Wound Device

Study and development of device for wound indicators towards VR-Technology

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Master Thesis project within Master Program Product Development

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Abstract

This report covers the work that have been done in the Master Thesis project at Master Program Product Development at Chalmers University of Technology. This includes the product development process, from idea to finished prototype, of a device that can measure wound indicators such as applied pressure and possibly send data to computer via Bluetooth protocol. It also includes research of different methods and tools used in emergency healthcare exercises within the Police, Military and Home Guard in Sweden together with result from several interviews with representatives in these different organisations as well as conducted experiments of final concept and description of developed prototype.

Keywords: Wound Indicators, Emergency Healthcare, Bluetooth Low Energy (BLE), Smart Tourniquet, Force Sensing Resistor, Microcontroller.

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Karin Albråten, Gothenburg, June 2023.

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1
Introduction

This chapter will give an overview of the company Tactisim, their background, organisation, goals and future ambitions. This chapter also gives an overview of the project and its goals.

1.1 Background

Three minutes is the estimated time it takes to bleed out and die from a large wound if no action is taken. In warfare zones this is a reality many soldiers risk to face, but also people involved in car accidents or other type of situations where there is a risk of getting large wounds and limited access to instant medical care [1].

Having the right equipment and exercises during training is essential for the chance of saving lives in real-life scenarios, which today often consist of mannequins or on peers. This also a very costly approach with often difficulties to increase the realism, with stress factors such as screams or radio traffic, without increasing cost significantly [2].

Today in the military, police and home guard a lot of focus in on the educate soldiers in emergency medical care with the method Tactical Combat Casualty Care (TCCC), which suggest that the parts of the body that are injured the most during warfare are throat, arms, legs with up to 35% of the total injuries in war. This emergency care method is based on almost 20 years of research of injuries within the US Military force when conducting war where military forces take or defend against another military group [3]. When looking at the war in Ukraine for example it shows completely different type of injuries and number of injured soldiers. In Ukraine injuries such as TBI (Traumatic Brain Injury), different types of concussions, splinter and-/or blast damages are more common. Where a big part of the splinter damages are located on parts of the body and extremities that are not protected by any safety vest. After these in numbers gun wounds come [4].

1.2 Tactisim

Tactisim is a new found startup since 2022 within the area of defense industry targeting solutions for healthcare exercises with help of VR-Technology [2].

1.3 Purpose

The purpose of the project is to investigate different possible solutions for facilitating healthcare exercises that include catastrophic bleeds within the area of military defence and police forces.

1.4 Projects' aim

The aim of this project is to model and prototype a device/ devices that monitor wound indicators that could have electrical/ wireless interfaces that could integrate towards VR-software and games.

1.5 Scope & Delimitation

In this project there was only one model and prototype built for training scenarios for catastrophic bleeding from arms and/ or legs and not real-life emergency situations.

1.6 Overview of report

This report is covering the development of a prototype of a product that could register applied pressure when applying a tourniquet. Chapter 2 is about theory behind product development process and key concepts about some emergency medical procedures, chapter 3 dives into the different methods used in the project. In chapter 4 results from the interviews conducted during the project are presented, the generating and selection of final concept is covered in chapter 5 and in chapter 6 the experiments conducted with the final prototype are presented. In chapter 7 the chosen method, the results from the interviews, market analysis, concept selection and similar patents and conducted experiments are discussed. Chapter 8 includes recommendations of future work and chapter 9 is conclusion.

2

Theory

In this chapter theory about different methods and tools used in emergency medical procedures are presented together with theory about the product development process.

There are several different methods and tools when caring for injured and sick in a pre-hospital environment, this report is covering some of them which are connected to how Swedish Police, Military and Home Guard operates.

For emergency health care methods for pre-hospital care there are several different combination of steps that should be worked through to give the patient the best emergency care possible. There are methods such as L-ABCDE [5], S-XABCDE [6], cABCDE [7]. In this report focus is on the methods S-XABCDE and cABCDE.

The use of Tourniquet is today a mean to stop catastrophic bleed in legs or arms, this is the primary tool used by many authorities such as Police, Military and Home Guard in situations where catastrophic bleeding's can occur in Sweden today [8]. Along with this tool the method Tactical Casualty Combat Care (TCCC) [3] is a method specially developed by the US military to specifically handle, among other, catastrophic bleeds in legs or arms also often used by the Police, Military, Home Guard in Sweden and therefore included in this report.

2.1 Application area

2.1.1 Algorithm S-XABCDE and cABCDE

In healthcare exercises today, both for emergency service pre-hospital and at the hospital, emergency medical training is taught after the model S-XABCDE (Safety-, Exsanguinated bleeding, Airway and cervical spine control, Breathing, Circulation, hemorrhage and perfusion, Disability, Expose/environment) which includes certain steps to be followed in order to give the most optimal emergency medical assistance when first arriving at an accident scene. This model is very similar to cABCDE where the safety (S-) step is atomically included, often used in the Military where ensuring safety of the scene is done automatically in every situation. The different steps stand for

- Safety - Safety on the scene, secure your own safety, and patient safety.
- Exsanguinated bleeding - Catastrophic bleeding that empties the wounded of blood.
- Airway and cervical spine control - Ensure the patient have free airways and do manual fixation of cervical spine.
- Breathing - Ensure ventilation of lungs/breathing.
- Circulation, hemorrhage and perfusion - Ensure there is circulation, no hemorrhage and perfusion of the patient.
- Disability - Check consciousness, if the patient can feel, motion ability, control of pupils.
- Expose/environment - Full body examination to check for other possible injuries.

During accidents there could arise possible life threatening situation depending on the type of accident that happened, for example if a car crash the vehicle could catch fire or if landslide more possible unforeseen landslides could occur after the first accident. Therefore it is crucial to first of all when arriving at an accident scene to secure the scene. The step Safety includes three sub-steps as mentioned above, Safety on the scene, secure your own safety, and patient safety [6].

The first sub-step includes first secure the scene which includes if possible remove the injured persons from the accident scene, put out possible fires near the injured person if possible. Second, secure your own safety if you have arrived to help, as for example medical personnel, if the person who is there to help take care of the injured people get injured too than he/she can't be of much help. secure your own safety is done by wearing the correct protective gears such as gloves to protect against possible blood infection, urine, vomiting or other bodily fluids the injured could have. Wear a special mask to use when performing mouth-to-mouth and googles to avoid splash of fluids in eyes. Third sub-step is patient safety, in this step examination of the patient is performed by preforming an primary and secondary examination of the injured. While examining the patient with primary and secondary examination the first thing to look for is catastrophic bleeding (Exsanguinated bleeding) and stop any of those, or the patient will bleed out in minuets and die. This is the step X in the algorithm S-XABCDE [6] which is the same as little c in the other method cABCDE [7].

In this step the rest of the algorithm is gone through ABCDE as mentioned above. The primary survey is done in maximum 15-30 seconds where the medical personnel checks for life threatening injuries where measurements can be taken. The second survey the medical personnel perform a more thorough check to make sure already applied bandages and pulse of the injured person are ok [6].

2.1.2 Tourniquet

A tourniquet is a tool to get the same effect as a loosening bandage on the extremity that is bleeding heavily [6]. A tourniquet is essentially any type of bandage, at least 1 cm wide with a stick placed between the applied bandage and the extremity and turned to apply even more pressure to the extremity. Medical personnel often use a type of commercial tourniquet (CAT-Tourniquet) that consist of a strap with Velcro which is applied above the wound as high up as possible without being placed over any joint, is pulled tight until the bleeding stop. If the bleeding don't stop when pulling the Velcro strap there is also a pin placed at the tourniquet that when turned on it tightens the strap further [9]. The Tourniquet is used if necessary during the step X (Exsanguinated bleeding - Catastrophic bleeding that empties the wounded of blood) in the S-XABCDE or little c in cABCDE algorithm to stop possible life threatening bleeding's in arms or legs [6].

2.1.3 Tactical Casualty Combat Care (TCCC)

Tactical Casualty Combat Care (TCCC) [3] is a emergency combat care method developed by the US Military after almost 20 years of research about what type of injuries soldiers sustain the most during their wars in both Iraq and Afghanistan. It is a method designed to give optimal treatment for injured of wounds such as bullet wounds to the throat, legs and/ or arms, this since these type of injuries made up 35% of the injuries soldiers died from but that they saw could have been prevented with the right tools [3].

2.2 Product Development

Product Development is about taking an idea and through a series of well defined steps turn that idea into a final product or process that is ready for the market. This development process is the same if it is a completely new product or process that is going to be developed or if there is to be continuous development of already existing product or process. Although the steps are well defined, there should be an idea, how to gather data needed, a design idea, a plan to find out which the target market of the product or process is, an assembly plan if the product or process contains different components, a manufacturing plan of the product or process, there are still many different ways in how to go through these steps and development methods differs depending on the development team. What is needed in a Product Development process is in general a plan for what different steps to go through, in which order and how to execute there different steps. For example, how should the data collection be conducted, how to sort the data gathered and turn this data into measurable and understandable requirements regarding function and/or design of the product or process that is being developed, should interviews or surveys, literature research be conducted and how to extract the data necessary for development of the product/ process [10]?

The different steps in the Product Development process is often divided into different stages with some type of gate between each stage the check if the development process is going in the right direction and to reduce number of unnecessary and possibly costly iterations between the different development phases. The different stages often include the following, first there is an idea of a product or process to be designed, then plan how to gather data for further develop the idea/ design, this data is then turned into requirements for how the different functions of product/process should be designed, after that the design process itself, what components are needed and how should they be assembled into a final design of product or process. During development process there are also many iterations and re-defining of phases and design, often since ways to improve the design is not discovered until after a model or prototype is built of the product or process and tested [10].

As mentioned above a Product Development process can be divided into different stages or phases. The first phase could be the pre-development phase which contains or idea generation stage where the idea is forming and a plan of how too make this idea into a real product or process. The next stage include data collection and market analysis about the intended target market of the product or process. Data collection can be done in various ways such as primary data collection with surveys, interviews, observations and secondary methods such as literature research, statistical analysis. The market analysis often include finding target market, finding the customers need and wants, competitors analysis. In the next stage requirement specification and concept generation is performed together with screening out unfeasible concepts. A requirement specification of the functions and design of the product or process is based on the data collection and together with market analysis gives a set of functional and design requirements for the different possible products or processes. Different possible concepts can then be generated and compared against the requirement specification too investigate which concepts meet the requirements, possible re-evaluation of requirements can also be done should some concepts seem superior in functionality or design but not fit exactly all requirements. In this phase cost calculations are also performed such as production cost, development cost and the product performance cost of different possible concepts [11]. In this stage customers can also be involved too get feedback on the potential concepts. The third phase is the development phase which would contain two stages, the development stage where designing all parts of the product or process is conducted and the test and validation stage where test and validation of the prototype of product of process is performed [11]. In the development stage a life cycle analysis (LCA) can also be performed to investigate the environmental impact the developed product or process could have during their lifetime. Here a end of life-cycle cost would also be included, how and the possible cost for disposing of the product or process after end of usage, end of life cycle [12]. In the test and validation stage the end user could be brought into the development process for additional feedback. In general, involving the customers in every step of the development process is a good way to get feedback too see if the development is going in the right direction to capture the intended target market. The last phase is manufacturing or launch phase where the new developed product or process is manufactured in intended selling volumes and prepared to be transported to reach the target market [11].

In all of the stages as mentioned above it is important to listen to the voice of the customer during the product development process have been increasingly important over the years, this due to research shown that involving the customer early on in the development phase can steer the development of the product(s) into something the customer wants and are willing to pay for. This would raise the customer satisfaction and thus give higher market shares, more customers willing to purchase the product when launch to market if they feel involved in the development process in some way. This according to a more and more popular product development method that is used more often today Design Research Methodology (DRM) [13].

In each development phase the three pillars of sustainable development is also incorporated, economic, social and environmental. These three pillars where created as a framework of sustainable development goals (SDG) by the United Nations Department of Economic and Social Affairs (UNDESA) in 2015 to incorporate goals for all membership countries to work with for building a more sustainable planet now and in the future [14]. The three pillars act as a framework of what to consider in each phase during the development process, for example in every phase from idea to manufacturing phase the economic aspect should be considered, how to lower cost and maximize profit but also in relationship with how would the product or process impact the society during development and after release to the market, how will the use of the product or process impact the daily life of the people using it and in the society around them, and together with what environmental impact would for example design, choice of material, transportation of raw material, manufacturing methods when developing the product or process [12].

2.3 Research Motivation

In healthcare exercises today the only way to know if a Tourniquet is applied correctly is if the instructor says it is. This since during exercises there is no catastrophic bleeding in legs or arms that will stop when the Tourniquet is applied with the correct pressure. There is no to very few devices existing today that register the applied pressure of the Tourniquet on any extremity and therefore the right pressure is based upon the instructors knowledge and experience. Knowledge and experience can be different depending on where the exercises takes place and therefore there is need for more standardised way of how to measure when a Tourniquet is applied correctly with the right pressure.

3
Method

In this chapter the research question and the different methods for data collection are presented as well as theory behind the different methods.

3.1 Research question

The Research questions meant to be investigated in this report are listed below, where the first one is about product development process early stages with data collection and prototyping hardware that can collect specific data and the second research question is about how to transfer this data wirelessly.

- How to model a device that could monitor wound indicators in situations where there is catastrophic bleeding in arms or legs.

- How to build and prototype device that integrates electronic circuits that could send data over Bluetooth.

