Developing a future safety alarm for elderly

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MASTER THESIS

Developing a future safety alarm for elderly

Digitalizing elderly care

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Abstract

The population of the world is growing larger and getting older. This growth is causing an increased load on the current healthcare system, thus lowering the standard of healthcare. One group, specially affected by this, is the elderly and their homecare service and retirement homes. To unburden these services, safety alarms were created. However, these are in much need of design, ergonomic and technical improvements.

It was therefore, for this thesis, interesting to, from an end-user perspective, investigate how to further develop and improve safety alarms in combination with the digitalized world to come.

In accordance with the double diamond design process, the thesis was set off by fully understanding the user needs, market and current technology by conducting user and literature studies. These studies resulted in defining a clear design brief and personas. Deriving out of from this stage was a concept generation resulting in sketches, 3D-models and lo-fi prototypes. By conducting user tests on the lo-fi prototypes, a concept screening could be performed. The concept screening derived into developing a final high-fidelity safety ring prototype and corresponding conceptual platform.

The results of the master thesis were a high-fidelity prototype, a conceptual platform and the certainty that the future lies in digital healthcare.

Keywords: Safety alarm, heart rate, internet of things, digital connected healthcare, product design, development

Sammanfattning

Världsbefolkning blir allt större och äldre. Denna tillväxt orsakar en ökad belastning på sjukvården, vilket resulterat i en minskad standard inom patientvården. De äldre, deras hemtjänst och äldreboenden är en grupp som drabbats hårt av denna utveckling. För att avlasta dessa tjänster så togs trygghetslarmet fram. Dagens trygghetslarm är dock i stort behov av förbättringar vad gäller ergonomi, estetik och teknik.

Det var därför intressant att, i detta examensarbete, undersöka hur trygghetslarmen i kombination med det uppkopplade samhället kan vidareutvecklas utifrån ett slutanvändarperspektiv.

I överenstämmelse med “the double diamond design process” inleddes detta examensarbete med att utforska användarbehoven, marknaden och tillgänglig teknik genom användar- och litteraturstudier. Förstudierna resulterade i en klart definierad designbrief och personas. Ur dessa inleddes en konceptgenereringsfas i form av skisser, 3D-modeller och enklare prototyper. Genom att utföra användartester för att utvärdera dessa prototyper, så kunde en konceptsållning utföras. Denna sållning resulterade i skapandet av en säkerhetsring och tillhörande konceptuell plattform.

I sin helhet, resulterade detta examensarbete i skapandet av en säkerhetsring, tillhörande plattform och visdomen att uppkopplad sjukvård är framtiden.

Nyckelord: trygghetslarm, pulsmätning, IoT, uppkopplad sjukvård, produktdesign, produktutveckling

Acknowledgments

The completion of a thesis is much dependant on outside co-operation, insight and help. The outcome result of this thesis would not have been the same without the help of the following people:

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Lund, May 2018

Karim El Ghamrawi

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List of acronyms and abbreviations

The DDDP	the double diamond design process
IoT	internet of things
AmI	ambient intelligence
AI	artificial intelligence
ECG	Electrocardiography
PPG	Photoplethysmography
SLS	Selective Laser Sintering
IMU	Inertia measurement unit
GSM	Global System for Mobile Communication
GPS	Global Positioning System

The noun “elderly/elders” is used extensively throughout the thesis and is therefore defined below:

- Elderly
    - Age of 65 +
    - Living in a senior care or utilizing services as home care
    - Possesses a safety alarm

Introduction

1 Background

1.1 Issue and aim

The group of people over the age of 65 in Sweden has been increasing steadily in numbers over the last century because of two reasons [1]. One, the average life expectancy has since 1860 been increasing and this trend is continuing [2]. Consequently, it is estimated that the group of people over the age of 65 will constitute 25% of the Swedish population in 2060 [3]. Two, there are more births than deaths [3]. On top of that, as seen in figure 1, during the 1940s and 1960s the number of new-borns in Sweden reached record levels, resulting in Sweden presently having a large number of elders [4]. Thus, both short- and long-term, there is and will be an increased load on the healthcare system.

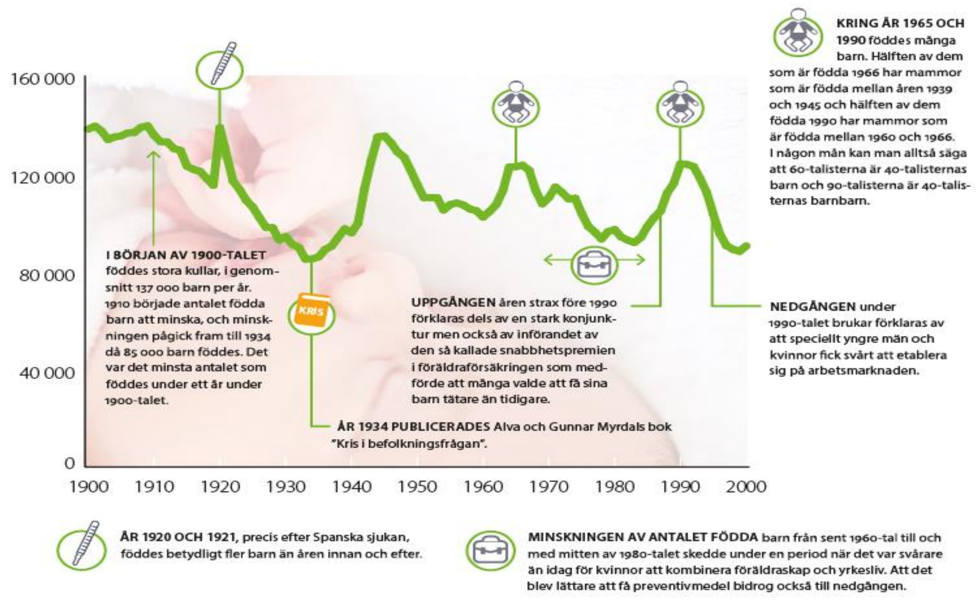

Figure 1 Number of new-borns in Sweden between 1900-2000 [4].

Available on today's market are safety alarms, which are developed to unburden the elderly healthcare system by giving the patients more responsibility. When a serious situation occurs, the user may independently call for aid, thus the focus of doctors & nurses is only acquired when needed. However, the widely available analogue safety alarm has several drawbacks; users have experienced ergonomic issues where people with rheumatism for example find it difficult to press the alarm button. Most importantly however, the current system is based on an outdated, analogue technology which causes more problems than it solves. Due to this lacking technology there has been cases of lost alarm-signals, which has resulted in cases of death, injuries and extreme discomfort [5].

It was therefore interesting to study how to develop the future safety alarms with the objective of unburdening the healthcare system, while also improving the direct and perceived safety of elders and their relatives. Important as well, was developing a safety alarm which is technically up to date, ergonomic and considered appealing.

1.2 Project description

As discussed in 1.1, the elderly healthcare system is heavily burdened and the current safety alarm solutions are not optimal. With the help of a design process, it was for this thesis, interesting to explore how to improve the current situation. Through exploration of different designs, existing solutions and technology, the mission of this project was to develop a modern, aesthetically appealing and ergonomic safety alarm which monitors heart rate. The implementation of heartrate measurement was interesting to investigate as it in collaboration with an AI may foresee disease, further discussed in 3.2.2.1.

Alongside this product, the aim was to develop a conceptual, digital platform which simplifies the caretaking of the elders for all involving actors; medical staff, relatives and patients.

At the start, an initial plan including literature studies, interviews, benchmarking, sketching, prototyping and user tests was set up. The initial plan as well as the outcome plan is presented in *Appendix A.*

1.3 Goal

As this thesis was not provided by an external company, the goal was initially very open, thus the final product was a result of following a design process. By localizing user needs, researching competition, current technology, concept-generating, prototyping, testing and iterating, the goal was to create a high-fidelity prototype and a complementary, conceptual platform.

1.4 Delimitations

In regard to the time-frame and the lack of knowledge within the field of electrical and computer science, the following delimitations were established:

- A high-fidelity prototype will be created, not a finished product
- Electronic components meant for prototyping will be used, thus the size of the prototype's electrical components will be disregarded. Appropriately sized production components have, however, been identified to ensure the feasibility of the concept
- The considered platform is strictly conceptual

1.5 Scope of the thesis

This master thesis was carried out at the Department of Design Sciences in the Faculty of Engineering at Lund University during 20 weeks, starting in January 2018 and ending in June 2018.

The project was set off with research, including literature studies and interviews. From these studies, conclusions regarding the user needs were established. This result then laid the foundation for the iterative design process, consisting of sketching, concept generation, computer modelling and prototyping. The result of this process is presented in a final, high-fidelity prototype and a complementary, conceptual platform.

2 Methodology

As seen in figure 2, the design process utilized for this project is mainly based on "The Double Diamond Design Process" (Further on called the DDDP) [6]. Substantial inspiration and guidance was obtained from other sources as well [7,8]. This combined methodology is presented below.

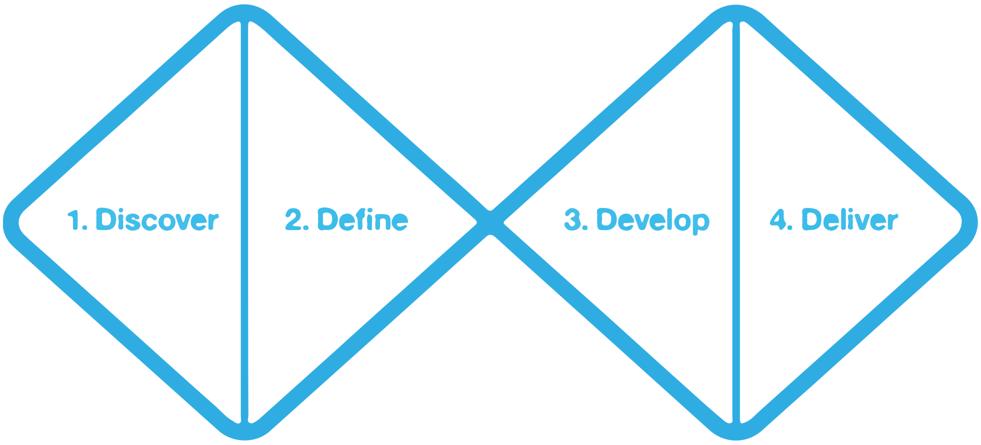

Figure 2 ***The Double Diamond Design Process*** **[6]**

2.1 Approach

The aim of this thesis was to create a high-fidelity prototype, of a next generation safety alarm. With this functioning prototype, a combined, conceptual platform was to be created. The complete solution should primarily be beneficial for the elderly users and their user needs. However, if possible, approaching a wider market could be of interest to improve sales. This could for example be the market of caretaking for children, people with mental issues or simply people scared of walking home alone late at night.

To achieve this, several different design methodologies were applied to this thesis's design process. As mentioned, the main method was the *DDDP*, but inspiration and guidance were also brought from [6-8].

The *DDDP* consists of four stages; *discover, define, develop* and *deliver*. As can be seen in figure 2, there are both divergent and convergent phases of the *DDDP*. The divergent stages allow endless creativity and possibilities, while the purpose of the convergent stages is to narrow down the objective. Provided by *[6]* are applicable tools and guidelines for each step of the process. For each of the four stages, given tools and methods, combined with methods from other sources, were used to suit the thesis. Each stage of the *DDDP* is described below.

The original plan for the project, as well as the outcome plan is presented in *Appendix A.*

2.1.1 **Discover**

The first part of the *DDDP* is *the discover phase*. This part covers the start of the thesis and is where inspiration and insight are found. By gathering both qualitative and quantitative data, the designer builds a rich bank of knowledge. This bank of knowledge allows the designer to regard the identified problem from an end-user perspective. Opportunities and needs are therefore more easily identified. For this thesis, methods such as literature studies, user-studies, interviews, observations and benchmarking were used [6]. These methods are further described in section 3.

2.1.2 **Define**

The second part of the *DDDP* is *the define phase*. This phase consists of analysing the results from *the discover phase* and synthesising the vital user needs and problem statements. Through this, a clearly defined design brief can be set up. This by help of methods such as function analysis, personas and design briefs [6]. All of which are described further in section 4.

2.1.3 **Develop**

The third part of the *DDDP* is *the develop phase*. In this phase, concepts, in regard to the design brief, personas and brainstorms from *the define phase*, are created. For this thesis, brainstorming, sketching, mood boards and lo-fi prototyping were design methods which were used to create concepts. These concepts where then put through an iterative process consisting of prototyping, testing and further development. *The develop phase* is further described in section 5.

2.1.4 **Deliver**

The fourth and final part of *the DDDP* is *the deliver phase*, here the prototype/concept is finalised and then submitted to user tests. The final user-tests are conducted to prove the fulfilment of the identified user needs and are usually performed by staging different scenarios. From these tests, new knowledge is often gathered and used to suggest further development.

3 Discover

This part covers the start of the thesis and is where inspiration and insight were found. By gathering both qualitative and quantitative data, a rich bank of knowledge was built. This helped identifying problems from an end-user perspective, which simplified the finding of opportunities and needs. For this thesis, methods such as literature studies, user-studies, interviews, observations and benchmarking were used.

3.1 Methods

3.1.1 **Literature Studies**

Mainly as part of *the discover phase*, but throughout the whole project as well, literature studies were carried out. From the literature studies, new knowledge, facts and references were found. By studying scholarly papers, articles and books a wide knowledge on the subject and trustworthy foundation was gained. The spectrum of the literature studies consisted of topics coherent with the subject of the thesis. Examples of such topics are; *safety alarms, heart rate monitoring, sensors, design for elderly, eHealth, wearables, connected health devices* etc.

3.1.2 **Benchmarking**

The benchmarking consisted of an exploration of potential partners, competitors, markets, and available products on the e-health market. This with the objective of gaining inspiration and unveiling possible opportunities and solutions.

3.1.3 **Interviews**

To apprehend the users and their needs, the main method of user-need-investigation was interviews. The choice of interviews as main research method was motivated by its qualitative characteristics [6].

Initially in a design process, open and allowing interviews are preferable as they tend to give the researcher a wider knowledge in the studied area and help prepare for eventual semi-directive interviews [9]. Therefore, totally open interviews were performed initially. Subsequently a total of 11 semi-directive interviews were conducted with the following end users: *Patients/Elderly, Medical staff and relatives*. These groups of users and their characteristics are further described below:

- Patients/Elderly (total of 5 interviews)
  - Age of 65 +
  - Living in a senior care or utilizing services as home care
  - Possesses a safety alarm

- Medical staff (total of 3 interviews)
  - Cardiologist (Heart and blood vessel specialist)
  - Work experience with elderly

- Relatives (total of 3 interviews)
  - Have a close relative between the age of 65+

Since the interviews were conducted on different end-users, three different formats were created, these are all presented in *Appendix B.*

3.1.4 Observations

Interviews are fundamental for user investigations. However, they are not sufficient on their own. People might do things differently than they say, therefore observations are a necessary complement to interviews.

The layout of an observation differs from different types of research, but often it is the cognitive behaviour that is studied. Further described in section 3.2.3 is the layout of the performed observations, as well as the results.

[6]

3.1.5 Triangulation

By using different data collection methods, as well as different sources, the credibility of recurring results is increased [6]. Therefore, the results and conclusions gathered in each data collection method were analysed and compared.

Common results and conclusions were highlighted and studied further to enhance the understanding of the user needs.

3.1.5.1 Affinity diagram

Affinity diagrams were utilized to categorize the collected data, to ease the analyse process [6]. This method was used to highlight reoccurring issues and problems and to get a better overview of the collected data as a part of the triangulation.

3.2 Research results

3.2.1 **Literature Studies & Benchmarking**

The literature studies & benchmarking was divided into three main areas presented below; connected healthcare, heartrate measurement and benchmarking

3.2.1.1 Connected Healthcare

From the literature studies and benchmarking one thing was clear, connected healthcare is a big, future trend. It was therefore desirable to investigate how this could be combined with a safety alarm. To fully understand the concept of connected healthcare, one had to acquire knowledge of IoT and related terms. These are presented below.

3.2.1.1.1 Internet of Things (IoT)

The concept of *IoT* is a world where all everyday objects are connected and have the possibility of intelligent communication. Use of sensors and intelligent systems allow these smart devices to gather data. From this, one big information system can be created [10]. An information system like this could be interesting for storing and analysing the gathered data from the safety alarm.

3.2.1.1.2 Ambient Intelligence (AmI)

Main tools in the concept of *IoT*, are *Ambient Intelligence* and *Artificial Intelligence*. The concept of *Ambient Intelligence* is to develop environments, integrated with sensors and intelligent systems. Sensors in this environment should be able to apprehend the following properties:

- Presence of individuals
- Individual's identities
- Activities
- Change of individual's needs

By apprehending the above, the *AmI* may service the current personal needs of the environment's users.

[11]

3.2.1.1.3 Artificial Intelligence (AI)

The concept of *Artificial Intelligence* is the creating of intelligent machines that may analyse data in a human-like manner. This could be interesting to consider when developing a future safety alarm, having an intelligent system that may analyse gathered data. To resemble human-thinking, the *AI* should include the following traits:

- Knowledge
- Reasoning
- Problem solving
- Perception
- Learning
- Planning
- Ability to manipulate and move objects

The *AI* consists of two main parts, knowledge engineering and machine learning. To implement knowledge engineering the *AI* needs full access to the information and the relationships gathered from the smart, everyday objects, closely connected to *Ambient Intelligence*. Another main part of the knowledge engineering is the ability for the *AI* to establish a common sense and reasoning in its problem-solving. Machine learning is the ability of the *AI* to independently, identify patterns and solve problems.

[11]

3.2.1.1.4 Connected healthcare

Connected healthcare is a socio-technological concept where modern technology, in a safer, more efficient and user-centred manner provides healthcare services remotely [12]. This is made possible by connected, wearable, health devices in combination with *IoT, AmI and AI*. These wearables have sensors which monitors heart rate, activity, blood pressure, patterns, vital signs etc [13]. The collected data is often visualized in user friendly applications. A future trend is that many of these connected health devices are becoming medically certified [13]. This, not only to save money but to reduce the demand on the healthcare system and make patients more independent. The concept of connected healthcare is therefore relevant for this thesis and the prototype which is to be developed.

The future of connected healthcare devices is moving rapidly and there are many developing areas, some presented below:

- Big data collection

Integrating *IoT* with wearables that perform continuous monitoring. Collected data is studied and analysed by smart systems and collected in one big information system.

- Sensor development

The development of sensors is moving rapidly. Sensors are now able to measure several parameters, the quality and accuracy is increasing while prices are falling.

- Smart Algorithms

The development of intelligent algorithms, *AmI* and *AI* is constantly improving. The improved algorithms may foresee certain problems, diseases, falls etc.

- New measuring methods

As seen in figure 3, the most common wearable is the wrist worn “smartwatch”. However, new technology including smart clothes, eyewear, earwear, patches etc is developing, examples of these are presented in figure 4.

[14,15]

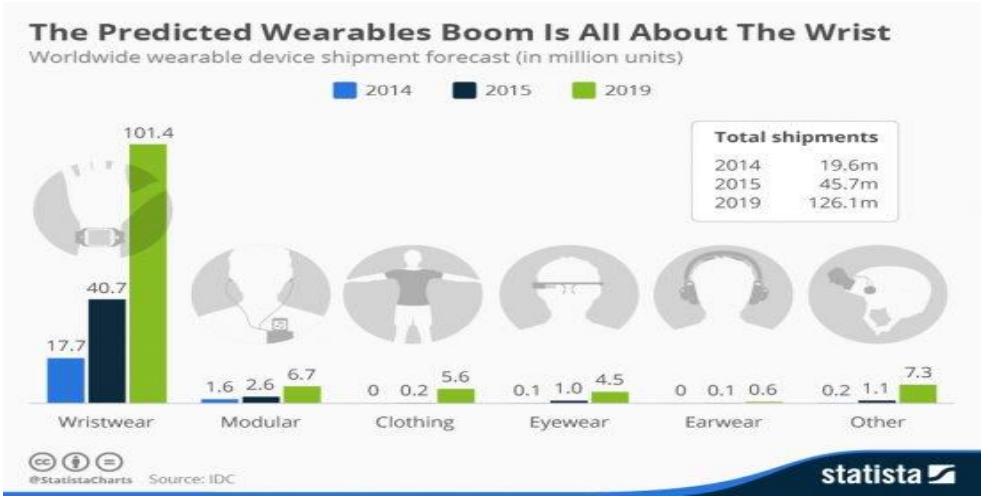

Figure 3 Statistics from 2014 and 2015 of shipments of wearables, and predictions of 2019 [14]

Figure 4 Examples of existing wearables

3.2.1.2 Heartrate measurement

As it was desirable that the final product should be able to measure heartrate, research on different technologies and optimal location for measurement were conducted. Primarily there are two technological methods out on the market for measuring heartrate, these are presented below:

3.2.1.2.1 Electrocardiography sensors (ECG)

ECG, also known as EKG measures the bioelectrical signals that triggers our heart to beat. This method is very precise and reliable and is therefore mainly used in medical appliances. ECG sensors have been used in wearables as well, however these are expensive and need further technical development [16].

3.2.1.2.2 Photoplethysmography (PPG)

PPG is a light-based sensor technology which measures the volumetric change in arteries. Light is shined into the skin, the amount of reflected light corresponds to the volume of blood in the arteries. Volume changes are caused by contractions of the heart, which cause increase of the blood pressure, from this data the heartrate is retrieved [17-19]. In figure 5, an example of a PPG signal is presented.

