Bachelor thesis Creative Technology

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Preventing hypothermia among Sheltersuit users

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Abstract

The Sheltersuit is a jacket that can be zipped to a bag around the legs, that provides warmth to the homeless people, sleeping on the street. However, it does not guarantee that the user is protected against hypothermia (a core body temperature below 35 °C). This report will therefore investigate how to develop a monitoring and notification system to prevent hypothermia among the Sheltersuit user.

Hypothermia is normally measured using invasive methods, like a rectal probe, and these methods are therefore unsuitable to be implemented in the Sheltersuit. Through literature research and brainstorming, other types of methods were researched that could derive the core body temperature from other factors. In the end a concept was produced that focussed on measuring shivering (symptom of mild hypothermia) and the temperature and humidity level inside the Sheltersuit (risk factors of hypothermia) to determine the risk of getting hypothermia.

The shivering data needed to be distinguished from other ordinary movements of the user. Through filtering and classification techniques based on the time and frequency domain, this was accomplished. To know how the temperature and humidity inside the Sheltersuit influence the risk of getting hypothermia, an estimated guess was used to determine how temperature and humidity level relate to each other and to the amount of heat loss of the user.

Because only emulated and simulated shivering data could be used, it is not possible to say how the system would function in a real situation. However, based on the evaluation of the shivering classification function, it is possible to distinguish between shivering and other types of ordinary movements of the user and therefore shivering is a promising factor to use to determine the risk of getting hypothermia. Due to using simulations, the temperature and humidity level could not be tested.

The notification system depends on the preferences of the end user, the homeless people. However, during this project it was found out that it is a difficult target group to come in contact with. As a result all decisions had to be made without involving them.

It was also investigated if the Sheltersuit user’s mobile phone could be used to contact aid organisations, because it is possible that the end user is not capable themselves to react on the notification. Based on literature research it was concluded that the system could use a mobile phone, however the system should not depend on it fully.

Acknowledgment

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1. Introduction

In this chapter the graduation project will be introduced. The first section describes the problem statement, to make clear what the problem is. This problem statement is followed by the project goal, which describes what this project aims to achieve. Based on this, a research question is formulated and in the end of this chapter, the report outline can be found.

1.1. Problem statement

The amount of homeless people increased with 74% during the last six years in the Netherlands [1]. In 2009, of the 16.5 million inhabitants of the Netherlands [2], the total amount of people that were living on the street was estimated at 18.000. This includes people that don't have a permanent residence, are sleeping in shelters, on the street or with friends and families. This number was increased to 31.000 homeless people in the year 2016 [1], when the Netherlands had a total of 17 million inhabitants [2].

There are non-profit organisations that want to help this growing group of people. The Sheltersuit Foundation [3] is one of these organisations. They produce water-resistant and windproof jackets which can be transformed into a body suit by zipping the jacket to the sleeping bag. After use, the sleeping bag can be stored in the duffle bag. This Sheltersuit concept is especially made for homeless people living on the street. This concept aims to make the lives of these people a bit more bearable when outside temperatures drop below 0 °C [4].

The Sheltersuit Foundation wants to help the homeless community as much as possible, and therefor always looking for improvements to their Sheltersuit concept. One way of improving the Sheltersuit can be by means of technology. Technology can be a powerful tool; e.g. for measuring certain variables, giving information in certain situations, or to change the behaviour or perspective of the user [5]. Because of this, it is possible that homeless people can benefit from technology. That is why Sheltersuits wants to investigate how to increase the functionality of their Sheltersuit concept with the help of technology, consequently making the life of the homeless on the street more comfortable or safe.

1.2. Goal

To keep in line with the current functionality of the Sheltersuit concept, this project will focus on cold weather related problems a homeless person can have, in particular protection from hypothermia. Hypothermia is the decrease of (human) body temperature to a dangerous state of 35 °C and lower [6-8]. It is found to be one of the mortality causes in the homeless community [9, 10].

The goal of this project is therefore to develop an appliance, incorporated in the existing Sheltersuit concept, aiming to prevent hypothermia of a homeless person due to cold weather conditions. The solution should be able to monitor hypothermia related variables and use a notification system to signal risk of hypothermia. Because the Sheltersuit foundation is totally dependent on donations, the solution should also be low-cost.