3.2 Method Theory

3.2.1 Design Research Methodology (DRM)

Design Research Methodology is a framework for how to conduct product development process where focus on customer satisfaction is a key point. It is important during a development process to establish several measurable success criteria too evaluate if the development of the product of process is going in the right direction. One measurable success criteria is customer satisfaction as mentioned above, others could be time-to market, quality of product but also number of modifications done during the development process, which could indicate the quality of the pre-work and planning conducted before staring to screening and scoring different concepts into choosing a final one [13]. The methodology can be divided into four main stages Research clarification, Descriptive study 1, Prescriptive study and Descriptive study 2. Each of theses stages can be considered to be used in product development process where the first stage Research clarification is about clearly define a research question to answer which can be a problem to solve, for example it could be how to build a product in a certain way. It also contains defining preliminary measurable success criteria such as for example the ones mentioned above customer satisfaction, time-to market, quality of product and number of modifications. This stage can be considered the planning phase in product development process where a project plan is formulated and execution of how and when all the different phases are to be done with deadlines and milestones [13]. In the stage Prescriptive study here the success criteria that are going to the measured through the project is set, it could be the same as in the previous stage Research clarification but it could also differ some depending on the available tools and methods, resources that are now defined for the project's disposal. In the third stage Prescriptive study the data collection is done with potential interviews and more extensive literature research, here development of support for the development process is initialized, such as what methods to use for facilitating the potential concept screening, scoring and selection. In the last stage evaluation of the methods, chosen concepts and also the success criteria. What quality did the development process hold, what could have been done better etc. In this last stage closure of the project can be considered to be done [13].

3.2.2 Semi-structured interviews

Semi-structured interviews are a type of interview where the interviewer ask open-ended questions to the interviewee, to make to interviewee give explanations and wide descriptions of the answer rather than questions which can only be answered with a yes or no answer. The questions at first have a wider scope to during the course of the interview be narrowed down to the core questions [15].

3.3 Applied Method

In this project both qualitative and quantitative study has been used for data collection where literature research and interviews have been qualitative research to gather data about existing practises and technology and the conducted experiments quantitative research to gather different numeric data. The data collection have been conducted with primary research methods such as interviews and experiments of concept and secondary research methods such as literature research. The research design is flexible, concept is developed during the duration of the project [13].

In this project a model and prototype of a monitoring device for wound indicators was developed. A prototype of a device that can measure wound indicators during catastrophic bleeding from arms and/ or legs and capture and possibly transfer data via Bluetooth was developed.

A literature research was conducted to investigate what type of training devices that exist and how practices are today when it comes to monitoring wound indicators for catastrophic bleeds in arms and legs.

Several interviews where conducted with representatives of the company Tactisim as well as different personnel within the Swedish Police force, Military, and Home guard such as coordinator of Advanced Medical Training within Catastrophic medicine, ambulance nurses educating in emergency medicine in Police force, Coordinators of basic training within Police force, specialized nurse educating in emergency medicine in military forces, specialized nurse responsible for emergency medical training within Swedish Armed Forces, specialized nurse educating within emergency medicine in the Swedish Home guard. This to gather data about how healthcare exercises are done today and how they could be improved within these different areas, both military and civil.

Several experiments where also conducted to test the product concept and investigate possible improvements.

3.4 Ethics

In this project a model and prototype is planned to be created for training purposes which monitor wound indicators on a mannequin or peer during training session. The device is planned to have a electrical interface which could capture and send data via Bluetooth. Since the device is planned to monitor wound indicators at the precise location of the simulated wound there will be no sensitive information gathered by the device and with that no ethical aspects to consider regarding capture and transferal of data in this project. There is also no ethical aspects to consider if this device would facilitate knowledge about emergency healthcare exercises and thus also contribute to that, for example, soldiers with this knowledge gained during these exercises with this product continued to conduct war since this is solely a prototype that would monitor wound indicators. To use this to, for example, a weapon the thing to do would be to not do any emergency medical measurement on wounded person at all, which is something this device would not contribute to give knowledge about during exercises.

4
Results

In this chapter the data gathered during market analysis and interviews are presented.

4.1 Market Analysis

Target market for the product are the three different authorities Police, Military and Home Guard in Sweden, this since the Company Tactisim have been targeting these areas and the product is developed in collaboration with the company.

4.1.1 Competitor Analysis

There are a few companies who manufacture devices that can measure applied pressure when using Tourniquet. All of these companies sell wound models that have a pump system with liquid connected to them, to simulate fake blood coming out of the wound although none of them have a digital display or possibility to connect to one to register the applied pressure when applying for example a tourniquet. Only one of the companies sell a product specially designed to measure pressure applied from CAT-Tourniquet often used by the Police, Military and Home Guard in Sweden and as the one used in this project.

MedicFX, an Australian company that manufacture and sell realistic wound models used for training simulation of emergency medical care. The company manufacture and sell silicone models with realistic wounds that can be used for healthcare exercises, among these a wound model of leg that bleed when pumping a bottle filled with liquid connected to the leg. On this wound model a tourniquet can be applied during simulation of healthcare exercises with catastrophic bleeding [16].

TruCorp is a company in Northern Ireland specializes in realistic wound models as the previously mentioned company MedicFX. The difference from MedicFX is that the models that TryCorp develops also have the ability to move with the help of a mechanical system instead of being a piece of silicone leg that lay still on the ground with pump system connected to it [17].

MediQuip is an Australian company that specialize in medical equipment for healthcare sector, simulation and wound models, veterinarian sector. The company have a wound model of a bleeding arm with sleeve on, to have the appearance of an arm being torn off. The arm stump is connected to a pump system with liquid and a tourniquet can be applied on the arm [18].

CHIsystems is a company based in the USA manufacturing product for US government and military and have a developed a wound model of a leg with a digital display built into it. On the wound model a tourniquet can be applied and the digital display show the applied pressure, the time the tourniquet have been applied, how the patients (wound model) status is and if the tourniquet is applied in the right place [19].

4.2 Interviews

For data collection interviews where conducted with different personnel working within the Military, Police and Home Guard as mentioned in chapter 3. During these interviews it became clear that healthcare exercises within the Military, Police and Home Guard are conducted very similar with focus on going through the model with the different steps mentioned above. It also became clear that there are several differences between how the healthcare exercises are conducted, what tools are used and the goal of the exercises depending on what educational facility is holding the exercises. For example at one facility there is extensive use of fake blood when simulating wounds and injuries during exercises and in a another facility there is almost no fake blood used at all. The exercises also vary from a few hours up to several days depending on if the exercise is held within Military, Police or Home guard. Tools often used in all three departments are fake blood, tourniquet, wound packing bandage with a box to pack in, actors to play people with different injuries for the students to practice their medical emergency training on. Other tools used more in basic technical training is sticky notes to put on the area where the simulated wound is and have to instructor tell a narrative about what type of wound it is to the students.

During the exercises it is also important to incorporate a degree of realism so that the exercise situation is as similar to a real accident situation as possible, this too better prepare the students for how to act in real life threatening situations and how to perform their future job. Some tools used that are used, as mentioned above, to create realism is fake blood, where a bottle is filled with fake blood and someone is manually squeezing the bottle to simulate blood flowing out of a wound. The fake blood is also sometimes heated to give even more realism to the exercise since when a injured person is bleeding in reality after an accident the blood is often body temperature instead of cold direct from the fridge.

4.2.1 Police

Within the police basic training the students get up to 36 h of pure healthcare exercises during e period of 2.5 years incorporated in lessons with only medical emergency training but also incorporated in other major exercises about for example how to act when arriving at accident scenes like pub brawl, car accident, a dispute where people have gotten physically hurt by example fists, knives etc. Different tools that are used often differs between different educational facilities, for example one facility use a lot of fake blood and actors during emergency healthcare exercises, but also wound packing bandage with a box to pack in. While another facility let the students pack bandage in each other hands or transparent PET-bottles where it is visualized clearly if the packing is airtight or not, this too ensure that the students learn to pack wound correctly. They also don't use actors as much since it is very time consuming to set up according to one interviewee. They also use less fake blood since they find it difficult to get the students to visualise the right wound and measure for it, for example the instructor use fake blood to simulate a catastrophic bleed which requires to put on a tourniquet but the student think it is not enough blood and perform another measure instead.

A lot of the exercises the students do they do on each other or themselves to experience and get understanding for what they will do to others in their future profession. This involves for example to put on Tourniquet on themselves and each other, which can be extremely painful but also save lives when a person have a catastrophic bleeding in arms or legs. They also get to learn to often put on more than one tourniquet on a leg since one tourniquet is often no enough to stop a catastrophic bleeding in leg. When applying tourniquet on simulated catastrophic bleed on arms or leg the students during training learn how to apply it above the simulated injury and then wait for the instructor to come and check if it is applied correctly with the right pressure. Today during training the right pressure is checked by the instructor who apply one/ two fingers between the tightened tourniquet and the simulating wounded person's leg, if one/ two fingers can be put in between the tourniquet is not tight enough. After finished training the students at Police basic training should be able to apply a tourniquet within 30 s. In the Police basic training the instructor check the tourniquet and loosen it after maximum 5 minutes and the person who has the tourniquet on him/ her is also allowed to walk a short distance of maximum 50 meters just to get and understanding of how the applied tourniquet limit the ability too continue moving around and also to perform one's job as a police.

What also came up during the interviews was that it is difficult to get high realism during the exercises since for example doing chest compression on an elderly person in their nineties is easier, less resistance, compared doing chest compression on a young person in their twenties that just been dragged up of an ice cold lake. Also when applying the tourniquet you have to apply more or less pressure depending on if the injured person have bigger och smaller arms and/ or legs. It all depends on the injured persons physiology and it is difficult too simulate all this during emergency medical training within all of the different departments.

4.2.2 Military

According to one interviewee the exercises within the Military are conducted to give the military personnel a little bit broader emergency healthcare training this since, in a military context such as for example in war zone, the soldiers cannot rely on a ambulance to come a pick up the injured person as the police can civil context where there is always an ambulance responding to the accident scene. In a Military context the soldiers have to transport the injured back from the accident scene to a secure location themselves.

The Military healthcare system is build up with several different levels from the basic group of soldiers, 6-8 people where one is a combat medic soldier who's primary job it is to act as a soldier, but when someone get injured he/she can perform life saving measurements as for example pack a bleeding wound, apply thorax bandage, apply tourniquet, apply needle to let out air of over pressured lungs, and thus have the medical training to keep the injured person alive for a longer period of time. The next level is a medic group with a combat nurse, ambulance driver, a medic and a group leader, who act as a Military ambulance, with the ability to, for example, distribute medicine. This group take care of transport of the injured person back from injury site toward a more secure place where more advanced medical treatment can be performed, and from this site the injured can either recover or be transported to a hospital if needing surgery.

The basic soldier get 1 week of medical emergency training whilst the group medics get about 6-8 weeks of specialized medical emergency training. And the combat nurse who is often a nurse in the civil context but specially trained as a combat nurse have the same amount emergency medical training as a civil nurse.

According to the interviewee 35% of injuries in war are injuries on arms, legs, throat, which makes exercises in how to stop catastrophic bleeding from theses areas high prioritized during a basic emergency healthcare training on a basic soldier level, since these are the injuries most soldiers die of. The basic soldier training is also only conducted during 10 months with a lot of other important exercises like how to handle weapons etc which makes it even more important to prioritize in what exercises and what tools to use to teach at basic emergency training for soldiers.

The Military also work after the algorithm CABCDE compared to S-ABCDE as mentioned earlier in chapter **??** which put Catastrophic bleed as a first priority to check for before anything else. Within the Military as within the Home Guard it is implied that the situation the soldiers are in are always unsecured so therefore the step Safety in the algorithm is already incorporated automatically and what the medical personnel are suppose to focus on as a first step in the algorithm is therefore C - Catastrophic bleeding.

During healthcare exercise within the Military tools such as fake blood is used frequently, sleeves looking like a wound are put on a person and connected a bottle with fake blood that is pumped manually to simulate gushing of blood out of the sleeve wound. Actors specialized in acting injured are also used to some extent in different healthcare exercises, although this is a more expensive cost. A human sized doll filled with sand is used in some healthcare exercises where the instructor points out the simulated wound and the students are to do the correct measure. There are also model with integrated wounds onto which a bottle with fake blood can be connected. The students learn how to apply a tourniquet on themselves and their fellow student and the instructor check that it is applied correctly and loosen it after maximum 1 minute. The goal is that the students should be able to correctly apply a tourniquet within 60s.

One interviewee mention that the realism is difficult to get during exercises due too even if there is a person laying on the ground screaming with fake blood around him/ her the student who are training on emergency medical procedure still knows it is an exercise. The interviewee also mentioned that the highest psychological realism during an exercise is still gotten with an actor playing injured and that have the ability to use his/her whole register of emotions. The exercise with the most physiological realism is when for example apply tourniquet on a person instead of a doll or model so that you can feel the lack of pulse under the simulated wound after applying the tourniquet correctly. A tool the interviewees spoke of that could benefit realism would be a wound model, where if you would press on the simulated wound it wound stop bleeding. In one education facility a human sized doll with both legs amputated where blood is gushing out during exercise is used to enhance realism, this have shown to be very positive according to one interviewee since when practising emergency care like wound packing, applying tourniquet etc on the doll the students don't look for the instructor to say when they're done but always try too really look at the simulated injury and apply correct measurements to stop the simulated bleeding which makes the students learn better. One way to increase knowledge and also in extent realism is to let the student practice with for example applying tourniquet repetitively in different conditions such as stress, fatigue, in darkness, physical exhaustion, this since it is more realistic to be in one or several of these states if you would perform emergency healthcare in a war zone as a soldier. The interviewee also mention the development of an exercise environment with smells, sound, visual impression and other different stimulus to enhance realism during exercises. If for example the soldiers would know the sound of artillery fire from exercises they might not be so shook by it if encountering it in a war zone when they're suppose to give emergency healthcare to injured people. As well as the stress that is often experienced when there are shootings around you.

