the most common ways of giving feedback in wearables technology and other electronic devices. This feedback is done mostly with the use of a display on the device or through the use of an app on a mobile phone. Because the method is relying on a form of screen it can be quite distracting. As is suggested by Marchal-Crespo et all [34] this can lead to that novice athletes do not benefit from the system as much as skilled athletes are. However as is stated by Igrist et all [30] there might not be any difference between haptic feedback and visual feedback for rowers.

Overall the studies suggest that a system which uses sensory live feedback with the emphasis on the knowledge of performance or the knowledge of result. This has to be tested what is more effective.
The research on vibrational feedback versus visual feedback seems inconclusive. Therefor both options need to be considered for this research. Based on the requirements of the prototype a decision has to be made.

3.2 Parameters in rowing

The parameters in rowing derive from the four parts of the rowing stroke as described by Redgrave [26]: the catch, the drive, the finish and the recovery. These phases all have similar parameters that can have an impact on the efficiency of the rower and thus have an affect the average boat speed. Other parameters that have impact on the average boat speed are hull resistance, wind resistance, and water viscosity.

The catch is the phase where the athlete places his blade in the water and applies power to the foot stretcher (the footplate). The parameters that determine an effective and powerful stroke are: catch factor (as discussed by Biorow [17]), the joint angles (as stated by Kleshnev [21] and Rowperfect [18]). These parameters influence how fast the athlete connects to the water and using his power to move the boat. This is important because this time for connection determines how efficient the rower is; the longer the catch-factor the more the boat loses speed and thus have lower average speed.

FIGURE 14 CATCH PHASE

The drive is the phase after the catch when the rower is connected to the water and applies power. Parameters that influence this phase are: body sequencing (as discussed by Soper et al. [10]), foot stretcher pressure, oarlock pressure and the fitness of the athlete.

FIGURE 15 THE DRIVE PHASE

Body sequencing is the term used when rowers are separating their power application into phases. They start by applying pressure with the legs, then the hips and trunk and lastly the arms. The pressure at the foot stretcher and the oarlock display the show the difference (and therefore) the efficiency of the rower. The fitness of the athlete determines how much power it can produce to propel the boat forward.

The finish is the phase where the rower ends the power application and gets the blade out of the water. The parameter that influences this phase is the finish position. As stated by Soper et al. [10], the peak force increases when the oar handle is pulled to the finish height at umbilicus level. This is important because this part of the stroke determines how the next stroke is taken; if there is any imbalance here then this will determine how the athlete moves and performs at the next stroke.

FIGURE 16 THE FINISH

The recovery phase is the phase when the oar is out of the water and rower moves towards the stern of the boat and the catch phase. Parameters that influence this phase are: oar handle height and speed of movement. The oar handle height determines the balance of the boat. When done correctly the blade of the oar will not touch the water and slowdown boat down. The speed of movement needs to have a good drive to recovery ratio, as stated by Soper et al. [10], because it is strong negatively correlated.

The remaining parameters are hull resistance, wind resistance, and water viscosity. However, because these are hard to measure through wearables and not relevant for coaching these will not be further examined.

3.3 ROWING ACTIVITIES

Rowing performance is influenced by many factors such as the catch-factor and the joint angles. Most of these factors are either measured on land or on the water. The following tests are done on land: power output (2k/6k/100meter test) and lung capacity (VO2 max test). These tests are mostly done on Concept 2 ergometers [23] or Rowperfect ergometers [18]. These mimic the rowing motion on a stable platform. During the power output tests the athlete rows a standardized distance as fast as possible; the faster the time the higher the power output. These are then used to determine the fitness of the athlete. The VO2 max test is done in a similar way, except the fact that the distance is covered with a mask over the nose and mouth which can measure the air breathed in and out. Using this data the oxygen intake can be determined.

The measurements done on the water are the following: oarlock pressure, oarlock angles, boat speed and stroke rate. Oarlock pressure and angles are measured with systems like the NK Empower oarlock [22]. This data is then used to determine optimal stroke length and to give feedback if technique is maintained during extended periods of rowing. Boat speed is measured through GPS sensors like the NK Speedcoach [22] .This data is used to see in conjunction with the stroke rate if the crew if performing as expected or not.

Although it was normal to have this hard distinction between on land and on water testing, it is the trend nowadays that distinction is blurring. Technologies like the COSMED k5 [12] give the option and the flexibility to the coaches and rowers to do a VO2 max test on the water.

3.4 INTERVIEW

To get more information from stakeholders an interview was held with people from the rowing world. These people have different backgrounds; this group consisted of rowers, coaches with experience and novice coaches. It was chosen to get opinions from stakeholders with different backgrounds to get to know what people from different parts of the demography needed in such a system. Five basic questions were asked from which a discussion was held about the topics. The objective of the interview was to get to know what they pay most attention on in training sessions, and also what concept they thought was the most interesting. The full interview can be read in the appendix.

From the discussions it became clear that the most interest was in the behaviour of the body during the power application of the stroke and in the catch factor. All three had different ways and points on which they focussed, two focussed on the catch phase and to other focussed the whole stroke; not on one particular thing. They all wanted to have information about the use of the body and how this is related to the power output on either the foot stretcher or the oarlock. There was some difference in what requirements they had for a rowing wearable. Two of them clearly stated that it was important that it connects with aspects of the trainings program; it has to be able to be implemented in current training activities. This means that no special training has to be invented to make sure the wearable is of use. For instance; when the wearable is designed to measure body angles, the only thing that has to be done is to put the wearable on and then a normal training can be carried out. It is also important that the output of the data also has to be clear and simple to interpret. This was made clear by all of the interviewed persons because then it could also be used by novice coaches and rowers.

3.5 CONCLUSION

In the analysis some key topics are discussed which give some good insight in what is the industry standard and what needs to be considered which can give a solid foundation for the further development of this research.

Rowing technologies are widely used in the rowing training programmes and everyday practices, with only a few designated wearables among them. All these technologies have their own purpose and benefits, but none of them measure aspects of technical skills directly and give feedback on this aspect. From the interview it became clear that the aspects which would be most interesting to measure are body posture, muscle use and catch-factor. These aspects would then be measured using different sensors.

Research has shown that there is not a best way of giving feedback for learning a complex motor skill like rowing. This means that the different options of giving feedback have to be considered for this research.

4 IDEATION AND EXPLORATION

This section describes the ideation process of the concept rowing wearable. This includes results of brainstorms about the feedback system.

4.1.1 PRODUCT IDEA 1

The first concept which was considered revolved around body angles. This could be measured in two ways: with the use of stretch sensors [7] and/or with the use of gyroscopes. This suit would measure the body angles and give feedback through the use of an app. This idea was created because of the importance of body use and coordination of the athlete is of great importance to determine the efficiency of the rower.

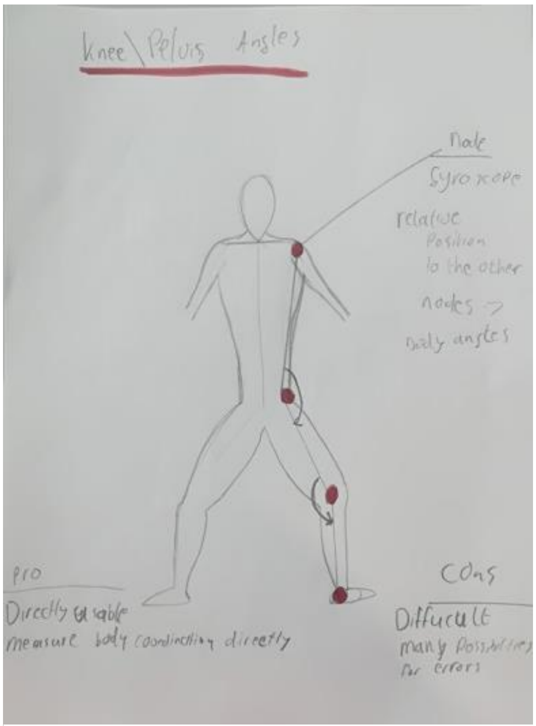


FIGURE 17CONCEPT IDEA 1

Pros:

- The product is directly usable in training: coaches are already training on posture; this device could measure the posture of the athlete during the stroke and send the data to the coach. This can then be analysed and adjusted accordingly.
- Measures body coordination directly. This gives tangible to the training of the athlete.

Cons:

- Inaccurate: the sensors which are used to measure the angles of the specific body parts are quite inaccurate.
- Calibration: there is a probability that the sensors need to be calibrated often before the training
- Ambiguous: there are different opinions on what good posture is.

4.1.2 PRODUCT IDEA 2

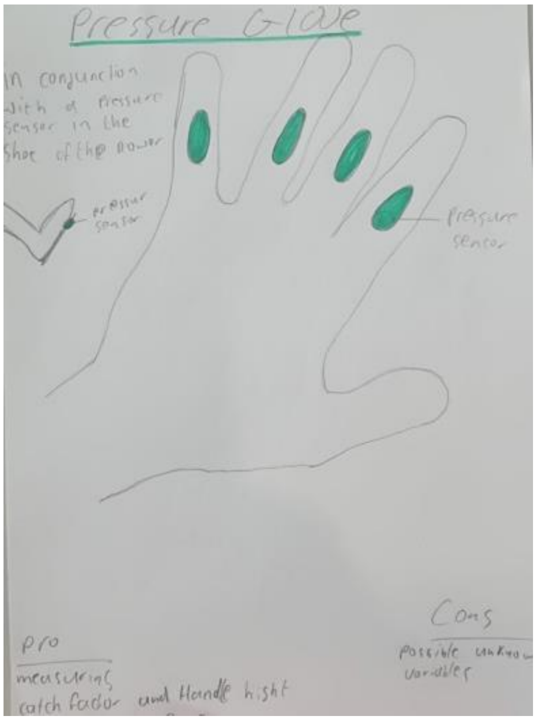


FIGURE 18 CONCEPT IDEA 2

The second concept revolved around the catch factor. This would be measured through FSR sensors [29] which would be placed at the hands and the feet. The difference in time will determine the catch factor. As stated by Biorow [17] the catch-factor determines the efficiency of the rower at the catch and is a big factor in the average speed of the rower. This is why this idea was created.

Pros:

- Measures catch-factor(critical part of the stroke): Coaches and rowers are laying emphasis on this part of the stroke
- Few sensors(easy to maintain and use)
- Non ambiguous: there is no debate on what a good catch must look like.

Cons:

- Possible unknowns: there may be underlying variables which can determine the catch-factor.