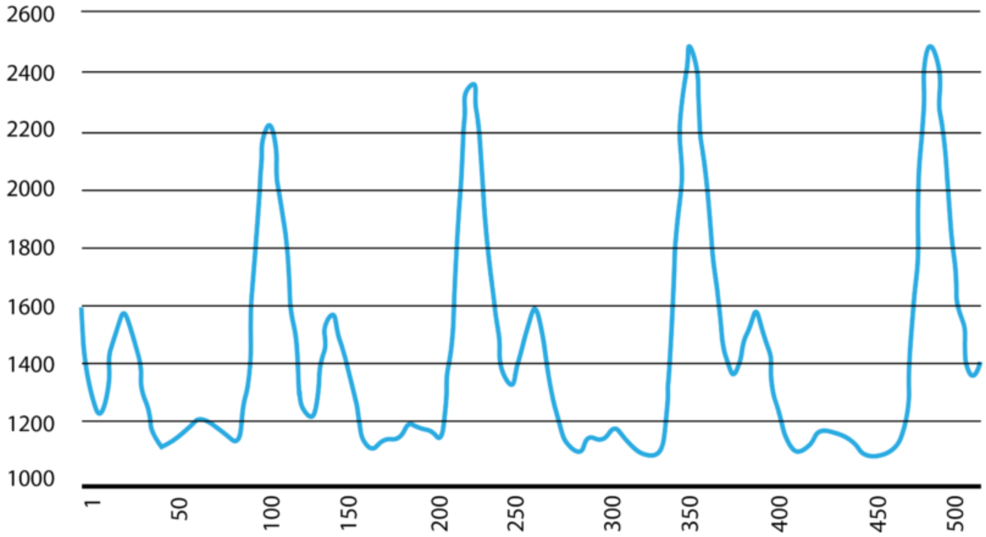

Figure 5 Example of a typical PPG signal. Time on x-axis. Blood flow on y-axis [17]

3.2.1.2.3 Comparison of PPG & ECG

- ECG sensor measure bioelectrical signals to retrieve the heartrate
- PPG utilize light technology to measure heartrate
- PPG sensors located on moving body parts have issues with optical noise.
- ECG is traditionally seen as more accurate, but studies show that PPG, in the right environment, is equally accurate
- PPG has a relatively long settling time
- With motion-tolerant PPGs, many biometrics can be accurately measured, sometimes even more precise than ECG

[16-23]

3.2.1.2.4 Location of heartrate measurement

There are several areas on the body where heartrate can be measured. The accuracy of the measurement is dependent on several factors like body type, environment, level of body movement, sensor technology used etc. Presented below in figure 6, is an illustration showing different parts of the body where measurement with PPG sensors is or is not suitable.

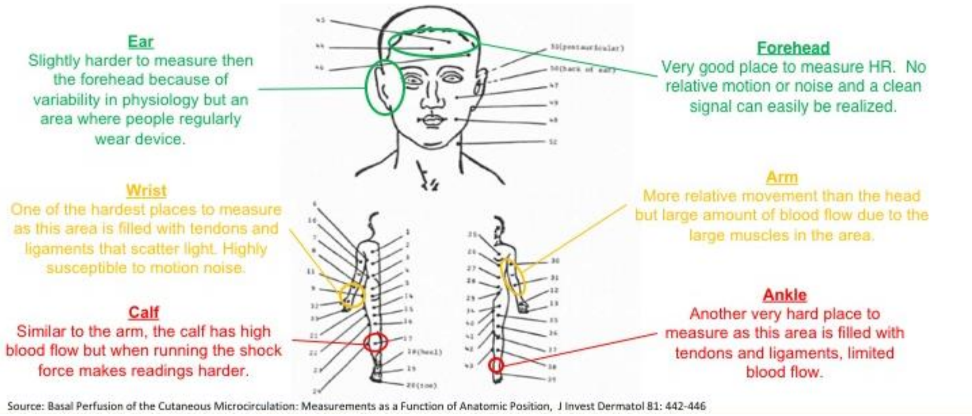

Figure 6 Description of accuracy and difficulty of measuring heartrate on common body parts [19]

3.2.1.3 Benchmarking

To develop a product which can compete with the existing products it was important to investigate the current market. This benchmarking is presented below in 3.2.1.3.1-3.

3.2.1.3.1 Comparison of different heartrate measuring wearables

It was desirable that the developed safety alarm of this thesis incorporated heartrate measurement technology. Therefore, it was interesting to research and compare available products utilizing this technology. This is briefly presented in table 1.

Table 1 Comparison of available wearables

Brand	Sensor	Water resistant	Battery time	GSM	GPS
Apple Watch 3	*PPG*	*Yes*	18 hours	Yes	*Yes*
Fitbit Ionic	PPG	*Yes*	4 days	*No*	*Yes*
JBL Under Armour Headphones	*PPG*	*Sweatproof*	5 hours	*No*	*No*
Polar Heartrate Belt	*ECG*	*Yes*	400 hours	*No*	*No*
MIO Link	*PPG*	*Yes*	6–8 hours	No	*No*

Samsung Gear IconX	PPG	Splash resistant	7 hours	No	No

3.2.1.3.2 Comparison of available safety alarms

Of interest was also to research available safety alarms, this for two reasons. One, to find out which essential functions the available alarms have. Two, to localize how a niche product could be created. This is briefly presented in table 2.

Table 2 Comparison of safety alarms

Brand	**Sensors**	**Water resistant**	**Battery time**	**GSM**	**GPS**
Vevios	None	N/A	N/A	Yes	N/A
Aifloo	Fall	Yes	1 year	N/A	N/A
Municipality	None	Yes	70 hours	No	No
SureSafe	Fall	Yes	400 hours	Yes	Yes

3.2.1.3.3 Municipal safety alarm

Currently, the municipalities are the main buyers on the Swedish market. Approximately, they stand for 95% of the purchases of safety alarms and are therefore a huge potential customer. When it comes to the procurement of safety alarms however, the municipalities often lack in knowledge of new technology and therefore have outdated requirement specifications. The chosen procurement is therefore decided after the principle of which is cheapest. Current safety alarm providers therefore claim that there are small margins of profit, which slows or completely stops the development process.

The safety alarms offered by the municipalities utilize analogue technology to send alarm-signals. This outdated technology causes many problems. For example, if more than one person set of their alarms simultaneously only one will succeed to reach the alarm central.

When the municipalities agree on their procurement, a central which receives the alarms is often included (usually *Svenska trygghetsjouren* or *Trygghetscentralen).* Their task is to receive the alarms and act accordingly, this process is neatly presented in figure 7.

[24]

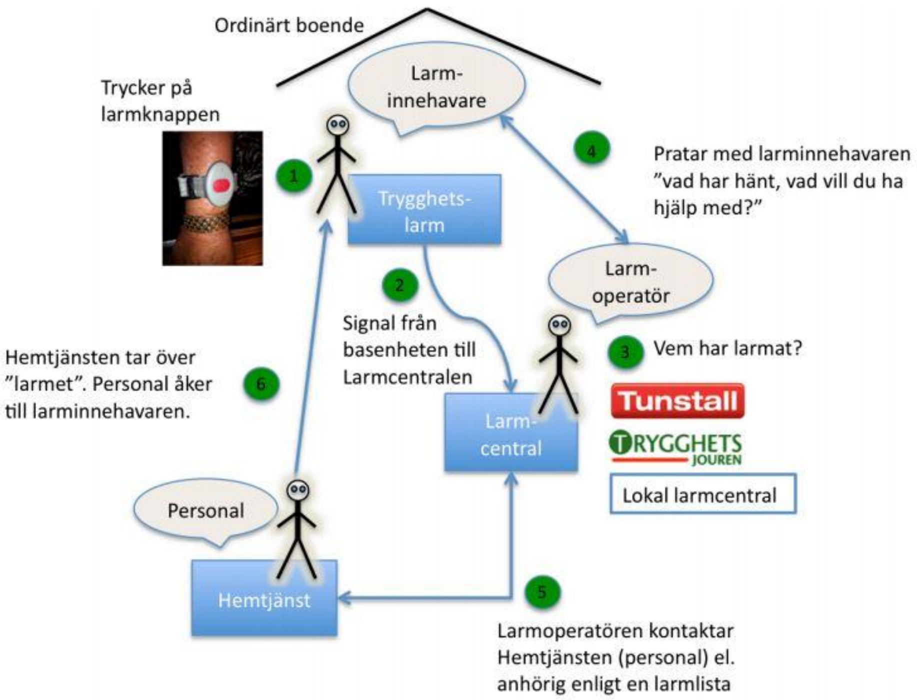

Figure 7 Illustrating the consecution when an alarm is set off [24]

3.2.2 Interviews

3.2.2.1 Medical staff

Through interviews with medical staff, plenty of enlightening information was given. Primarily, knowledge regarding heart rate measurement, diseases, the correlation of both and elderly care was obtained. Initially, a thorough semi-directive telephone interview was conducted with Dr. Olle Melander, professor and doctor in hypertension and cardiovascular disease. From this interview, the following conclusions were established:

- Heartrate and blood pressure reveals a lot about your health
- Future risks of heart problems can be discovered by measuring heartrate
- An average heartrate over 100 bpm should be investigated by a doctor (If over 120 bpm, urgently)
- Solely, heartrate cannot expose specific diseases. But indications and warnings can be distinguished
- Four or more heartrate measurements per day is sufficient to get a decent average

At *Mårtenslunds senior care* two semi-directive interviews were conducted, one with Marlene Rosén, overseer at *Mårtenslund* and one with a fellow nurse. From this interview, the following conclusions were established:

- The healthcare system is burdened, and it is getting worse
- There is room for improvement of safety alarms
- Digital, connected healthcare solutions are good to some extent. But they are solely not the solution

3.2.2.2 Elderly & Relatives of elderly

Through interviews with elderly, useful insight was gathered. A total of five semi-directive interviews were conducted; four with elderly living at *Mårtenslunds senior* care and one with Hugette, who solely lives in Stockholm and utilizes home-care. From these interviews the following conclusions were established:

- Elders overall health pose an issue for their safety
- Independence, freedom and a social life is important
- "My safety is more important than integrity"
- "When I alarm my safety alarm, the recipient cannot hear me clearly, and I do not hear them"
- The range of the safety alarm is limited (100-200m)
- "Freedom is life quality for me"
- Generally, the elders are satisfied although there have been several issues with their alarms
- Technical knowledge is limited
- Simple and clear products are preferable
- Grip strength and ability push buttons is difficult for some
- Some feel that they are a burden
- Many have daily routines

A total of three semi-directive interviews were conducted with relatives of elderly. Two of the interviewees had elderlies who utilizes safety alarms, one who is living in an elderly care and one who is living at home with home-care service. The third interviewee, solely cares for her elderly by regular visits. From the interviews with the relatives the following conclusions were established:

- Many wish they had more time to care for their sick elderly
- Feelings of stress and insecurity for the safety and health of one's elders is common
- Common methods of caring for one's elders: Shared homes, retirement homes, regular visits, safety alarms
- Many would like to easily be aware of their elder's real-time health and safety situation

3.2.3 Observations

As seen in figure 8, a field trip to *Mårtenslunds senior care* was executed to observe the residents using their safety alarms and cell/smartphones. *Mårtenslunds senior* care is managed by Lunds municipality and was the place of choice for the observations. Mainly, because many of its residents utilizes a safety alarm but also because a good contact was established with Marlene, the overseer at *Mårtenslund.* The observations were divided into two parts; safety alarm usage and cell/smartphone usage. For the first part, safety alarm usage, the ladies were asked to present and discuss the use of their safety alarms. For the second part, cell/smartphone usage, the ladies were asked to present their telephones, perform simple tasks and discuss their technological knowledge. A total of four ladies, age 75+, were observed. In retrospect it would have been good to interview males as well. The following results were gathered from the observations:

- The utilized safety alarms are simplistic and contain only an alarm button
- Some have made personal adjustments to their safety alarms to make them more appealing
- There have been technical problems with the safety alarms
- Many wore their safety alarm as a wristband, some in hidden places, such as a necklace on their chest e.g.
- Doro phones were used extensively, smartphones were not
- Low expertise on smartphones

Figure 8 Group picture with the lovely ladies from Mårtenslunds retirement home

3.2.4 Triangulation

At the end of the *Define phase* a triangulation was performed. Repeating results and conclusions were highlighted and studied further. These reoccurring topics are presented below:

- There is room for development of safety alarms; design, technology and ergonomics
- Trust issues
- Technological knowledge is generally vague
- Safety is superior (Safety > Integrity)
- IoT – Connected health devices. The future?
- Foresee diseases
- Real-time health check-ups

3.2.5 Affinity Diagram

As part of the triangulation, affinity diagrams were used to gain a better overview. The affinity diagrams were solely produced by comparing the gathered data from the literature studies, benchmarking, interviews and observations. Reoccurring topics such as safety, integrity, IoT etc were pinpointed and related subjects were written down as seen in figure 9 and 10.

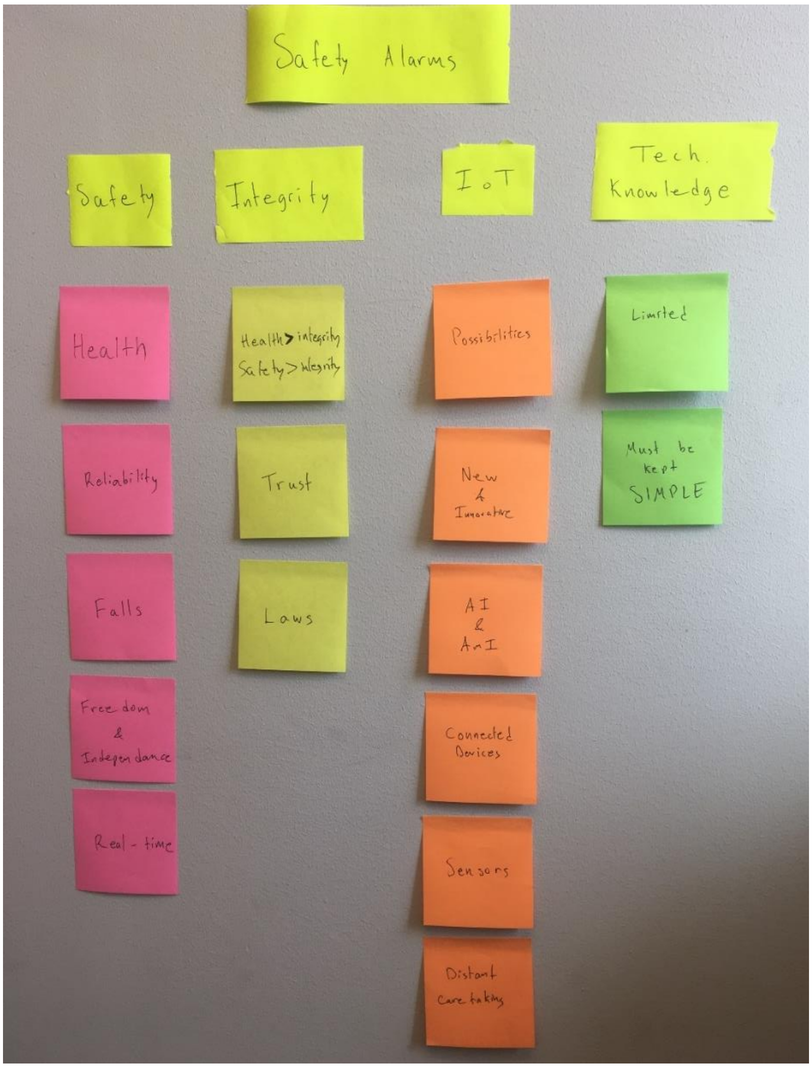

Figure 9 Example of one of the affinity diagrams

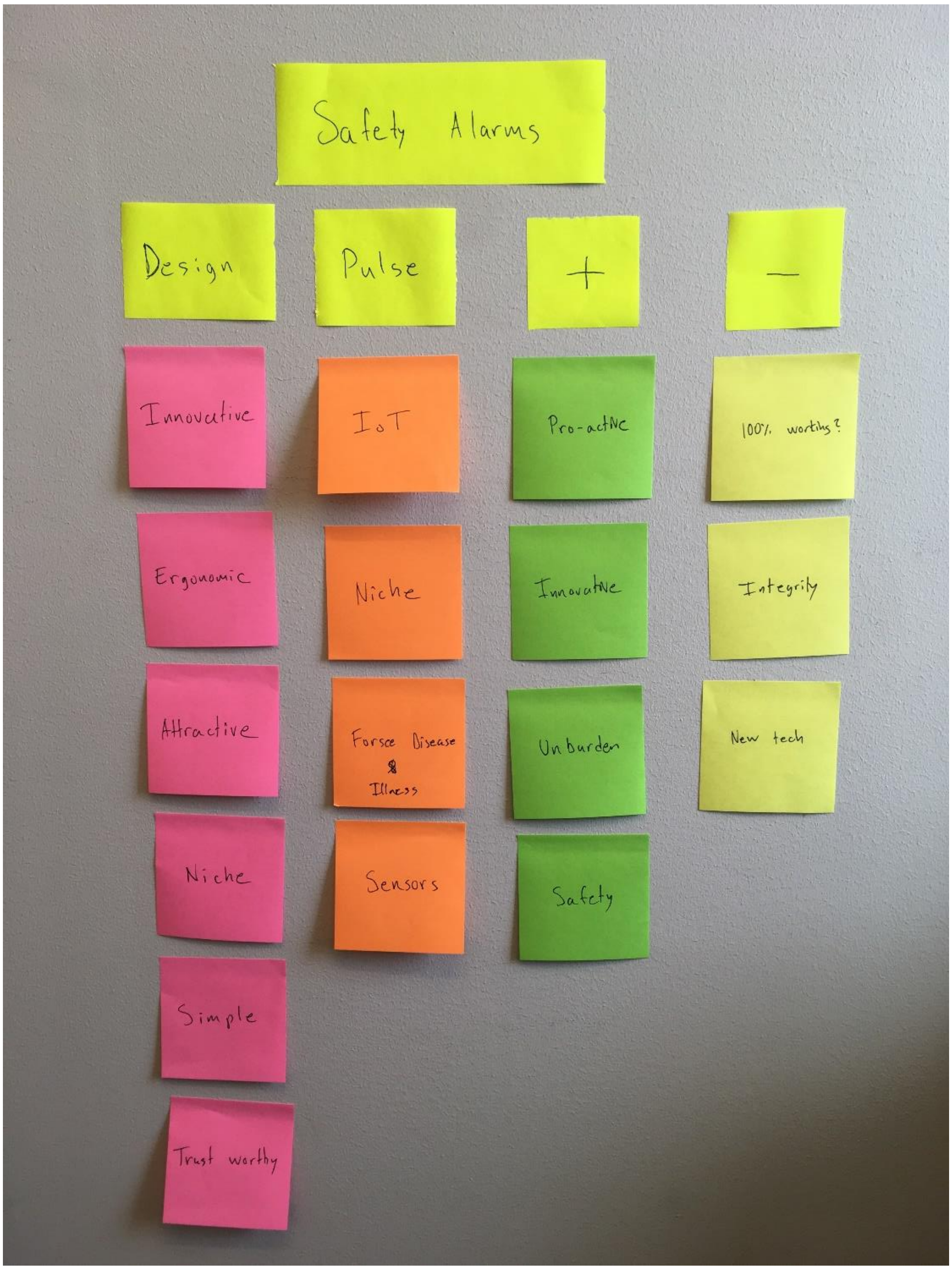

Figure 10 Example of one of the affinity diagrams

4 Define

The Define phase consists of analysing the results from the discover phase and synthesising the vital user needs and problem statements. Through this, a clearly defined design brief can be set up. This by help of methods such as function analysis, personas and design briefs [6].

4.1 Methods

4.1.1 **Personas**

A persona is a hypothetical individual, created from collected user-data. It is a tool that allows the designers to gain empathy and understanding for the users. By creating a persona, the designer gets a clear and concrete interpretation of the end-user.

[6,7]

4.1.2 **Need Statements + Function Analysis**

Need statements are used to interpret the collected raw data into user needs [8]. Guidance for writing these is presented below in table 3. The chosen need statements were subjected to a function analysis, were each need was translated into a function. These functions were then analysed and labelled with MF, N, W (Main function, Needed, Wished).

Table 3 Guidelines for writing need statements [7]

Guideline	Customer Statement	Need Statement—Right	Need Statement—Wrong
"What" not "how"	"Why don't you put protective shields around the battery contacts?"	The screwdriver battery is protected from accidental shorting.	The screwdriver battery contacts are covered by a plastic sliding door.
Specificity	"I drop my screwdriver all the time."	The screwdriver operates normally after repeated dropping.	The screwdriver is rugged.
Positive not negative	"It doesn't matter if it's raining; I still need to work outside on Saturdays."	The screwdriver operates normally in the rain.	The screwdriver is not disabled by the rain.
An attribute of the product	"I'd like to charge my battery from my cigarette lighter."	The screwdriver battery can be charged from an automobile cigarette lighter.	An automobile cigarette lighter adapter can charge the screwdriver battery.
Avoid "must" and "should"	"I hate it when I don't know how much juice is left in the batteries of my cordless tools."	The screwdriver provides an indication of the energy level of the battery.	The screwdriver should provide an indication of the energy level of the battery.

4.1.3 **Design Briefs**

As a result of the methods above and the *discover* phase, a design brief was composed. The design brief is more or less a compass, which shows the direction throughout the project. A specific end goal and method is usually not specified in a design brief. However, it clearly describes the user-needs that must be fulfilled [7].