To simulate the stress today the interviewee say that they let the soldiers run a short distance to get the pulse up. Although this is not ideal at all according to the interviewee since when running and get short of breath one loose oxygen since it it consumed by the muscles and thus also loose cognitive functions which are used to assessed the situation. One might not make the accurate assessment if one is short of breath as one would coming in calm to a situation and can without stress assess it. The interviewee says they try to incorporate different stressful sounds such as for example children screaming, sound of gun fire and the sudden appearance of perpetrators at the scene to increase the stress level in the exercises instead of letting the students run to increase stress level.

Another difficulty the interviewee mention is how to know for example when a tourniquet is applied correctly, as for now during exercise the student apply a tourniquet and the instructor measure if the pulse disappear on the extremity below the tourniquet. This method however is not the most accurate since even if there is no pulse there could still be blood flow in the extremity, the pulse is just low enough that it is not detectable and thus the person can still bleed out. Usually if there is no pulse in toady's exercise the students are taught to turn one extra turn on the stick on the tourniquet just to be sure that the blood flow would stop.

Another important things that is difficult to simulate in toady's exercises is the fact that the injured person often tries to remove the applied tourniquet on their own due to the extreme pain it gives. It is difficult to simulate since the tourniquet are only allowed to be applied for maximum 1 minute compared to in for example war situations where a tourniquet can be applied for up to two hours which during this time the injured often tries to remove it due to the extreme pain it gives.

The interviewee also mentioned that if Sweden would go to war it could look a lot like in Ukraine and we would be likely not well prepared. This since the emergency medical training that's is conducted within the Military is based on the concept TCCC which is taken from years of research within the American Military who conduct military operations where soldiers is sent to a place to do a military task against other military forces and which often result in the type of injuries such as catastrophic bleeding on throat, arms, legs up to 35% of all injuries are these. When compared to Ukraine where two different states shoot with artillery fire, robots which gives a whole other type of injuries like for example major injuries at thorax and/ or legs according to the interviewee. There are also shockwave injjuries where soldiers are thrown in the air by blast form artillery and bombings which often result in head injuries, bleeding in abdomen and the amount of injuries a larger in Ukraine than the numbers shown in the research about TCCC.

This makes the number of 35% injuries is done to the throat, arms, legs somewhat inaccurate and thus emergency medical training conducted according to this would give little preparation for the soldiers in case of possible future war.

4.2.3 Home Guard

In the Home Guard training the emergency medical training look a bit different, the students get education about how to care for a person from injury site until ambulance arrives for 9 days during two different periods. It also done in setting like forests and not so much fake blood us used during this exercises since it takes a lot of time to clean according too one interviewee. During medical training sticky notes are often used to mark the spot where the simulated wound is and the instructor also give a description about how the person got injured and what type of injury it is. This does not give much psychological or physical realism to the exercises although it is lower cost for material supply. The Home Guard work after the algorithm cABCDE which put Catastrophic bleed as a first priority to check for before anything else, the step Safety is automatically incorporated in the algorithm the same way as mentioned above when going through it as within the Military. The Home Guard also use wound packing bandage with box to pack it in and tourniquet which is applied for maximum 1 minute before the instructor check that it is applied correctly and loosen it.

5

Product Concept

In this chapter the idea generation, requirement list, concept generation and final concept is presented followed by different similar patents.

5.1 General Requirement Specification

After data collection a number of requirements where listed, seen in the table below.

Table 5.1.1: *General Requirement Specification*

General Requirement specification						
No	Criteria	Justification	Evaluation method	Marginal value	Ideal value	Requirement/Desire (1-5), where 5 being the most important
1	should be able to measure which pressure is applied when putting pressure with hands or putting on tourniquet	Measuring pressure gives indication on vwhen to stop applying pressure	Research, Experiments	acc ± 10%	acc ± 0%	R
2	should be able to measure the time from when the torniquet/ hands are applying pressure until the torniquet is correctly fastened with the right pressure	Measuring the time can give indicationvon when to stop applying pressure	Research, Experiments	-		R
3	Should be able to measure if pressure is applied in the right place on arm or leg	Can give indication of if pressure is applied at a distance enough to have effect in stopping blodflow	Research, Experiments	-	-	D3
4	Should be able to send data to either computer/tablet, VR-headset via Bluetooth connection	Enable device to be used without being connected with cables to computer	Research, Experiments	-	-	R
5	Should be able to be powered wirelessly	Enables uasge without need of being connected with cables to computer, tablet, VR-headset	Research, Experiments	-	-	R
6	should be able to measure within range 0-270 mmhg	This due to in project maximum pressure needed to stop bleeding is 250 mmhg	Research	-	-	R
7	should be able to be used 1 time/ halfday (2 times/ day) for 365 days/ year	The approximate time for basic exercises with tourniquet	Research	-	-	R
8	should be able to be used indoor environment, 20 °C	The excersises are conducted in a indoor environment	Research	-	-	R
9	should withstand liquid	Fake blood are often used in exercises	Research, Experiments	-	-	R
10	should be easy to handle	customers should not need advanced technical knowledge for usage	Research, Experiments	-	-	R

5.2 Idea generation

In idea generation brainstorming method was used to generate as many different ideas as possible of different possible concepts, based on the General requirement specification.

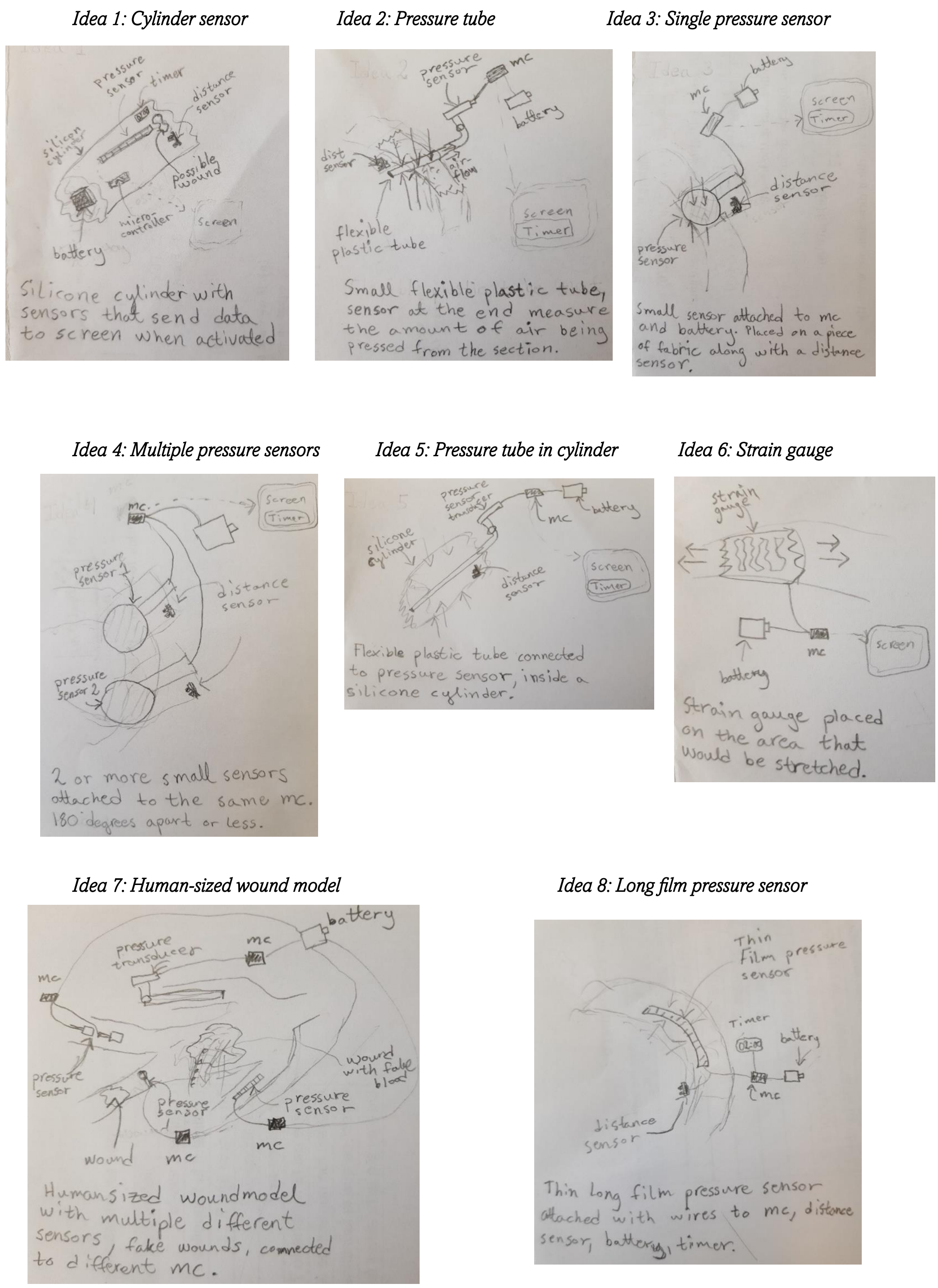


Figure 5.2.1: *Ideas with sketches and explanation*

5.2.1 Idea Evaluation

Evaluating the different ideas was done with the help of Elimination matrix where one solution where eliminated as seen in the table below.

Table 5.2.1: *Elimination matrix*

Elimination matrix						
Solution alternative	Solve main problem	Fulfill all requirements	Realizable	Reasonable cost	Safe	(+) Fufill criteria (-) Don't fulfill criteria (?) Need more information ● Continue ● Discard Decision
Idea 1	+	+	+	+	+	
Idea 2	+	+	+	+	+	
Idea 3	+	+	+	+	+	
Idea 4	+	+	+	+	+	
Idea 5	+	+	+	+	+	
Idea 6	+	+	+	+	+	
Idea 7	+	+	+	-	+	
Idea 8	+	+	+	+	+	

After eliminating inferior solutions with the different possible concepts where evaluated compared to a reference solution how well they fulfilled the different criteria. After evaluation four concepts where selected:

- Idea 2: Pressure tube
- Idea 3: Single Pressure sensor
- Idea 4: Multiple Pressure sensors
- Idea 8: Long film Pressure sensor

Table 5.2.2: *Pugh matrix*

Criteria	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 8
Measure Pressure	-	0	-	-	DATUM	+	-
Measure Time	+	0	0	0		+	+
Send data via BLE	+	0	+	+		+	+
Powered wirelessly	0	0	0	0		0	0
Measure within range	0	0	0	0		0	0
Ability to use daily for 1 year	-	+	-	-		-	-
Ability for usage in indoor environment 20°C	0	0	0	0		0	0
Water resistant	+	+	+	+		-	+
Easy to handle	-	-	+	+		-	+
Σ+	3	2	3	3	0	3	4
Σ-	3	1	2	2	0	3	2
Σ0	3	6	4	4	9	3	3
Total	0	1	1	1	0	0	2
Ranking	3	2	2	2	3	3	1
Decision	Eliminate	Keep	Keep	Keep	Eliminate	Eliminate	Keep

To further eliminate concepts and find the best solution scoring was done with the help of Kesselring matrix. The table below show the relative importance of the different criteria compared to each other where 0 means the criteria is of less importance, 0.5 means it is of equal importance and 1 means it is of greater importance. Each criteria get a weight based upon their summed score divided by the total summed scores of all criteria. For example criteria "Measure pressure" have a summed score of 8, this gives the weighted score of

$$\frac{8}{8+5.5+1+0.5+7.5+2.5+4.5+5+2} = 0,219.$$

Table 5.2.3: *Weights for Kesselring matrix*

Criteria	A	B	C	D	E	F	G	H	I	Σ	Σrel
A (Measure pressure)	-	1	1	1	1	1	1	1	1	8	0,219
B (Measure Time)	0	-	1	1	0	1	1	1	0.5	5,5	0,151
C (Send data via BLE)	0	0.5	-	0.5	0	0	0	0	0	1	0,027
D (Powered wirelessly)	0	0	0.5	-	0	0	0	0	0	0,5	0,014
E (Measure within range)	0.5	1	1	1	-	1	1	1	1	7,5	0,205
F (Daily usage for 1 year)	0	0.5	1	1	0	-	0	0	0	2,5	0,068
G (Usage indoor environment 20 °C)	0	0.5	1	1	0	1	-	0.5	0.5	4,5	0,123
H (Water resistant)	0	1	1	1	0	1	0.5	-	0.5	5	0,137
I (Easy handling)	0	0	0	0	0	1	0.5	0.5	-	2	0,055

Table 5.2.4: *Kesselring matrix*

Kesselring matrix											
Concepts →		Ideal		1		2		3		4	
Criteria	w	v	t	v	t	v	t	v	t	v	t
Measure pressure	0,219	5	1,095	4	0,876	4	0,876	4	0,876	3	0,657
Measure Time	0,151	5	0,755	3	0,453	3	0,453	3	0,453	4	0,604
Send data via BLE	0,027	5	0,135	2	0,054	4	0,108	4	0,108	4	0,108
Powered wirelessly	0,014	5	0,07	1	0,014	5	0,07	4	0,056	5	0,07
Measure within range	0,205	5	1,025	5	1,025	5	1,025	5	1,025	5	1,025
Daily usage for 1 year	0,068	5	0,34	3	0,204	2	0,136	2	0,136	2	0,136
Usage indoor environment 20 °C	0,123	5	0,615	4	0,492	4	0,492	4	0,492	4	0,492
Water resistant	0,137	5	0,685	2	0,274	3	0,411	3	0,411	3	0,411
Easy handling	0,055	5	0,275	1	0,055	5	0,275	4	0,22	4	0,22
Σt_i		5		3,447		3,846		3,777		3,723	
Standarddeviation		0,372365748		0,365359754		0,335662777		0,34110299		0,316515008	
T/T_{max}		1,00		0,69		0,77		0,76		0,74	
Ranking		-		4		1		2		3	

As seen in the table above once concept was selected with the highest score, "Single pressure sensor".