1.3. Research question

Based on the problem statement and the goal of this graduation project, the following research question and one sub-question were formulated:

- *How to develop a monitoring and notification system to prevent hypothermia of a Sheltersuit user?*
    - *What are the possibilities of using the Sheltersuit user's mobile phone as a notification gateway to aid organisations?*

Note:

In the context of this research question a Sheltersuit user is a homeless person living in urbanized areas.

1.4. Report outline

This report is organised as follows. In chapter 2 the context analysis can be found, which describes the background information, the literature study and the state of the art for this project. Chapter 3 till 6 will cover the design process of Creative Technology, which consist of the ideation, specification, realisation and evaluation phase of this project. Each phase having its own chapter. In the end of this report, chapter 7, the conclusion and recommendations for future work can be found.

2. Context analysis

This chapter will give an analysis of the context in which this research is executed. First the background research can be found, which will describe the current situation of homeless people in Enschede, the organisations that are involved and the current policy of the municipality of Enschede regarding homelessness. This is followed by a literature review. This part gives more information about hypothermia and the perspective of homeless people regarding technology and in particular mobile phones. Furthermore there is the state of the art, reviewing what devices and applications are already on the market regarding ‘helping homeless people’ and ‘measuring hypothermia’. In the end there is a conclusion which will describe the relevance of the research question.

2.1. Background research

This section will describe the information that was obtained by talking with the municipality of Enschede, a volunteer of ‘De Wonne’ [11], two Salvation Army employees and one of their clients, who was homeless in the past for a small amount of time. This information is divided in three parts. First the policy of the municipality of Enschede is described, which is followed by a section about social interactions of homeless people and then a section about their possessions. This section ends with a conclusion.

2.1.1. Policy of Enschede

Enschede has three major organisations that are helping the homeless community: Humanitas onder dak [12], Salvation Army [13] and Tactus (specialized in addiction care) [14]. These three organisations are for a big part funded by the municipality of Enschede and are therefore mostly following the policy of Enschede. Beside these three big organisations, there are also some small parties that are helping the homeless community in whatever way they can. One of them is ‘De Wonne’ [11], an apartment-sharing community partly for people that do not have another place to stay. They also provide sleeping places and food for the homeless people in Enschede. De Wonne is not funded by the municipality and therefore does not have to follow the same policy as the other three organisations.

In Enschede, all homeless people that want to get shelter at Humanitas onder dak, Salvation Army or Tactus, need to agree on getting help. This help differs per person and is focussed on getting them of the street. People that are not from Enschede are send back to their place of origin[1]. If needed, these people get help with purchasing transportation tickets. At De Wonne there is no such obligation, and per night there is place for three homeless people. During the afternoon, it is also possible for homeless people to get something to eat at this place.

Between October and April, when the temperature drops below 2 °C, a temporary night shelter at Humanitas onder dak opens from 19.00 till 8.00. The weather forecast of weeronline [15] is used to determine if the shelter goes open or not and this is often decided three days in advanced. The shelter can be used without further obligations although the sleepers are registered, so the organisations know who is using the night shelter. At this night shelter, people can shower and have

[1] Within the Dutch legal boundaries.

breakfast. Enschede chose not to have a constant open night shelter, because it thinks that this does not help in getting people of the street. When the night shelter opens, De Wonne closes its doors for homeless people and sends them to the night shelter at Humanitas onder dak. During the day, the homeless people can in the morning go to Tactus and in the afternoon to the Salvation Army. The municipality of Enschede did say that last year (winter 2016/2017) around 95 people made use of the night shelter. Some of them often, others only a couple of nights. All these people do have some kind of mental illness or are addicted. People that do not want to make use of any shelter are not monitored by one of the three organisations. This is part of the policy in Enschede and can differ in other cities. Sometimes the police will encounter a homeless person and send them to Humanitas onder dak.

The employees of the Salvation Army say that there are probably cases where people suffer from hypothermia, but because they are not the crisis shelter in Enschede, they do not encounter them. If the police finds someone laying outside in the cold, that person is send to Humanitas onder dak. The municipality of Enschede did say that a man died a couple of years ago due to hypothermia [16], but that this is an exception.