4.1.3 Product idea 3

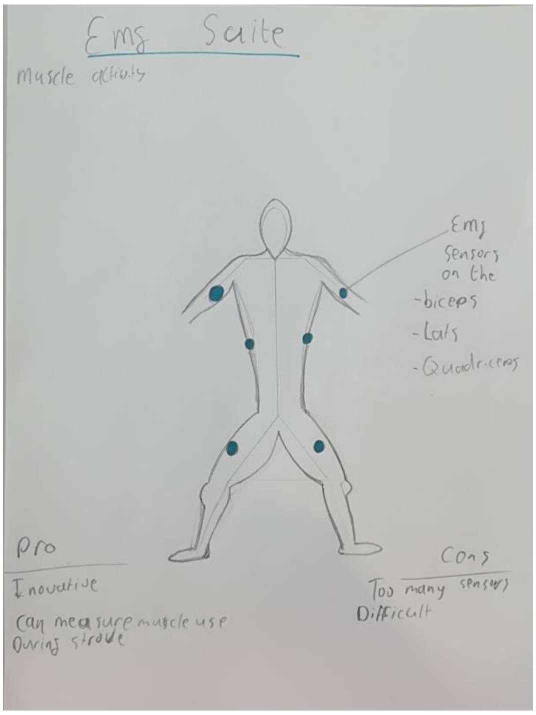


FIGURE 19 CONCEPT IDEA 3

The third concept revolved around muscle activity. This system would measure how the muscles where used and when they were activated. This would then give insight in how effective the rower used his body. The measurements are done with the use of EMG-sensors. This concept allows coaches and rowers to have a better understanding in the muscle use of the athlete during the performance, which is important considering the use of muscles determines the amount of power which is created and is this is done in an effective way. This system would make use of a haptic feedback system, because this would be natural to interpret. For instance, when a rower would use to little legs, then it would get haptic feedback on the legs.

Pros:

- Can measure muscle use: This is innovative and a part of the performance not much is known about at the moment.

Cons:

- Difficult: EMG/ECG sensors are difficult to use.
- Ambiguous: There are differing opinions on what good muscle use is. Some countries use the legs more, as for some countries have more body swing, as stated by Kleshnev [21].

4.2 INITIAL CONCEPT

From the analysis and the interview it became clear that the system would be the most interesting and helpful if it revolved around the catch-factor. Most coaches were already revolving most of their training around this and they stated that the catch has the most impact on the stroke as a whole. Furthermore it became clear that the system would need a live feedback system, because this would enable the coach and the rower to change their technique while they are training.

Secondly, it was thought that a visual feedback for the rower was the better option. First of all because it would be easier to interpret; a good catch-factor would get feedback like a green coloured screen and a bad catch-factor would get a red coloured screen. Secondly because the evidence for haptic feedback for using to learn difficult motor skills was not strong enough.

4.2.1 CONCEPT ONE: ACCELEROMETERS

The First concept made use of accelerometers at the hands and the pelvis. These sensors would measure the difference in time in they would change direction. If done properly it can then sense if the drive is done properly and if the pelvis and the feet (and therefore the boat) are connected to the hands (and therefore the oars). This would enable the system to determine if the catch factor is proper, according to Biorow [17]. This system would take the form of two click-on devices on the back of the rower and on the hands of the rower.

The placement of the hand sensor depends on the rower's preference. If done correctly, it is chosen as such way that the sensor would not sit in the way.

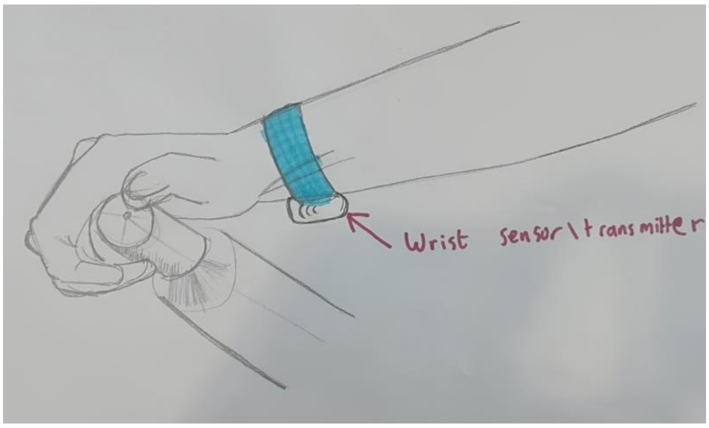


FIGURE 20 SKETCH CONCEPT 1 OF RIGHT HAND

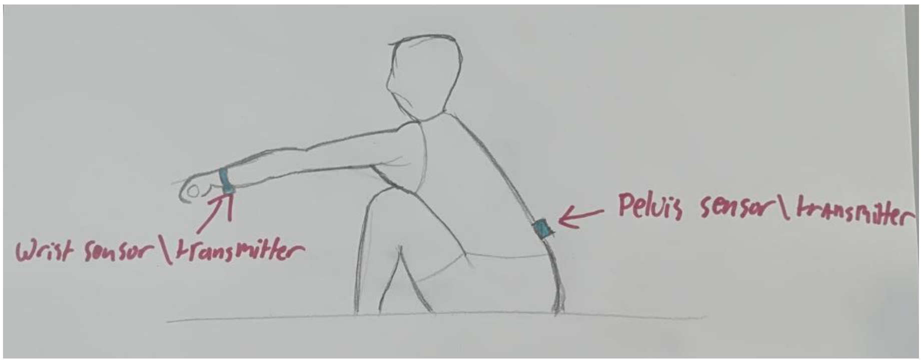


FIGURE 21 SKETCH CONCEPT 1

4.2.2 Concept two: Force sensor

The Second concept made use of force sensitive sensors at the hand and feet. These would measure the time between the application of force on the feet and the hands. This difference which is measured determines the catch-factor and therefore how effective the rower is applying the force. This system would take form of a glove/ shirt with sleeve which has a sensor at the hands and a sock, which has a sensor underneath the feet.

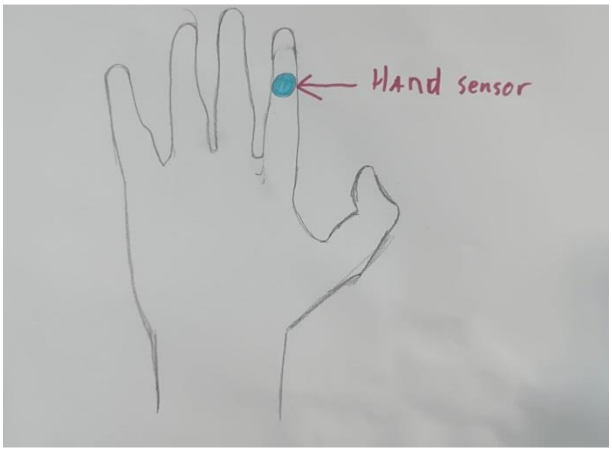


FIGURE 22 SKETCH CONCEPT 2

FIGURE 23 SKETCH CONCEPT 2

4.2.3 Final concept

After consideration concept 2 was chosen. This concept format was chosen because of the following:

- Form: the format of having two pieces of gear (glove and sock) seemed more fitting then a click-on device. In other words: the glove/sock format is more fitting and practical for this application.
- Sensors: the FSR sensors easier to program then the accelerometers. This in consideration of the time frame gives an advantage to the FSR sensors.

This concept would be paired with a feedback system in the form of an app.

5 PRODUCT SPECIFICATION

5.1 SYSTEM REQUIREMENTS

As stated earlier in chapter 3, there are multiple factors that are interesting to measure and give feedback on. However, most of these factors involve movement, which should not be hindered because this would affect the performance of the athlete. As described by Martindale [19] athletes tend to be negatively influenced when the wearable is obtrusive/ uncomfortable but most of all not beneficial. However, when the product shows a good improvement or big benefits for the performers, then they are more than willing to use the product. The product also should be long lasting, not only regarding the quality of the materials but also in battery life. This insures a good and easy usability without often occurring problems with reliability. The product should also be easy to use. This means that it would cost not too much time to make the product ready for use. So no plotting or calibration should be needed.

The requirements for the feedback system are that is should be easy to interpret. This means that while performing the athlete should take a glimpse at the feedback system and read very quickly what the situation is and go on with the activity.

5.1.1 PLAY TESTING

Based on the requirements the wearable would need a feedback system for the rower that was natural and easy to understand and read. Two systems were designed, one based on colours (qualitative) and one on numbers (quantitative). Both these systems were tested in a play test. Besides the different forms of the feedback system other aspects of the concept would be tested, such as the positioning of the sensors and the other electronic components. The results from this user test brought several things to light.

FEEDBACK SYSTEM

Firstly, the rower needs a feedback system which is easy to understand and not distracting. In light of this insight it was chosen that the app (feedback system) would have two options. In the home screen there would be the option of choosing the rowing mode or the coach mode. The rower mode would give feedback in a qualitative way with the use of colours. The coach mode would give the feedback in a quantitative way, namely in the way of numbers (milliseconds). The option for the rower was also considered to have a gradient in colour. This would then show green if the rower had a good catch-factor, orange if it was close to ideal and red if it was not good. However, it was chosen not to use three colours, because this was hard to distinguish while rowing. This lead to the decision to show green when the catch-factor was good and red when it was bad.

SENSOR POSITIONING

Secondly the positioning of the sensors was tested. Both sensors were placed on different placed of the foot and hand. For the foot sensor it was first placed in the middle of the foot. This brought to light that the sensor would not pick up a signal throughout the entire stroke cycle. This was noticed using the Arduino serial port reader during test strokes. Therefor the placement of the foot sensor was determined to be on the ball of the foot, because this lead to a constant signal due to the fact that this ensured constant contact with the foot stretcher.

The hand sensor was firstly placed on the first phalange of the forefinger. However this resulted in a uncomfortable positioning of the hand. The second and final placement was on the second phalange which was effective and comfortable for the rower.

5.1.1 FUNCTIONALITIES

The functionalities derive from the requirements and the play testing which are earlier discussed in the requirements paragraph. The functionalities of the app are as follows:

Home screen:

Here there will be an overview of the modes from which can be chosen. The options are;

- **Rower mode**
- **Coach mode**.

These differ in the way they give feedback. The Rower mode gives feedback using colour; green when the catch-factor is good and red when the catch-factor is bad. The Coach mode gives feedback in a qualitative way; it gives the catch-factor in milliseconds.

The coach mode would only give the milliseconds of the catch-factor as feedback. This was chosen as the coach should have to knowledge of what a good time would be, so it is only necessary to give the time as feedback.

5.2 FEEDBACK SYSTEM

As discussed in 5.1.1 it is opted for an option in the feedback system. This was chosen because it would be easier to interpret the feedback if it would only consist of colour feedback, but it was also needed for the coach to have quantitative feedback about the performance.