5.3 Requirement specification for Single pressure sensor

In addition to the general requirements listed in chapter 5.1 some specific requirements were listed for the concept Single Pressure sensor as seen in the table 5.3.1 below.

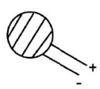
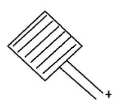
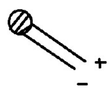
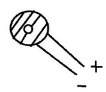
Table 5.3.1: *Requirement specification Single Pressure sensor*

Requirement specification Single Pressure sensor						
No	Criteria	Justification	Evaluation method	Marginal value	Ideal value	Requirement/Desire (1-5), where 5 being the most important
1	Should be able to be detached from Tourniquet or hand easily when no pressure is applied	For easy handling and portability	Research, Experiments	-	-	R
2	Should have a switch to turn on and off	For safety and duration, less risk of overheating and battery last longer	Research, Experiments	-	-	R
3	Must be able to be bent without functionality affected	Area where measuring pressure on arm/ leg is often curved	Research, Experiments	-	-	R
4	Should be able to be used on both human and wound model	Exercises when applying pressure can be done on both humans and wound models	Research, Experiments	-	-	D5
5	Should be able to be dropped on the ground without breaking	Need to be durable if used often	Research, Experiments	-	-	R
6	Should be able to be cleaned without functionality affected	Sometimes fake blood is used in exercises which can then cover the device	Research, Experiments	-	-	R
7	Should be easy to handle/carry	Heavier/ bulkier device will difficult to use with Tourniquet	Research, Experiments	-	-	D5

5.4 Concept generation

During the concept generation different possible solutions for each functional requirement where combined into several different concepts. In the Morphological matrix below all possible sub-solutions are listed.

Table 5.4.1: *Morphological matrix Single Pressure sensor*

Morphological matrix - Single Pressure sensor						
Subsystem	Subsolutions					
	S1	S2	S3	S4	S5	S6
Measure pressure at applied area	 Thin film force pressure sensor Long (D 1.5 cm)	 Thin film force pressure sensor (4.0 x 4.0 cm)	 Small head film sensor (D 0.5 cm)	 Thin film force pressure sensor short (D 1.5 cm)	 Thin film force sensor with hole (D 2.0 cm)	
Measure time from when applying torniquet/ pressure with hands until correct pressure is applied	Digital stopwatch with lace	Timer in program that run the mc, print in serial monitor	Digital table alarm clock	Wrist watch	External monitor connected to program that run the mc	
On/Off switch	Button connected to sensor	Switch connected between mc and battery	App on phone			
Read/ store data from sensors	Arduino UNO microcontroller	Seeed XIAO BLE nRF52840 Seeed Studio microcontroller (intagrated bluetooth module)	Arduino Nano microcontroller	Arduino MEGA microcontroller	Arduino MKR WiFi 1010 (integrated bluetooth module)	Bluno Beetle DFRobot
Send data via bluetooth to computer/tablet/ VR-headset	Arduino Bluetooth module HC-05 HC-06	Seeed XIAO BLE nRF52840 Seeed Studio microcontroller (intagrated bluetooth module)	DSD TECH HM-10	DFRobot bluetooth module DFR0781	Arduino MKR WiFi 1010 (integrated bluetooth module)	RN4871U-V/RM118
Powered wirelessly	AAA Battery	AA Battery	C Battery	9 V Battery	CR2032 Battery	AAAA Battery

5.5 Concept Evaluation

In total 16200 possible concepts can be generated from the Morphological matrix of Single Pressure sensor. To eliminate unfeasible concepts and inferior solutions a screening was conducted where the different inferior solutions were screened out. The possible concepts left where are shown in the table below along with their score in a Pugh matrix as seen below to narrow it down further.

Table 5.5.1: *Possible concepts of Single Pressure sensor*

Morphological matrix - Single Pressure sensor						
Subsystem	Subsolutions					
	S1	S2	S3	S4	S5	S6
Measure pressure at applied area	Thin film force pressure sensor Long (D 1.5 cm)	Thin film force pressure sensor (4.0 x 4.0 cm)	Small head film sensor (D 0.5 cm)	Thin film force pressure sensor short (D 1.5 cm)	Thin film force sensor with hole (D 2.0 cm)	
Measure time from when applying torniquet/ pressure with hands until correct pressure is applied	Digital stopwatch with lace	Timer in program that run the mc, print in serial monitor	Digital table alarm clock	Wrist watch	External monitor connected to program that run the mc	
On/Off switch	Button connected to sensor	Switch connected between mc and battery	App on phone			
Read/ store data from sensors	Arduino UNO microcontroller	Seeed XIAO BLE nRF52840 Seeed Studio microcontroller (intagrated bluetooth module)	Arduino Nano microcontroller	Arduino MEGA microcontroller	Arduino MKR WiFi 1010 (integrated bluetooth module)	Bluno Beetle DFRobot
Send data via bluetooth to computer/tablet/ VR-headset	Arduino Bluetooth module HC-05 HC-06	Seeed XIAO BLE nRF52840 Seeed Studio microcontroller (intagrated bluetooth module)	DSD TECH HM-10	DFRobot bluetooth module DFR0781	Arduino MKR WiFi 1010 (integrated bluetooth module)	RN4871U-V/RM118
Powered wirelessly	AAA Battery	AA Battery	C Battery	9 V Battery	CR2032 Battery	AAAA Battery
	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6

Table 5.5.2: *Pugh matrix - Single Pressure sensor*

Criteria	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6
Easily detached from Tourniquet	0	0	0	0	0	D A T U M
Easy On/Off Switch	0	-	-	0	0	
Bendable without loosing functionality	+	+	0	-	+	
Usable on both human and model	0	0	0	0	0	
Resistant to bumps, being dropped	0	0	+	0	+	
Ability to be cleaned without functionality affected	+	+	-	-	+	
Easy handling/ carrying	-	-	+	-	+	
Σ+	2	2	2	0	4	0
Σ-	1	2	2	3	0	0
Σ0	4	2	3	4	3	7
Total	1	1	0	-3	4	0
Ranking	2	2	3	4	1	3
Decision	Keep	Eliminate	Eliminate	Eliminate	Keep	Eliminate

5.6 Concept Description

In this chapter the selected concept is described.

This device is meant to be used in, the future, together with VR-simulation of a scene of injury where a person is laying on the ground with catastrophic bleeding from arm(s) or leg(s) and another acting as a medical emergency personnel. During the healthcare exercise the person acting as medic will wear the VR-headset, the person laying on the ground acting as injured with some mark on arm or leg indicating placement of injury. The medic see in the VR-headset a person laying on the ground with catastrophic bleeding from arm or leg and the apply a tourniquet on the injured extremity of the real person with the wound device placed between the extremity and tourniquet. The wound device then continuously send pressure readings to the VR-headset, where in the VR-headset the pressure readings are shown, not as numbers but, as a change of simulated blood flow gushing out of the injury. The more pressure the tourniquet is applied with on the real person the higher pressure the wound device register, and in the VR-headset the blood flow gushing out of the wound is seen decreasing.

5.6.1 Single Pressure sensor

The sensor chosen for the concept was a force sensing resistor (fsr sensor) which is a sensor that measure the resistance in Ohm when force is applied on it. The more force is applied on the sensing surface the less resistance the sensor register. It is built of semiconducting materials with one active area which register applied force as decrease in resistance, one adhesive layer which holds the active contact surface together with the conductive film that enable decrease in resistance when applied force increases [20].

The system used for reading the measurements from the fsr sensor was a microcontroller, which is a self contained integrated circuit system with a central processing unit (CPU), memory for storing the execution code written with compatible software and one memory that holds the data collected when the code is executed [21].

To try and send data wirelessly Bluetooth Low Energy protocol is used since this protocol is compatible with applications that have limited battery supply. The battery consumption is reduced since BLE technology are going to sleep mode between operations compared to classic Bluetooth technology that were designed for continuously sending data [22]. When using BLE protocol there is need of a BLE peripheral that advertise different services written in for example Arduino IDE and a BLE central that scan for this BLE peripheral to connect to. It can be visualized as the BLE peripheral being a bulletin board where different services containing different characteristics that specify different operations to be done The BLE central scan for BLE peripheral and when found the BLE central connect to the BLE peripheral and read the services provided and the characteristics of these services and thereafter execute different commands [22], such as for example print some data in a serial monitor on a computer.

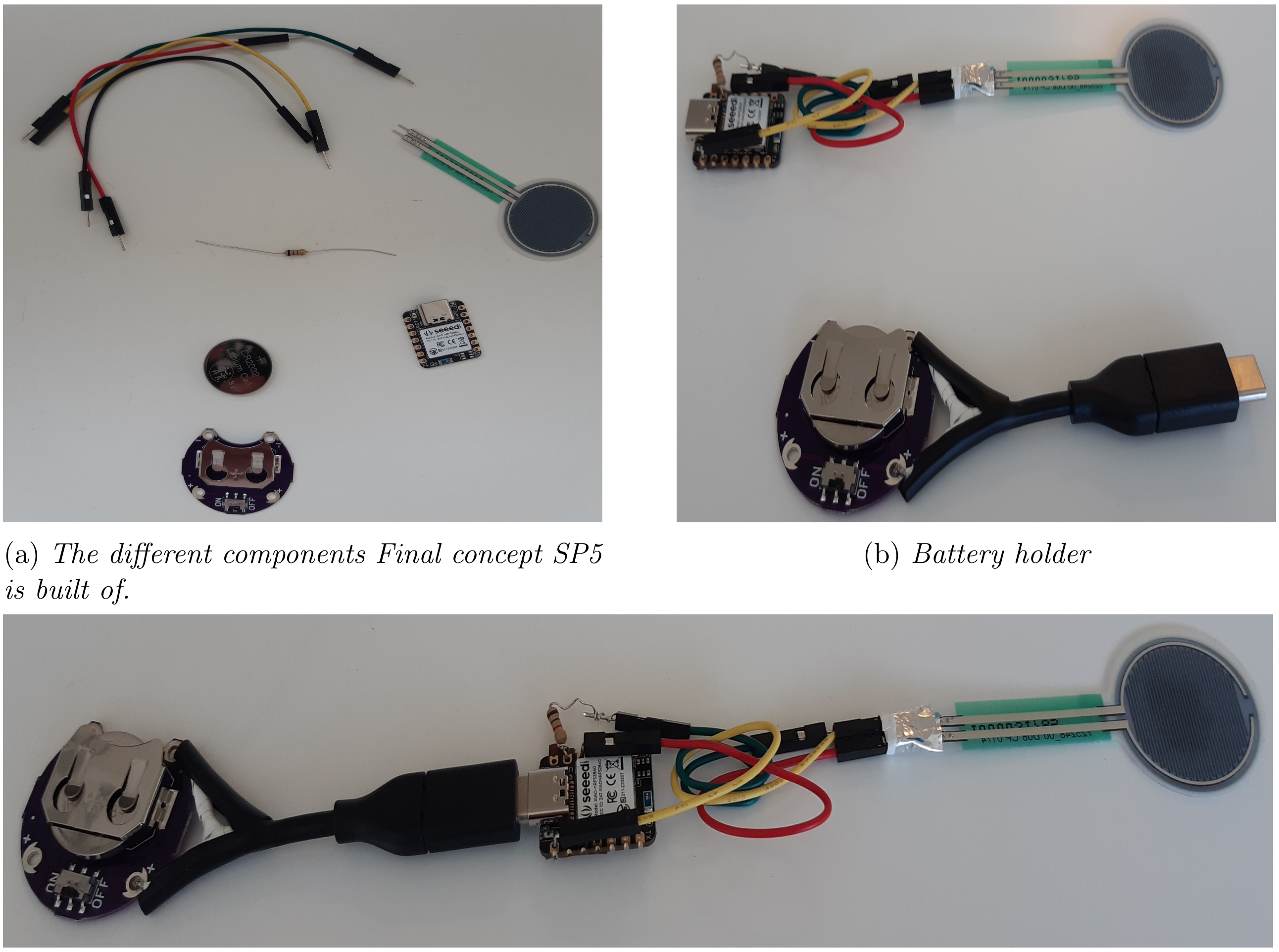
The concept chosen was concept SP5 as it had the highest ranking according to table

5.5.2. Only concept SP5 was chosen instead of both concept SP1 and SP5 since both concept where so similar but SP5 were built of components that had less weight and somewhat smaller in size and more adjustable when using it with a tourniquet. Concept SP5 consist of a fsr sensor fsr 402, microcontroller Xiao BLE nrf52480, one resistor of 1 kOhm, one battery model CR2032 [23] and a LilyPad Coin Cell Battery Holder with Switch [24], several jumper wires [23] connecting the microcontroller with fsr sensor and resistor and a short USB-C cable connecting the battery holder with battery to the microcontroller power outlet. All components are connected with jumper wires and the microcontroller is programmed to read signals from the fsr sensor with program written in integrated development environment Arduino IDE which contains a text editor for programming and a console for executing the code. The IDE connects hardware with software commands [25]. Bluetooth Low Energy protocol (BLE) [22] was used to connect the prototype wirelessly via nrf-connect mobile app and was also used to try and send data to computer without USB-C cable connected between the prototype and the computer. The choice to use BLE instead of Bluetooth was made since BLE protocol is designed for being used when there is limited battery supply [22], such as in small wearable devices as the prototype is considered to be. In the circuit there is 1 kOhm resistor connected between GND and the sensor.