4.2 Results

4.2.1 **Personas**

To synthesize the gathered user-investigation results, three different personas were created. These are presented below:

Agda

Agda is 74 years old and peacefully lives an independent life in retirement. She lives her life with everyday routines and has a passion for strolling in parks and knitting. Since Agda's technical knowledge is limited she owns a Doro phone. Agda praises her safety and freedom, however, her health situation is making it difficult for her to live freely and safely, especially when she is out walking.

Because of this, Agda has received a safety alarm from the municipality. Generally, when it works, she is satisfied with it. However, she has experienced issues with her safety alarm. At one point, she tried to send an alarm but did not receive an answer. Agda has also had issues with reaching the alarm button, this because of the position she fell in. She is also not satisfied with the fact that the safety alarm only works within in a radius of 100m around her home. Agda would also like to know more about the market of safety alarms.

Markus

Markus is 38 years old and pursuing his dream career as a technical designer. Outside of work, Markus prefers to spend time with friends, colleagues and his family of four (one wife and two kids). Markus has an elderly, widowed mother who lives alone and has home care service. Unfortunately, Markus finds it hard to balance his lifestyle with caring for his mother.

Therefore, he bought one of the safety alarms offered by the municipality for his mother. However, he is not entirely satisfied with this. Feelings of insecurity and obliviousness for the well-being of his mother is common. Therefore, he would like to have the ability to do real-time check-ups.

Dr. Ola

Dr. Ola is 48 years old and works as a cardiologist and professor. He has many years of experience in working with elderly and heart disease. Dr. Ola thinks the increased population and average life expectancy will burden the healthcare system. He thinks connected health devices may play a big, future role in unburdening the healthcare system.

4.2.2 Function Analysis

Seen below in table 4, is the function analysis for the safety alarm which is to be developed. It is essential and necessary that the main function (MF) and the needed functions (N) are fulfilled. The wished functions (W) are not equally important, but still meaningful for designing a desirable product. The functions and their grade are a result of the knowledge gathered from the literature studies, benchmarking, interviews and observations. "Be niched" is for example a wished function for competitive reasons, however, it is not needed for developing a functioning safety alarm.

Table 4 Function analysis

Provide user with safety	MF
Be comfortable/ergonomic	W
Offer appealing aesthetics	W
Measure heartrate	N
Be waterproof	W
Be niched	W
Offer real-time information	N
Be trustworthy	N
Offer freedom and independence	N
Foresee disease	W
Be simple	N
Unburden the healthcare system	W
Be connected (IoT)	W
Be rechargeable	N
Be minimalistic	W
Offer durability	W
Offer required battery-time	N
Offer easy cleaning	W

Offer required temperature resistance	N
Allow communication with platform	N
Remind to charge	W
Be suitable/befitting for all users	N
Reminder to wear	W
Offer an alarm button	N
Use fall sensors	W
Use GSM	W
Use GPS	W
Voice activation alarm	W

4.2.3 Design Brief

To provide the elderly with safety and freedom, the assignment is to design a next generation, connected safety alarm. It is desirable that the designed safety alarm is ergonomic and aesthetically attractive, but essentially, it should have a trust-worthy design. As the product is for elderly, the design should be minimalistic and simple. It is also preferable that product has a long battery-time, warnings of low-battery, is rechargeable and is waterproof and durable.

Technically, the product should be able to measure heartrate, have an alarm button and be connected to a related platform. It is wished that the safety alarm uses GSM and GPS technology. Apart from the heartrate sensor, a fall sensor and other sensors could be beneficial.

A complementary platform is to be designed. The platform should have the ability to study and store heartrate measurements, through this, smart algorithms should be able to foresee diseases. Caring relatives should have the possibility to oversee the real-time well-being of one's elderly through this platform.

A goal of this design process is to unburden the healthcare system by reducing hospital visits. Instead, heart measurement data can be obtained directly on the platform associated with the safety alarm. Another goal is to involve relatives in the care-taking process. However, the main goal is to provide the elderly with safety, freedom and independence.

5 Develop

In this phase, concepts in regard to the design brief and personas from the define phase were created. Brainstorming, sketching, mood boards and lo-fi prototyping were design methods that were used. These concepts where put through an iterative process consisting of prototyping and testing.

5.1 Methods

5.1.1 **Brainstorming**

Brainstorming is one of the most common ideation techniques, often used to distinguish solutions and opportunities. By using brainstorms, patterns, connections and new ways of thinking are often established. To achieve good results, an open mind and creative environment is necessary. [6,7]

5.1.2 **Mood boards**

Mood boards are collages of pictures based on certain topics or feelings. They are used to visually illustrate which type of mood/feeling the developed product aims to achieve. For medical devices, such a mood could for example be; cleanliness, trustworthiness and/or precision.

The mood boards for this thesis were assembled in Adobe Illustrator and are presented below in section 5.2.2.

5.1.3 **Sketching**

Sketching is a good tool for visually presenting ideas. By using different illustrative methods such as pen & paper or digital tools, concepts are easily presented for outside parties.

At the beginning of the concept generation phase, sketches were mainly done by use of pen & paper. However, digital illustrations were created for concepts which were further investigated and developed.

5.1.4 **Concept Screening**

Concept screening is good tool to use for evaluating different concepts. Matrices are set up with different criteria, each concept is then evaluated on each criterion. Each criterion is given a score of +, - or 0 in comparison to the reference, giving each concept a net score (+ if the criterion is better than the reference, 0 for same as reference, - for worse than reference). The net score is then used to compare the different concepts. An example of a concept screening is presented below in table 5.

[7]

Table 5 Example of a concept screening [7]

	Concepts						
Selection Criteria	A Master Cylinder	B Rubber Brake	C Ratchet	D (Reference) Plunge Stop	E Swash Ring	F Lever Set	G Dial Screw
Ease of handling	0	0	–	0	0	–	–
Ease of use	0	–	–	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	–	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	–	–	0	0	–	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum –'s	0	2	3	0	1	2	1
Net Score	2	–1	–2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

5.1.5 **Lo-fi prototyping**

Lo-fi prototyping is a good method for evaluating and testing simple concept ideas. By these early-stage tests, elementary design mistakes and wrong-doings may promptly be discovered [7].

For this thesis, lo-fi prototypes were created for further developed concepts, which were then put through user-tests, as described below in 5.1.6.

5.1.6 **User tests**

The purpose of a user test is to, in an early stage, localize design faults and necessary improvements of the product from an end-user perspective.

Therefore, the final lo-fi prototypes were put through open user tests including discussion and follow-up questions, this from an end-user perspective. Initially, open user tests were conducted on colleagues to gain insight of a young and modern mind and to prepare for the more crucial end-user tests. The end-user tests were conducted at *Mårtenslunds retirement facility* and are briefly described below:

- Short introduction of each lo-fi prototype concept
- Wearability test - how easily can the users wear/put on the safety alarm?
- Open discussion

The test described below was performed on three different students:

- Test 2: 12-hour test – wear for 12 hours to localize issues and opportunities

5.1.7 **Concept-Scoring**

Concept scoring is a more detailed concept screening and is utilized to clearly compare and differentiate competitive concepts. In a concept scoring, different criterions are relatively compared, the total scores of a concept is determined by the weighted sum of each criterion's score. An example of a concept scoring is presented below in table 6 [7].

Table 6 An example of a concept scoring [7]

		Concept							
		A (Reference) Master Cylinder		DF Lever Stop		E Swash Ring		G+ Dial Screw+	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Ease of handling	5%	**3**	0.15	3	0.15	4	0.2	4	0.2
Ease of use	15%	**3**	0.45	4	0.6	4	0.6	3	0.45
Readability of settings	10%	2	0.2	**3**	0.3	5	0.5	5	0.5
Dose metering accuracy	25%	**3**	0.75	3	0.75	2	0.5	3	0.75
Durability	15%	2	0.3	5	0.75	4	0.6	**3**	0.45
Ease of manufacture	20%	**3**	0.6	3	0.6	2	0.4	2	0.4
Portability	10%	**3**	0.3	3	0.3	3	0.3	3	0.3
	Total Score	2.75		3.45		3.10		3.05	
	Rank	4		1		2		3	
	Continue?	No		Develop		No		No	

5.2 Results

5.2.1 **Brainstorming**

As seen in figure 11, brainstorms were created on topics closely related to the thesis and *Discover phase*. The brainstorms were solely created and took about 15 minute each to create. The starting point for the brainstorms were the topics *Connected healthcare, wearables, safety* and *interviews & observations.* Recurring and interesting phrases were circled in green and were thought to be of high importance when developing different conceptual ideas, these are presented below in table 7.

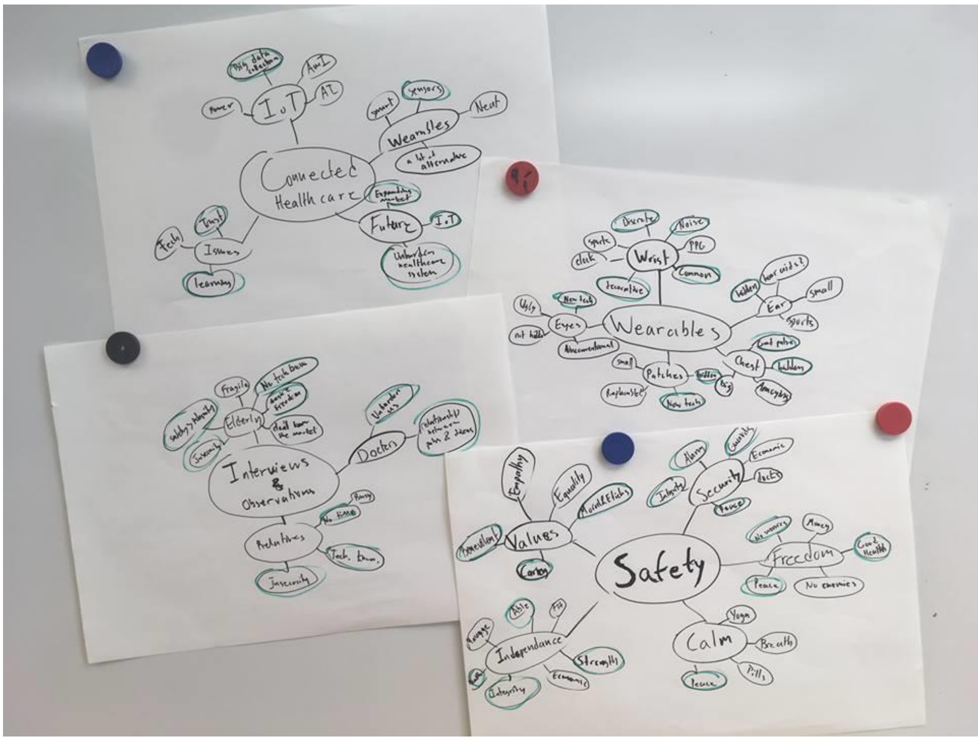

Figure 11 Created brainstorms

Table 7 Highlighted phrases from brainstorming session

Health	**Ability**	**Reliability**
Caring	**Integrity**	**Benevolent**
Moral & Ethics	**Peace**	**Alarm**
Guard	**No Worries**	**Good Health**

Pulse	**Security**	**New Technology**
Decorative	**Discreet**	**Common**
Noise/Disturbance	**Trust**	**Simple**
Unburden	**IoT**	**Expanding market**
Sensors	**Big Data Collection**	**Busy**
Technology knowledge	**Insecurity**	**Hidden**
Safety > Integrity	**Relationships**	**Reliable**

5.2.2 **Mood boards**

Two mood boards were created to inspire the sketching and prototyping process. The first one was created to describe the desired feeling of the product, the other one was established to find design inspiration from similar products. Both are presented below in figure 12 and 13.

Figure 12 Mood board illustrating the desired feeling of created safety alarm

Figure 13 Mood board of similar products

5.2.3 **Sketching**

To initialize the inspiration process, quick sketches were made to visualize common body parts where heart rate can be measured; this is presented below in figure 14. For each body part, several sketches were created with inspiration from possible solutions and mood boards, these are presented in figure 15-19.

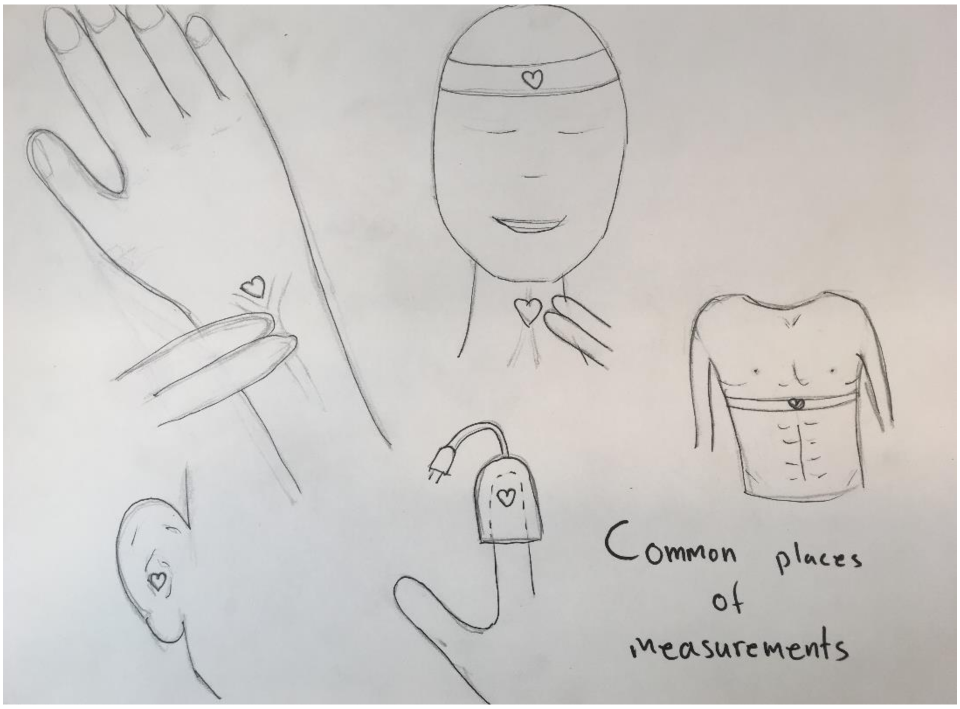

Figure 14 Sketches of common places to measure heartrate

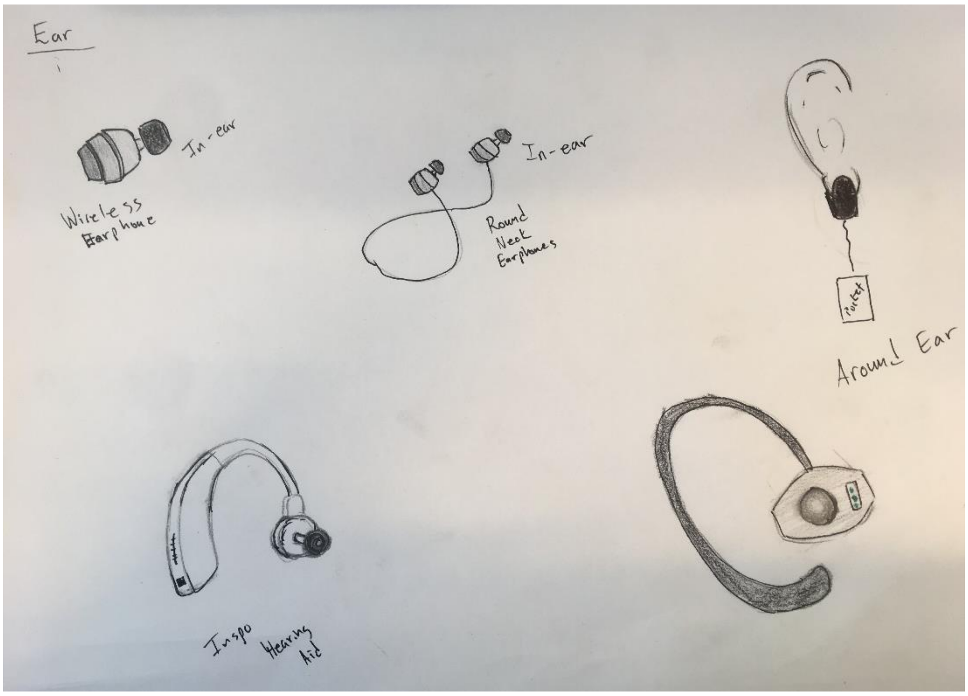

Figure 15 Sketches of possible ear-worn solutions

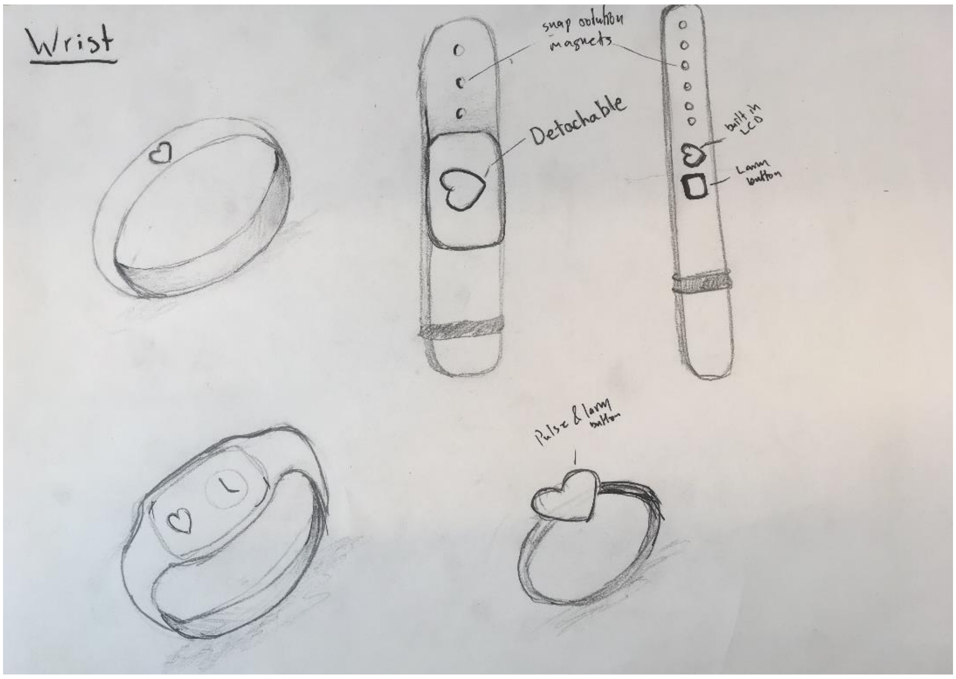

Figure 16 Sketches of possible wrist-worn solutions

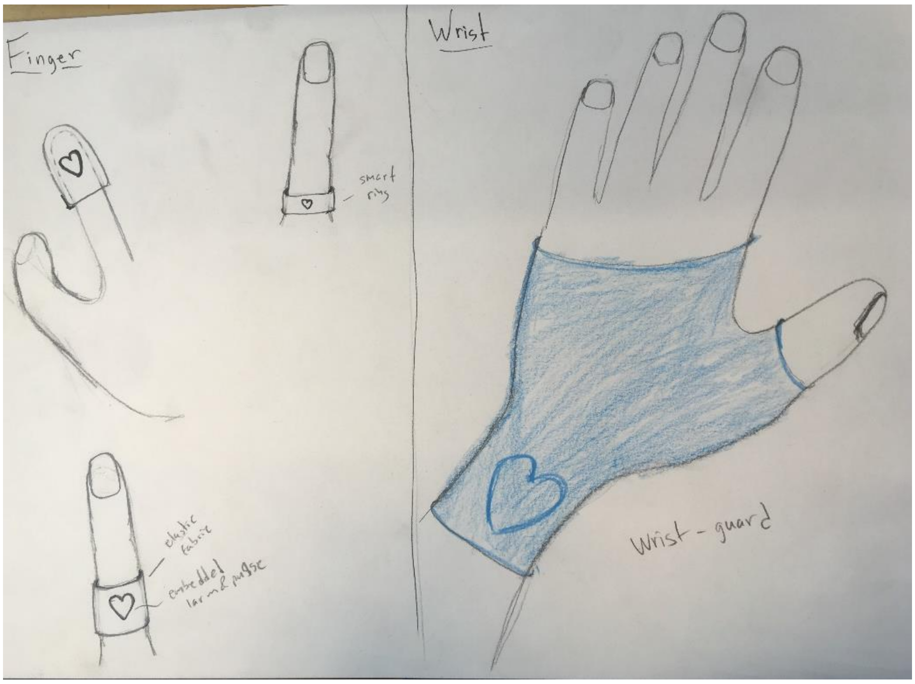

Figure 17 Sketches of possible finger- and wrist-worn solutions

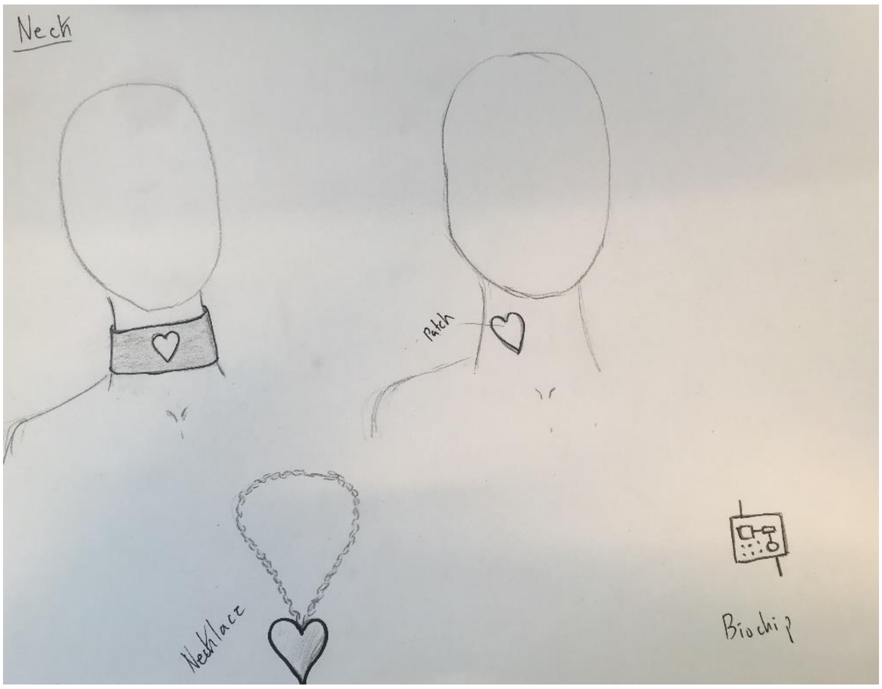

Figure 18 Sketches of possible neck-worn solutions

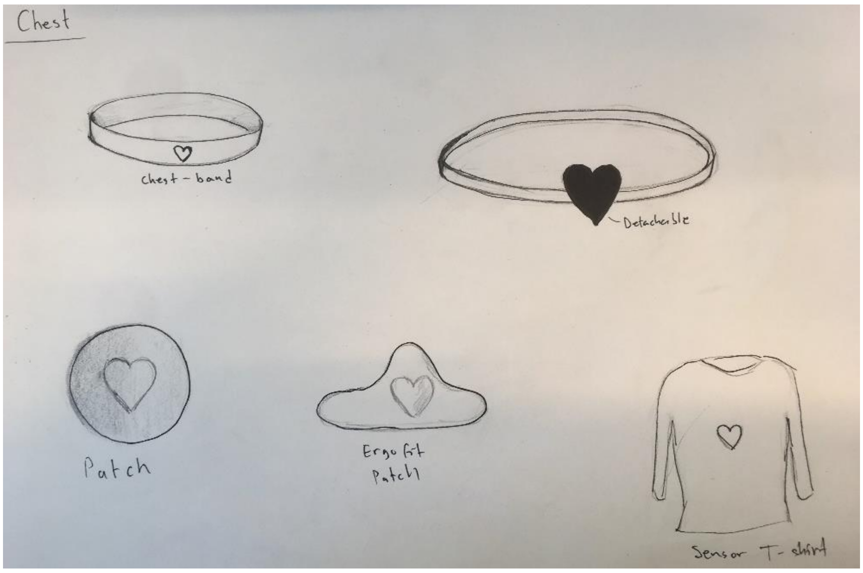

Figure 19 Sketches of possible chest-worn solutions

5.2.3.1 First evaluation of concept-sketches

To evaluate the different concepts, a concept screening was performed. Worth mentioning is that it was difficult to evaluate the sketched concepts at this stage of the thesis, the scores of the concept screening were therefore solely based on own experience and insight. The result of the concept screening is presented below in table 8.