Because the main focus of the policy of Enschede is to get people of the street, this vision is in contrast to the vision of Sheltersuit, which is to provide warmth (comfort) for the people living on the street. Enschede thinks that providing Sheltersuits will encourage people to stay on the street, which they believe is not in the best interest of these people. Therefore Enschede and the organisations that are funded by it, do not support the distribution of Sheltersuits. Besides making sleeping on the streets more comfortable, another objection is that the Sheltersuits can be sold for money, which then can be used for drugs or alcohol. Sheltersuit however says that there are always people that, for different reasons, do not want to use the shelters, and are therefore sleeping on the street, regardless of having a Sheltersuit or not. For these people, the Sheltersuit can provide a bit more comfort.

2.1.2. Social interactions

Based on the talk with a client of the Salvation Army, the homeless community is not very social, as in that they are often living by themselves. This is supported by literature [17, 18]. However, because they have the same problems there is some kind of group forming: everyone knows each other. Also having the same kind of addiction is a reason to cluster together. So, some homeless people do seek the company of other homeless persons, for safety or comfort, while others stay rather on their own. If it is cold, the tendency to stay together is bigger and they are then often helping each other. Also, in winter, people come together to discuss the different weather forecasts they have heard.

2.1.3. Possessions

The employees of the Salvation Army and their client say that most homeless people do own a tent or sleeping bag that they use during the night. The ones in contact with the Salvation Army also often have a mobile phone and a charger. However, there are cases that people do have a mobile phone without the charger. Sometimes they also possess a power bank for charging their mobile phone when no wall outlet is available. In the city centre of Enschede there is free wifi, so the homeless people can use internet on their phones. This is often used for keeping in contact with people but also for checking weather forecasts, news or sites like Marktplaats.

2.1.4. Conclusion

The purpose of this background research was to gather more information about the current situation and policy regarding homeless people in Enschede. Unfortunately this information is only based on 3 meetings. Because the vision of these organisations are in contrast to the vision of Sheltersuit, it was very hard to get them to cooperate. Besides this, Tactus does not work with students and also the Salvation Army gave as a reason that they do get a lot of request from students and that they are therefore not very interested anymore in participating. It would also have been nice to include the homeless population more. But because the organisations are in principle a good way to get in contact with homeless people, without their cooperation it was very hard to contact this group. Sheltersuit did distribute some of their Sheltersuits via the Salvation Army of Emmen, and it would have been nice to talk to the people that had received a Sheltersuit. However, they did not replay on the emails send.

For this graduation project it is important to keep in mind that both the municipality of Enschede and the three organisations do not support the vision of Sheltersuit and that they are against products that increase the comfort level while sleeping on the street. The envisioned solution of this graduation project should therefore do more than only make the homeless people's life more comfortable.

When looking at hypothermia as a problem among homeless people, the Salvation Army said that hypothermia was not often encountered in their organisation, but this could be because they are not the winter crisis shelter for the night. However, the municipality did say that a man died in Enschede a couple of years ago due to hypothermia.

Another aspect to keep in mind is that homeless people sell their stuff often to get quick money. The envisioned solution should therefore be, as much as possible, uninteresting to sell. This can be by making it low-cost, or another option is to make it personalised, such that it is of no interest to other people.

Most homeless persons do own a mobile phone and charging their phone is often not a problem. Besides this Enschede offers free wifi, making it possible for them to use the internet cheaply. Based on the situation in Enschede, it is therefore possible to use the mobile phone of the homeless people in the envisioned solution. Furthermore, they are in winter more prone to cluster together, which can be useful information for designing the notification system. However, there are still some homeless people that do live solidary.

2.2. Literature review

There are two aims of this literature research. The first is to get a better understanding about hypothermia and its impact on the homeless society. The second focuses on the perception towards technology among homeless people. For the latter however, almost no articles could be found that focussed on technology in general, therefore the mobile phone is used as an indication how the homeless community perceives technology.

However, before focussing on hypothermia and technology perception, this literature research starts with a definition of the homeless, which is then used throughout this report. To give a clear definition is important, because the homeless society is a broad definition and not all kinds of homeless people are meant when in this report the homeless society is mentioned. In the end the conclusion of this literature review can be found.

2.2.1. Defining homelessness

There is not one clear definition for describing homeless people. However, there are two main perspectives that can be used when defining homeless people. First is a house related perspective and secondly there is a 'type of person' related perspective. When looking at homelessness from a house related perspective, according to Toro [19], the problem in defining homelessness lies in that there is not a universal single answer for issues like duration (how long should a person live on the street before called homeless), quality of the house (what is the minimal quality a house should have before the person living there is called homeless) and crowding (should a person living with relatives or friends be called homeless).