The choice of resistor in the circuit was calculated as followed. According to the datasheet of the fsr sensor 402 the sensor can take maximum $1mA$ current per cm^2 applied force [26]. And according to the datasheet the contact surface area of the sensor is $D = 2.120cm$ [26]. This means that the sensor can take max $1mAcurrent/cm^2area$ of the contact surface when pressed on and a resistor with the Resistance $R = \frac{V}{I_{Total}}$ is needed according to Ohms law. See calculations below for what resistor can be used in the circuit.

- Surface area of circular contact surface sensor $Area_{sensor} = p * \frac{2.120}{2^2} = 3,52989cm^2$.
- With this the total current that the sensor can take is calculated by multiplying the maximum amount of current per cm^2 which gives $I_{Total} = 1mA * Area_{sensor} = 1mA * 3,52989cm^2 = 3,52989mA$ (approximately since rounding decimals).
- This gives the resistor needed to $R = \frac{V}{I_{Total}} = \frac{3.3V}{3{,}52989mA} = 0,93487kOhm = 1.0kOhm$.

This gives that a resistor of 1 kOhm can be used between GND and the sensor. In the figure 5.6.1 the Final concept is shown as well as the different components.



(a) *The different components Final concept SP5 is built of.*

(b) *Battery holder*

(c) *Final concept SP5 with all components*

Figure 5.6.1: *The different components separately and assembled into Final concept.*

When pressing on the contact surface of the fsr sensor a analogue reading is registered by the microcontroller Xiao BLE nrf52840 which, with a built in AD-converter then convert the analogue signal into a digital signal, a 10-bit number between 0 - 1023 and with some programming commands in the integrated development environment Arduino IDE print this in the serial monitor on the computer screen. This digital representation of the analogue signal is then mapped to the input voltage range of the Xiao microcontroller in the Arduino IDE program, 0 – 3.3V. The voltage read from the device is then calculated with $fsr_{voltage} = \frac{V_{cc}*R}{R+FSR_{Resistance}}$ where $R = 1K$ and $V_{cc} = 3.3V$. And the fsr voltage is then used to calculate the resistance measured when pressing on the sensor with the equation $FSR_{Resistance} = \frac{(V_{cc}-V)*R}{V}$. In the programming code of Arduino IDE the applied force is calculated and together with the registered resistance ($FSR_{Resistance}$) the pressure in mmhg and Pa is calculated and printed in the serial monitor on the computer screen.

5.7 Patent Analysis

A patent search was made in the patent database Espacenet and Google patents, both for patents in Europe and worldwide and only patents issued between 2003 - 2023 where searched for since the patents before 2003 now have expired and can no longer risk being infringed on. To be a similar patent the product needed to measure applied pressure when applying a tourniquet on arm or leg and possibly send the data digitally to a screen. A few patents where found and are listed below.

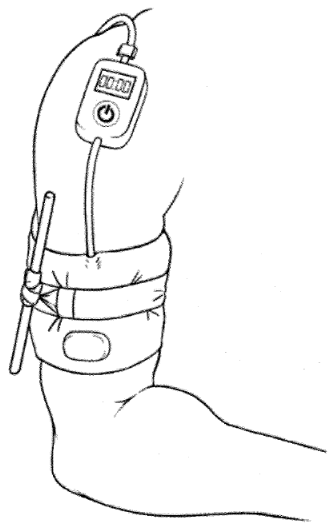


Figure 5.7.1: *Patent 1: Tourniquet Training Device*
[27]

The first patent is a band that is applied around an extremity with a digital monitor connected to it via a cable as seen in Figure 5.7.1 above. The band have several pressure sensor in it and send out shock to the user if the user is applying pressure less than a specific lowest limit. This patent is used for training on how to apply a tourniquet [27].

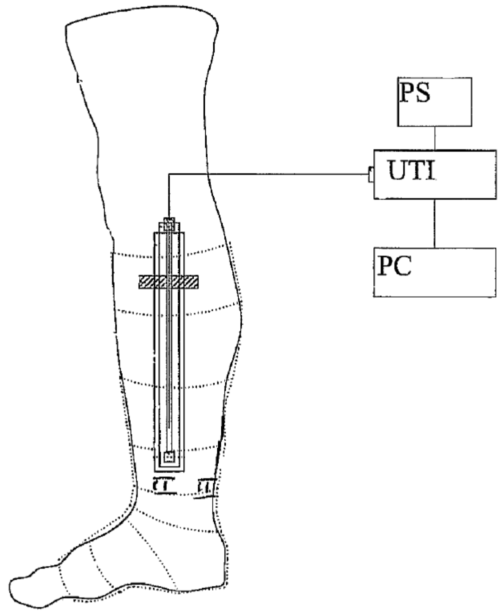


Figure 5.7.2: *Patent 2: A Transducer apparatus for measuring biomedical pressures* [28]

The second patent was a transducer apparatus that have senors that register applied pressure embedded between two polymer films, can be seen as the rectangular shape placed between the leg and the bandage in Figure 5.7.2. This device measure applied pressure with these sensors and send the pressure to a PC [28].

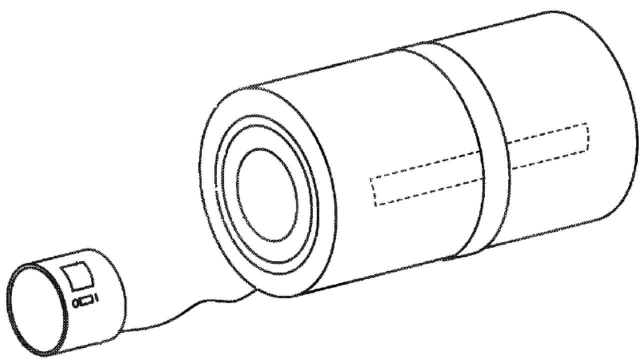


Figure 5.7.3: *Patent 3: Tourniquet Training Device* [29]

In the third patent there is a cylinder with pressure sensor built into it where a tourniquet can be applied. It is used for training purposes and when tourniquet or hand pressure is applied the registered pressure data is send to a smaller monitor to the left as seen in Figure 5.7.3 above [29].

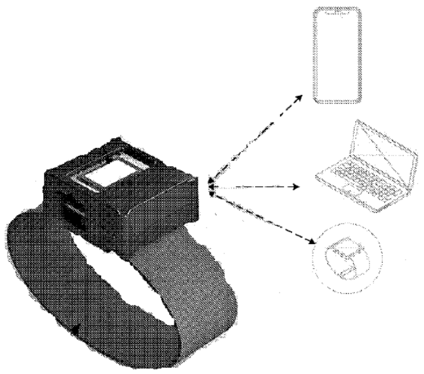


Figure 5.7.4: *Patent 4: Systems and methods for tourniquet operation and control* [30]

The last patent shows a monitoring device with sensors that register applied pressure, tissue oxygen levels, the amount of time the tourniquet is applied and send a user report via Bluetooth to a PC or mobile phone as seen in Figure 5.7.4 [30].

6

Experiments

This chapter presents the different experiments conducted with the developed prototype.

In the project there where several experiments conducted where the prototype was tested. There where several different experiments where two sensors where measuring applied pressure at the same time, to test the accuracy of the prototype. Sensor 1 was connected to the microcontroller Xiao BLE nrf52840 and thus was the prototype and sensor 2 was connected to a multimeter for reference. The measuremenst in pressure mmhg and Pa are used as treshold points to give some idea about how much pressure was applied. The lower resistance value the more pressure was applied. For all the experiments the following set up was applied in addition to what is specific to each experiment.

- The testing have been conducted by applying tourniquet on leg.
- Microcontroller used is Xiao BLE nrf52840, which is connected to PC with USB c cable.
- Pressure applied on the sensor is printed on the Serial Monitor in Arduino IDE
- The reading starts/ stops when clicking connect on the nrf-connect mobile app used on Android phone, the connection too nrf connect mobile is done via BLE protocol.
- The pressure registered on the fsr pressure sensor is printed in Serial Monitor every 1000 ms = every 1 s.
- The test data is saved in a txt file using the program CoolTerm, free download from internet.
- Sensor 1 is connected to micro-controller and sensor 2 to multimeter. Since sensor 2 is connected to the multimeter sensor 2 us used as a reference.
- Sensor 1 and sensor 2 are new

6.1 Experiment A1

In experiment A1 sensor 1 was connected to micro-controller and multimeter at the same time too see if the measurements printed out on Serial Monitor in Arduino IDE is the same readings that the multimeter gave. The mulitmeter didn't read anything on sensor 1 after it had been connected to the micro-controller, there was not enough space on the jumpwires connected to the microcontroller to connect the multimeter before connecting it to the microcontroller.

6.2 Experiment A2

In experiment A2 sensor 1 and 2 were placed under the plastic plate of the Tourniquet at the same time, next to each other. In this experiment the accuracy of the prototype was tested, this by measuring different increasing resistance values corresponding to different pressure values registered by the microcontroller. Table 6.2.1 shows the different measured values from sensor 1 and 2 below.

Table 6.2.1: *Experiment A2*

Experiment A2 **Sensor 1 and 2 placed under the plastic plate of tourniquet**			
Xiao BLE nrf52840 Sensor 1 (kOhm)	Xiao BLE nrf52840 Sensor 1 (Pa)	Xiao BLE nrf52840 Sensor 1 (mmhg)	Multimeter Sensor 2 (kOhm)
8.939	2832.95	21.25	6.05
4.593	5665.90	42.50	4.90
4.045	8498.85	63.75	3.90
2.579	11331.80	85.00	2.98
2.270	14164.75	106.24	2.86
2.072	16997.70	127.49	2.66
1.672	19830.64	148.74	2.48
1.526	22663.59	169.99	2.30
1.374	25496.54	191.24	2.18
1.205	28329.49	212.49	2.01
1.135	31162.44	233.74	1.96

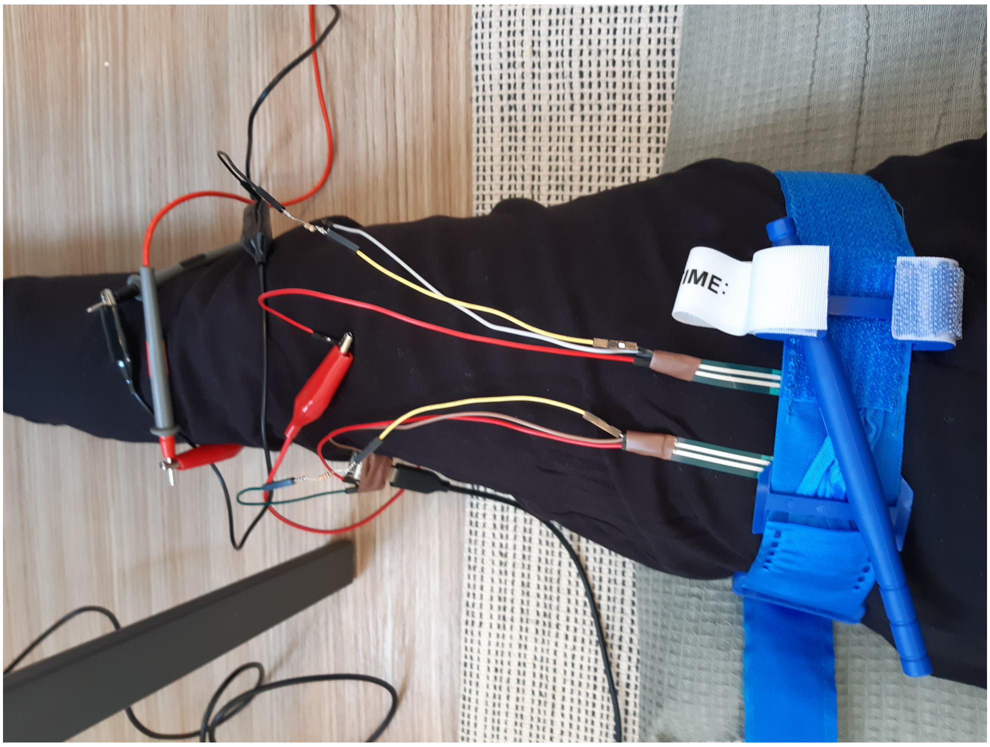


Figure 6.2.1: *Experiment A2, comparing sensor readings when applying tourniquet*

The microcontroller connected to sensor 1 always read approximately 0.3-0.5 kOhms less resistance than the multimeter connected to sensor 2. This is independent of if sensor 1 is placed to the left side under the plastic plate or right, it still shows the same difference. This suggests that the microcontroller doesn't read the resistance accurate which could be true since it reads an analogue value between 0 -1023 which in the Arduino code is then mapped with voltage level between 0.0 – 3.3 V (sensor is connected to GND and power supply 3.3V on microcontroller) with the help of a function called map and the decrease in resistance is then calculated with the help of Arduino programming code.

The more pressure applied to the sensors the more the reading from microcontroller differed from the resistance reading on the multimeter. From approximately 0.5 - 0.6 kOhm less on sensor 1 for readings under 0.1 kOhm up to 0.8 kOhm less on sensor 1 for readings between 110 -233 mmhg.