Table 8 Concept screening

	Concepts						
Function	Ear-clip	Patch	Biochip	Wristband (Reference)	Ring	Wrist-guard	In-Ear
Ergonomic	-	0	0	0	+	+	0
Appealing	-	-	0	0	+	0	0
Simple	0	+	-	0	+	+	0
One size fits all	+	+	+	0	0	+	0
Rechargeability	0	-	-	0	0	0	0
Uniqueness	0	+	+	0	0	+	0
Possible Noise	0	0	0	0	+	+	+
Net score	-1	1	0	0	4	5	1
Rank	**5**	**3**	**4**	**4**	**2**	**1**	**3**
Continue?	**NO**	**NO**	**NO**	**NO**	**YES**	**YES**	**NO**

5.2.3.2 Further evaluation of concepts

The concept screening as seen in table 8, resulted in continued work with the following concepts: A smart ring and a smart wrist-guard. To initiate the creative process, research and benchmarking was conducted. This to gain inspiration and insight of possible and available solutions. The benchmarking is presented below in figure 20-21.

Figure 20 Benchmarking of available smart rings and their design

Figure 21 Benchmarking of available wrist guards

Sketches and 3D-models were created to commence the concept generation. These were produced to investigate possible forms, solutions and design and are presented below in figure 22-26.

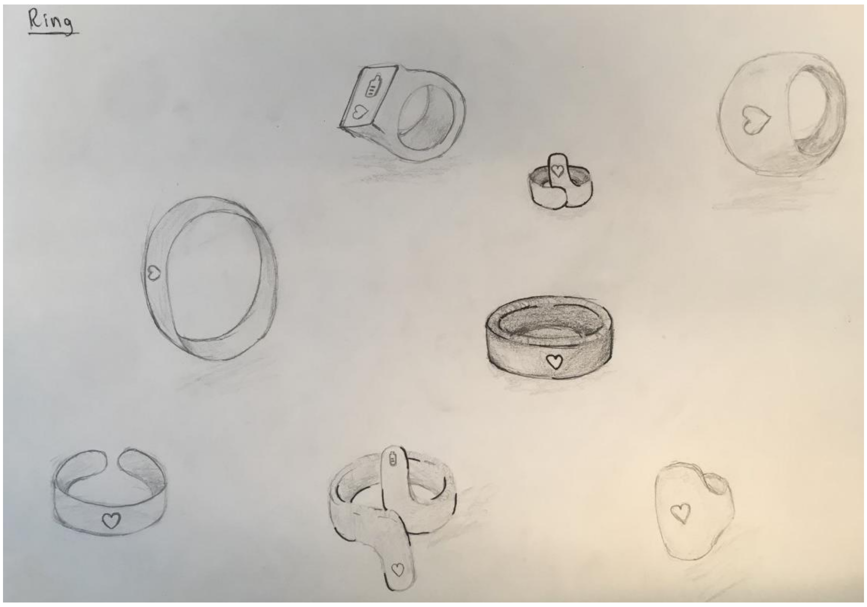

Figure 22 Sketches of possible ring designs

Figure 23 Sketches of possible wrist-guard designs

Figure 24 3D-models of possible ring designs

Figure 25 Illustrator sketches of possible wrist-worn designs

Figure 26 Investigation of different colour schemes

5.2.4 **Lo-fi prototyping**

To acquire a sense of size, design and fit, several lo-fi prototypes were created. These were constructed in different ways and in various materials such as paper, plastic, foam and fabric. Described below is the prototype-process for the ring and wrist-worn concepts.

5.2.4.1 The ring

Initially, several ring-prototypes were created in different types of foam. These foam prototypes gave a lot of insight about size and comfort. To wear comfortably, the rings should not be too thick, inflicting the space between the fingers. The top part of the ring did not affect the comfort, but the aesthetics.

Moving on from foam-rings, rings were created by sawing and sanding plastic tubes. The first prototype was too rigid and small, therefore the second prototype was formed as an open ring (ring 6), which is seen in figure 27. Deriving out of this was the insight that an open ring is preferable. An open ring is flexible and therefore easier to put on and may fit more people.

Of interest as well, was the choice of material. Soft, stretchy and ductile material was preferable as it may fit several different users and is simple to put on, however it is necessary that the internal electronics are protected. Presented below in figure 27-28 are these simple, lo-fi prototypes.

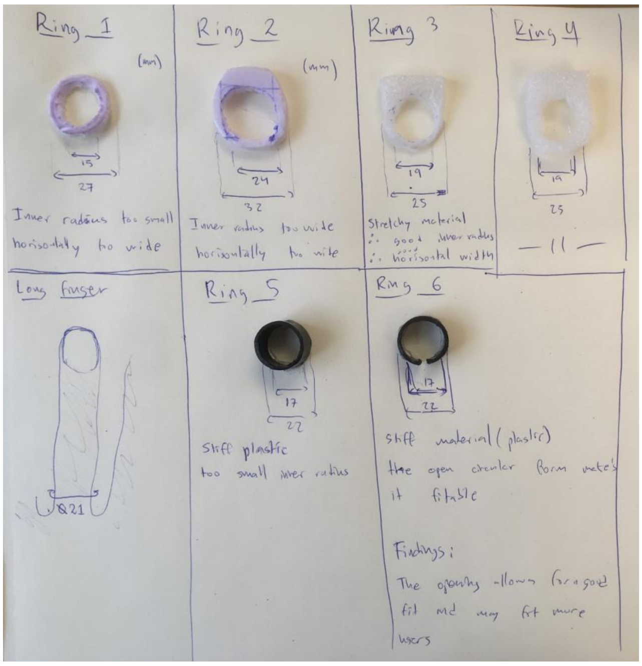

Figure 27 Overview of the initial lo-fi ring prototypes made from foam and plastic tubes

Figure 28 simple lo-fi fabric prototypes

The above results were further refined by creating 3D-printed prototypes. These were constructed to furthermore investigate form, design, ergonomics and to try different concepts, these are presented below in figure 29-30. From these prototypes, further insights were gathered by testing and evaluating them both solely and on fellow thesis workers. The gathered insights are presented below:

- An open ring is preferable
- The thickness of the ring is of importance for comfort and ergonomics
- The top part of the ring only affects the aesthetics
- The width of the ring should not be longer then 1/3 of the finger
- The direction of materials fibres affects the flexibility
- Rectangular cross-sections with rounded edges are comfortable and give more room for internal components
- Circular cross-sections leave less room for internal electronics. For circular cross-sections, open ring designs tends to uncomfortably pinch the skin. This was not as big of problem for rectangular cross-sections
- As seen to the far right in figure 29, the top third of the ring may be larger, this will not affect the ergonomics and fit, but the aesthetics
- A helix ring design was more rigid and not comfortable

Figure 29 3D-printed prototypes

Figure 30 Close-up of 3D-printed prototypes.

5.2.4.2 The wrist-guard

Initially, simple wrist-worn prototypes were created to explore different solutions, design and fittings. These prototypes were mainly constructed in fabric, plastic and other soft and flexible materials. It was quickly discovered that a wrist-worn solution has the possibility to fit many different users, has plenty of room for technical component and can be ergonomically designed. As for choice of material, it was desired that the safety alarm is water-proof, therefore fabric solutions are not optimal, an option could instead be silicone or other kinds of soft plastics and rubbers. However, for these lo-fi prototypes, this aspect was not thought of. Presented below in figure 31 are some of the different lo-fi prototypes.

Figure 31 Lo-fi prototypes of wrist-worn solutions

By use of 3D-printing, these wrist-worn concepts were further investigated. One idea was a modular solution which is presented below in figure 32 & 33.

Figure 32 Lo-fi prototype created by combining 3D-printing and fabric

Figure 33 Lo-fi prototype created by combining 3D-printing and fabric

5.2.4.3 Comparison of ring and wrist-guard concept

The further developed concepts both had their strengths and weaknesses. It was therefore interesting to in an early stage, localize these and explore how to strengthen an entire concept. This comparison is presented below in table 9.

Table 9 Comparison of strengths and weaknesses in the concepts

Ring (strengths)	**Ring (weaknesses)**	**Wrist (strengths)**	**Wrist (weaknesses)**
Steady		Steady	
	Small space for internal tech.	Plenty of space for internal tech	
	Does not fit all	Fits many	
Discrete			Not discrete
Innovative		None on market	
Attractive			Not attractive

There were two major problems with the ring concept, compared to the wrist-worn. One, there is not much space for internal, electrical components. However, there are smart-rings with pulse measurement and other electronic components available on the market. A concept like this is therefore considered to be realisable. Secondly, there is not one size that fits all.

The last issue was interesting to investigate further, therefore different solutions, similar to wristband solutions, were sketched and inspected. These are presented below in figure 34.

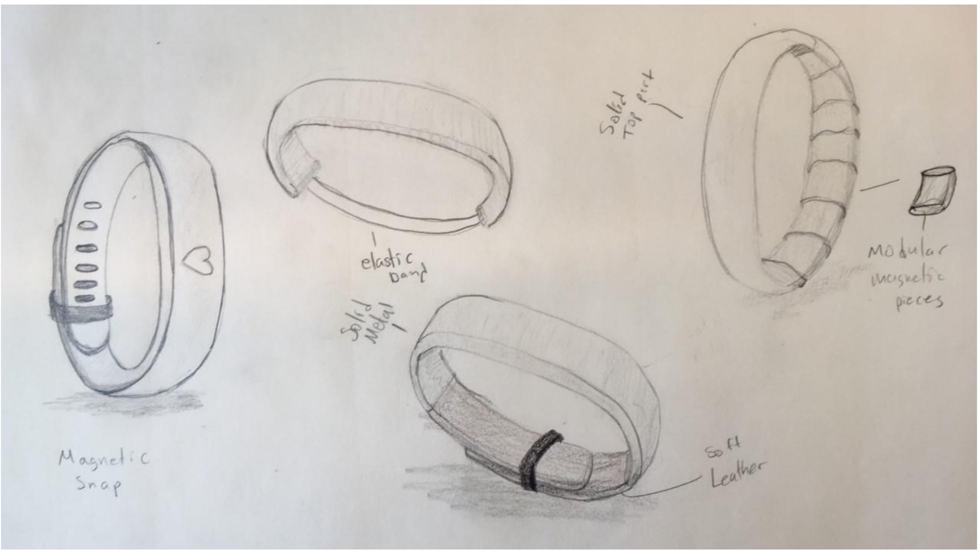

Figure 34 Sketches of possible adjustable ring concepts

The above concepts would make the size of the rings adjustable, however, much like wristbands, many would not give all users a perfect fit. A big problem with pulse measuring wristbands is that they are loosely worn and do not offer a perfect fit. This may set off unwanted noise which disturbs the heartrate measurements. In reality, these solutions are just miniaturized wristbands, and it is therefore reasonable to presume that they will experience the same difficulties, plus will require smaller and more expensive components. The elastic band solution was however interesting to investigate further, as well as an open ring solution.

As for the wrist-guard concept, at this stage, the only issue was the aesthetics. It was therefore interesting to study how a wrist-guard concept could be designed to be discrete and aesthetically appealing. This was explored by different types of sketches presented below in figure 35.

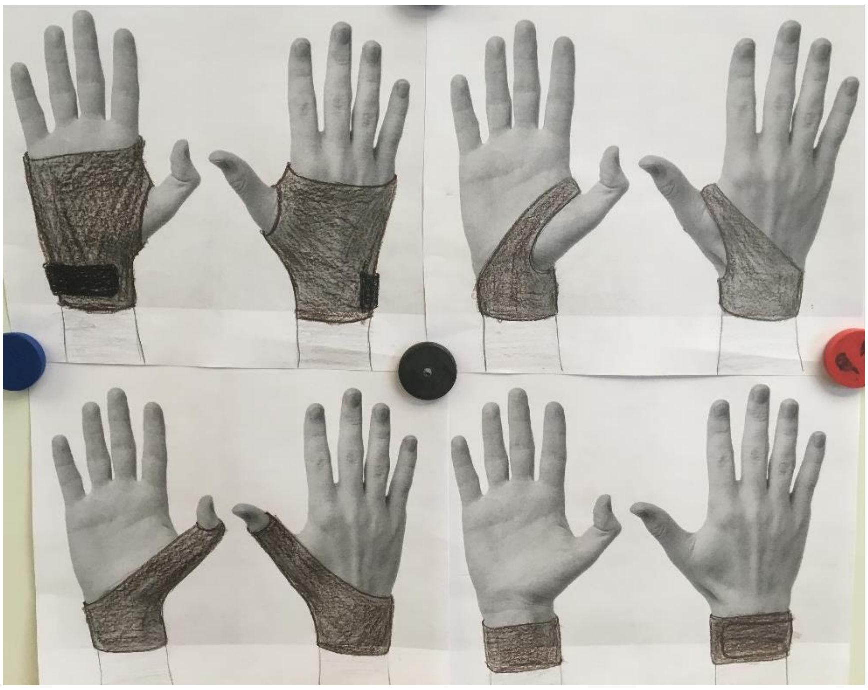

Figure 35 Sketches of possible wrist-guard designs

5.2.4.4 Final lo-fi prototypes

Deriving out of the above research was two, final lo-fi prototypes for each concept which are presented below in figure 36-38.

Figure 36 final open ring lo-fi prototype

Figure 37 final elastic ring lo-fi prototype

Figure 38 The two, final lo-fi wrist-worn prototypes (Wrist-guard concept to the left, Glove concept to the right)

5.2.5 User tests

At this point, it was time to decide which concept to continue with. To do so solely was impossible. The ambition of creating an innovative and high-tech product was pushing towards the ring concept. However, the research was pointing in the direction towards the wrist-guard concept. Therefore, user tests were conducted to decide which concept to develop further.

User tests were performed on elderly at *Mårtenslund retirement home* and on fellow students at LTH. The purpose of the tests was to evaluate how each concept fit the users, the comfort and the user experience. To achieve this, users were asked to try and wear the different prototypes, one at a time and discuss the comfort and user experience.

Much insight and inspiration were achieved from the user test, these results are summarised below:

Glove concept

- Easy to put on
- Soft and comfortable
- Free and easy movement of hand
- Not discrete
- Not aesthetically appealing
- Easily associated with a person in need/with a disability – not appreciated
- Warm, sweaty, may collect dust, dirt, bacteria and develop fungus

Wrist guard concept

- Difficulties with understanding how to correctly put it on
- Appreciation for leaving the palm of the hand free
- Easily associated with injuries – not appreciated
- Warm, sweaty, may collect dust, dirt, bacteria and develop fungus
- Different opinions on comfortability and aesthetic beauty

Open ring concept

- Very discrete
- Simple to put on if it fits you
- Does not fit all
- May be worn on different fingers
- Arthrosis is common with elderly and therefore the ring could not fit
- Lumpy fingers are common with elderly and therefore the ring could not fit
- Trivial product, easily forgotten, in a good sense
- Some males were unaccustomed to wearing rings
- Males preferred a simpler design, no top part
- Widely appreciated by females

Elastic ring concept

- Smart
- Fits all
- Simple to put on

- Discrete
- Widely appreciated by females
- Many thought it was comfortable, some had minor issues with the tightness of the elastic band
- Trivial product, easily forgotten, in a good sense
- Mostly appreciated out of all concepts

5.2.5.1 Concept screening

To analyse the results from the user tests in a structured manner, a concept screening as seen in table 10, was set up. Different criteria for each concept was relatively compared, the different criterions were given a score of 1-5 and the weighed sum was then calculated and compared. The scores and weight of the concept screening were based on the results gathered from the user tests.

Table 10 Concept screening

	Concepts				
Criteria	**Weight %**	Wrist guard	Glove	Open ring	Elastic ring
Ease to wear	30	2	5	3	5
Fit many	25	5	5	3	5
Ease to use	15	2	3	5	5
Cleanliness	15	1	1	4	4
Discreteness	10	1	1	5	5
Innovative	5	3	3	5	5
	Total Score	2.25	3.60	3.75	4.85
	Rank	5	3	2	1
	Continue?	No	No	No	Develop

Deriving out of the user tests and concept screening was one clear favourite; the elastic ring concept. This concept was widely admired for being discrete, comfortable and for fitting many users. Therefore, the elastic ring concept was chosen to be further developed.

Figure 39 User test of open ring concept

5.3 Further concept development of a smart ring

As a result of the user tests, it was decided to continue developing a smart ring concept. This process is presented below.

5.3.1 **Research**

To gain wide knowledge and inspiration of technical possibilities and designs, further benchmarking was conducted.

5.3.1.1 Benchmarking – Smart rings

Generally, technology has come far, and anything seems possible. Available are small, specially designed sensors, Bluetooth communication, long lasting batteries and other small technical solutions. Although, benchmarking was conducted on many different types of smart rings, only smart rings with pulse sensors and/or alert functions are presented below in figure 40 – 43.

Motiv ring

Figure 40 Motiv ring [25]

The *Motiv* ring is constructed in three ring-layers, the two, outside ring-layers form a titanium shell which protects the inner ring containing the technology. This provides the ring with a lightweight, durable and waterproof design.

The *Motiv* ring is mainly used as a fitness device, monitoring steps, distance, activity and heart rate (PPG technology). It is waterproof for up to 50m, the battery lasts for 3-5 days and is rechargeable.

As for fitting, the *Motiv* ring does not fit all users. Therefore, the developers send out a size measurement kit to the customers beforehand. The *Motiv* ring costs 199 USD.

[25]

Oura ring

Figure 41 Oura ring [26]

Like the *Motiv* ring, the *Oura* ring is made of titanium. It is developed and marketed as a smart ring which improves the quality of your restorative sleep. The ring has several advanced sensors such as pulse sensors, 3D accelerometer, gyroscope and temperature sensors. Bluetooth communication and internal memory is also available within the ring. The ring is water resistant and has a battery time of up to one week. The ring costs 299 USD.

[26]

Blinq

Figure 42 Smart ring from Blinq [27]

Kickstarter-launched *Blinq* is a startup that has developed a smart ring aimed at keeping users fit and safe. The ring has a fitness tracker which tracks steps, distance and calories. For personal safety, there is a built-in panic button which alerts the users relatives in case of emergency and sends your GPS location. A Blinq ring costs around 120 USD.

[27]

Nimb ring

Figure 43 The Nimb ring [28]

The *Nimb* ring, as presented in figure 43, is mainly used for personal safety. It is made out of hypoallergenic material and has a battery life of up to two weeks. The *Nimb* ring has an alarm button, which alerts your choice of contacts, this button is specially designed to prevent false alarms. The internal electronic components are laid out as seen in below in figure 44. The *Nimb* ring has no internal GSM and must therefore be connected to the user's smartphone via Bluetooth. Retail price for the *Nimb* ring is around 150 USD.