When looking at homelessness from the 'type of person' related perspective, both Toro [19] and Minery and Greenhalgh [20] argue that still too often homeless persons are defined as addicted, single males, which in reality is not always the case, see figure 1. It is therefore important to distinguish between different types. Toro [19] divides homeless people in homeless single adults, homeless families, and homeless youth. Minnery and Greenhalgh [20] define more groups, resulting in: families, women, children, youth, the elderly, and marginalized ethnic or migrant groups. Because there is no universal single answer for the house related issues and because there are so many different types a homeless person can be, the result is that how homelessness is defined changes per country and can even change per municipality [21].

Figure 1: Different types of homeless people [22-27]

Both the United States and Europe base their definition of homelessness on the quality of housing. In the United States, both Toro [19] and Shinn [28] state that homelessness is by most researches defined as being literally homeless. These are people that are sleeping in homeless shelters, on the street or someplace else in the city that is not meant for sleeping. They both do not state a minimum duration required for sleeping in these places. Koegel et al. [29] use a comparable definition, but they add two things, firstly, people that temporarily have a place because they are in a program for homeless people, and secondly, the person should have slept in such a way at least one night in the last 30 days.

The definition of homelessness in Europe is more broad than the definition used in the United States. In Europe there are four types of homelessness classified by the European Typology of Homelessness and Housing Exclusion (ETHOS) [30]: roofless, houseless, insecure accommodation and inadequate accommodation. Shinn [28] argues that the definition of literally homeless is comparable with the categories roofless and houseless. Roofless is defined as people living rough and people in emergency accommodation, and houseless is defined as people in accommodation for the homeless, in women's shelters, in accommodation for migrants, people due to be released from institutions and people receiving long-term support due to homelessness. Shinn [28] concludes that defining these four groups as homelessness only makes sense if it is done in a developed country. Because, if in developing countries these four groups are defined as homelessness, the result will be that most people are homeless.

For the graduation project especially adults and youth that are living on the streets are relevant. Therefor the definition of the literally homeless is used in this report. This includes people, which can be adults or youth, that are sleeping sometimes or always on the street or someplace else in the city that is not meant for sleeping.

2.2.2. Hypothermia

The following section will start with explaining what hypothermia is and which symptoms are related to hypothermia. This is followed by a description of the risk factors for getting hypothermia. In the end information can be found about the amount of deaths due to hypothermia among the homeless population worldwide.

2.2.2.1. Hypothermia and the symptoms

A human suffers from hypothermia when the core body temperature drops below 35 °C [6, 8, 31]. In normal conditions, the body is capable of keeping the body temperature around 37 °C by producing metabolic heat [32]. This heat is transported from the body through conduction, convection, radiation and evaporation [7, 32, 33]. If the heat loss exceeds the heat production, the overall body temperature will drop [34] and the body is incapable to continue its normal functions [8]. Core temperature is often measured using invasive methods, like inserting a thermistor probe in the oesophagus (if person is intubated), or putting the thermistor probe in contact with the tympanic membrane, or using rectal probes [8, 31].

There are three different ways in which hypothermia is classified. All are based on the core body temperature, but the upper or lower limits of the stages can differ. Biem et al. [6], Ulrich and Rathlev [8] and Fudge [34] use in their study three stages, namely mild (with a core temperature between 32 and 35 °C), moderate (with a core temperature between 28 and 32 °C) and severe (with a core temperature lower than 28 °C). Sansone et al. [35] and Nixdorf-Miller et al. [7] add a fourth stage, profound, which is a core temperature lower than 20 °C. Durrer et al. [36] uses a classification that divides the core temperature in 5 stages namely HT-I (32-35 °C, similar to mild), HT-II (28-32 °C, similar to moderate), HT-III (28-24 °C), HT-IV (23-13,7 °C) and HT-V (<13.7 °C, death). Brown et al. [31] states that this last classification is best used when the core body temperature cannot be measured readily. However, no explanation is given why this classification is better in this case.

The symptoms related to hypothermia are not always the same, and can differ or be the total opposite of each other depending on the stage of hypothermia. Table 1 shows a summary of the symptoms often mentioned in literature for the different stages. Because traditionally the stages are divided in mild, moderate, severe and profound [31], this classification is also used in table 1.