5.2.1 ROWER

The feedback interface for the rower will look like this:

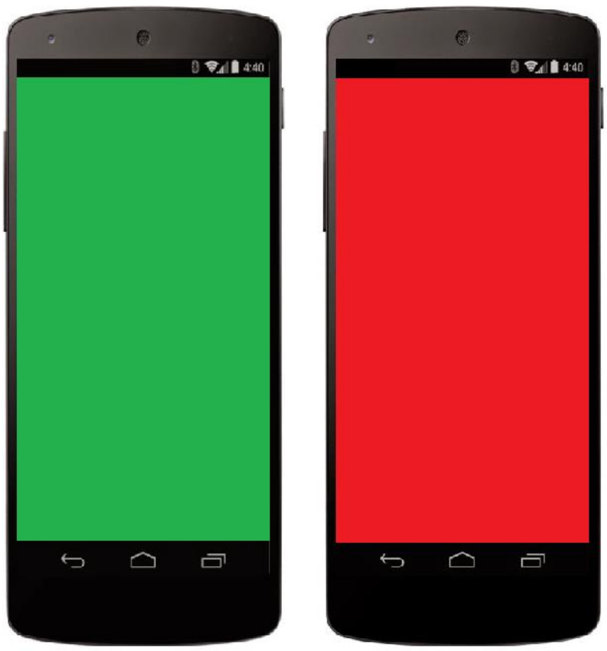


FIGURE 24 APP INTERFACE ROWER MODE

The app would light up green when it receives a value which indicates a good catch-factor and will light up red when it receives a value which indicates a bad catch-factor. It was chosen to light up the whole screen as this would help with the easiness of reading the display. As discussed in 5.1.1, the option of three colours was opted out; because of the difficultness rowers had distinguishing the colours while rowing.

5.2.2 COACH

. The feedback interface for the coach mode would look like this:

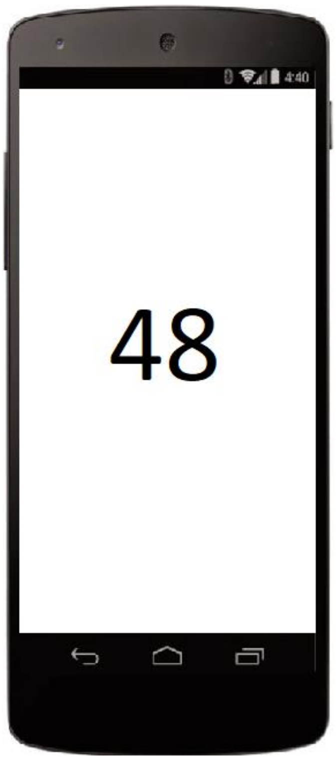


FIGURE 25 APP INTERFACE COACH MODE

It was chosen to keep the simple and straight forward as possible. The reasoning behind that was that the coach knows what a good catch-factor is and therefor would only need to know what the actual time is. In the case that an unexperienced coach is using the app he/she will get a brief instruction when installing the application. An alternative is that the system would state if the catch-factor of the rower is good, close to good or far off ideal.

6 PRODUCT REALISATION

6.1 HARDWARE COMPONENTS

The core of the system consists of an Arduino UNO which supports the FSR 402 sensor and the HC05 Bluetooth module. An Ardafruit ESP32 was opted, but rejected due to the inconvenience that it was hard to couple with the FSR 402 force sensor. The circuit configuration can be seen in figure 26. To make sure the sensors could run all the way to the Arduino, they had to have long wires connected to the outlets. In the first test it came to light that a break line would be needed in this wire to ensure that the sensor would not break. This can be seen in figure 25 The Bluetooth module and the FSR sensors both draw power from the Arduino Uno. The HC-05 needed the 3.3 volt output, whereas the FSR sensor needed 5 volt output to work properly.

To make sure they would stay in place, they would be taped into place onto the athlete. This was done because it was argued that rowers would not want to wear full gloves, so they would only have one little piece on one finger. This can be seen in figure 27. To support the circuit, the sensors are integrated into a sock and thermoshirt with sleeves, as can be seen in figure 27. The Arduino and Bluetooth module are encased in a plastic container which is put in the shirt on the back of the rower. The container can be seen in the figure on the next page.