[28]

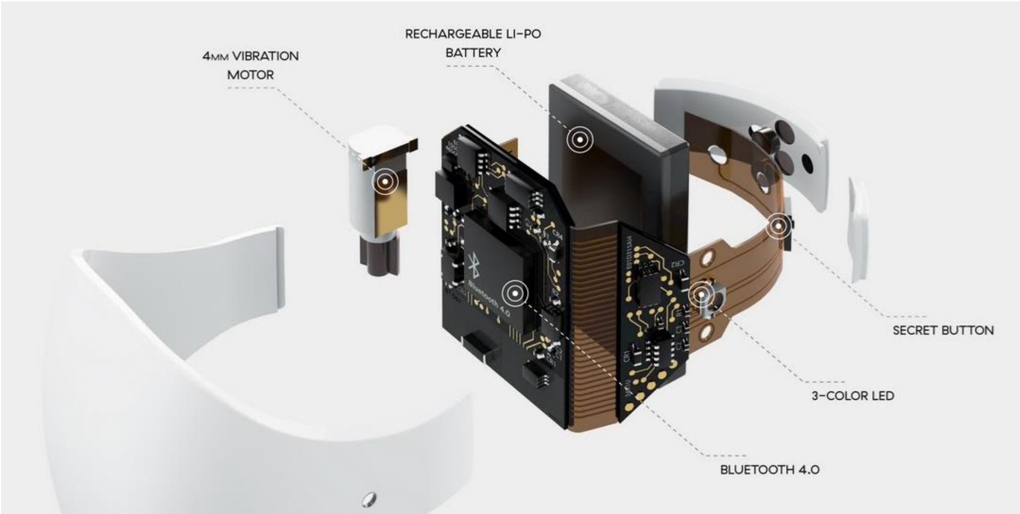

Figure 44 Layout of internal electronics in the Nimb ring [28]

5.3.1.2 Sketches

Inspired by the benchmarking above and the elastic ring concept, sketches were produced to explore possible form and design. These sketches are presented below in figure 45-46.

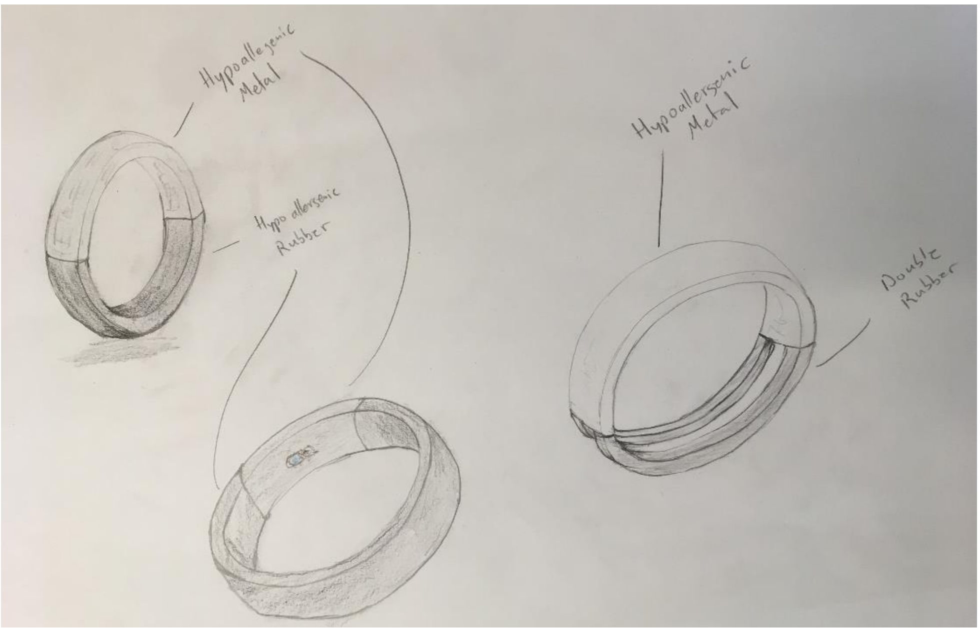

Figure 45 Sketches of possible elastic ring solutions

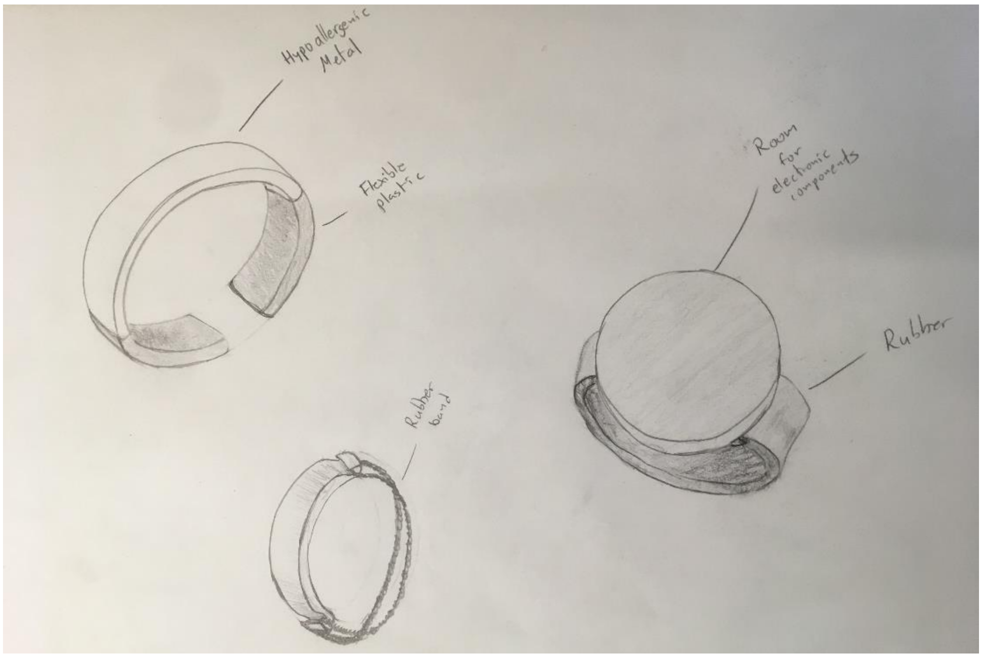

Figure 46 Sketches of possible elastic ring solutions

5.3.1.3 3D – models

To acquire a more vivid sense of the sketches, simple 3D-models were produced for some of the elastic ring concepts presented in the sketches above.

The first model, as presented in figure 47, is *"the half elastic"*. This concept is designed in two, joined halves, the upper half is made of a hypoallergenic metal and contains all the electronics. The bottom half is made of an elastic rubber material to fit all users.

Figure 47 The half elastic

Secondly a model of *"the elastic two"* was produced. This is presented below in figure 48 and is much similar to *the half elastic*, however *the elastic two* is using less material.

Figure 48 The elastic two

The third concept, *"the elastic fifth"*, as presented below in figure 49, is also similar to *the half elastic*. However, *the elastic fifth* has a smaller metal detail, and therefore less space for internal electronics.

Figure 49 The elastic fifth

The fourth concept was named *"the module"*. As seen in figure 50, this concept was designed as a modular solution. It consists of a metallic top module which is connected to an elastic rubber ring.

Figure 50 The module

The fifth concept was named *''the flexi ring''* and is presented in figure 51. This concept is designed as an open ring solution where the top half is made of a hypoallergenic metal. As seen in figure 51, the bottom part is a claw solution which is produced in a flexible material.

Figure 51 The flexi ring

The sixth and final concept, *"the hard half"*, was designed with a hard top and hard bottom connected with an elastic middle section. This concept is presented in figure 52.

Figure 52 The hard half

5.3.1.4 Lo-fi prototypes

Deriving out from the 3D-models was the creation of lo-fi prototypes for *the flexi ring, the half elastic* and *the hard half* concept. *The flexi ring* and *the half elastic* were created in three 3D-printed parts as seen below in figure 53. As for *the hard half,* it was also constructed in three parts, however assembled differently.

Figure 53 The three 3D-printed parts that make *the flexi ring* prototype

The two, black 3D-printed parts in figure 53 were created in ABS, which is a rigid plastic. As for the white 3D-printed part, it was printed in a semi-flex material. These three parts were assembled as seen below in figure 54. *The flexi ring*, *the half elastic* and *the hard half* prototypes are presented in figure 55-57.

Figure 54 Assembly of *the flexi ring* concept

Figure 55 The flexi ring prototype

Figure 56 The half elastic prototypes

Figure 57 The hard half prototype

5.3.1.5 Evaluation of lo-fi prototypes

The flexi ring

This concept was an interesting solution with many similarities to the open ring solution. The flexibility (elastic modulus) of the “claws” needs to be further investigated, as the prototype did not strain as much as desired. An advantage with this solution is the simplicity of putting it on. However, an issue, depending on choice of material for the claws, could be creep and flexibility. The risk of the claw pinching the users finger could also be an issue.

The half elastic

As for advantages and disadvantages, this solution differed from *the flexi ring*. This solution was more difficult to put on, due to the low elasticity of the bottom part. This could however be further investigated and solved. Another issue was that the elastic band easily rolled up when the ring was put on. Unlike *the flexi ring* there is no risk of pinching, but the elastic band could strain some users too hard. However, the issue with creep is relevant for this concept as well.

The hard half

This solution was aimed at user who might prefer a solid bottom. A disadvantage is that the size adjustments provided by the elastic band only will apply to vertical size differences and not horizontally, wider fingers. The issue of creep is relevant for this concept as well.

Decision

By weighing the pros and cons brought up and through discussion and evaluation with tutors and colleagues it was decided to continue developing *the flexi ring*.

5.4 Further development of the flexi ring

Presented below is the continued development process of the flexi ring which includes solving and researching the following issues: Choice of material, optimal angle of the open flexi-ring and integrating an Arduino pulse sensor.

5.4.1 **Sketches**

To initiate the development process of *the flexi ring*, sketches were created to easily visualise the complete design. One of these sketches is presented below in figure 58.

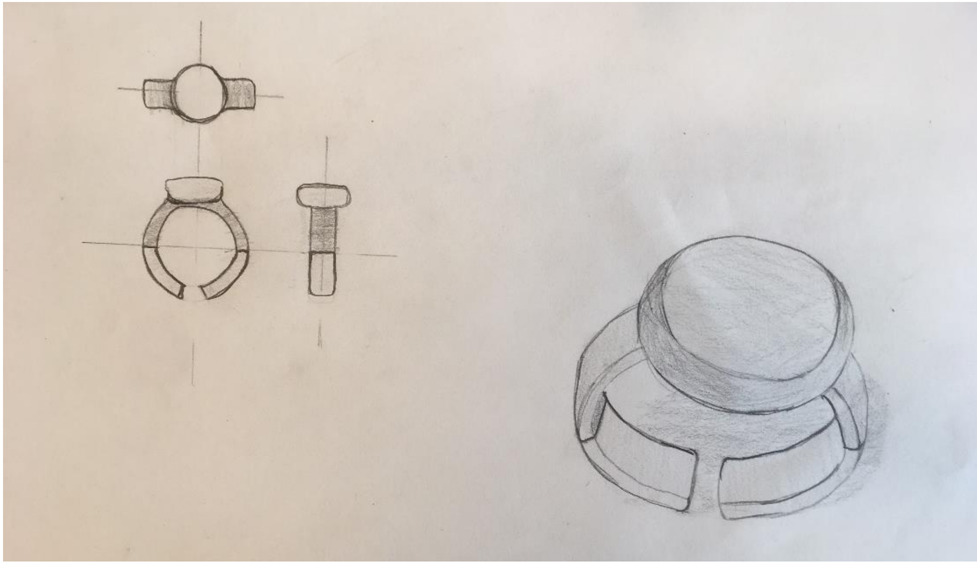

Figure 58 Sketch of the flexi ring

5.4.2 **Elements of the flexi ring**

5.4.2.1 Top half

5.4.2.1.1 Material

The upper half of *the flexi ring* is to be constructed in a hypoallergenic metal, preferably titanium for its mechanical properties. Titanium is a low density and high strength metal with corrosion resistance, and most importantly has hypoallergenic properties. It is therefore commonly used when developing smart rings, as well as other medical appliances such as implants, scalpels etc.

5.4.2.1.2 Design

The top half of the final *flexi ring* is to contain all internal electronic and mechanical locking mechanisms. However, for this project, the upper half should only fit a pulse sensor and mechanical locking mechanisms. Below, in figure 59, is a sketch of how the top half is designed, presenting mechanical locking mechanisms and space for internal components.

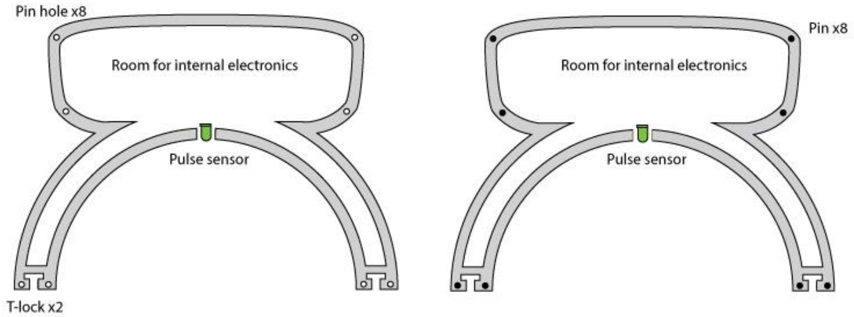

Figure 59 Sketch of the upper half of the flexi ring

5.4.2.2 Bottom Half

5.4.2.2.1 Material

The bottom half of *the flexi ring* is to be constructed in a sturdy but flexible material, either stainless spring steel with hypoallergenic properties or an elastomer. To investigate which material to choose for the claw solution, prototypes were created and tested as presented in 5.4.2.3.

5.4.2.2.2 Design

The bottom half of *the flexi ring* was designed as a claw with spring-like properties. This design is presented below in figure 60.

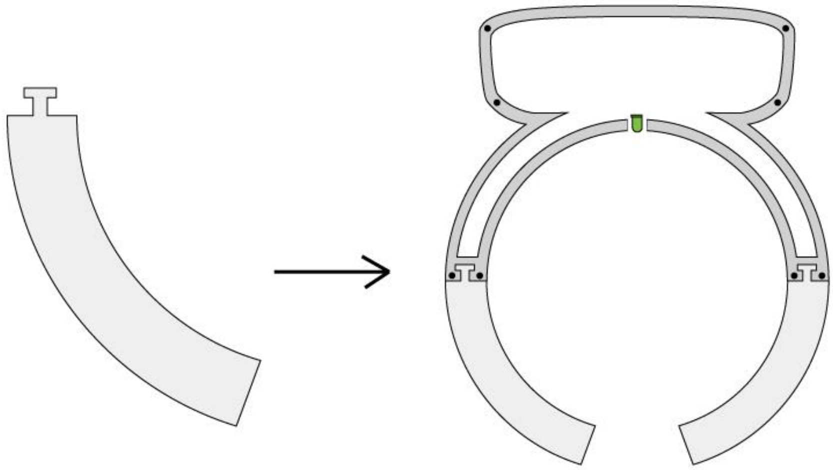

Figure 60 Sketch illustrating the bottom half of the flexi ring

5.4.2.3 Prototyping

As it was desired that *the flexi ring* should fit many users, the bottom half was designed as flexible claw. The choice of material for the bottom claws was either spring steel or SLS printed nylon. To decide which material to continue with, prototypes were created and tested. These prototypes are presented below in figure 61 and 62.

5.4.2.3.1 Spring steel

Spring steel is a type of steel commonly used for producing springs. These steels have a high yield strength and may therefore maintain the same mechanical properties after many load cycles [29]. For the spring steel prototype, the top part was created in ABS plastic, using 3D-printing. The bottom part was handmade in spring steel, generously provided by *Bångbro Strip Steel.*

Figure 61 Prototype of flexi ring made with spring steel

5.4.2.3.2 Nylon

Nylon is a strong, thermoplastic elastomer, which similarly to spring steel has flexible and durable properties. [30].

To resemble the flexible properties of a 3D-printed nylon prototype, a specially designed ABS 3D-print was created. This prototype had a hollow and thin-walled design to acquire good flex, as seen to the far left of figure 62. The direction of the 3D-print's layers were parallel with the flex-direction to acquire maximum flex-strength.

Provided with the informative sketch as seen in figure 63 by [31], the angle of the open ring should be between 60° and 80° to provide a good fit and flexibility. For this initial prototype the angle was set to 60°. Proof of the flexibility is seen in figure 64.

Figure 62 ABS 3D printed prototype with similar flex properties as nylon.

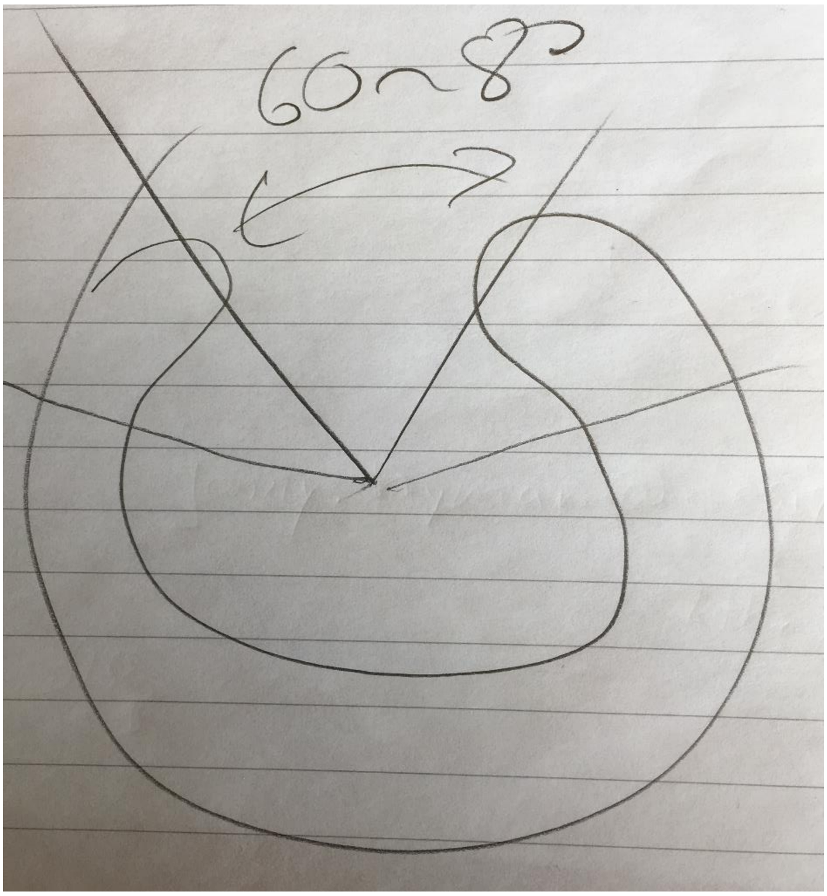

Figure 63 Parameters for creating snap-on rings, provided by [31]

Figure 64 Proof of flexibility

5.4.2.3.3 Evaluation

For creating a functioning prototype, nylon is the superior choice of material. High quality prototypes can quickly be produced and tested. However, for the final product, a polymer might not be optimal due to creep. Creep occurs in materials that are subjected to continuous stress over a long period of time, finally resulting in a rupture [32]. This mechanism is exhibited in both metals and polymers, however it is much more significant in polymers [33]. Therefore, in the final product, the use of stainless spring steel is more relevant for the flexible parts that are subjected to continuous stress. To make it more comfortable for the user, the spring steel part could have a soft, polymer coating.

Spring metal has as mentioned earlier, superb mechanical properties. However, due to these properties, spring metal is expensive and very difficult to work with. The decision was therefore to continue developing the prototype in nylon. However, before creating the prototype in the SLS 3D-printer, it was interesting to investigate the optimal angle of the open ring and the incorporation of the pulse sensor.

5.4.2.4 Angle studies

When developing a snap-on ring, the angle of the open ring, as shown in figure 63, should be between 60° and 80°. This was interesting to test; therefore, three different prototypes were created and compared, these are presented below in figure 65.

Figure 65 Prototypes created to investigate the angle of the open ring. From the left; 60°, 70° and 80°

5.4.2.4.1 Evaluation of the different angles

To evaluate the different angles a quick concept screening was performed. This concept screening was based of simple tests conducted on myself and a fellow thesis student. The result is presented below in table 11.

Table 11 Concept screening

	Angle			
Criteria	**Weight %**	60°	70°	80°
Ease to wear	35	3	4	5
Fit	40	5	4	4
Comfort	25	4	5	4
	Weighed Score	4.05	4.25	4.35
	Rank	3	2	1
	Continue?	No	No	Yes

According to the concept screening the 80° angle was the best out of the three. However, after testing and evaluating the different fits, there was a sense that the overall, optimal design was between 70° and 80°. Therefore, another prototype was created, this had an angle of 75°. This design was then compared to the 80°-design and was found to be superior. Therefore, it was decided to implement the 75° angle in the final design.

5.4.2.5 Incorporating the pulse sensor

Since the ring prototype was to contain an Arduino-compatible pulse sensor, early tests were conducted on the co-operation between the lo-fi prototypes and pulse sensor. This pulse sensor is further presented in section 5.4.3.1.