It is often mentioned that shivering increases in the mild or HT-I stage to increase the body temperature [8, 34]. But because shivering is intensive for the body, the body will lose this ability in the other stages [7, 8, 34, 36]. Fudge [34] also points out that the amount of body fat influences the shivering intensity, with more body fat reducing the intensity.

The breathing behaviour and heart rate can also change depending on the stage. In the mild stage, the breathing is rapid [6-8], while in the other stages this changes to unnatural slow breathing [6, 7]. The heartrate is fast in the mild stage, but can change to very slow in the moderate stage and to ventricular fibrillation (a cardiac rhythm disturbance) in the severe stage [6, 7, 34]. Fudge [34] and Brown et al. [31] point out that the possibility of cardiac arrest increases if the core temperature drops below 32 °C. Biem et al. [6] also mention that together with the decrease of blood pressure in later stages, shock is possible.

Furthermore, the central nervous system starts to dysfunction due to hypothermia. Nixdorf-Miller et al. [7], Fudge [34], Baumgartner et al. [37], Ulrich and Rathlev [8] and Biem et al. [6] mention that this can lead to all kind of behavioural changes (i.e. irrational behaviour, slurred speech, hallucinations, confusion, loss of reflexes) and below 28 °C it can lead to unconsciousness. Baumgartner et al. [37] points out that losing the ability to think clearly can lead to unwise decisions, which can then again increase the loss of body heat. Nixdorf-Miller et al. [7] also describe paradoxical undressing, the victim removes all their clothes like they are burning instead of freezing.

Some other symptoms that are mentioned by Biem et al. [6] and Nixdorf-Miller et al. [7] in later stages of hypothermia are muscle tissue that breaks down, kidney failure and blood clotting because of the increase of cells and solids in the blood.

2.2.2.2. Risk factors for hypothermia

The possibility of getting hypothermia depends on a lot of different factors and can therefore differ for each person and for each situation. As explained above, the human body is constantly losing heat to the environment and hypothermia occurs when this heat loss (i.e. through radiation, convection, evaporation and conduction) is higher than the heat production [8, 32, 34]. Risk factors are therefore factors that increase the heat loss or decrease the heat production of a body. Factors that are often mentioned are weather, age, health, nutrition and fat percentage, alcohol and drug related.

The body loses heat through conduction, convection, radiation and evaporation, see figure 2. Conduction is when heat transfers between two masses in direct contact with each other. The amount of heat transferred depends on the difference in temperature between the two masses, but also on the material. Water is around 25 times more conductive then air. So if the air temperature is low or if the relative humidity is high, the amount of heat transferred away from the body, due to conduction, increases. [7, 32, 33]

Note:

Humidity can be expressed as an absolute value or as a relative value. Throughout this report, when referring to humidity, the relative humidity level is meant. This value describes how close the air is to saturation [38].

Table 1: Symptoms of hypothermia [6, 7, 34]

Stage	Core temperature	Clinical symptoms
Mild	35 – 32 °C	• Conscious • Shivering • Confusion • High blood pressure – hypertension • Abnormal high heartrate – tachycardia • Abnormal rapid breathing – tachypnea
Moderate	<32 – 28 °C	• Impaired Consciousness • Not shivering • Fixed dilated pupils • Hyporeflexia • Abnormal low heartrate – bradycardia • Low blood pressure - hypotension • Blood clothing impairment – coagulopathy • Rigidity • Abnormal slow breathing – bradypnea
Severe	<28 – 20 °C	• Unconsciousness • Not shivering • Rhabdomyolysis • loss of deep tendon reflexes • Apnoea • Blood clotting - Disseminated intravascular coagulation • cardiac rhythm disturbance– ventricular fibrillation, ventricular dysrhythmias • Extremely low blood pressure – extreme hypotension
Profound	<20 °C	• No detectible vital signs • Risk of cardiac arrest - asystole

Convection is another way the body loses heat. It is when heat is transferred by the flow of liquid or gases away from the source [7, 33]. So in windy conditions, more heat is transferred away from the body. This is also known as the wind-chill factor [34, 39]. Heat loss through convection can be prevented by adequate clothing [33]. With good clothing a static layer of warm air is produced between the body and the clothing, preventing the wind from transferring too much heat away [37].