6.3 Experiment A3

Experiment A3 is the same as Experiment A2 except for that Sensor 1 is place right onto the fabric 180 degrees from where sensor 2 is placed under the plastic plate on the Tourniquet. This experiment is conducted to compare how much difference there is between sensor 1 and 2, and when looking at experiment A2 and experiment A3 from these differences between sensor 1 and 2 determine the best place on the Tourniquet to place the sensor during an exercise, the test with the least difference is considered to be the best place to put the sensor. There are also other factors that determine where to put the sensor such as convenience when for example turning the pin or the strap so that the wound device is not in the way and the person applying the tourniquet can operate freely. The results from the experiment are shown in the table below.

Table 6.3.1: *Experiment A3*

Experiment A3 **Sensor 2 under plastic plate and sensor 1 180 degree opposite under fabric**			
Xiao BLE nrf52840 Sensor 1 (kOhm)	Xiao BLE nrf52840 Sensor 1 (Pa)	Xiao BLE nrf52840 Sensor 1 (mmhg)	Multimeter Sensor 2 (kOhm)
7.616	2832.95	21.25	6.05
4.593	5665.90	42.50	3.71
3.247	8498.85	63.75	3.69
2.630	11331.80	85.00	3.28
2.412	14164.75	106.24	3.04
1.915	16997.70	127.49	2.70
1.707	19830.64	148.74	2.40
1.521	22663.59	169.99	2.30
1.357	25496.54	191.24	2.12
1.191	28329.49	212.49	2.05
1.127	31162.44	233.74	1.99

It was difficult to get accurate readings and the strap felt like it had to be pulled harder for the same reading in mmhg would show on the serial monitor. This might be because there is no flat surface directly under the fabric where the sensor 1 was placed, 180 degree from the plastic plate and sensor 2, and the sensor 1 was not as flexible and bent the same as the fabric did when pulling the strap. It needed more pressure when pulling the strap to make sure the sensor bent the same way and therefore also way and had continuous contact with the fabric surface against the "sensing side" of the sensor and could register the pressure.

6.4 Experiment A4

In this experiment sensor 1 and 2 was both connected to the microcontroller, both to common GND and power 3.3V, sensor 1 to analogue pin A0 and sensor 2 to analogue pin A1.

Only readings from sensor 1 was registered and after a few tries the board was fried (stopped working). If for some reason some of the cables either connected to sensor 1 or 2 where disconnected from the micro-controller then the microcontroller registered random data. Otherwise only readings from sensor 1 was registered from pin A0, but printed out on serial monitor as values of sensor 2.

6.5 Experiment A5

In experiment A5 different weights were placed on both sensors to see what resistance was registered. If they registered the same they were calibrated the same. The weights were put on the sensors for 1 min. Different weights used where: 50g, 100g, 150g, 200g, 250g, 500g, 1000g, 1500g.

The resistance readings of both sensor 1 and 2 were unstable and fluctuate a lot if putting weights on that give less than 21.25 mmhg. When comparing the data Force vs Resistance gathered during the calibration of both sensors to a commercial graph of fsr sensor 402 it showed that sensor 1 and 2 showed significantly lower resistance value when applying the approximately same force as the commercial graph. This error could depend on that sensor 1 and 2 had been used several times in other experiments e.g they were not new and therefore could be somewhat torn which could have made the accuracy less, sensor 1 was connected to the microcontroller which could have given slightly different values, the Force vs Resistance values in the graph were done with completely new sensors that were not connected to any microcontroller but both to the same type of multimeter. For some reason sensor 1, after applied pressure during this test, continued to register the applied pressure even though the weight had been taken off the sensor. Sensor 2 connected to multimeter showed 0 the same second the weight was lifted off. The result is shown in the table below and the reference graph in the figure.

Table 6.5.1: *Experiment A5*

Experiment A5 Calibrate the sensors		
Applied force (g)	Xiao BLE nrf52840 Sensor 1 (kOhm)	Multimeter Sensor 2 (kOhm)
0	17.644	0
50	15.256	13.36
100	5.693	6.64
150	4.148	4.55
200	3.247	4.11
250	2.923	3.67
500	2.579	3.40
1000	1.736	2.66
1500	1.347	2.35

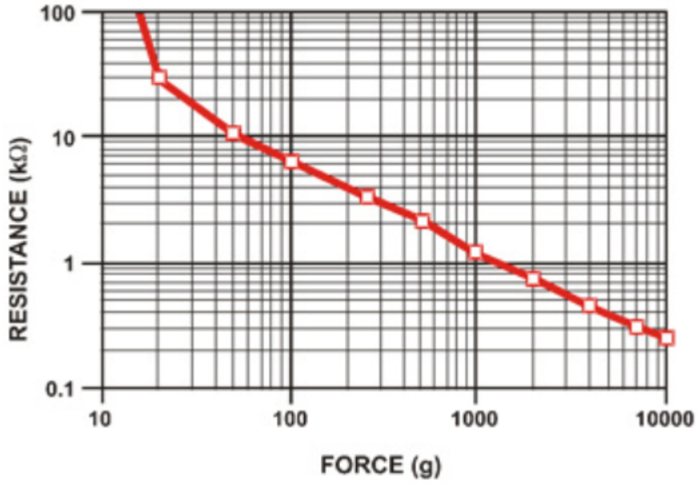


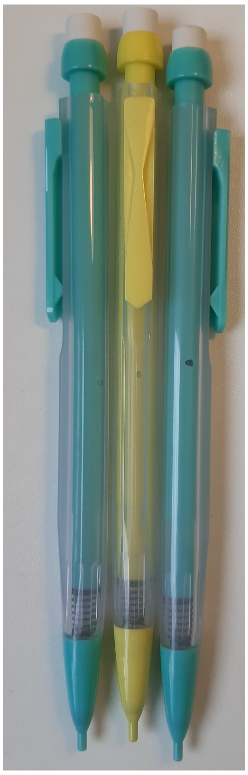
Figure 6.5.1: *Commercial graph of Force vs Resistance of fsr senor 402* [26]

6.6 Experiment A6

In this experiment different objects were placed between the leg and the Tourniquet, sensor 1 was connected to the microcontroller and sensor 2 to the multimeter. Both sensors were placed under the plastic plate and the object on the outside of the leg simulating having the object in pocket of pants. The objects used in the experiment were 1 pen, 3 sets of pens, 1 wallet, 1 set of keys, 1 glasses case and 1 mobile phone. To not risk breaking a mobile phone a calculator of the approximately same depth and width as a mobile phone was used. The results are shown in the table below followed by pictures of the different objects when used in the experiments.

Table 6.6.1: *Experiment A6*

Experiment A6 Place objects between tourniquet and leg									
Objects	Xiao BLE nrf52840 Sensor 1 (kOhm)	Xiao BLE nrf52840 Sensor 1 (Pa)	Xiao BLE nrf52840 Sensor 1 (mmhg)	Multimeter Sensor 2 (kOhm)	Objects	Xiao BLE nrf52840 Sensor 1 (kOhm)	Xiao BLE nrf52840 Sensor 1 (Pa)	Xiao BLE nrf52840 Sensor 1 (mmhg)	Multimeter Sensor 2 (kOhm)
1 pen	7.684	2832.95	21.25	6.03	1 set of keys	8.141	2832.95	21.25	5.98
	4.536	5665.90	42.50	4.00		4.246	5665.90	42.50	5.53
	3.551	8498.85	63.75	3.80		3.429	8498.85	63.75	3.68
	3.094	11331.80	85.00	3.60		2.937	11331.80	85.00	3.30
	2.423	14164.75	106.24	3.30		2.188	14164.75	106.24	2.86
	2.035	16997.70	127.49	2.85		2.035	16997.70	127.49	2.63
	1.678	19830.64	148.74	2.54		1.616	19830.64	148.74	2.42
	1.538	22663.59	169.99	2.30		1.408	22663.59	169.99	2.27
	1.299	25496.54	191.24	2.20		1.290	25496.54	191.24	2.18
	1.249	28329.49	212.49	2.08		1.145	28329.49	212.49	2.09
	1.105	31162.44	233.74	2.00		1.101	31162.44	233.74	2.01
3 pens	9.891	2832.95	21.25	6.50	1 glasses case	10.660	2832.95	21.25	5.60
	5.021	5665.90	42.50	4.02		5.918	5665.90	42.50	4.39
	3.336	8498.85	63.75	3.80		3.247	8498.85	63.75	3.20
	2.937	11331.80	85.00	3.38		2.654	11331.80	85.00	3.05
	2.170	14164.75	106.24	2.87		2.313	14164.75	106.24	2.96
	2.000	16997.70	127.49	2.76		2.019	16997.70	127.49	2.70
	1.678	19830.64	148.74	2.45		1.713	19830.64	148.74	2.45
	1.408	22663.59	169.99	2.31		1.477	22663.59	169.99	2.34
	1.263	25496.54	191.24	2.16		1.342	25496.54	191.24	2.25
	1.182	28329.49	212.49	2.06		1.234	28329.49	212.49	2.09
	1.131	31162.44	233.74	2.00		1.114	31162.44	233.74	1.95
1 wallet	9.576	2832.95	21.25	6.48	1 mobile phone	6.366	2832.95	21.25	5.02
	5.445	5665.90	42.50	4.38		5.962	5665.90	42.50	4.45
	3.247	8498.85	63.75	3.50		3.969	8498.85	63.75	3.50
	2.567	11331.80	85.00	3.11		2.529	11331.80	85.00	2.90
	2.197	14164.75	106.24	2.99		2.412	14164.75	106.24	2.70
	1.933	16997.70	127.49	2.80		1.849	16997.70	127.49	2.53
	1.736	19830.64	148.74	2.56		1.616	19830.64	148.74	2.33
	1.546	22663.59	169.99	2.37		1.414	22663.59	169.99	2.28
	1.315	25496.54	191.24	2.19		1.290	25496.54	191.24	2.15
	1.210	28329.49	212.49	2.07		1.145	28329.49	212.49	2.08
	1.105	31162.44	233.74	1.99		1.071	31162.44	233.74	1.99



(a) *Pens*

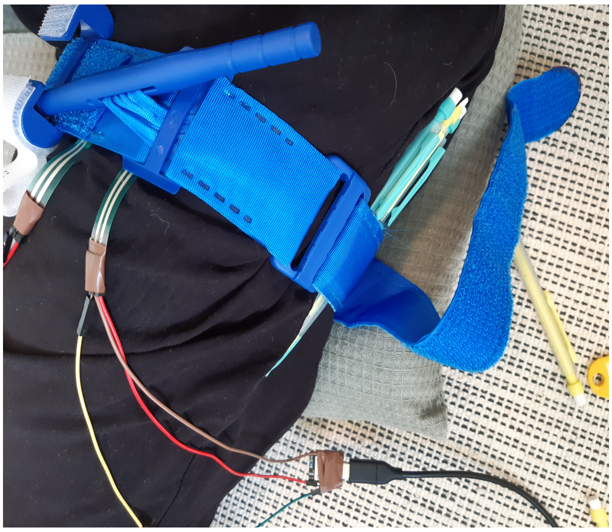
(b) *Wallet*

(c) *Set of keys*

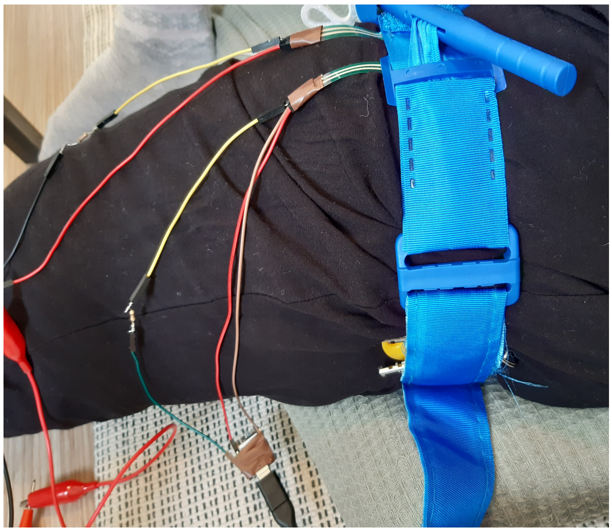
(d) *Glasses case*

(e) *"Mobile phone case"*

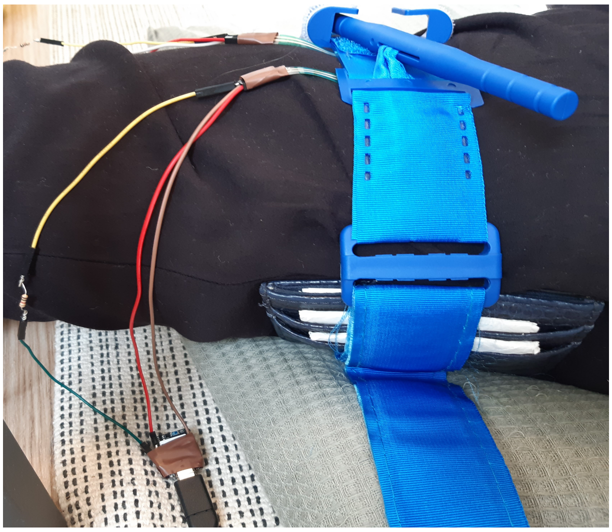
Figure 6.6.1: *The different objects used in the experiment.*