FIGURE 26 HC-05 BLUETOOTH MODULE

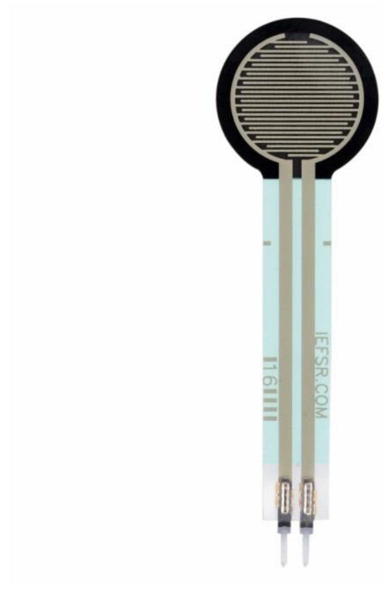


FIGURE 27 FSR 402 SENSOR

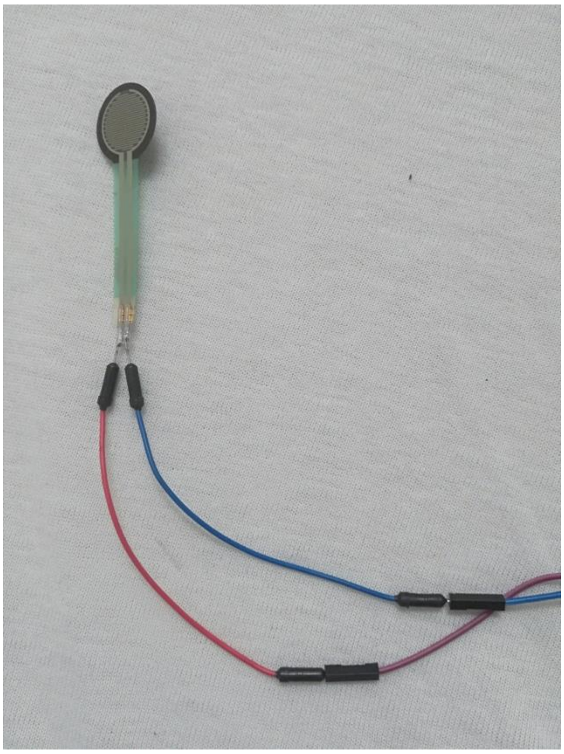


FIGURE 28 FSR SENSOR WITH BREAK LINE

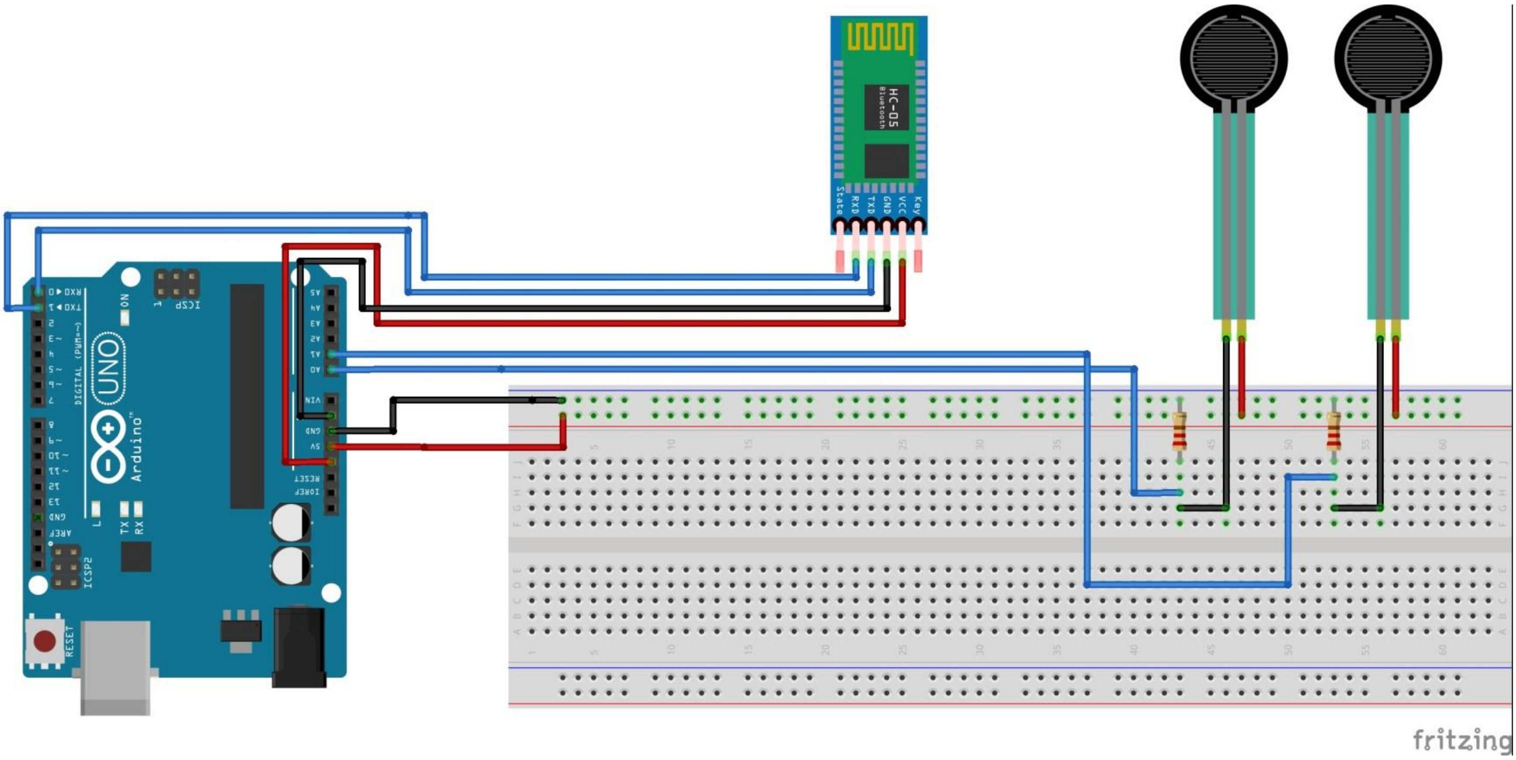


FIGURE 29 ARDUINO, BLUETOOTH AND SENSOR CIRCUIT

FIGURE 30 SENSORS PLACED IN SOCK AND AT THE HANDS

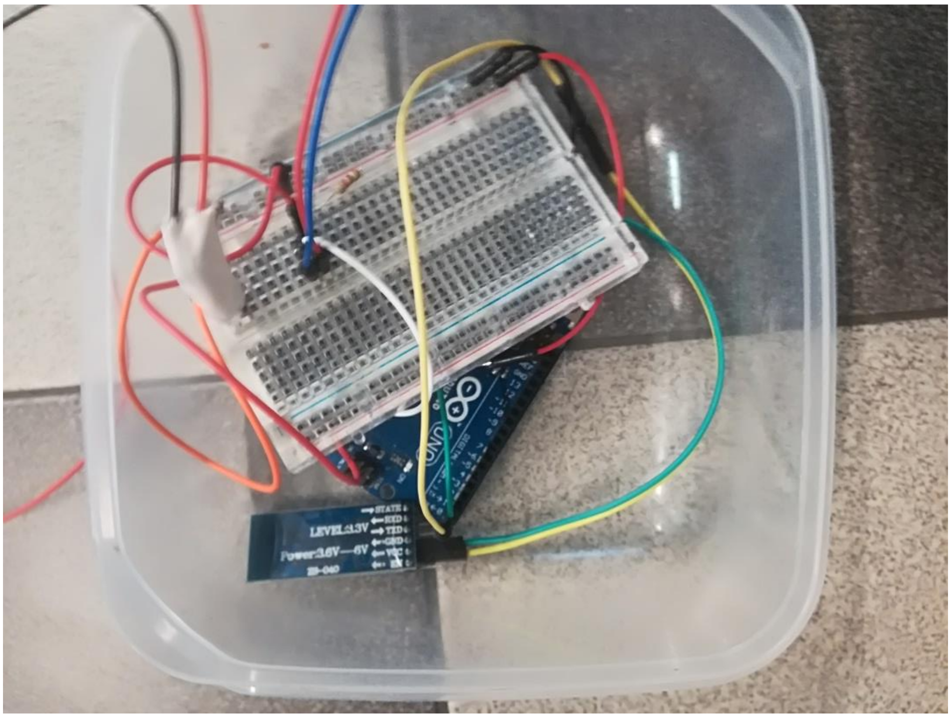


FIGURE 31 CASING WITH ARDUINO AND BLUETOOTH MODULE

6.2 Software components

Both Arduino and Processing require code to perform its functions, which have been built from the ground up for the purpose of this project. Because of the use of specific sensors and modules, specific libraries needed to be used.

6.2.1 Arduino code

The Arduinos main task is to process the signals coming from the sensors and send that information to the application or to processing.

The signal which comes from the FSR-402 sensor consists of a number which can be between 0 and 900. The Arduino code reads out the analog pin which the sensor of the feet is attached to and starts the timer if the pin reads a value over 450. This value was chosen because it is not passed when the rower is recovering (going towards the catch) . When the analog pin of the sensor which is attached to the hands reads a value higher than 300 then it stops the timer. The value of 300 was chosen for the same reason as before; it is not passed when recovering. The value of the timer is then send via the Bluetooth module to the mobile phone which is coupled with the HC-05.

The full code can be seen in the appendix.

6.2.2 Processing code/app

The processing code was developed initially to have a feeling how the interaction would be with the feedback system. This system would also act as an backup for the case that the app would not work or if the PC was needed as feedback system. The feedback of the processing code would be the samen as the app has, the only difference being that it would be displayed on the laptop instaed of the mobile phone. This means that when it is said that data is read in the code, then this means that for the PC version it is serial communication and for the Phone version it is via bluetooth communication.

The code works as follows; first it will look in what mode it wil run; rower or coach mode. When the code is in rower mode then the received data in the form of a number is evaluated. This number is evaluated, which means that a condition is set for which it will be compared with. This number is smaller than 55 then the background will turn green. If the number is bigger then 55 then it will turn the background red.

When the code is in coach mode, it is more simple. The code will directly print the number it receives on the white background.

The full code can be seen in the appendix.

7 EVALUATION

7.1 EVALUATION SETUP

The evaluation of this concept feedback system is done using rowers with different experience levels. The land based test is done using a Concept 2 ergometer[12] . The water based test was done using a single scull rowing boat. The rower was equipped with the system and used the system in rowers mode; the qualitative feedback system.

LAND-BASED TEST

The rower was asked to row without the feedback system at a stroke-rate of 20 for 2 minutes. After that they were asked to row with the feedback system at stroke-rate 20 for 2 minutes. The difference in average catch-factor was then analysed for significant improvement. When the tests were over they were asked the following questions:

- Does this system help you with getting feedback about your rowing?
- Was the prototype system obtrusive?
- Would you use it in training?
- What would you improve?

The protocol can be seen in the appendix

FIGURE 32 ROWER SETUP WITH SENSORS

[2] www.concept2.com

WATER-BASED TEST

For the water based test the rower was asked to put on the system and use both systems. After they rowed for 5 minutes with both systems they were asked the following questions:

- What feedback system did you prefer?
- What did you find positive about the system?
- What would you improve about the system?

The protocol can be seen in the appendix

7.2 LAND-BASED TEST SUMMARY

The test went smoothly apart from a couple hiccups caused by wire displacement. At first the rowers needed time to adjust and get familiar to the system. They said they needed to figure out how they needed to use their bodies to get positive feedback from the system. After some time most of them got the technique under control which let to positive feedback and a good catch-factor. It came to light that the less experienced athletes lacked the knowledge of a good catch-factor. This was their own explanation why they were not able to get positive feedback from the system. This is further substantiated by the fact that one of the inexperienced athletes was able to make progress after they asked how they should row.

7.2.1 REQUIREMENT EVALUATION

To get a better understanding of the feedback it is analysed in parts which are important for this research and the evaluation of the system. Based on the requirements these are:

- Obtrusiveness
- Ease of use/interpretation
- Benefits

7.2.1.1 OBTRUSIVENESS

Based on the feedback which is given, the results suggest that the system provides no irritating obtrusion to the rower. Although some adjusting time was needed because of the wires and such, the amount of adjustment was minimal. People did suggest that the sensors should be woven into the clothing for better experiences, which is true.

7.2.1.2 EASE OF USE

The rowers suggest that the system is easy to interpret when the colours were given as feedback. However, the more experienced rowers could handle the numbers as feedback because they did not need to concentrate as much on their rowing, because the technique they have is already more natural for them. Based on the results it can be said that the system is easy to interpret if the colour based feedback is used.

7.2.1.3 BENEFITS

The results suggest that rowers with less experience think that the system helps them in their training. They liked the fact that it made a part of the rowing stroke more tangible. The more experienced rowers were less convinced, although they could see the point of such a system when used on the water or In bigger crews. This should however be better tested.

7.2.2 TEST RESULTS

The average test results can be seen in the table 1. The before row is the average catch-factor before getting feedback on it. This number is in milliseconds. The after row is the catch-factor after getting feedback on it. A diagram with a list of all the measurements can be seen in the appendix.

Rower	1	2	3	4	5
Before	102	75	71	97	80
After	94	60	54	81	58

TABLE 1 AVERAGE CATCH-FACTOR

Based on these results it can be said that the catch-factor system does have a positive influence on the performance of the rower. It can be seen that the average time decreases by 15.855 milliseconds. When you look at the progression of the rowers' catch-factor it can be seen that the rowers needed some time to learn to use their bodies to improve their catch-factor. Most of them eventually got better and improved.

7.3 WATER-BASED TEST

To get a better understanding of the on water behaviour of the system a water-based test needed to be conducted. This was done in a qualitative way because the system was already tested quantitatively which provided results that the system did work. Now it needed to be tested if the system works on the water. The test was done using one tester which tested both feedback systems and on basis of that gave feedback on the whole system.

During the test it became clear that the system had one flaw. The fact that sculling uses two oars and the system only has one sensor for the hand made it impossible to measure if the hands hade different catch-factors. This is a problem because when the timing is off between both oars, this could lead to the boat not going straight forward. Besides this flaw the system did work properly. Both systems were tested by the rower. The rower stated that he preferred the quantitative feedback system, because this was what he was used to. However after figuring out how the other system behaved he saw the potential of this system too. It was also stated that this system should be used with a coach or some form of background knowledge to make sure that the athletes know how the technique can be improved and what benefits it has.

8 CONCLUSION AND DISCUSSION

The goal of this research was to design a wearable which could give live feedback to the rower and the coach about an aspect of the performance of the rower. To get insight into the possibilities of the wearable, research was conducted into relevant existing technologies. The result was a catch-factor system which measures the catch-factor of the athlete. To evaluate the concept there has to be looked at the research questions and the results. To answer the main research question, first the sub-questions have to be answered. The first one is:

- *What are the technological standards for sport wearables?*

Looking at the studied work it can be seen see that the technologies of today's standard revolve around basic aspects that most athletes can use. These aspects are speed, heartrate, stroke-rate GPS tracking etc. These wearables use a variety of sensors like ECG sensors, pressure sensors, GPS sensors and many more. Looking at the wearables which are specifically made for rowing it can be seen that there are very few wearables designed for this purpose. The one which was made revolved around the body angles of the athlete. The things that can be learned from these technologies is that the wearable should be kept simple and revolve around one important aspect of the athletes performance. It is also important that the wearable can be used as much as possible. Concerning the feedback that the wearables use it can be seen that the wearables use different kind of feedback and that there even more options. The options for feedback can be divided in quantitative and qualitative feedback. Examples of quantitative feedback systems are heart-rate watches (which give literal feedback on the heart-rate), GPS monitors (which give literal feedback on speed) and the NK Empower oarlock (which gives literal feedback on oar angles and power curves). Examples of qualitative feedback systems come in the form of haptic feedback systems. The Samsung Smartsuit and the Sensoglove are examples of these kinds of systems. The Samsung Smartsuit uses gyroscopes and accelerometers to determine the body angles of the athlete. It gives vibrational feedback to the athlete when he/she has bad posture. These different systems show the possibilities of feedback that a rowing wearable could use. The choice of feedback depends on the type of system which is developed, because research shows that there is little difference between the different kinds of feedback.

The second question is:

- *What are parameters for rowing?*

Research showed that the parameters which can be measured for rowing derive from the different phases of the rowing stroke. Parameters which are interesting for a rowing wearable are: body angles, catch-factor, handle height, and speed of movement. These aspects of the stroke cycle all have their possibilities and opportunities, there for an interview was held. This interview was held was rowers and coaches. These stakeholders stated that the catch-factor system would be the most interesting, because this was what they were most interested in and because they thought this was one of the most important parts of the stroke-cycle.

The third question is:

- *How to measure rowing activities?*

Rowing activities can be divided in land activities and water activities. The land activities consist of ergometer tests (and training sessions) and lung capacity tests. The measurements done on the water are: oarlock pressure, oarlock angles, boat speed and stroke-rate. These measurements are done with systems like the NK Empower oarlock and the NK Speedcoach.