The objective of the mentioned tests was to check whether the current design was compatible with the sensor or not. As the upper part of the ring was designed to fit the pulse sensor, the ring and sensor fitted perfectly. However, when assembled, there were issues with acquiring a clear pulse signal. This was an issue since the sensor was not in direct contact with the skin. Therefore, an iterative process was initialized to find out how thin the "floor" of the top part had to be to acquire a solid pulse signal.

Figure 66 Illustration of the different "floor" thicknesses. To the left, 1.5 mm thick. In the middle 0.6 mm thick. To the right 0 mm thick

As seen in figure 67, this was a three-step process leading to the answer that the best pulse signal is acquired with no "floor", this because of the full skin contact. With the optimal design chosen, it was time to develop the ring in the SLS nylon printer.

5.4.3 **Internal electronics**

As mentioned in the delimitations, because Arduino components were used, the size and design of the internal electronics in the prototype will differ much compared to a final product. Arduino is an open-source and user-friendly platform for creating electronic prototypes which is further described in 6.1.1.1. For the final product however, the internal components would be specially designed and not bought off the shelf. Presented below are both the electronics used for this thesis as well as electronics that are interesting for a future product.

5.4.3.1 Pulse Sensor

As previously mentioned, a pulse sensor was incorporated in the design of the ring to study and foresee disease. The sensor presented in figure 67 was provided by [34] and utilizes PPG-technology to measure heartrate. It has a diameter of 16 mm, is 3 mm thick and has a 4mA current draw at 5V [34]. This sensor was utilized as it was the smallest Arduino compatible pulse sensor on the market.

Figure 67 The Arduino compatible sensor provided by [34]

5.4.3.2 Accelerometer & Gyroscope

A common cause for injuries and deaths of elderly are falls. Therefore, it was relevant to incorporate a fall sensor in the final product. Used for this thesis was an IMU (inertia measurement unit) sensor named MPU 6050, which is presented in figure 68. The choice was motivated by the small size, Arduino-compatibility and the availability of open-source code for developing a fall sensor by use of an MPU 6050. The MPU 6050 contains both an accelerometer and gyroscope and is for example used to develop self-balancing robots and in wearables to measure movement [35]. For this product it would be used to detect falls, which is major cause of injurie and death of elderly. How an accelerometer and gyroscope works is briefly described below.

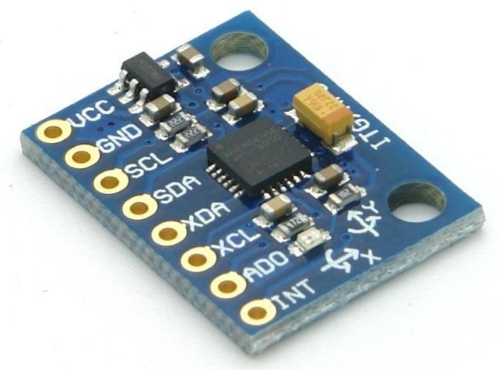

Figure 68 MPU 6050 – accelerometer and gyroscope

5.4.3.2.1 Accelerometer

An accelerometer measures the acceleration or deceleration of an object. It is constructed as a container withholding a small ball, as seen in figure 69. Due to gravity, the ball is forced to move when the box tilted in a certain direction. The ball then hits one of the walls with a certain force creating a piezoelectric current. It is called a piezoelectric current when an electric charge is produced due to an applied, mechanical load. Algorithms in the MPU 6065 calculate the direction and magnitude of the tilt depending on which wall is hit and the magnitude of the piezoelectrical current. From this the acceleration and direction can be calculated.

[35]

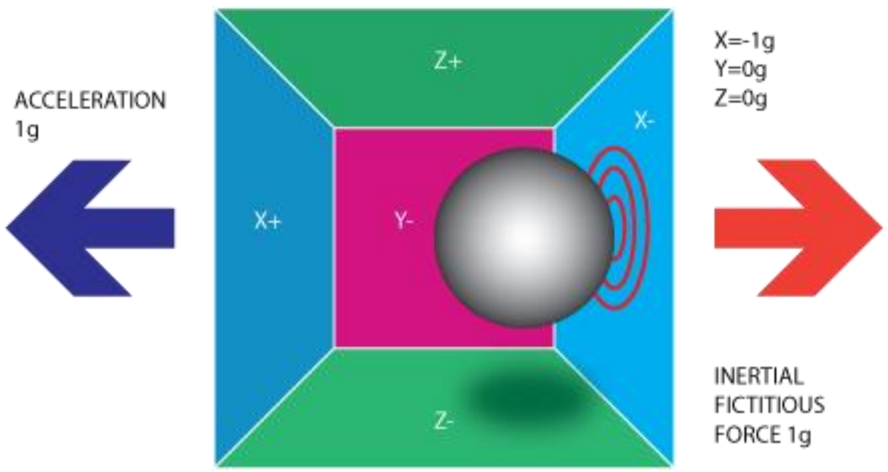

Figure 69 Illustration of how an accelerometer works [34]

5.4.3.2.2 Gyroscope

A gyroscope determines the orientation of an object and similiar to the accelerometer, it utilizes the principle of piezoelectrical effect. Inside the gyroscope there is a fork-like construction that is in constant movement, back and forth. When the gyroscope is tilted, the piezoelectric crystals that holds it in place experience a force in the tilt-direction. This, because of the piezoelectrical effect, creates a current which describes the change in orientation. [35]

How the accelerometer and gyroscope was used to detect falls is described in section 6.2.1.2.3.

5.4.3.3 GSM & GPS

For the final product it would be beneficial to introduce GSM- and GPS-technology. The GSM would allow mobile communication. While the GPS would figure out precisely where the ring user is positioned if an alarm is sent off. Both these components would have to be specially designed for such a small object as this ring and was therefore not included in this prototype.

5.4.3.4 Alarm button

Like all safety alarms, it is vital that this product has an alarm button that may be utilized when in need or if the automatic safety algorithms fail. This function was incorporated into the final prototype by use of Arduino components. However, it would be designed and placed differently in the final product.

5.4.3.5 Battery

To power the ring's internal electronic components there should be a rechargeable battery. Preferably this battery should be in a flat, circular shape. Although one could be specially designed, there are plenty of button cell batteries on the market. It is important that the power of the battery is sufficient, long-lasting and rechargeable.

5.4.3.6 Charging port

It is necessary that the final product is rechargeable, but for demonstrating this concept, it was not desired. However, by studying other smart-ring developers, it is important the recharging-technology is swift and intuitive. On the market today there are wireless chargers, magnetic chargers etc. Some examples of these are presented below in figure 70.

Figure 70 Variety of chargers available on the smart-ring market

5.4.3.7 PCB and microcontroller

To control all internal components a uniquely designed PCB and microcontroller would have to be produced. This was not done for the prototype, instead, an Arduino was used to control the electronics.

6 Deliver

The fourth and final part of the DDDP is the deliver phase, here the prototype/concept is finalised and then submitted to user tests. The final user-tests are conducted to prove the fulfilment of the identified user needs and are usually performed by staging different scenarios. From these tests, new knowledge is often gathered and used to suggest further development.

6.1 Methods

As mentioned, in this phase, the prototype was to be finalised. All input and knowledge gathered in the develop phase was narrowed down to a final, high-fidelity prototype and coherent conceptual platform.

6.1.1 **High-fidelity prototyping**

The high-fidelity prototype was created using different methods such as Arduino programming, 3D-printing, milling and assembling.

The final prototype was then evaluated by performing different user tests as described in 6.1.3.

6.1.1.1 Arduino

Arduino is based on a user friendly and open-source platform, designed to make electronic hardware and software development simple for all [36]. It used by a wide variety of people for many different projects. For this thesis Arduino was used to fully present and understand the concept of this safety alarm.

6.1.2 **Conceptual application prototyping**

By use of the application sketching program, Invision, a conceptual application was created. This was developed to give the users a whole, comprehensive picture of how the smart ring and application could co-operate.

6.1.2.1 Invision

Invision is a digital prototyping tool used to easily design conceptual digital platforms [37].

6.1.3 **User test**

User tests were performed to evaluate the final high-fidelity prototype and conceptual platform. The tests were initiated by presenting the concept, the high-fidelity prototype and the corelating platform. This was followed by the tests described below:

Ring

- Wear-test: simple to put on?
- Movement-test: good fit?
- Comfort-test: comfortable?

Button

- Reach-test: is the button easily reached?
- Press-test: is the button easy to press down?

Application

- Navigation-test: is it simple to navigate within in the application?
- Missing components?

To finish the tests, discussions in regard to the product and performed tests were conducted.

6.2 Results

6.2.1 **High-fidelity prototyping**

6.2.1.1 Ring

From the research and testing in section 5, an optimal ring design was established. The design of the ring has a 75° opening at the bottom, providing a good fit while being easy to put on. This flexible, open ring design also allows one ring size to fit many. However, it would not fit all. Therefore, the ring is to be designed in three ring-categories; small, medium and large. The diameter of these sizes is decided by studying the results presented in figure 71, which presents a study of average ring-finger sizes based on 5000 people world-wide.

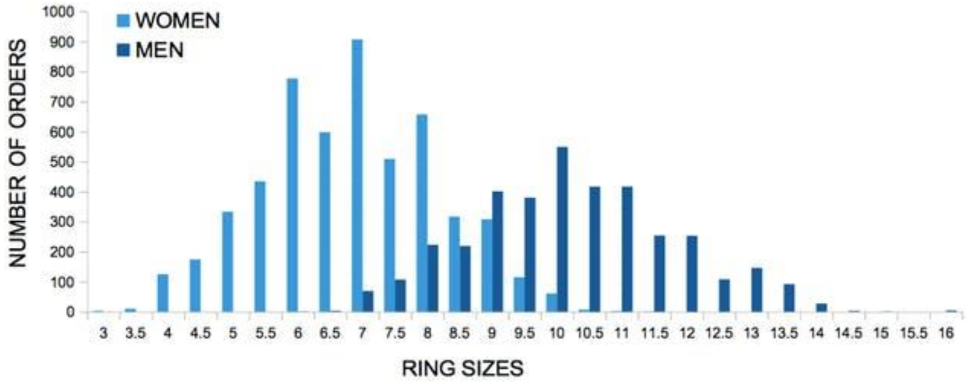

Figure 71 A presentation of average ring sizes for men and women, the unit on the x-axis (the ring size) is the numerical values according to the US ISO 8653:2016 [38]

From the data provided in figure 71, the following ring sizes where decided upon:

- Small: 6 (Ø16.4 mm)
- Medium: 8 (Ø18 mm)
- Large: 10 (Ø19.8 mm)

Presented in figure 72 is the optimal design for a medium sized ring and given parameters.

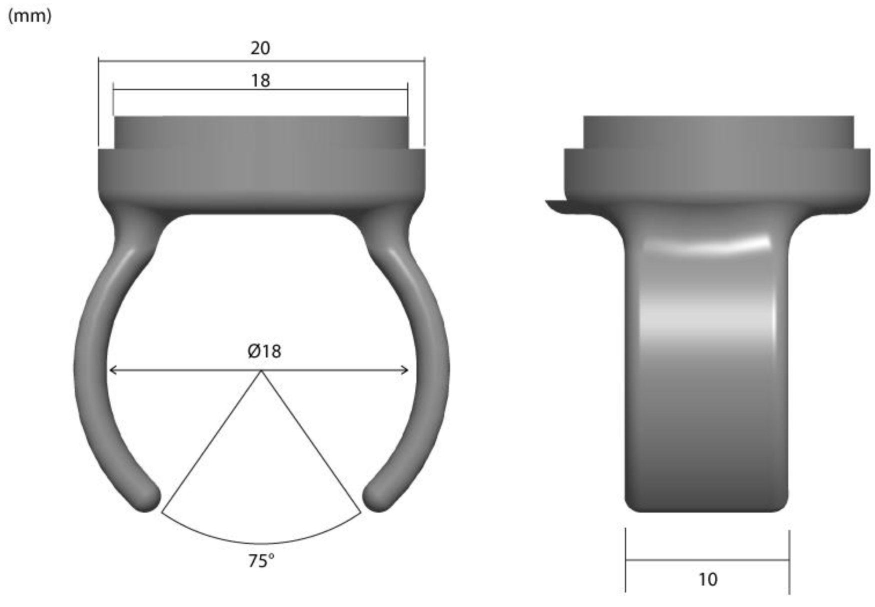

Figure 72 Design of the medium sized ring. Only fitting parameters included, not a full drawing

As mentioned earlier, the ring prototype was created in nylon, in an SLS 3D printer. The printed prototype is presented below in figure 73. This prototype was then put through surface finishing and painting to resemble a finished product.

Figure 73 Picture of the SLS printed prototype

6.2.1.1.1 Surface finishing

To provide the high-fidelity prototype with a genuine, visual appearance, surface finishing, including sandpapering, priming and painting, was conducted. The prototype was initially finished with sandpaper with different grit-sizes and then coated with plastic primer. This process was repeated three times to achieve a smooth surface and provide perfect paint-adhesion. Finally, it was spray-painted with a thin layer of silver paint. The painted prototype is displayed below in figure 74.

Figure 74 Painted high-fidelity prototype

6.2.1.1.2 Top Lid

To enclose the ring, a top lid was created. This lid was created in aluminium, in a lathe. Aluminium was the choice of material to acquire a sense of how an end-product would feel, although it preferably would be produced in titanium. Seen below in figure 75 is the final aesthetic design of the high-fidelity prototype.

Figure 75 Final aesthetic design of the high-fidelity prototype

6.2.1.2 Arduino

As mentioned in section 5.4.3, Arduino components were used to present certain functions of a final product. Before combining all these electronic components, each one was solely tested and tried out. After understanding each function, they were all combined. This process is presented below.

6.2.1.2.1 Pulse Sensor

Initially, the implementation of an Arduino pulse sensor was commenced. As with many Arduino components, there were open-source code and wiring instructions available and provided by [34]. This code was implemented, fully understood and then altered to function in accordance with the prototype. The pulse sensor was programmed to make a LED blink in sync with the measured heartbeat. As seen in figure 73, the lamp blinks for every peak in the output graph, resembling a pulse. Although not fully incorporated in the prototype, the idea was that the average BPM should be studied by an AI to foresee diseases. The Arduino code can be found in appendix C.1.

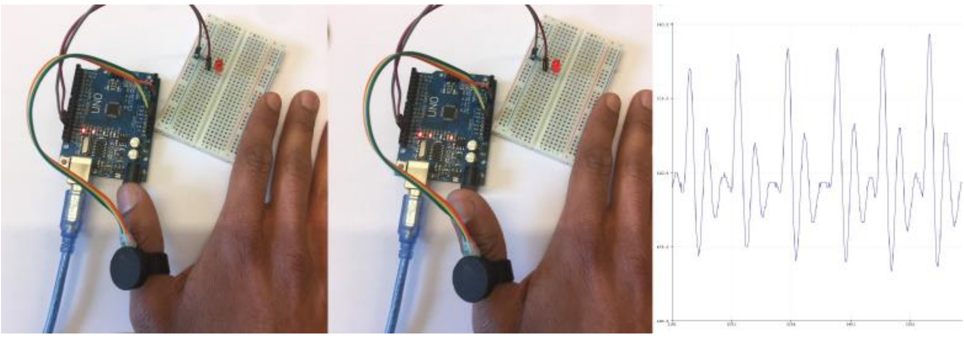

Figure 76 Initial work with the Arduino pulse sensor

6.2.1.2.2 Alarm button

Secondly, an alarm button was implemented. Since no mobile communication was incorporated in the prototype, the alarm button was programmed make a light blink when the button was pushed. This was done to resemble an alarm being sent off. This process is presented below in figure 74.

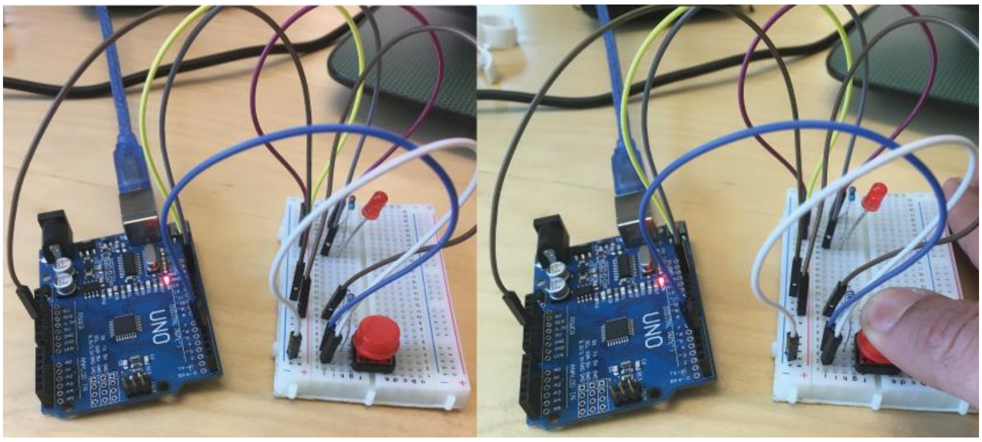

Figure 77 Demonstrating the alarm button

6.2.1.2.3 Accelerometer and Gyroscope

A common cause for injuries and deaths of elderly are falls. Therefore, it is relevant to incorporate a fall sensor in the final product. As described in section 5.4.3.2, an accelerometer and gyroscope were utilized to detect falls. These sensors were implemented to co-operate with a sophisticated algorithm to identify falls. This algorithm was provided by [39] and is described roughly in figure 75. The algorithm works after the concept that a falling person, initially experiences a momentary freefall (deceleration), which is quickly followed by a large acceleration and finally a change of orientation. If all these steps, presented in figure 78, are followed, an alarm is sent off. If, however, one is interrupted, the algorithm starts over. To resemble a fall-alarm being sent off in the prototype, a LED was programmed to light up for 10 seconds if a fall was detected.

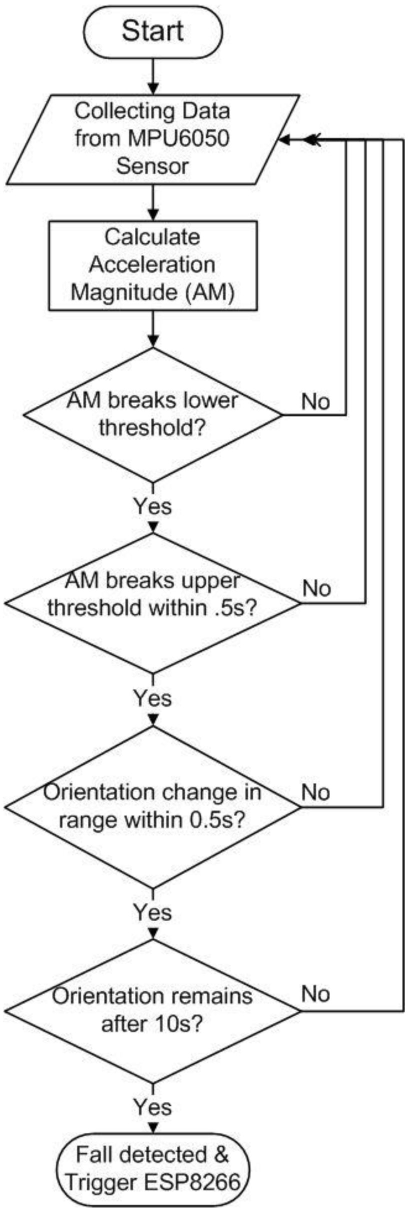

Figure 78 Flowchart of the fall algorithm [39]

6.2.1.2.4 Combining

After understanding all components and relevant code, it was time to combine them. This was done by simply combining and modifying the code for all three parts to co-operate as one. The full code is presented in appendix C.4.

6.2.1.3 Introducing the electronics to the prototype

6.2.1.3.1 Soldering

After testing and calibrating each component, it was time to go from an experimental breadboard to a final soldering board and switch to a smaller controller (Arduino Uno to mini). To initiate this process, simple sketches of the electronic architecture were produced. These are presented below in figure 79.

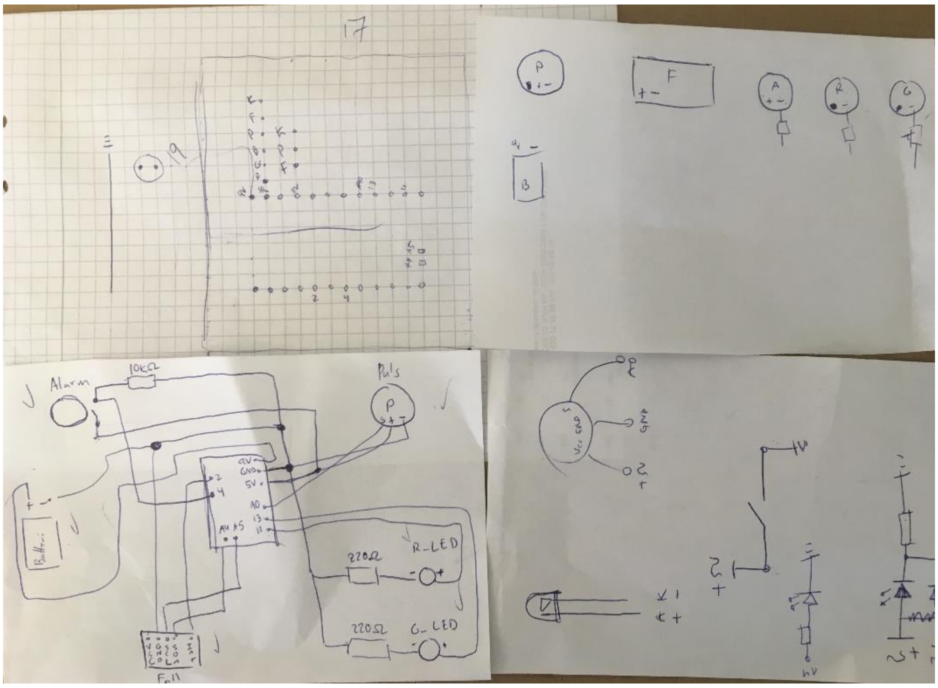

Figure 79 Sketches of the electronical architecture

With the help the sketches presented above, the soldering process was set off. Presented below in figure 80 is the complete soldering board.