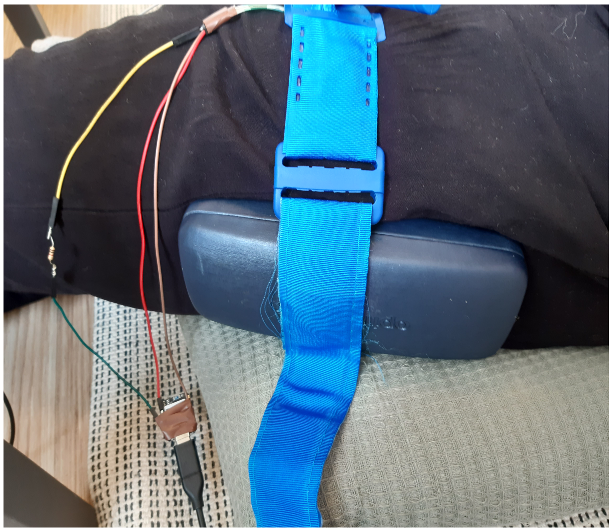
(a) *Experiment A6, objects pens*



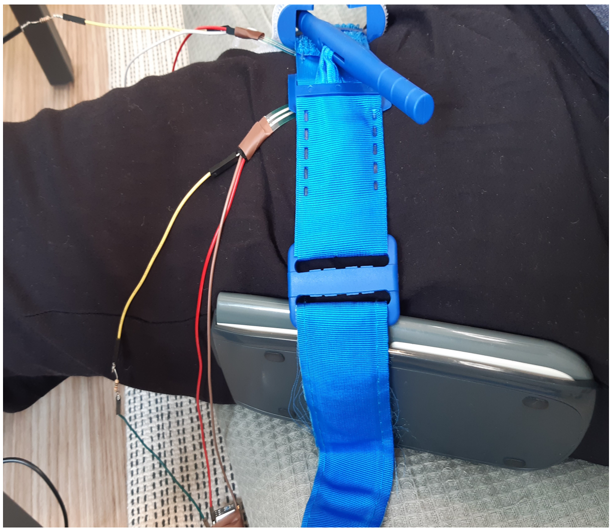
(b) *Experiment A6, objects keys*



(c) *Experiment A6, objects wallet*



(d) *Experiment A6, objects glasses case*



(e) *Experiment A6, object calculator, same size as mobile phone*

Figure 6.6.2: *The different objects when used during the experiment.*

As seen in table A6 and in figures above objects like 1 pen, 3 pens, 1 set of keys give approximately the same resistance values. There was not much difference compared to experiment A2 when having no object between Tourniquet and leg. Objects such as wallet, glasses case and mobile phone also gave similar readings as the other objects. This due too since the threshold value was the specific pressure values in mmhg which gave approximately the same values in resistance.

7

Discussion

In this chapter discussion about the methods used in the project is done as well as the results from the market analysis and interviews, the concept generation and selection together with discussion of environmental impact of concepts and similar patents and the different experiments conducted of the developed prototype.

7.1 Method Discussion

The different methods used to gather data was literature research, interviews and experiments. Literature research is a good way to do secondary data collection such as gathering research from different articles about for example how S-XABCDE algorithm works or how to apply a tourniquet and the methods of TCCC mentioned in this report. Interviews are primary data collection method, as is conducting experiments. When conducting interviews however the answers collected are only from the specific people that are interviewed and cannot be considered being representative of all people working in the same industry or geographical area. To be sure of that the data collected from interviews would be representative for the whole geographical area, for example Sweden, interviews would have to bee conducted with a larger group of interviewees than the 10 interviewed in this project, and one would have to make sure that all interviewees would be working in the same industry but at different geographical areas, for example Gothenburg and Stockholm. This is however not feasible to do due to lack of time, the project has a deadline, and it would take a lot of time to select suitable interviewees to make sure the sample size would be representative for all of Sweden for example. The interviews in this project gave valuable information but there is still a question about how much more information and if the information would differ if there had been more time for contacting more interviewees in other geographical areas than the ones participating in this project.

Experiments as data collection is a good way to test a newly develop product, in fact would say the only way. How else would you know it f works? There is also a lot of preparations to be done before conducting experiments, and there are often difficulties in setting up and conducting each experiments with the exact same basic settings.

7.2 Result Discussion

When conducting a market analysis the target market was already established by the company Tactsim and was the Swedish police, Military and Home Guard. During analysis of the market for different competitors and similar competitive products a few were found, although most of these competitors manufactured wound models made of silicone with realistic wounds where a tourniquet could be placed around and these were often models of arms or legs. The models could be connected to a pump system, often a bottle filled with liquid that could be squeezed on. Only one of the competitors CHIsystems as described in chapter 4.1 had some type of digital display that showed pressure, the time tourniquet had been applied, how well it was applied, in the correct place/ distance from the wound but did not have the ability to be connected to a pump system to simulate fake blood gushing out of the wound/ torn off limb. These wound models where less realistic which is logic since it is difficult to at least according to some of the interviewees to really create that realistic look of a leg or arm where muscles look real if having an open wound, since for example silicone and real muscles and organs have a completely different texture and surface and the behave differently when one for example put the hand inside a wound and try to squeeze shut a bleeding vessel.

During the interviews with people responsible for the healthcare exercises within the police, Military and Home Guard it was clear that a lot of things where different, different views, but there where also any similarities such as all of the authorities expressed the wish for having more realistic wound models, both of full human sized models with wounds and pump system with fake blood and different extremities such as an arm or leg for the students to practice on. This would according to the interviewees give more realism to the healthcare exercises but also the instructors didn't have to run around in a class of 10 or more people to loosen all applied tourniquets within 1 minute as is for example the maximum amount of time a tourniquet is allowed to be applied during healthcare exercises within the Military. Another way to give realism was according to interviewees to after applying the tourniquet check the pulse underneath the applied tourniquet, if there was no pulse the tourniquet was applied correctly, simulating no blood flow in the extremity and bleeding stopped. This method of evaluating if the tourniquet was questioned at the same time since even if there is no pulse, no pulse can be detected with stethoscope, this don't necessarily mean that there is no pulse or blood flow in the extremity, only that it can be detected, an interviewee explained. According to the interviewee if the pulse is lower than 80-90 bpm than it is not detected with stethoscope easily, almost like it has stopped, but there is still blood flow, only very slow.

There was a difference between the Police and the Military and Home Guard, In the Military and Home Guard (which is a branch of the Military that only act within Swedish borders) the tourniquet was only allowed by regulations to be applied with maximum force for maximum 1 minute, this to avoid affecting the nerves of the extremities. Here interviewees also spoke of having maybe some sort of tube over the extremity during exercises so as an instructor one didn't have to run around loosening all tourniquet, to be able to loosen all maybe 10 tourniquet applied during an exercise, within 1 minute. If there would be something like that as an instructor one could focus more on quality rather stress around the whole exercise. In the exercises within the Police however interviewees spoke of having the tourniquet applied for maximum 5 minutes during exercises while referring to that the maximum amount of time the tourniquet could be applied at maximum force was 2 h before any severe nerve damage would set in according to research. In the police the students was also allowed to walk 50 m or so with applied tourniquet to get an understanding that they could maybe not work after being injured but move out of harms way if needed. Although it was mentioned from the interviewees working within the Military and Home Guard that there where strict regulations of maximum 1 minute since they where the Military or Home Guard, it was just how it was done. This difference caused some confusion since it didn't seem to be because of risk of potential nerve damages the restriction would be for 1 minute max but rather there need to be strict rules within the Military. All interviewees within police, Military and Home Guard that worked in civilian job as an ambulance nurse spoke of nerve damages for having a tourniquet for to long, but it was not until reaching 2 hours instead of 1 minute or 5 minutes as the regulations indicate.

In the interviews with the police they also spoke about their time limit of 30 seconds when applying a tourniquet while in the Military and Home Guards the students where taught to apply a tourniquet within 60 seconds. This difference was not explained by any of the interviewees but it could be imagined that within the police there is a civilian context and maybe more secure in the sense that there might be less situations where the police are being shot at while trying to give emergency healthcare to someone than it would be within the Military. The Military train in context of that there is always a risk of being shot or injured by enemy fire and in often difficult terrain such as for example forests, and since the Home Guard, even though they might not be in situation of war as the Military, the are still a part of the Military and therefore follow their regulations.

In the Military compared to the Police there is no ambulance arriving to the scene but instead the soldiers have to care for the wounded and find a way to transport him or her back to high medical instance. This would give that the Military would have different education with for example 1 person in each group of soldiers of 8, as is the basic soldier group, have higher and longer medical training such as distributing medicine and possibly placing chest tube if a persons lungs wound be injured in addition to applying tourniquet and packing wounds. In the police group they have lighter training with applying tourniquet, packing bleeding wounds and HLR since they can rely on an ambulance always coming to the scene.

Another difference, however horrible, pointed out by an interviewee is that in the Military context the ambition level on the emergency healthcare service need to be much lowered compared to in civil context as when Police are first at scene. This since in war there are often many more injured people than there are medical emergency responders, maybe 1 healthcare personnel on 3-4 injured, than there are adequate tools and there is often more inaccessible terrain. This is very different form for example a city or on a highway where there have been maybe a car crash and the police responds with the security of being able to call an ambulance, with 2 people on 1 injured, and have a hospital that can receive all the injuries within reasonable time.

All interviewees in Police, Military and Home Guard spoke of that they would like to have more emergency healthcare exercises, more hours and occasions, and more wound models to increase the quality of the healthcare exercises but there was a cost to this that had to be weighed into consideration.

7.3 Discussion Environmental impact of concepts

The product is intended to be used for at least 6 months 2 times a day, several times during healthcare exercises. The product is developed from idea to finished prototype, where the different sub-components such as fsr sensor, Xiao BLE nrf52840 microcontroller, resistors, battery holder with switch, battery and several jumper-wires are all bought from suppliers and then are assembled into the product. The batteries are model CR2032 have a shorter life cycle than the rest of the components, and might have to be replaced more often than every 6 months, maybe every other week or more, this since they have capacity of 80-100 h depending on application [31]. In every component of the product there are multiple sub-components and materials and difficulties to separate all material before recycling. For example the microcontroller Xiao BLE nrf52840 contains more then 10 different materials and sub-components [32] on a small area which makes it more complicated to recycle. Due to this all components of the product such as fsr sensor, microcontroller, battery, battery holder, jumper-wires and resistor is disposed of in electrical waste at local recycling stations after end of life-cycle. Regarding all of this there will be an environmental impact when extracting raw materials, transportation and production of materials and components, purchasing components from suppliers and transportation, during assembly of product, transport product to customers, usage cycle, disposal at end-of usage/ life-cycle. Due to all components containing several sub-components and several different materials although in very small quantities there were difficulties in assessing for example the carbon footprint of the product and therefore there was an estimation of difficulties and the general environmental impact of the whole product from extracting different raw materials and acquisition, purchase components from suppliers until end-of-life cycle. Some of the materials in the different components of the prototype are metals such as copper, lead, cadmium, conductive polymer, lithium, aluminium [23]. These different materials even though in small quantities in the prototype requires high amount of energy to produce material used for producing the different components out of the raw material, and to produce the different small components such as the approximately 2cm x 2cm size of microncontroller, 0.2 cm D x 6.370 cm L fsr sensor or battery and battery holder of 2.0 cm D, and 10.0 cm L jumper wires with materials such as thin aluminium threads, plastic shell and polymer shell [23]. All components thus have higher impact on the environment compared to the amount produced. There is also a risk during usage cycle that customers might throw the product in average garbage disposal instead of returning it to either local recycling station or parts of components to manufacturers for recycling. This due to the small size of the product which can make it easily misplaced or accidentally dropped and get stuck in some small space and forgotten. This will make it have higher environmental impact due to risk of the product to reaching the right recycling facilities.

7.4 Patent discussion

When searching for similar patents a search was made for patents considering the whole world. There was only four patents similar to the prototype developed in this project found when searching in both Espacenet patent database and Google patents, search language was English. All patents measured applied pressure and send the data digitally but none was similar in design as the developed prototype. From this assumption can be made that this developed prototype has never been developed before or some patent could also have been missed when searching the database. Since the database Espacenet and Google patents together show patents from the whole world one could assume that it was enough to search in these databases, it would also be too time consuming to search for patents in every different country in the whole world. The target market is also in Europe and possibly USA which makes utilise only these to databases enough. Search words used where Smart Tourniquet to highlight the search for patents about tourniquet with some form of smart, wireless element connected to it.

7.5 Experiments discussion

During the experiments the tourniquet was only placed on my own leg, this due to it was the easiest place to reach since the experiments where done by myself on myself, the arm was more difficult to place a sensor and pull enough tight and in correct place compared to the leg where I had both my hands available for all experiments. The experiments could have been done on other people if it wasn't also for the extreme pain that a rose when pulling the strap tight enough to simulate cutting of blood supply in leg or arm. Therefore a choice was taken to only do experiments on myself and on my legs during the development of the prototype. Another idea would have been to place the sensor and tourniquet around a bigger seized water bottle filled with water but I wanted the experiments to simulate as similar exercise conditions as was spoken about during the interviews, which was that the students put the tourniquet on themselves or fellow students.

A cable was used during experiments since at the time there had been no solution found in how to send the registered pressure from the fsr sensor via BLE to the serial monitor on the PC. To be able to test the prototype at all the decision was made to try it with a usb c cable between the PC and the microcontroller power supply.