- *What are the requirements for a rowing wearable*

Research has shown that the requirements for a (rowing) wearable mainly revolve around the movement of the athlete and the benefits that the system can provide. This means that the wearable should be practical, easy to use, easy to interpret and non-obtrusive.

Based on these sub-questions the results of the prototype can be derived.

Firstly: did the prototype meet the requirements? Based on the results which came forth out of the test and the interview we can state that this is mostly true. The participants stated that the device was not hindering them in their rowing, that the feedback was easy to interpret, the device was easy to use and that the device was useful. Some participants stated that they were used to getting quantitative feedback with established technologies, which caused the adjustment time for them. In the end they got used to the qualitative feedback and found it useful. The other issue that inexperienced rowers had was that they lacked the knowledge of a good rowing technique and how they could improve their catch-factor. They pointed out that this system is helpful for them, but only when they get coaching while they are using it.

Secondly: did the system have impact? From the test results it can be said that the system does have impact on the rower's performance. The before and after testing showed an improvement of 15,855 milliseconds. Given that only five participated this may not be too insightful. It is not clear if the system was the factor which contributed to the better results or the fact that the rowers were more conscious about the technique and therefor got a better score. However if you look at the responses of the rowers it can be seen that most of them do think that the system quantifies the catch-factor for them and that they have a better feeling for this part of the stroke. Although this is not hard evidence it does show that the system can improve awareness of the rowing technique, which on itself is an improvement.

8.1 Future work

For a better understanding and in depth knowledge about this system there is still room for improvement. First of all more participants should use the system, because then a more significant conclusion can be derived. This could enable a statistical analysis which could lead to a more knowledgeable conclusion of the impact

WEARABLE

Furthermore there work needs to be done to make the system into a real wearable. To realise this more work needs to be done. Firstly research needs to be done into the material choice. Materials should provide a comfortable experience while the athlete is wearing the garment, but also needs to protect the electronics from water and sweat. There should also be research done in how the system would be cleaned therefor it should also be researched how this would affect the design and the implementation of the electronics. This can be done in a couple of ways, of which wireless systems and detachable sensors are the most likely. The development of the sensors should also be done, because these are still too vulnerable for the elements. One solution might be that they are encased into silicon.

SIZE
The overall size of the container containing the microcontroller, battery, and Bluetooth module should be reduced. The positioning of the system was good, but the fact that this container was big made it awkward to put into place, inconvenient to use and carry around. Options for smaller microcontrollers are readily available.

SENSORS
The system has two environments in which it can be used; the water and on land. Both need different amount of sensors, which was came across during the water-based testing. Especially because sculling uses two independent oars, the situation can occur that there is a difference between both oars in catch-factor. For this case it is recommended that both hands are equipped with sensors. The system should therefore have an option for the water-based usage for sculling and sweep rowing.

9 APPENDIX

A REFERENCES

[1] M.Tesconi, A.Tognetti, E.P.Scilingo, G.Zupone, N.Carbonaro, D.De Rossi, E.Castellini, and M.Marella, "Wearable sensorized system for analyzing the lower limb movement during rowing activity," 2007 IEEE International Symposium on Industrial Electronics, June 2007.

[2] R. C. King, D. G. McIlwraith, B. Lo, J. Pansiot, A. H. McGregor, and G.-Z. Yang, "Body sensor networks for monitoring rowing technique," in 6th International Workshop on Wearable and Implantable Body Sensor Networks (BSN), 2009,

[3] Samsung (2018). [online] Available:http://www.samsung.com/nl/samsungsmartsuit/?cid=nl_ppc_ds%7cGOOGLE_SmartSuit_20160101_NL+-+IMD+-+Smartphones_SmartSuit&kw=smart+suit+samsung&gclid=EAIaIQobChMIiYG0uNux2QIVhsmyCh0a5wR_EAAYASAAEgLg_fD_BwE&gclsrc=aw.ds

[4] J. J. Abbas and H. J. Chizeck, "Feedback Control of Coronal Plane Hip Angle in Paraplegic Subjects Using Functional Neuromuscular Stimulation," IEEE Trans. Biomed. Eng. Vol. 38, No. 7, pp. 687-698, 1991.

[5] MCGREGOR, A. H., Z. S. PATANKAR, and A. M. J. BULL. Spinal Kinematics in Elite Oarswomen during a Routine Physiological "Step Test." Med. Sci. Sports Exerc., Vol. 37, No. 6, pp. 1014 –1020, 2005

[6] Wei Quan Hua Wang and Datong Liu. "A Multifunctional Joint Angle Sensor with Measurement Adaptability", 2013 Nov 8

[7] Stretchsense (2018). [online]. Available: https://www.stretchsense.com/article-resources/case-study/how-to-measure-joint-angle-with-stretch-sensors/

[8] Korner, T. and Schwanitz, P. (1987). Rudern. Berlin: Sportverlag. McLean, B. and Lafortune, M. (1988). Improving pedalling technique with `real time' biomechanical feedback. Excel, 5, 15±18.

[9] Baudouin A, Hawkins D A biomechanical review of factors affecting rowing performance British Journal of Sports Medicine 2002;36:396-402.

[10] Soper, C. & Hume, P.A. Sports Med (2004) 34: 825. https://doi.org/10.2165/00007256-200434120-00003

[11] Paul Hartog (25 June 2015). [online]. Available: https://www.youtube.com/watch?v=9qnuycJBbnA

[12] Cosmed(2018).) [online]. Available: https://healthmanagement.org/products/view/k5-wearable-metabolic-system

[13] GPsports(2018) [online] Available: http://gpsports.com/

[14] Sensoglove (2018) [online] Available: http://www.sensoglove.com/en/

[15] Myoware(2018) [online] Available: https://www.sparkfun.com/products/13723

[16] Christopher M. Janelle, Jingu Kim, and Robert N. Singer, Subject-Controlled Performance Feedback and Learning of a Closed Motor Skill, Perceptual and Motor Skills 1995, Vol 81, Issue 2, pp. 627 – 634

[17] Biorow (2018) [online] Available : http://biorow.com/index.php?route=information/news/news&news_id=4

[18] RP3 (2018) [online] Available :https://www.rowperfect.co.uk/rowing-coach-2/rowing-posture/

[19] Martindale J (2014) [online] Available: http://wearable.co.uk/blog/pro-sports-begin-global-acceptance-wearables/

[20] Janti K (23 January 2017) [online] Available: https://www.reaktor.com/blog/what-makes-a-wearable-successful-design-wise/

[21] Kleshnev V, Kleshnev I. Dependence of rowing performance segments. J Sports Sci 1998; 16 (5): 418-9

[22] NK(2018) [online] https://nksports.com/empower-oarlock

[23] Concept2(2018) [online] http://www.concept2.com/indoor-rowers/model-d

[24] Polar(2018) [online] https://www.polar.com/us-en/products/sport/M430-gps-running-watch

[25] Garmin(2018) [online] https://buy.garmin.com/en-US/US/p/564291

[26] S. Redgrave(2000), complete book of rowing, Partridge Press; 2nd edition 2000

[27] Gabriele Wulf , Nathan Mcconnel , Matthias Gärtner & Andreas Schwarz (2002) Enhancing the Learning of Sport Skills Through External-Focus Feedback, Journal of Motor Behavior, 34:2, 171-182, DOI: 10.1080/00222890209601939

[28] Van Breda, E., Verwulgen, S., Saeys, W., Wuyts, K., Peeters, T., & Truijen, S. (2017). Vibrotactile feedback as a tool to improve motor learning and sports performance: a systematic review. BMJ Open Sport — Exercise Medicine, 3(1), e000216. http://doi.org/10.1136/bmjsem-2016-000216

[29] Digikey(2018) [online] Available: https://www.digikey.nl/en/product-highlight/i/interlink/fsr-402-round-force-sensing-resistor?utm_adgroup=Resistors&mkwid=sUnG2Md0v&pcrid=239671630956&pkw=&pmt=b&pdv=c&gclid=EAIaIQobChMIvp-usJ3L2wIVGJ7VCh2QGAN_EAAYASAAEgJa4PD_BwE

[30] Igrist, R., Rauter, G., Riener, R. et al. Psychon Bull Rev (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review

[31] Foster, C. (1998) Monitoring training in athletes with reference to overtraining syndrome

[32] Coxmate(2018) [online] https://www.coxmate.com.au/?v=7516fd43adaa

[33] van Erp, J. B. F., Saturday, I., & Jansen, C. (2006). Application of tactile displays in sports: Where to, how and when to move. In Proceedings of the Eurohaptics International Conference.

[34] Robotshop (2018) [online] Available: https://www.robotshop.com/en/22-10k-flexible-sensor.html

B INTERVIEW

QUESTIONS

1: What do you do in rowing?

2: Where do you focus on when you coach a rower's stroke?

3: What would you like to measure on during the rowing stroke?

4: What are your requirements for a rowing wearable?

5: What basic concept are you the most interested in?

RESPONSE 1

1: I have been coaching for 3 years.

2: I focus on a couple of thing: the rowers catch has to be quick and fluid; the rower should not be sitting still for too long, the rower pushes first with the legs and the quickly 'opens his body' to apply more force by using the pelvis muscles. When this is done correctly then the arms will not be used when the legs and hips are pushing and generating big forces. I do think that the whole stroke has to be complete, but I believe that the application of power is the most important part of the rowing stroke.

3: like I already said, I think the power application is the most important, so that is why I would like to this; how the body is used during the power application.

4: First of all it has to be useful; I have to be able to work with it and really use it. If it is not giving me information I can use then I would not use it. Secondly it has to be practical for me and the athlete. If it is hard to get it working or to put on, then I would hesitate to use it, because it would to too much time which I could also use to train on the water.

5: I am the most interested in the catch-factor system. This because it aligns the most with my training philosophy.

RESPONSE 2

1: I mainly coach at the moment, but I have been rowing for 6 years now.

2: My view is that there are 2 separate parts you can coach. The first part is the stroke as a whole; the rhythm of the movement has to correspond with the speed of the boat. This means that the movements have to be slower when the speed is lower. The second part is where you focus on the action ‘under water’. This is a world of its own because here are some options on how you move and use your body in this part. I think that when the blade is in the water, force should be generated by the body in such a way that the change of knee angle should be as identical as the change in hip angle. This way of using your body generates the most amount of power with the most control. Besides that it is easier to learn than other ways.

3: In regards of my explanation of the rowing stroke I think it is interesting to know how the body angles change during the stroke cycle. However, this should be possible to be compared to the force curves.

4: As long as it is not too expensive I do not think that there are new things that I can add. Typical things as easy to use etc. will already be considered.

5: I have no real opinion on this, only thing I think is that the muscle use system is not needed.

RESPONSE 3

1: I have rowed for 4 years and I am coaching for 4 years now.