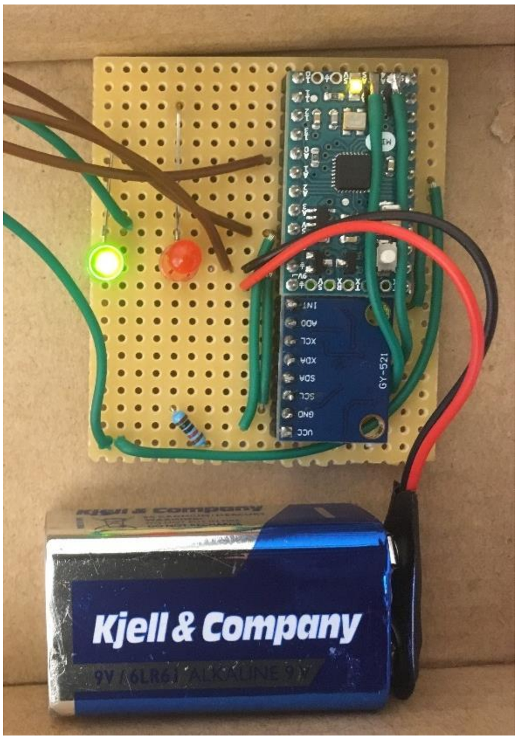

Figure 80 Final soldering board

6.2.1.3.2 Functioning high-fidelity prototype

The prototype ring was only to encapsulate a pulse sensor and an alarm button, while the fall sensor, battery and communication-LEDs were to be placed in a 3D-printed box. The LEDs, as seen through the box in figure 81, were implemented to symbolize wireless communication. Whenever the ring wearer pushes the alarm button, the red LED lights up to resemble an alarm being sent off. The fall sensor was also connected to the red LED, if triggered, the red LED lights up for 10 seconds to resemble an alarm due to a fall. To visualize the pulse-function, a green LED was programmed to blink in sync with the ring wearer's pulse.

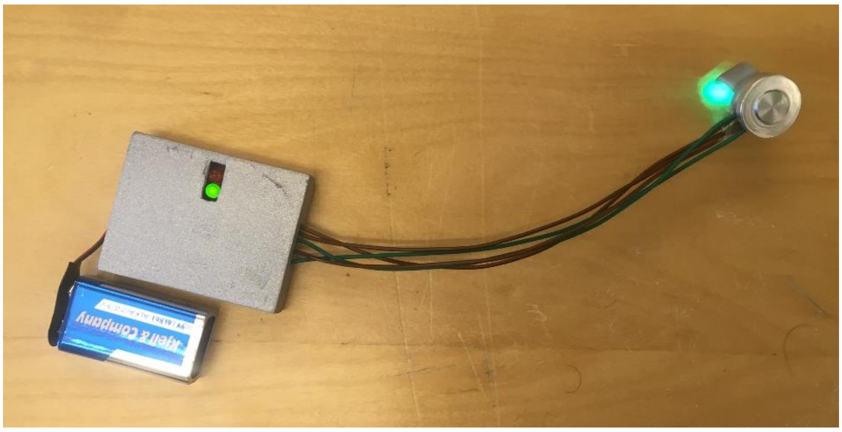

Figure 81 Picture showing the ring connected to the 3D-printed box withholding the electronics

6.2.1.3.3 Visual high-fidelity prototype

To complement the functioning prototype, a visual prototype was created to present the aesthetics and feel of a final product. This was produced similarly to the functioning prototype but without any internal electronics and is presented below in figure 82.

Figure 82 Visual prototype

6.2.2 Creating the conceptual application

6.2.2.1 Concept

To complement the high-fidelity prototype, a conceptual application was created. Through this application, the user, the user’s relatives and medical staff should easily be provided with an overview of the real-time well-being of the user and necessary health parameters.

Depending on what type of application user you are, different data is available and in different formats:

Users

- Simple layout and navigation
- Easily understandable health data
- Modify In Case of Emergency contacts and alarm settings
- Full access

Relatives

- Real-time wellbeing of user
- General health data
- No personal or sensitive health data

Medical staff

- Full access: Health data and journals

6.2.2.2 Sketches

To commence the ideation process, sketches of the application layout were produced. An example of these sketches is presented below in figure 83.

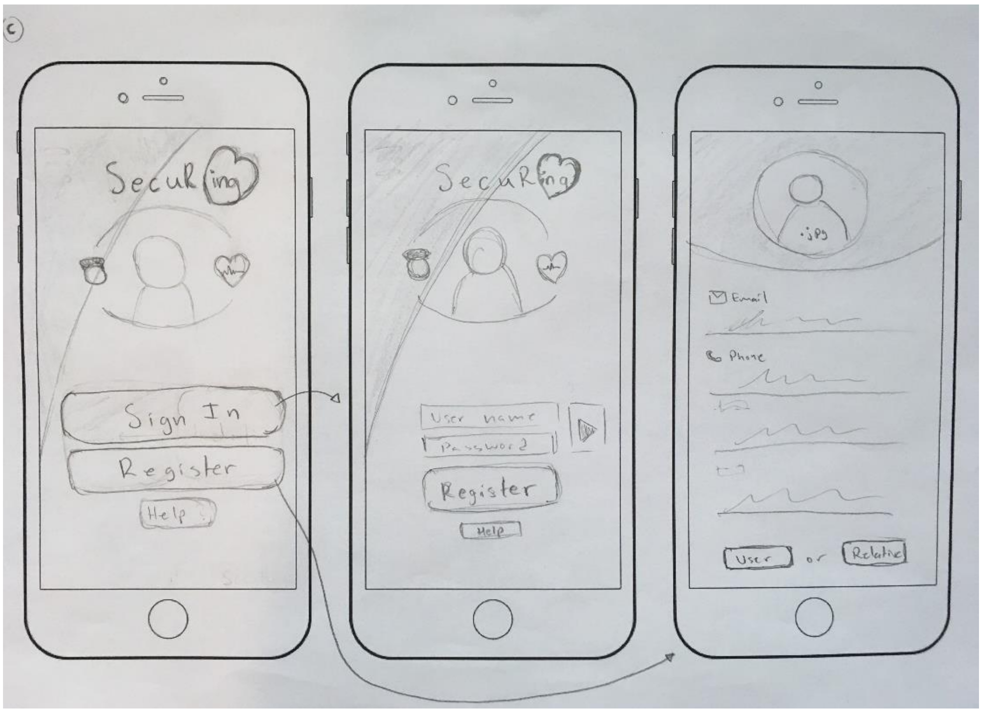

Figure 83 Hand-drawn sketches

6.2.2.3 Illustrator

Inspired by the hand-drawn sketches, the final layout of the application was produced in *Adobe illustrator*. Presented below, in figure 84, are the correlating digital illustrations to the sketches presented in figure 83.

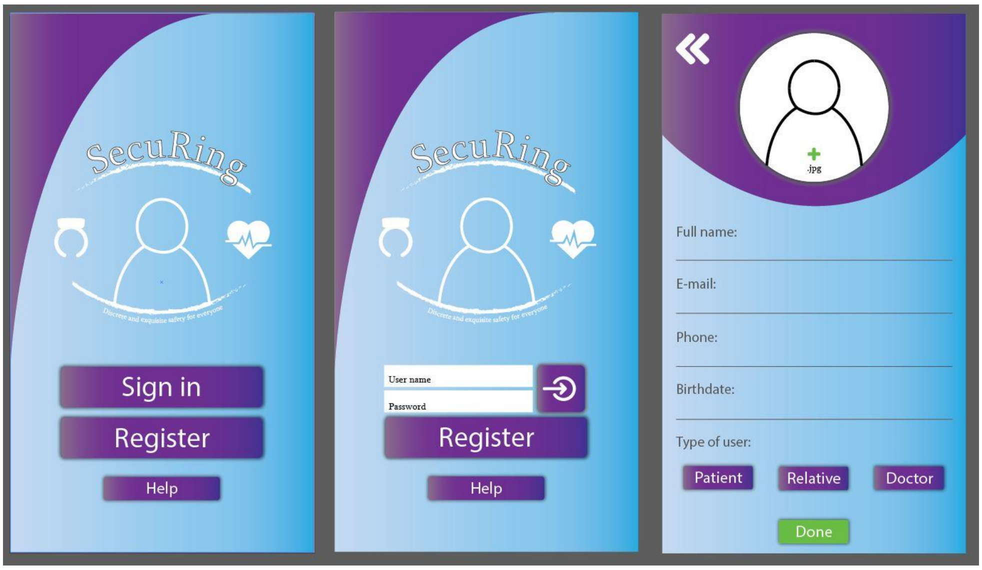

Figure 84 Digital sketches produced in illustrator

6.2.2.4 Final conceptual application

The digital illustrations, created in *Adobe illustrator*, were introduced to *Invision*, where the final conceptual application was constructed. As mentioned earlier, depending on who the application user is, different data is presented. Briefly presented below is the conceptual application for the elderly. To view the full application prototype, visit: https://invis.io/PVIHYAKJ2C6#/294727067_APP-07

There was an idea to create a conceptual application for the doctors and relatives as well, due to time constraint this was however not established.

6.2.2.4.1 General

Initially, all application users are presented the same log in and sign up page, as presented below in figure 85. Then, depending your type of account, the content within the application will differ.

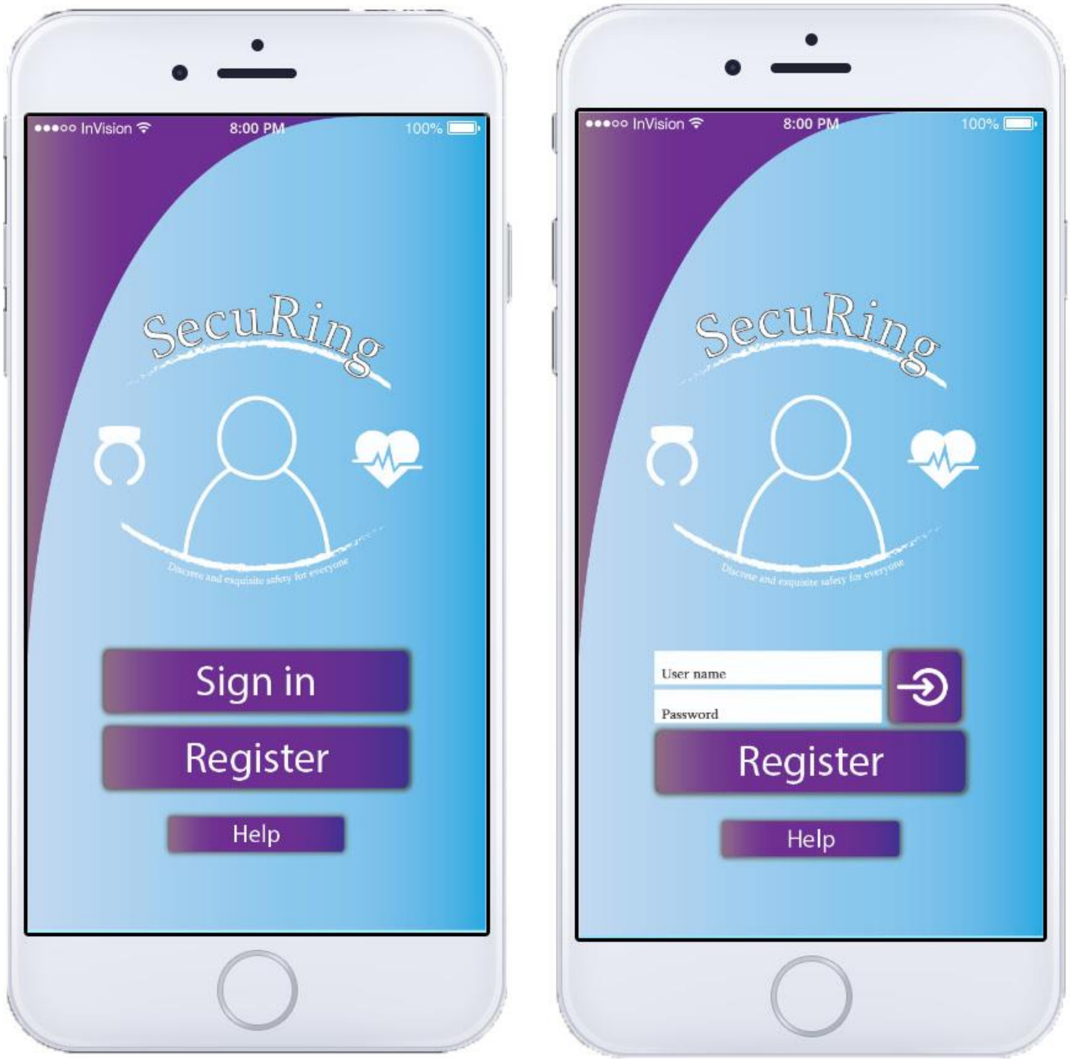

Figure 85 Layout of the applications sign in page

6.2.2.4.2 Elders

The idea is not that the elderly will be utilizing the application a lot, due to generally low technical knowledge. However, they should be able to, if they wish, keep track of their health data and adjust their integrity settings.

Presented below in figure 86 is an idea of how the gathered health data could be presented.

Figure 86 Layout of how the personal health data may be presented

Of interest as well, is the possibility for the users to personally edit their integrity setting. Solely, they should be able to control who is entitled to their personal data, what type of data and who is notified if an alarm is sent off. A concept presenting how to choose who to alarm is seen below in figure 87. The idea is that the users should similarly be able to choose what type of data that is presented and to whom.

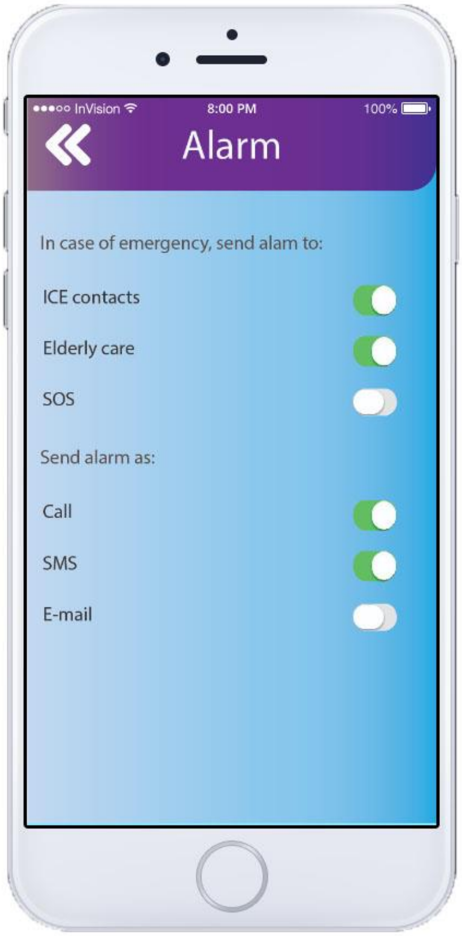

Figure 87 Layout of application over who to alarm, personally selected by the user

6.2.3 **Final User-Test**

To evaluate the final prototypes and platform, user-tests were performed at *Mårtenslund* retirement home as seen in figure 88. The tests were performed as described in section 6.1.3 and the results is summarised below:

Ring

- A medium sized ring was tested, those who it fit thought it was comfortable and felt steady – "Not bad at all"
- The ring fit all users on minimum 1/5 fingers, however some better than others
- The flex properties were appreciated
- It was desirable that the top of the ring was made smaller

- The ring was aesthetically appealing
- Too many functions, many felt that an alarm button is sufficient

Button

- The alarm button was easily reachable, given that both hands were used
- Many had issues with pressing the button

Application

- There was a huge lack of knowledge when it comes to smartphone usage
- Many did not own smartphones
- Little interest in own health data

The results of the final user-test are further discussed below in section 7.

Figure 88 One of the ladies at Mårtenslund retirement home testing the final prototype

7 Discussion

7.1 Fulfilment of aim

By following an established design methodology, a final concept has been delivered. A concept which discreetly aims to provide the users with safety and freedom. Looking back at the result of the thesis, there is a strong belief that the concept, if further developed, would benefit the healthcare system, relieve the stress of worried relatives and most importantly increase the real and experienced sense of safety of future users. However, as with any thesis there are many areas in need of further discussion and development, some which are discussed below.

7.2 Methodology

The main design methodology for this thesis, the DDDP, was much appreciated. By providing guidance with an open-mindset throughout the thesis, the opportunity to combine different methodologies was given. This both increased the credibility and efficiency. Literature studies, benchmarking, interviews, observations and user-tests were performed, providing the input and needs of many different users. In retrospect however, these methods could have been further practiced, especially the user-tests. Since it was desired that the thesis was user-centred, more user-tests could have been performed. For example, it would have been valuable to involve different users even more in the early stages. Examples of this could be presenting the different sketched concepts to the users and involving them in the concept screening process. However, this can easily become very time-consuming and priorities had to be set in regard to the scope of the thesis.

Worth mentioning is that this thesis was conducted by one person, which certainly has affected the decision-making. To avoid bias, fellow thesis-students and supervisors were involved in the project to some extent. This is however not comparable to having a thesis-partner, fully dedicated to project.

7.3 Further Development

When designing a new product, one tends to never be fully satisfied and there are always areas of improvement. Areas in need of further development are presented and discussed below.

7.3.1 **Aesthetics**

Aesthetically, the final user-tests revealed that the users were not fully satisfied with size of the top part of the ring. Therefore, it is interesting to further investigate how to make the ring smaller and more discrete. This is also further discussed in section 7.3.3.

As for the colour and material, there were no negative feedback from the user-tests. However, it would be interesting to investigate if an aesthetic variation of rings could be offered.

7.3.2 **Ergonomics**

Deriving out from the final user-tests were certain development areas regarding the ergonomics of the product, these are presented below:

7.3.2.1 Alarm button

The alarm button of the high-fidelity prototype was for some users difficult to press down. As this is an essential function of the safety alarm, it needs to be further investigated and developed. When designing an alarm button, the button should be easy to press down for all type of users. However, it should not be so simple that it accidentally sends false alarms.

Also worth further investigating, is the placement of the alarm button. For the final concept, the alarm button was placed on top of the ring as it was the most logical placement from a user-experience perspective. However, this demands the use of two free hands, to easily reach the alarm button. This might not always be the case, the user could for example fall down with one hand resting under the weight of the body. Therefore, an idea was that an alarm button would be placed as illustrated in figure 89. This way, the alarm button would be reachable with the same hand. However, this needs further investigating as it, at this point, is just a hypothetic idea.

Figure 89 Illustrating possible position of alarm button in a future product

7.3.2.2 Size

Although the desire was to develop a ring that would fit all user, this was not perfectly accomplished. The provided flex of the ring did however make one size befitting for many. Therefore, as briefly discussed, the ring was to be designed in three different sizes; Small, Medium and Large. However, for this thesis only a medium sized ring was developed which most certainly affected the result of the user test. In retrospect it would have been valuable to develop and test all three sizes to find out if three sizes are sufficient.

7.3.3 **Electronics**

Due to lack of electrical engineering knowledge, Arduino components were used to demonstrate the full concept. This clearly affected the final size of the high-fidelity prototype. However, it is reasonable to claim that the size of a final product would be smaller than the prototype. By returning to the benchmarking of available smart rings in section 5.3.1.1, we see that further developing this concept to a real product is feasible. However, as with the development of those smart rings, a team of electrical engineers would be much needed as all internal electronics would have to be specially designed and not bought off the shelf.

7.3.3.1 Sensors

As part of the electronic development, the internal sensors need further research and development. For this thesis, the pulse- and fall-sensors were programmed and calibrated after my body type and size. However, for a future product the sensors would have to automatically calibrate according to each user. Developing, calibrating and testing this could be a thesis of its own.

7.3.3.2 Design

To have the ability to design a final product, the size of the internal components would have to be established. A desire for this thesis was to present a suggestion of how the electronics would be placed within the ring. However, as the electronics would need to be specially designed, it is difficult to present this in a decent manner. Much inspiration for further development was found in figure 44 displaying the internal electronics of *The Nimb Ring* which consists of soft electronics as well as hard.

7.3.4 **Manufacturing**

7.3.4.1 Method

Another important area to further investigate is the optimal method of manufacturing. As the ring is symmetrical, a recommend manufacturing method is metal injection moulding. However, this needs to be motivated by further research.

7.3.4.2 Material

The choice of material and importance of its hypoallergenic properties has been discussed throughout the thesis. As discussed, it was decided that the top half of a final product would be developed in titanium, like most other smart rings. As for the bottom, flexible half, the choice of material was spring steel with a rubber coat. Due to the time constraint, this was not as fully explored as desired. Therefore, more research and development is needed.

7.3.5 **Platform**

Presented in this thesis was the conceptual platform available for the elderlies. However, the development of a platform for the relatives and doctors is also of importance. Similarly to the electronics, this is an area of development which in itself could be a thesis for computer and cognitive science students.

7.4 CE–marking

As part of developing a new product which is to be sold within the European Economic Area (EEA), it is extremely important that the product receives a CE–marking. The CE-marking assures that the product meets the safety, health and environmental requirements that are mandatory for sales within the EEA [40]. How to design a final product to obtain a CE-marking has to be further researched.