When investigating on how to connect the prototype via BLE an app called nrf-connect for mobile came up often as a mean to connect BLE services and possible control the prototype over BLE with the help of and Android mobile phone. The code for registering the applied pressure of the fsr sensor and print on the screen was written in Arduino IDE so when opening the nrf-connect app on my phone and clicking connect the readings of the fsr sensor was printed out on the serial monitor on the PC. There were many other apps mentioned when investigating but this one seemed most compatible and easiest to use with Android mobile phone as I have. For saving the data printed on the serial monitor another serial monitor than the built in version in Arduino IDE called CoolTerm was downloaded for free from internet and with this the idea was to save all data and then as a first step if needed this data would be able to be sent to VR-headset. Choosing to use the integrated development environment Arduino when programming the microncontroller to read signals from the fsr sensor was done due to it was one of the environment most familiar to me, since have used it in other projects where development of embedded systems was done. And it was compatible with the microcontroller Xiao BLE nrf52480 according to the retailer it was purchased from.

There was difficulties in setting up the experiments with the exact same setting for each experiment, for example when comparing the sensors one was placed to the left and another to the right under the plastic plate during one experiment and both of them always slid a bit in either one or other direction even if taped since friction of the fabric of the pants and when pulling the strap of the tourniquet the placement of the plate was always shifted a little bit when pulling tight.

In the first experiment A1 sensor 1 was connected to the microcontroller and the multimeter at the same time, the idea was to test if the prototype and the multimeter gave the same value while a the same time be sure that the sensor only showed on specific value. This experiment failed since when connecting sensor 1 to the Xiao microcontroller there was difficulties to attach the crocodile clamps from the multimeter on the jumper wires after. This resulted in that nothing was registered on the multimeter but only on the Xiao microtontroller.

In Experiment A2 as mentioned in the results the microcontroller connected to sensor 1 always read approximately 0.3-0.5 kOhms less resistance than the multimeter connected to sensor 2. This is independent of if sensor 1 is placed to the left side under the plastic plate or right, it still shows the same difference. This suggests that the microcontroller don't read the resistance accurate which could be true since it reads an analogue value between 0 -1023 which in the Arduino code is then mapped with voltage level between 0.0 – 3.3 V (sensor is connected to GND and power supply 3.3V on Xiao microcontroller) with the help of a function called map. When using this function to map the analogue readings to different voltage levels the accuracy could be affected. And it could be further affected since this mapped voltage level is then used again to calculate with a formula $R = \frac{3.3-voltage}{voltage*1000}$, where 1000 is 1 kOhm resistor used between GND and the sensor.

The more pressure applied to the sensors the more the reading from the microcontroller differed from the resistance reading on the multimeter. From approximately 0.5 - 0.6 kOhm less on sensor 1 for readings under 0.1 kOhm up to 0.8 kOhm less on sensor 1 for readings between 110 - 233 mmhg.

There could be a number of reasons to this but on crucial reason could be that in the Arduino code the analogue readings from when pressing the sensors are converted into digital signals with built in AD-converter on the microcontroller into a 10-bit number between 0 – 1023. This digital representation of the analogue signal is then mapped to the input voltage range of the microcontroller, 0 – 3.3V, since the sensor 1 is connected to GND and 3.3V on the microcontroller. The voltage read from the device is then calculated with $fsr_{voltage} = \frac{V_{cc}*R}{R+FSR_{Resistance}}$ where $R = 1K$ and $V_{cc} = 3.3V$. And the $fsr_{voltage}$ is the used to calculate the resistance measured when pressing on the sensor with $FSR_{Resistance} = \frac{(Vcc-V)*R}{V}$.

Compared to connecting a sensor to a multimeter some of the resistance and voltage could differ since there could be more voltage between connecting sensor with resistor to the microcontroller and then computer via usb c cable and map the AD bits to voltage again than connecting the sensor with resistance directly to a multimeter with no extra cables or microcontroller in between.

As mentioned in Experiment A3 in the results it was difficult to get more accurate readings from the prototype connected to sensor 1 when it was placed 180 degrees, opposite, to the sensor 2 connected to multimeter, directly onto to softer fabric of the tourniquet. When placing sensor 2 against the plastic plate under the pin there was a hard, rigid flat surface which was in contact with the whole sensing surface of the sensor 2 during the whole duration of the experiment. For sensor 1, which was placed directly against the flexible fabric of the tourniquet, was not in contact with a sensing surface during the whole duration of the experiment, this due to that the fabric was more flexible than the sensor which made it difficult to get more accurate readings since the sensor 1 had to bent just enough to get in full contact with the fabric surface of the tourniquet , it was only when it was in full contact pressure readings could be registered. There was a lot of tweaking to place sensor 1 in exact spot onto the fabric before one could get a decent reading. This suggest that the sensor of the prototype should be placed under the plastic plate under the twisting pin of the tourniquet to quickly get an more accurate pressure reading when pulling the tourniquet strap.

In Experiment A4 both sensor 1 and 2 was connected to common GND and common power pin of 3.3V, sensor 1 was connected to analogue pin A0 and sensor 2 connected to analogue pin A1. The idea was to read values from both sensor with the prototype and then calculate some middle value to try and get a more accurate readings due to that the accuracy of fsr sensors are less than many other sensors. This however, as in experiment A1, did not go as planned and the sensor 1 registered values but not sensor 2. Also if the best reading, and possible the only more reliable reading of the sensor is gotten when the sensor is placed under the plastic strap then there would be no point in using two sensors since they would then have to be placed almost at the exact same spot next to each other under the plastic plate. There is only room for two sensors there and they would basically give the exact same readings since placed in almost the exact same spot.

In Experiment A5 different weights were placed on sensor 1 connected to prototype and sensor 2 connected multimeter. What was noticed during the experiment was that when placing objects on sensor 1 the registered pressure was still registered on the serial monitor even after the weight had been removed during some of the heavier weights such as 250g, 500g, 1000g, 1500g. This was very odd since when placing the same weights on the sensor 2 connected to the multimeter it registered 0 kOhm directly when the weights was removed. And when testing sensor 1 and 2 like in experiment A2 on the leg while using tourniquet sensor 1 showed 0 kOhm registered as soon as the strap was loosened. This suggest that either the sensor 1 was torn after been used in many experiments before A5 or when applying lower pressure it took longer time for the sensor 1 to reset to 0 again since it had not be applied to enough force to come over a certain threshold value.

In Experiment A6 when placing objects in between the leg and tourniquet it was noticed that the bigger objects show less values in resistance than the smaller objects. These values being less could be explained by when having a bigger object between the Tourniquet and leg pressure it creates extra volume which would give that the strap had to be pulled harder (less resistance) to get the same amount of pressure in mmhg. Some values of bigger objects shows higher resistance than the smaller objects, this can be because of the sensors being torn some after being used in several experiments before and that when having an object in the way some of the pressure could be absorbed by the object, for example, if the leg was moved and the sensor shifted position somewhat. In this case the readings would give higher resistance readings since there was little less pressure applied due to the object in the way. During Experiment A6 the pressure sensor also showed the same values but the pain is extremely higher compared to with no object in between like in Experiment A1. This is logical since the strap is pulled to the same level but there is bigger volume between leg and tourniquet when placing an object such as, for example, a glasses case which will cause pressure on the leg in addition to the tourniquet. It was also noticed that for example keys with sharp edges was less painful as objects between than for example glasses case. This was and indication that the volume of the object placed in between leg and tourniquet mattered when it came to significantly increase pain rather than maybe sharp edges, the object had to be of a certain volume or bigger to give increased pain sensation.

As mentioned above at the time of the experiments a solution for sending data via BLE had not yet been found. This due to at the time I had not found a solution to how to write the code for to send data but only for the nrf-connect for mobile app to find the BLE peripheral of the prototype when scanning. This due to the code, when investigating what code to use for sending data via BLE when using Xiao BLE nrf52840 and development environment Arduino IDE there were many examples regarding other microcontrollers which where all to big in size for this prototype, but not many compatible with the Xiao BLE nr52480 model. There where also code for sending data via BLE in general but these examples that were to be used as ground for writing the code where outdated, the last updated similar code found was from 2017 or earlier. At least for me who is not familiar with coding and software development but more experienced hardware developer this was a problem encountered. Often finding pieces of code that could be developed or re-written to work with the prototype but it either after much investigation turned out to be incompatible or there was simply not enough time to learn how to re-write bigger pieces of code to work with the prototype.

After these experiments the question arise if the pain affected the readings, that pulling the strap until the first two or three readings showed the same value, for example 148.74 mmhg, and then quickly loosening it. Should 4-5 reading been registered on the serial monitor before noting it and then loosening the tourniquet or should the tourniquet be loosened at all before reaching the highest reading of 233.74 mmhg?

If not loosening the tourniquet between each 11 pressure values in mmhg and corresponding resistance as seen in the tables Experiments A2-A6 in chapter 6, there could be a risk of nerve damages (according to some interviewees) as the tourniquet would be applied for a longer time, maybe even more than 5 minutes which was the maximum limit some interviewees spoke about during exercises. With this there could also be a risk of less accuracy when register the values on serial monitor and on multimeter at the same time as the psychological effect of knowing it would be extremely painful to continue with the experiments could also have make it more difficult to get accurate readings, then there might have been done things to speed the experiment up instead of ensuring quality of the experiment.

7.6 Ethics discussion

When developing the prototype towards the target market Police, Military and Home Guard in Sweden questions arose about if this prototype would, if facilitating healthcare exercises together with the VR-technology, contribute to saving lives of for example soldiers who then could continue engaging in warfare against others. Even though this prototype is developed with the intention of facilitate exercises that would help saving lives in real-life scenarios would it also contribute to something more, real-life actions that could contribute to taking lives? For example if for some reason this device would be used by enemy forces and thus contribute to surviving rate of enemy forces and continuation of possible war? This thought is however very far fetched since the device is meant to measure pressure in healthcare exercises within Police, Military and Home Guard in Sweden and not directed to everyday consumer.

8

Recommendations and future work

During the project there have been a lot of work with choosing and developing the final concept considering that developing a product and working with embedded system with hardware parts and software part working together with BLE protocol was a new area for the author of this report. The development took much longer time than expected and several things should be considered for future work.

For example, if continuing to develop this prototype a suggestion is to conduct more interviews to try and get a wider spread of the area the interviewees represent, so it would be more representative for example whole of Sweden if that would the target market. In the future it is important to develop the connection points in the prototype, for example maybe considering soldering some jumper wires to the microcontroller and resistor as well as maybe the fsr sensor. This was not done during this development project due to time limit and the constant improvements done on the prototype until the end of the project. Another thing to investigate in future work would be possible change of microcontroller model from Xiao BLE nrf52840 to model Xiao BLE nrf52840 Sense which in addition to all features of Xiao BLE nrf52840 also contains a built in microphone and 6-axis Inertial Measurement Unit (IMU) that could with software register position on the micro controller and thus if needed measure position of the prototype with regard to any simulated wound or maybe joints. This to have another measurement to send to for example the VR-headset other than the registered pressure.

9

Conclusion

During this project as many other product development projects when there is development of new products there have been many iterations back and forth to try and improve the final concept and prototype. The first research question in this project where "How to model a device that could monitor wound indicators in situations where there is catastrophic bleeding in arms or legs". The product developed is an embedded system with a microcontroller register readings from a fsr sensor and sending data when connected via a USB-C cable to serial monitor on computer. With the development of the prototype the first research question can be considered thoroughly investigated during this project.

The second research question handled Bluetooth and sending data wirelessly, "How to build and prototype device that integrates electronic circuits that could send data over Bluetooth". This have due to meeting many more obstacles in form of programming instructions in the Arduino IDE not been handled as much as wanted to during the project. This due to lack of time, since many of the solutions tried didn't work for that specific version of Arduino IDE or with the microcontroller used in the prototype.

With the development of the prototype an issue that came up during almost all interviews about how to know when the tourniquet is applied correctly, other than checking pulse (or lack of) with a stethoscope which could be misleading, have also been investigated. And with the prototype the applied pressure can now also be incorporated into exercises as measurement if tourniquet was applied correctly in addition to checking the pulse (or lack of).

As mentioned in the discussion reaching out to more interviewees spread in geographical area could have generated different data but also it could have given a validation to the data collected during the interviews conducted in this project. A bigger sample size would ensure the data would be representative for the whole population, in this case the population being all of Sweden. The reason for conducting a set number of few interviews during this project was partly due to time limit but also the difficulty to getting in contact with people working within the Police, Military or Home Guard who would want to, and had the time to participate in an interview.

Even though the microcontroller chosen in this project worked well with the fsr sensor there was still, as mentioned above, struggle to find a way to send analogue data over

BLE. It might have been good to have done more research about how fsr sensors are used with different microcontrollers and the different development environments that could be possibly more compatible with different sensors and/ or microcontrollers.

It was much more psychological difficult to conduct experiment that would be as close to a real exercise as possible due to the extreme pain from when applying a tourniquet and pull it tight and try to read values on the serial monitor and multimeter at the same time. As done in the experiment, the tourniquet was loosened after register each of 11 pressure values in mmhg and corresponding resistance values as seen in the tables in chapter 6. This was a way to ensure that the pain from when applying the tourniquet wouldn't affect the quality of the readings, which was a better way than possibly keep the tourniquet on during the whole course of the experiment, reading of all 11 pressure value in mmhg, and also risk psychological stress and pain affect the readings.

After conducting experiments a conclusion is that Experiment A2 and A3 could have been one experiment to investigate most optimal placement of the fsr sensor between extremity and tourniquet.

Questions also arose about ethical aspects of developing a device that, with the knowledge gained when using this device during healthcare exercises, could also contribute to, if used in healthcare exercises in the Military, that more soldiers would survive and could then continue to conduct war and with this possibly more lives would be lost. For example if for some reason this device would be used by enemy forces and thus contribute to surviving rate of enemy forces and continuation of possible war? This thought is however very far fetched since the device is meant to measure pressure in healthcare exercises within Police, Military and Home Guard in Sweden and not directed to everyday consumer.

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