2: I think that the most important thing is that the catch is very sharp and direct. Under water it has to be as simple as possible, so I coach the rowers that they simply have to put their legs down and keep contact with the foot stretcher. As long as the rower does not ‘push under’ himself this is pretty effective. Also it is good to be abstract in the coaching, because then the rower can translate this into his or her own understanding.

3: I think it is interesting to measure the power output on the foot stretcher and on the oarlock. From this you can derive if the rower is outputting power efficiently.

4: Everything that a rower uses has a purpose, strokecoach measures the strokerate and the speed of the boat, the coxbox vocalizes the cox; so make sure that what the wearable that is made can be implemented in training sessions in an effective way.

5: The catch factor system has some interesting elements. Mostly the the force on the stretcher is interesting.

C ARDUINO CODE

```
/*Code made by Reint Dijkstra

 * Arduino code for FSR sensor sensing the catch factor and sending serially via bluetooth

 */

#include <SoftwareSerial.h>

int fsrPin1 = 0; //Analog pin input for FSR on ARduino

int fsrPin2 = 1;
```

```
int fsrValue1 = 0; //FSR values1

int fsrValue2 = 0; //FSR values2

SoftwareSerial BTserial(10, 11); // RX | TX


boolean stroke = false; //set stroke to false: no stroke is taken yet

boolean Catch = false; //sets catch to false

unsigned long start_time;


unsigned long elapsed_time;


int fractional;


void setup () {

  BTserial.begin(38400);

  Serial.begin (9600); //Set serial boudrate to 9600


}

void loop (){

  fsrValue1 = analogRead(fsrPin1);//reads FSR

  fsrValue2 = analogRead(fsrPin2);

  if (fsrValue1 >450 && stroke == false) {  // stroke is taken


start_time = millis();

stroke = true;

  }




if (fsrValue2 > 300 && fsrValue1 > 550 && Catch == false ) { // pressure in the hands -->catch
```

```
  elapsed_time = millis() - start_time;

  Catch  = true;

  fractional = (int)(elapsed_time % 1000L); //convert into seconds

     BTserial.print(fractional);
     Serial.println(fractional);  // print fractional part of time in seconds

}
  if (fsrValue1 < 500 && stroke == true) {  //recovery

    stroke = false;
Catch = false;

  }
 delay (40);//delay for 40 milliseconds
  }
```

C Processing code coach

```
import processing.serial.*;
Serial myPort;  // Create object from Serial class
String val;     // Data received from the serial port
float value;
void setup()
{
```

```
  String portName = Serial.list()[0]; //change the 0 to a 1 or 2 etc. to match your port
  myPort = new Serial(this, portName, 9600);
  size(1000,800);
  background(250);

}


void draw()
{
  if ( myPort.available() > 0)
  {  // If data is available,

  }
}
 void serialEvent(Serial p) {
  // get message till line break (ASCII > 13)
  String message = myPort.readStringUntil(13);
  int count = 0;
  if(message != null){
    background(250);
    value = float(message);
    println(value);
    Float s = value;
    fill(0);
    textSize(100);
    textAlign(CENTER);
    text(s,width/2,height/2);
```

```
 }

}
```

D PROCESSING CODE ROWER

```
import processing.serial.*;

Serial myPort;  // Create object from Serial class

String val;     // Data received from the serial port

float value;

void setup()

{

  String portName = Serial.list()[0]; //change the 0 to a 1 or 2 etc. to match your port

  myPort = new Serial(this, portName, 9600);

  size(1000,800);

  background(250);

}

void draw()

{

  if ( myPort.available() > 0)

  {  // If data is available,

  }

}
```

```
void serialEvent(Serial p) {

 // get message till line break (ASCII > 13)

 String message = myPort.readStringUntil(13);

 int count = 0;

 if(message != null){

  // background(250);

   value = float(message);

   println(value);

   //Float s = value;

   //fill(0);

   //textSize(100);

   //textAlign(CENTER);

   //text(s,width/2,height/2);*/

   if (value < 55 ){

     background(33,255,0);


   }

   if (value > 55) {

    background(255,0,21);

   }

 }


}
```

D Processing code rower

```
import processing.serial.*;

Serial myPort;  // Create object from Serial class

String val;     // Data received from the serial port

float value;

void setup()

{


  String portName = Serial.list()[0]; //change the 0 to a 1 or 2 etc. to match your port

  myPort = new Serial(this, portName, 9600);

  size(1700,800);

  background(250);


}



void draw()

{

  if ( myPort.available() > 0)

  {  // If data is available,


  }

}

 void serialEvent(Serial p) {

  // get message till line break (ASCII > 13)

  String message = myPort.readStringUntil(13);

  int count = 0;

  if(message != null){

   // background(250);
```

```
    value = float(message);
    println(value);
    //Float s = value;
    //fill(0);
    //textSize(100);
    //textAlign(CENTER);
    //text(s,width/2,height/2);*/
    if (value < 55 ){
      background(33,255,0);


    }
    if (value > 55) {
     background(255,0,21);
    }
  }


}
```

E Wearable testing

To test the prototype tests needed to be conducted. In order to do this a protocol was made and results were written down and analysed. This was both done for the land based as well as the water based testing.

1 Land based testing

1.1 protocol

1 Strap on wearable sensor system

2 Attach sensors, powerbank and wires to Arduino

3 Establish connection between Bluetooth module and mobile phone

4 Sensor check; check if sensors work

5 Start rowing without feedback system at stroke-rate 20 for two minutes

6 write down results of every stroke

7 Start rowing with feedback system at stroke-rate 20 for two minutes

8 Write down the results of every stroke

9 Ask questions

1.2 Questions

- Does this system help you with getting feedback about your rowing?
- Was the prototype system obtrusive?
- Would you use it in training?
- What would you improve?

1.3 RESULTS

The test was conducted with 5 rowers. During the two rowing cycles every catch-factor was observed and written down. After the tests every rower was asked the questions as cited before.

1.3.1 TABLE OF RESULTS QUANTITATIVE DATA

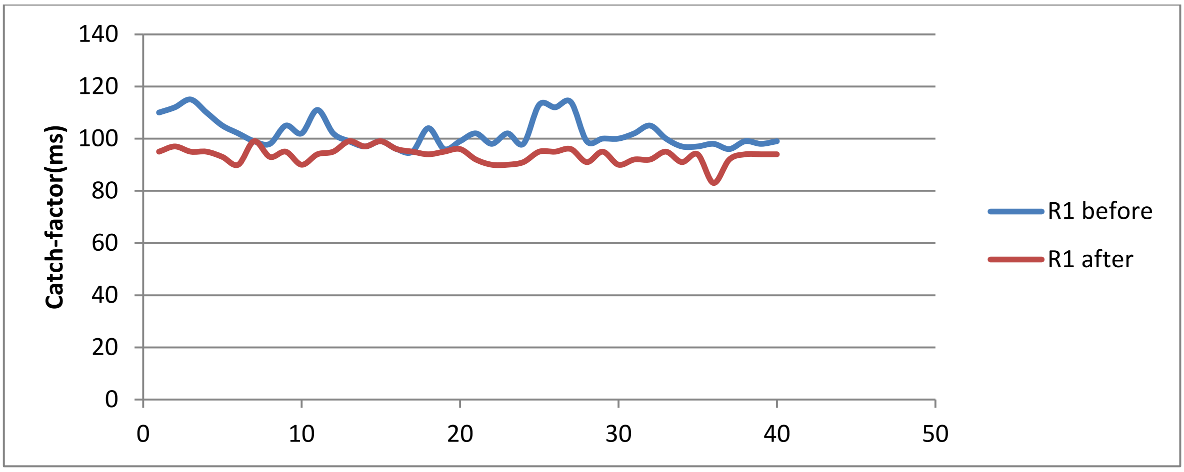
The following numbers were measured during the tests.

R1 before	R1 after	R2 before	R2 after	R3 before	R3 after	R4 before	R4 after	R5 before	R5 after	waarne
110	95	76	70	77	70	100	97	80	81	1
112	97	76	70	74	71	98	98	81	81	2
115	95	76	69	73	65	99	95	81	80	3
110	95	76	67	75	66	98	90	82	76	4
105	93	71	69	73	60	99	90	84	77	5
102	90	71	69	75	50	97	89	81	60	6
99	99	74	68	75	51	97	90	81	62	7
98	93	74	68	76	50	97	91	81	63	8
105	95	70	70	74	55	96	89	81	62	9
102	90	71	65	74	53	99	89	82	54	10
111	94	74	65	74	49	97	89	81	55	11
102	95	74	64	72	50	97	90	80	56	12
99	99	73	66	71	48	96	90	79	53	13
97	97	71	66	73	47	96	89	80	53	14
99	99	71	66	71	48	96	90	80	53	15
96	96	75	67	71	50	100	89	80	55	16
95	95	75	67	71	51	94	89	79	51	17
104	94	76	66	71	51	98	89	78	51	18
96	95	77	69	70	51	99	88	80	60	19
99	96	80	68	68	52	97	90	80	60	20
102	92	86	50	69	51	89	87	79	55	21
98	90	77	50	68	51	105	88	79	54	22
102	90	72	53	67	50	98	87	79	55	23
98	91	72	69	67	54	98	89	80	54	24
113	95	72	55	60	54	97	87	83	54	25
112	95	71	56	67	54	98	80	80	56	26
114	96	75	50	68	52	98	110	80	51	27
99	91	76	45	69	53	99	110	79	55	28
100	95	74	53	70	52	99	63	79	56	29
100	90	73	53	68	54	99	56	80	56	30
102	92	77	53	75	55	97	110	79	51	31
105	92	78	56	70	53	97	54	81	51	32
100	95	78	50	69	54	97	55	81	50	33
97	91	79	51	68	53	95	52	80	52	34
97	94	78	51	69	51	96	52	80	49	35
98	83	79	51	70	50	95	52	80	55	36
96	92	78	52	71	54	97	57	80	54	37
99	94	78	48	69	55	97	53	81	54	38
98	94	78	50	70	51	97	49	80	55	39
99	94	77	58	70	50	98	55	79	54	40

1.3.2 GRAPHS OF QUANTITATIVE DATA

ROWER 1

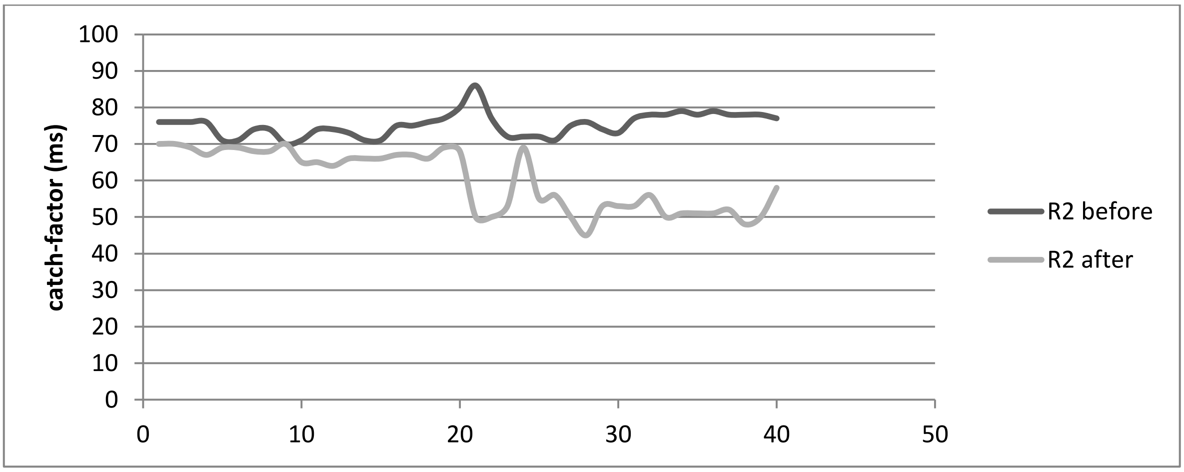
The first rower had little experience in rowing because he was a first year member at the club. The graph shows that his catch-factor is quite slow and inconsistent, which indicates the inexperience of the rower. The effect of the system therefor was very low because the rower did not know how to use its body to get a better catch-factor.