7.5 Patents

Equally important is further investigating question regarding patents: Will a new product be patentable? Will it inflict any current patents? If so, is it possible to buy or licence the patent(s)?

7.6 Connected Healthcare

Another vital part worth further research and development is how a future product may optimally be used for connected healthcare. To increase the reliability of a future product it would therefore be interesting to investigate how a future product may be medically certified.

7.7 Integrity

In the wake of the GDPR it is important to further investigate how to not inflict any personal data or integrity laws.

7.8 Economics

Of interest is also to investigate how to make this product economically sustainable. What does it cost to create? How should we charge the users? How could this product be marketed? Initially, the product should be marketed towards elderly care, the municipalities and concerned relatives. However, there are other potential target groups. Potential future users could for example include people with different disabilities, children or simply anyone in need of a sense of safety

It would also be interesting to investigate the specific economic benefits this product would generate by unburdening the healthcare system. But also investigating how a new product would affect the relatives in different aspects.

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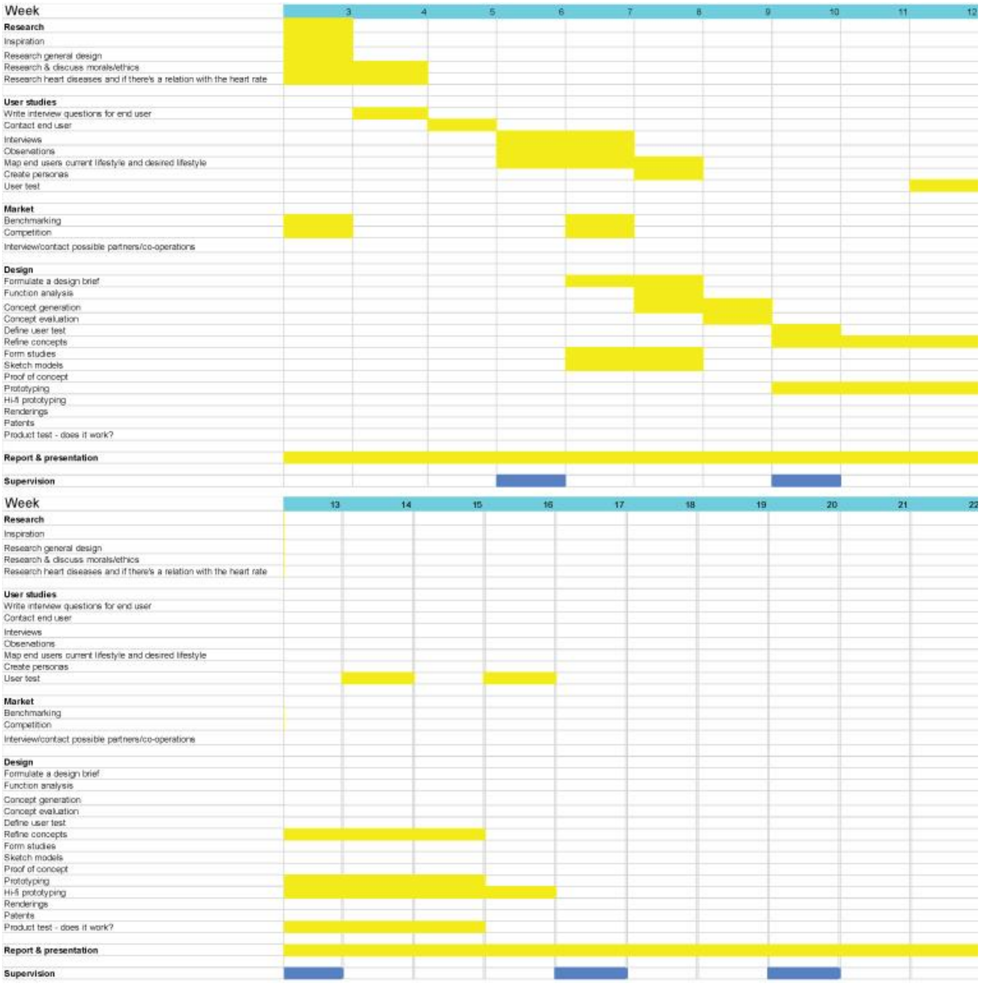
Appendix A – Project planning

A.1 Original plan



A.2 Outcome plan

Appendix B - Interviews

B.1 Doctors & Nurses

Bakgrund

Skulle du kunna ge oss en kort presentation av vem du är?

Pulsmätning

Vad kan pulsen hos en patient berätta för en läkare?

Finns det samband mellan puls och sjukdom?

Om man vill mäta pulsen över en lång period, med hur stora intervall görs detta lämpligen?

Vid någon form av hjärtfel, som tex stroke, hur pass viktig är reaktions-/larmtiden?

Belastning av sjukvården

Hur känner du att befolkningsökning har påverkat sjukvården?

Vad är din åsikt om applikationer som "min doktor"?

B.2 Elderly

Bakgrund

Skulle du kunna ge oss en kort presentation av vem du är?

Hur ser en normal vardag ut för dig?

Vad har du för fritidsintressen utöver din vanliga vardag?

Hälsa och säkerhet

Vad innebär god hälsa för dig?

Hur påverkar din hälsa ditt liv?

Undersöker du din hälsa regelbundet? Om ja, varför?

Vem utför dessa undersökningar? Vart sker dessa?

Vad får du ut av dessa undersökningar?

Hur anser du att din hälsa påverkar din säkerhet?

Har det någonsin hänt något hälsorelaterat som äventyrat ditt liv eller säkerhet?

Teknikvana

Använder du någon form av trygghetslarm? Om nej, skulle du kunna tänka dig att använda ett sådant?

Har du upplevt några problem med ditt trygghetslarm?

Vilka aspekter med ett trygghetslarm saknar du?

Vet du vad som finns på marknaden gällande trygghetslarm?

Vad använder du för “smarta” apparater idag?

Hur pass teknikvan skulle du påstå att du är?

Integritet

Vad är viktigast för dig, integritet eller säkerhet?

Hur skulle det kännas om en anhörig fick direkt kontakt med ditt trygghetslarm?

B.3 Relatives

Bakgrund

Skulle du kunna ge oss en kort presentation av vem du är?

Hur ser din vardag ut?

Har du någon anhörig vars ålder och hälsa påverkar dennes liv? Om ja, berätta gärna mer.

Anhörigas hälsa och säkerhet

Hur påverkar din anhöriges hälsa/tillstånd ditt vardagsliv?

Vilka känslor associerar du med din anhörigas hälsa?

Hur håller du koll på din anhöriges välmående?

Finns det något problematiskt med hur det fungerar idag?

Vad är det du främst vill veta om din anhöriga?

Hur skulle du vilja få denna informationen?

Teknikvana

Hur pass teknikvan skulle du påstå att din anhöriga är?

Använder hen någon form av trygghetslarm?

Har du upplevt några problem med trygghetslarmet?

Vilka aspekter med ett trygghetslarm saknar du?

Vet du vad som finns på marknaden gällande trygghetslarm?

Integritet

Vad är viktigast för dig, integritet eller säkerhet?

Hur skulle det kännas om du som anhörig fick direkt kontakt med trygghetslarmet?

Appendix C Arduino Code

C.1 Pulse Sensor

```
//  Variables
int PulseSensorPurplePin = 0;        // Pulse Sensor PURPLE WIRE connected to ANALOG PIN 0
int LED13 = 13;   //  The on-board Arduion LED


int Signal;                // holds the incoming raw data. Signal value can range from 0-1024
int Threshold = 700;            // Determine which Signal to "count as a beat", and which to ingore.


// The SetUp Function:
void setup() {
  pinMode(LED13,OUTPUT);         // pin that will blink to your heartbeat!
   Serial.begin(9600);         // Set's up Serial Communication at certain speed.

}

// The Main Loop Function
void loop() {

  Signal = analogRead(PulseSensorPurplePin);  // Read the PulseSensor's value.
                                              // Assign this value to the "Signal" variable.

   Serial.println(Signal);                    // Send the Signal value to Serial Plotter.


   if(Signal > Threshold){                          // If the signal is above "550", then "turn-on" Arduino's on-Board LED.
     digitalWrite(LED13,HIGH);
   } else {
     digitalWrite(LED13,LOW);                //  Else, the sigal must be below "550", so "turn-off" this LED.
   }
```

```
delay(10);


}
```

C.2 Button

```
int LED = 12;
int BUTTON = 4;

void setup(){
pinMode(LED,OUTPUT);
pinMode(BUTTON,INPUT);
}

void loop(){
if(digitalRead(BUTTON) == HIGH){
digitalWrite(LED,HIGH);
}else{
digitalWrite(LED,LOW);
}
}
```

C.3 Accelerometer and Gyroscope

```
// MPU-6050 Short Example Sketch
// Public Domain
#include<Wire.h>
const int MPU_addr=0x68;  // I2C address of the MPU-6050
int16_t AcX,AcY,AcZ,Tmp,GyX,GyY,GyZ;
float ax=0, ay=0, az=0, gx=0, gy=0, gz=0;

//int data[STORE_SIZE][5]; //array for saving past data
//byte currentIndex=0; //stores current data array index (0-255)
boolean fall = false; //stores if a fall has occurred
boolean trigger1=false; //stores if first trigger (lower threshold) has occurred
```

```
boolean trigger2=false; //stores if second trigger (upper threshold) has occurred
boolean trigger3=false; //stores if third trigger (orientation change) has occurred

byte trigger1count=0; //stores the counts past since trigger 1 was set true
byte trigger2count=0; //stores the counts past since trigger 2 was set true
byte trigger3count=0; //stores the counts past since trigger 3 was set true
int angleChange=0;


void setup(){
  Wire.begin();
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x6B);  // PWR_MGMT_1 register
  Wire.write(0);     // set to zero (wakes up the MPU-6050)
  Wire.endTransmission(true);
  Serial.begin(9600);

  pinMode(11, OUTPUT);
  digitalWrite(11, HIGH);
}
void loop(){

  mpu_read();
  //2050, 77, 1947 are values for calibration of accelerometer
  // values may be different for you
  ax = (AcX-2050)/16384.00;
  ay = (AcY-77)/16384.00;
  az = (AcZ-1947)/16384.00;

  //270, 351, 136 for gyroscope
  gx = (GyX+270)/131.07;
  gy = (GyY-351)/131.07;
  gz = (GyZ+136)/131.07;

  // calculating Amplitute vactor for 3 axis
  float Raw_AM = pow(pow(ax,2)+pow(ay,2)+pow(az,2),0.5);
  int AM = Raw_AM * 10;  // as values are within 0 to 1, I multiplied
                         // it by for using if else conditions

  Serial.println(AM);
```

```
//Serial.println(PM);
//delay(500);

if (trigger3==true){
   trigger3count++;
   //Serial.println(trigger3count);
   if (trigger3count>=10){
      angleChange = pow(pow(gx,2)+pow(gy,2)+pow(gz,2),0.5);
      //delay(10);
      Serial.println(angleChange);
      if ((angleChange>=0) && (angleChange<=10)){ //if orientation changes remains between 0-10 degrees
          fall=true; trigger3=false; trigger3count=0;
          Serial.println(angleChange);
            }
      else{ //user regained normal orientation
         trigger3=false; trigger3count=0;
         Serial.println("TRIGGER 3 DEACTIVATED");
      }
    }
 }
if (fall==true){ //in event of a fall detection
  Serial.println("FALL DETECTED");
  digitalWrite(11, LOW);
  delay(20);
  digitalWrite(11, HIGH);

  digitalWrite(12, HIGH);
  delay(10000);
  digitalWrite(12, LOW);
  fall=false;
 // exit(1);
  }
if (trigger2count>=6){ //allow 0.5s for orientation change
  trigger2=false; trigger2count=0;
  Serial.println("TRIGGER 2 DECACTIVATED");
  }
if (trigger1count>=6){ //allow 0.5s for AM to break upper threshold
  trigger1=false; trigger1count=0;
  Serial.println("TRIGGER 1 DECACTIVATED");
  }
```

```
  if (trigger2==true){
    trigger2count++;
    //angleChange=acos(((double)x*(double)bx+(double)y*(double)by+(double)z*(double)bz)/(double)AM/(double)BM);
    angleChange = pow(pow(gx,2)+pow(gy,2)+pow(gz,2),0.5); Serial.println(angleChange);
    if (angleChange>=30 && angleChange<=400){ //if orientation changes by between 80-100 degrees
      trigger3=true; trigger2=false; trigger2count=0;
      Serial.println(angleChange);
      Serial.println("TRIGGER 3 ACTIVATED");
        }
    }
  if (trigger1==true){
    trigger1count++;
    if (AM>=12){ //if AM breaks upper threshold (3g)
      trigger2=true;
      Serial.println("TRIGGER 2 ACTIVATED");
      trigger1=false; trigger1count=0;
      }
    }
  if (AM<=2 && trigger2==false){ //if AM breaks lower threshold (0.4g)
    trigger1=true;
    Serial.println("TRIGGER 1 ACTIVATED");
    }
//It appears that delay is needed in order not to clog the port
  delay(100);
}

void mpu_read(){
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);  // starting with register 0x3B (ACCEL_XOUT_H)
  Wire.endTransmission(false);
  Wire.requestFrom(MPU_addr,14,true);  // request a total of 14 registers
  AcX=Wire.read()<<8|Wire.read();  // 0x3B (ACCEL_XOUT_H) & 0x3C (ACCEL_XOUT_L)
  AcY=Wire.read()<<8|Wire.read();  // 0x3D (ACCEL_YOUT_H) & 0x3E (ACCEL_YOUT_L)
  AcZ=Wire.read()<<8|Wire.read();  // 0x3F (ACCEL_ZOUT_H) & 0x40 (ACCEL_ZOUT_L)
  Tmp=Wire.read()<<8|Wire.read();  // 0x41 (TEMP_OUT_H) & 0x42 (TEMP_OUT_L)
  GyX=Wire.read()<<8|Wire.read();  // 0x43 (GYRO_XOUT_H) & 0x44 (GYRO_XOUT_L)
  GyY=Wire.read()<<8|Wire.read();  // 0x45 (GYRO_YOUT_H) & 0x46 (GYRO_YOUT_L)
  GyZ=Wire.read()<<8|Wire.read();  // 0x47 (GYRO_ZOUT_H) & 0x48 (GYRO_ZOUT_L)
  }
```

C.4 Combined Code

```
#include<Wire.h>
const int MPU_addr=0x68;  // I2C address of the MPU-6050
int16_t AcX,AcY,AcZ,Tmp,GyX,GyY,GyZ;
float ax=0, ay=0, az=0, gx=0, gy=0, gz=0;

//int data[STORE_SIZE][5]; //array for saving past data
//byte currentIndex=0; //stores current data array index (0-255)
boolean fall = false; //stores if a fall has occurred
boolean trigger1=false; //stores if first trigger (lower threshold) has occurred
boolean trigger2=false; //stores if second trigger (upper threshold) has occurred
boolean trigger3=false; //stores if third trigger (orientation change) has occurred

boolean DEBUG=true;
boolean DEBUG2=false;

byte trigger1count=0; //stores the counts past since trigger 1 was set true
byte trigger2count=0; //stores the counts past since trigger 2 was set true
byte trigger3count=0; //stores the counts past since trigger 3 was set true
int angleChange=0;

//------------- KNAPP
int LED = 11;
int BUTTON = 4;

//------------- PULS
//  Variables
int PulseSensorPurplePin = 0;        // Pulse Sensor PURPLE WIRE connected to ANALOG PIN 0
int LED13 = 13;   //  The on-board Arduion LED



int Signal;                // holds the incoming raw data. Signal value can range from 0-1024
int Threshold = 545;            // Determine which Signal to "count as a beat", and which to ingore.

void setup(){
  Wire.begin();
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x6B);  // PWR_MGMT_1 register
  Wire.write(0);     // set to zero (wakes up the MPU-6050)
```

```
  Wire.endTransmission(true);
  Serial.begin(9600);

  pinMode(11, OUTPUT);
  digitalWrite(11, HIGH);

  //------------- PULS
   pinMode(LED13,OUTPUT);         // pin that will blink to your heartbeat!
}
void loop(){

  mpu_read();
  //2050, 77, 1947 are values for calibration of accelerometer
  // values may be different for you
  ax = (AcX-2050)/16384.00;
  ay = (AcY-77)/16384.00;
  az = (AcZ-1947)/16384.00;

  //270, 351, 136 for gyroscope
  gx = (GyX+270)/131.07;
  gy = (GyY-351)/131.07;
  gz = (GyZ+136)/131.07;

  // calculating Amplitute vactor for 3 axis
  float Raw_AM = pow(pow(ax,2)+pow(ay,2)+pow(az,2),0.5);
  int AM = Raw_AM * 10;  // as values are within 0 to 1, I multiplied
                         // it by for using if else conditions

  if (DEBUG) Serial.println(AM);
  //Serial.println(PM);
  //delay(500);

  if (trigger3==true){
    trigger3count++;
    //Serial.println(trigger3count);
    if (trigger3count>=10){
      angleChange = pow(pow(gx,2)+pow(gy,2)+pow(gz,2),0.5);
      //delay(10);
     if (DEBUG) Serial.println(angleChange);
      if ((angleChange>=0) && (angleChange<=10)){ //if orientation changes remains between 0-10 degrees
```

```
        fall=true; trigger3=false; trigger3count=0;
      if (DEBUG)  Serial.println(angleChange);
          }
     else{ //user regained normal orientation
        trigger3=false; trigger3count=0;
       if (DEBUG) Serial.println("TRIGGER 3 DEACTIVATED");
     }
   }
 }
if (fall==true){ //in event of a fall detection
 if (DEBUG) Serial.println("FALL DETECTED");
  digitalWrite(11, LOW);
  delay(20);
  digitalWrite(11, HIGH);


  digitalWrite(12, HIGH);
  delay(10000);
  digitalWrite(12, LOW);
  fall=false;
 // exit(1);
  }
if (trigger2count>=6){ //allow 0.5s for orientation change
  trigger2=false; trigger2count=0;
if (DEBUG)  Serial.println("TRIGGER 2 DECACTIVATED");
  }
if (trigger1count>=6){ //allow 0.5s for AM to break upper threshold
  trigger1=false; trigger1count=0;
if (DEBUG)  Serial.println("TRIGGER 1 DECACTIVATED");
  }
if (trigger2==true){
  trigger2count++;
  //angleChange=acos(((double)x*(double)bx+(double)y*(double)by+(double)z*(double)bz)/(double)AM/(double)BM);
  angleChange = pow(pow(gx,2)+pow(gy,2)+pow(gz,2),0.5); Serial.println(angleChange);
  if (angleChange>=30 && angleChange<=400){ //if orientation changes by between 80-100 degrees
    trigger3=true; trigger2=false; trigger2count=0;
  if (DEBUG) Serial.println(angleChange);
  if (DEBUG)  Serial.println("TRIGGER 3 ACTIVATED");
      }
  }
if (trigger1==true){
```

```
    trigger1count++;
    if (AM>=12){ //if AM breaks upper threshold (3g)
      trigger2=true;
    if (DEBUG)  Serial.println("TRIGGER 2 ACTIVATED");
      trigger1=false; trigger1count=0;
      }
    }
  if (AM<=2 && trigger2==false){ //if AM breaks lower threshold (0.4g)
    trigger1=true;
  if (DEBUG)  Serial.println("TRIGGER 1 ACTIVATED");
    }
//It appears that delay is needed in order not to clog the port
if (DEBUG)  delay(100);

  //------------- KNAPP
  if(digitalRead(BUTTON) == HIGH){
digitalWrite(LED,HIGH);
}else{
digitalWrite(LED,LOW);
}

//------------- PULS

  Signal = analogRead(PulseSensorPurplePin);  // Read the PulseSensor's value.
                                              // Assign this value to the "Signal" variable.

   if (DEBUG2) Serial.println(Signal);                    // Send the Signal value to Serial Plotter.


   if(Signal > Threshold){                          // If the signal is above "550", then "turn-on" Arduino's on-Board LED.
     digitalWrite(LED13,HIGH);
   } else {
     digitalWrite(LED13,LOW);                //  Else, the sigal must be below "550", so "turn-off" this LED.
   }


delay(8);

}
```

```
void mpu_read(){
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);  // starting with register 0x3B (ACCEL_XOUT_H)
  Wire.endTransmission(false);
  Wire.requestFrom(MPU_addr,14,true);  // request a total of 14 registers
  AcX=Wire.read()<<8|Wire.read();  // 0x3B (ACCEL_XOUT_H) & 0x3C (ACCEL_XOUT_L)
  AcY=Wire.read()<<8|Wire.read();  // 0x3D (ACCEL_YOUT_H) & 0x3E (ACCEL_YOUT_L)
  AcZ=Wire.read()<<8|Wire.read();  // 0x3F (ACCEL_ZOUT_H) & 0x40 (ACCEL_ZOUT_L)
  Tmp=Wire.read()<<8|Wire.read();  // 0x41 (TEMP_OUT_H) & 0x42 (TEMP_OUT_L)
  GyX=Wire.read()<<8|Wire.read();  // 0x43 (GYRO_XOUT_H) & 0x44 (GYRO_XOUT_L)
  GyY=Wire.read()<<8|Wire.read();  // 0x45 (GYRO_YOUT_H) & 0x46 (GYRO_YOUT_L)
  GyZ=Wire.read()<<8|Wire.read();  // 0x47 (GYRO_ZOUT_H) & 0x48 (GYRO_ZOUT_L)
  }
```