GRAPH 1 RESULTS ROWER1

ROWER 2

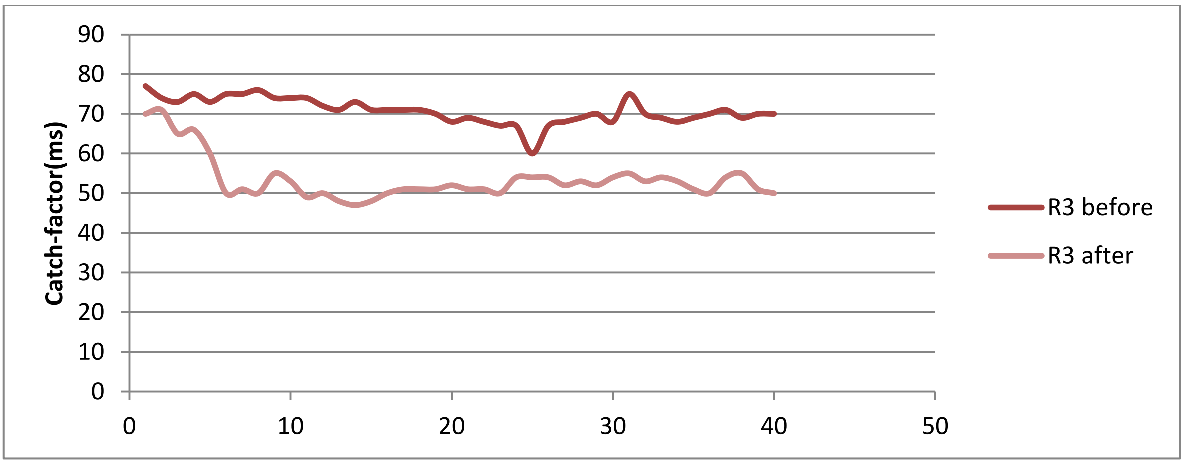
The second rower had been rowing for almost two years. This showed in the graph because the average catch factor of the rower before and after the use of the feedback system. Although the rower is still quite inconsistent in the before situation, it can be seen that the rower has more experience and knowledge in using its body. After a while of using the feedback system the rower figured how he could get good numbers and got better scores.



GRAPH 2 RESULTS ROWER2

Rower 3

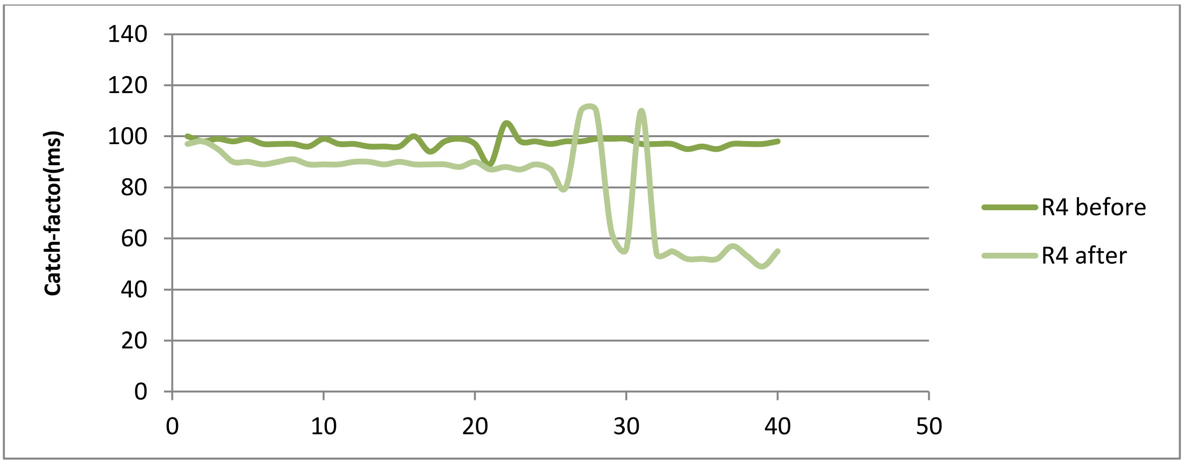
The third rower has rowed for 2 years of which 1 year with intensive training (training more than 5 times a week). This can be seen because the rower is quite consistent in its performance. When the rower used the feedback system it can be seen that after an initial hesitance and getting used to the performance increasingly got better and more consistent.



GRAPH 3 RESULTS ROWER3

Rower 4

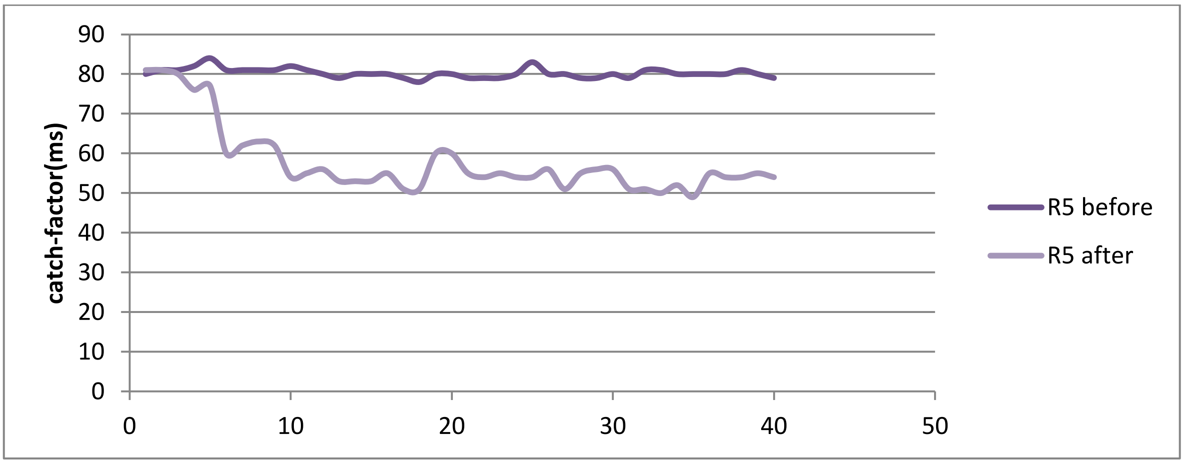
The fourth rower was a rower with little experience because he was a first year student and member of the club. Although he is quite consistent in its performance, the catch-factor is not optimal before the use of the feedback system. When the feedback system was used it first had little impact on the performance. The spikes in performance are a result of distraction because the athlete asked what was wrong and what he could do to improve. After the answer which was given to the rower the performance was improved and the rower knew what he had to do to get better results. It is hard if the system had the greatest impact or the system. However the system did give feedback to support the bettering in technique.



GRAPH 4 RESULTS ROWER4

Rower 5

The fifth rower was a rower with 4 years of experience in the rowing club. The measurements suggest that the rower has rowed considerably but not at a high standard. This can be derived from the fact that the base line is quite consistent but not optimal. When the rower used the system it needed some adjustment, but in the end gave better results. It can be said from this results that the system has a positive impact.



GRAPH 5 RESULTS ROWER5

1.3.3 Questionnaire results

Here are the questions and responses depicted which were asked during the land based test.

Question		Responses
Does this system help you with getting feedback about your rowing?	1	It is nice to have some form of quantified feedback about my rowing. However, I did need time to get used to the form of feedback (namely the colours) and how to improve. I never had good training on this part of the stroke. For me it was also annoying that I could not see if I improved while using the qualitative feedback, because I mainly got red as feedback.
	2	Never did I have a system which materialized the catch for me, which this system does. This is positive, although I do think that for it to be effective it has to be used regularly
	3	It took some getting used to, but when I was used to it, it gave some useful feedback about the stroke.
	4	Although I am not too experienced with technology in rowing, I do think that this system has given me good feedback on how I behave while rowing, so I do think it helped.
	5	Although the setup needed to be on the water, where it would be more useful, I do think that the feedback on land did prove itself effective.
Was the prototype system obtrusive?	1	Although this is a prototype with clumsy wires, I do not think it is obtrusive. I was able to row normally.
	2	I would have liked to test the system on the water, but even though that was not possible, the testing on land was good. The system was not too hindering and annoying.
	3	It was okay for a prototype. For further development it is advised to integrate the wires into the fabric.
	4	I thought that the worked well, when the wires kept in place. I can imagine that the wires will be less of a problem when they are woven into the clothes.
	5	It was not too bad for a prototype. When I was used to having sensors on my finger the rowing was not very different from normal.
Would you use it in training?	1	I think this can be helpful in training
	2	Even though I am not a fan of too much technology in training, I think this can be useful
	3	If this will work on the water I think this can be beneficial.
	4	I think that beginners do benefit from this system, because it gives them a feeling of what is good.
	5	It helped me pretty fast, so if it can help me than it will certainly help others.

What would you improve?	1	The colours were very annoying for me because I did not know if I was improving or not. However the numbers did not say much to me either. I think that I need more practise also. Background info would be helpful.
	2	I am more used to having numbers as feedback, as it is with conventional systems. Therefore I am sceptical about using colours, especially when using it on the water. However I do think the system has its benefits for rowers who are less experienced to work with the colours. The size of the electronics needs to be smaller, so this should be developed
	3	I did prefer the colours, because it helped me concentrate on the rowing more then on interpreting numbers. I do not think much needs to be improved to the core of the system. It needs further development to make it more slick.
	4	I liked the colours better, it was simpler. I do think that coaches would like the numbers better.
	5	I do think that numbers can be more useful then colours. This is my opinion, which can be influenced mostly because I'm used to having numbers as feedback. Also the system needs to be more polished: wires integrated maybe wireless?

1.4 SUMMARY RESULTS

Overall it seems that the results are positive. The difference before and after the use if the system shows a 15,855 millisecond reduce in catch-factor, which is a positive outcome. The question is if the system itself helped with getting a better result or the fact that the awareness of the technique made the difference in the results. If the results are only taken into consideration then one might think that this is the case, which would be very positive. If the questionnaire is also considered one could still argue that the system made the difference in the positive outcome of the test. But it might be the case that the fact that after they set the baseline results (the first row), and they knew what the test was for they became aware of what they needed to do and altered their performance accordingly. This is similar to the fact that when people are filling in a survey that they react in a fashion which they think is desirable. On the other hand this can only be done by those who have the skill to do so, which can be seen in the results, because of the fact that only the more trained rowers could get better results on their own.

2 WATER BASED TEST

2.1 PROTOCOL

1 Strap on wearable sensor system

2 Attach sensors, powerbank and wires to Arduino

3 Establish connection between Bluetooth module and mobile phone

4 Sensor check; check if sensors work

5 Start rowing with quantitative feedback system at stroke-rate 20

6 evaluate system and change feedback system

7 Start rowing with qualitative feedback system at stroke-rate 20

8 evaluate

9 Ask questions

QUESTIONS

- What feedback system did you prefer?
- What did you find positive about the system?
- What would you improve about the system?

2.2 SETUP

The setup for the water based test was as following

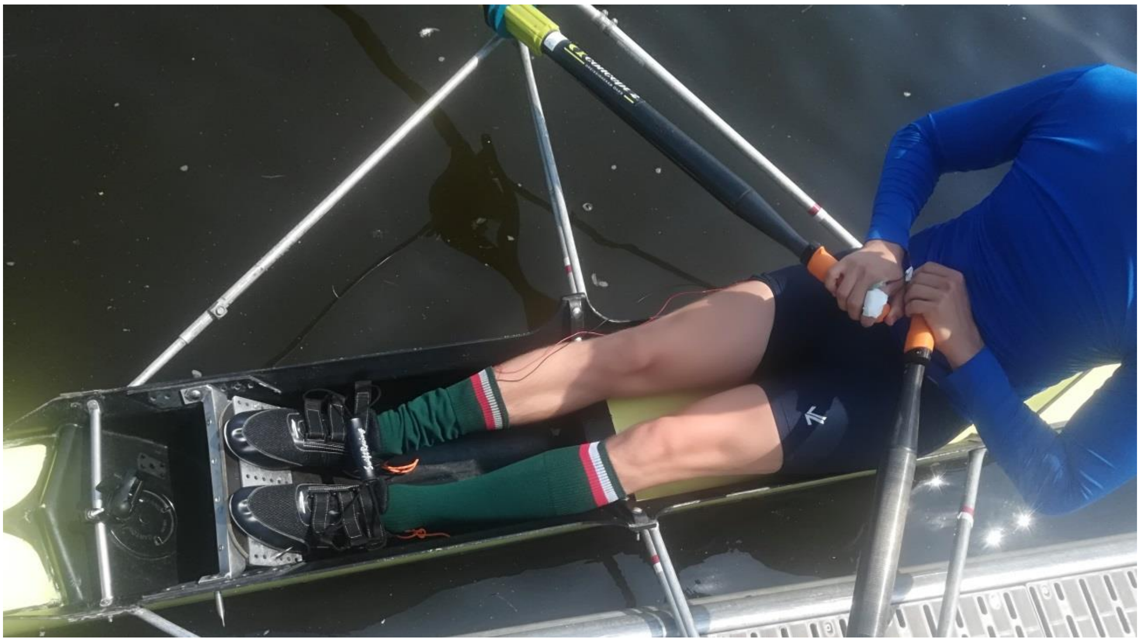


FIGURE 33 WATER-BASED TEST SETUP

FIGURE 34 WATER-BASED WIRING AND MICROCONTROLER PLACEMENT.

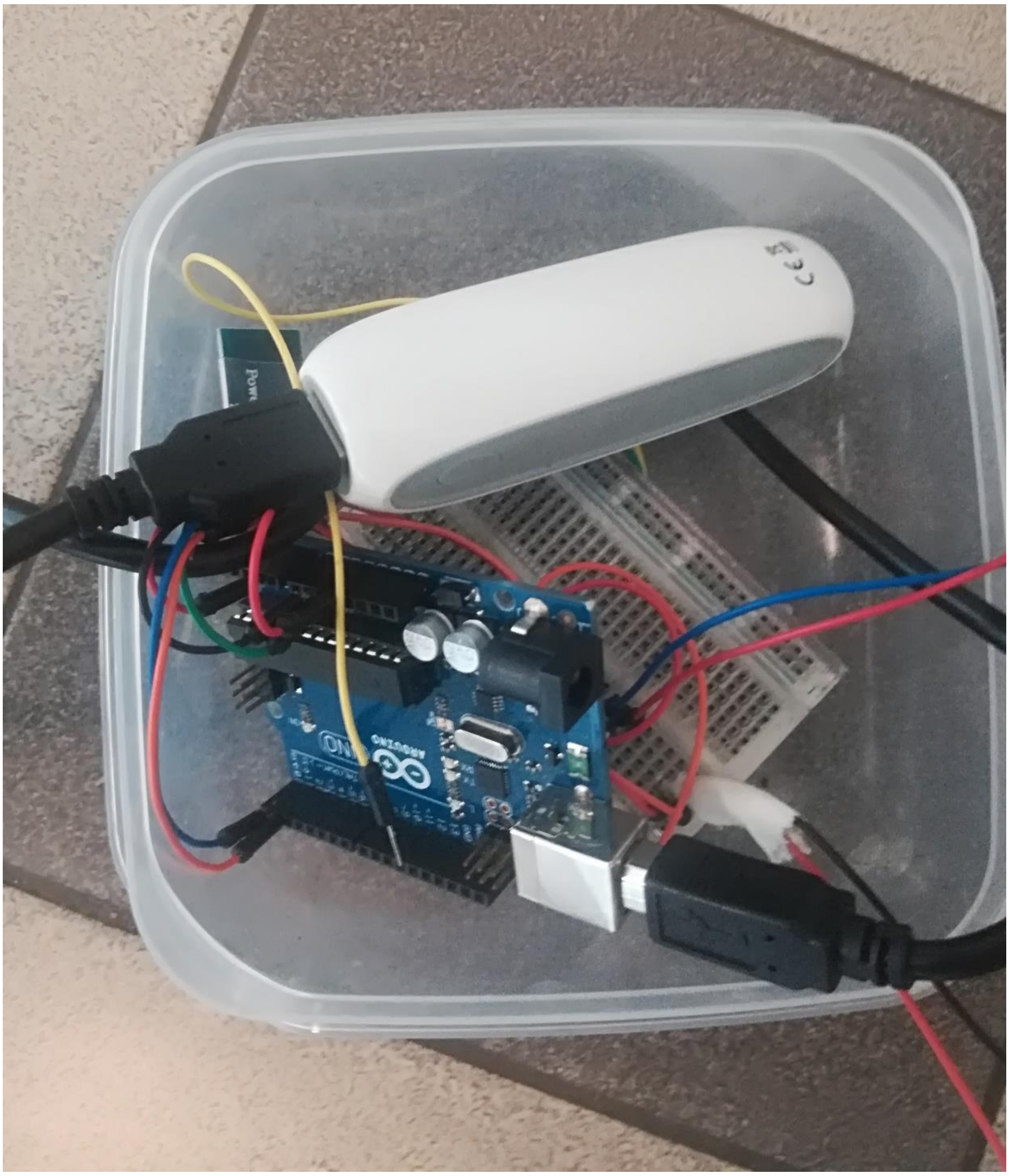


FIGURE 35 MICROCONTROLER CASING WITH BLUETOOTH MODULE AND BATTERY

2.3 RESULTS

During the process of preparing the sensors there were some questions that were raised. The first was: how should the wires should be integrated into the wearable? The second was: should there be two sensors for the hands; one for the left and one for the right? The big difference for the system between rowing on land and rowing in the boat is that the pressure build-up in the body is different for both cases. On land the build-up is nice and symmetrical where as in the boat (especially with sculling) the build-up can be asymmetrical. This means that one hand can feel pressure later than the other because the both hands act independently from one another and therefor can feel pressure on a different moment. This is an interesting part of the concept which should be looked at.

The placement of the microcontroller (Arduino) was good. The package together with the other components was not sitting in the way and did not compromise the performance of the rower. The size of the package however was cumbersome and therefore should be made smaller.

Both of the feedback systems were tested and used rowing at a steady state. The weather was sunny and cloudless during the testing which was between 14:00 and 15:00 PM. During this time of day the sun was making the reading of the screen a little difficult, however this was fixed by putting the screen of the mobile phone on maximum brightness. The colour difference between red and green was easy to distinguish. The rower which used the system was experienced because he rowed for 4 years rowing at high level. He experienced both systems useful, however he liked the quantitative feedback system better, because it was more familiar to him. After a while of testing he got familiar with the qualitative feedback system and found that he could also use that information to get his technique to a higher level. The rower acknowledged that he was biased towards the system using numbers because this was what he was used to. However he said that this would be different if he was used to qualitative feedback. The other point he made that the system is useful, but the system still needs some sort of background information which should be provided along with the feedback it gives. This can come in form of feedback which is given by the coach or through the app itself, but it should be there.

The integration of the wires is an interesting question which has to be figured out if the concept is further developed. Now the wires hang loosely in the shirt, however it might be better if these are integrated in the fabric. If so, then there should also be thought of how the garment then can be washed, and how the system is kept water proof. Maybe it is better if the sensors are made wireless.The rower was positive about the fact that the wires were not experienced at all while rowing. This means that the wires can be used with a more advanced prototype. However the system should be integrated into a wearable. But to make sure the wearable is washable the sensors and wires should be removable.

3 RECOMMENDATIONS

- Provide background information for the athletes. This can be done through the app or by advising a coach to be there when training.
- Decrease size of the microcontroller: the placement was good but the overall size was too cumbersome.
- Integrate system into a wearable: wires were not perceived as obtrusive while rowing. However the system is not a wearable yet.
- Integrate sensors for both hands: both hands are independent from one another while rowing so therefore both hands should have sensors.