Radiation accounts for more than half of the heat loss [33], but the actual amount depends on the humidity level and wind speed [7]. Radiation is the heat transfer because of electromagnetic transmission, and depends on the difference in temperature between the body and its surroundings [7, 33]. So lower air temperatures increase the amount of heat loss through radiation. However, with lower environmental temperatures, clothing can decrease the amount of heat loss through radiation [7].

Evaporation causes heat loss due to the conversion of liquid to vapour and can be from the skin surface or from the longs [7, 33]. The amount of evaporation depends on the difference in vapour pressure and on the air movement [33]. If the humidity is high, there is less evaporation and therefore less heat loss through evaporation [7].

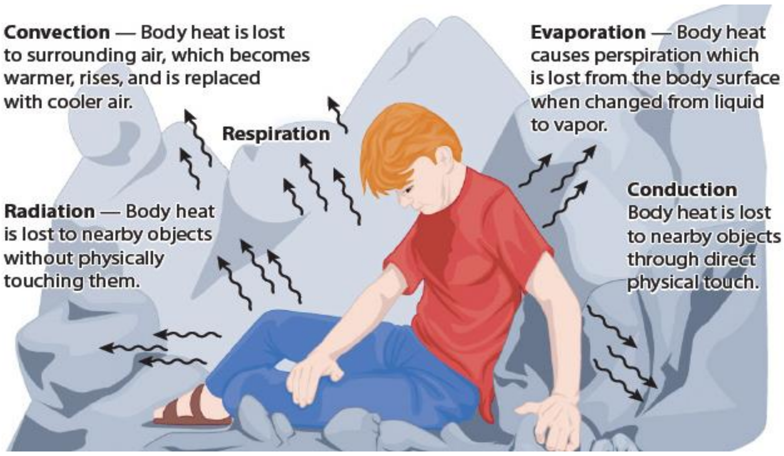

Figure 2: Different ways the body is losing heat [40]

Because weather conditions influence for a large part how much heat is transferred from the body to its environment, it is not strange that in literature, weather conditions are often mentioned as the reason for mortality due to hypothermia. Tanaka and Tokudome [41] and a study done by the New York City department of Health and Mental Hygiene and Homeless services [42] found more deaths among the homeless population due to hypothermia in the winter months, when the air temperature is the lowest. Kunst et al. [43] also found a correlation between air temperature and mortality. Pugh [44] found that most death among hikers, climbers and campers occurred when the conditions were wet and cold, with strong winds. However, Ulrich and Rathlev [8] point out that there are also quite some mortality cases known due to hypothermia in warm weather locations, like Florida or Texas, so temperature cannot be the only reason for hypothermia. Biem et al. [6], Fudge [34] and Castellani et al. [45] also argue that air temperature alone cannot be a good risk indication for hypothermia, because of the great influence of the humidity and wind-chill factor. Biem et al. [6] and Fudge [34] point out that athletes sporting under wet conditions are more at risk then athletes sporting under dry conditions. Castellani et al. [45] elaborates on this by mentioning that the heat loss under wet weather conditions can be big, even if the air temperature is mild.

Besides weather conditions, the age is often mentioned as a risk factor for getting hypothermia. It is often observed that people with an age of around 60 or older have a higher risk [34, 45, 46]. However, Tanaka and Tokudome [41] observe that the mortality due to hypothermia among homeless persons in Tokyo is the highest in the age group forty-fifty. This can be because this group is presented the most in the sample. There are three main reasons found why the risk for hypothermia increases with the age. Fudge [34], Castellani et al. [45] and Laaidi et al. [46] all state that the risk on hypothermia in older people can increase due to worse thermoregulation, because of reduced vasoconstriction and heat conservation. The overall decline in physical fitness of this group can also be a reason for an increase in risk, because the body is then not capable anymore of producing enough heat [8]. At last, Ulrich and Rathlev [8] and Castellani et al. [45] point out that the sensitivity to feeling cold decreases in older people. As a result, these people do not take action in time to prevent hypothermia.

The amount of nutrition and the percentage of fat are both factors that can increase the risk of hypothermia. Tanaka and Tokudome [41] found that the Rohrer index[2] of homeless persons, that died due to hypothermia, was lower compared to the average of the population. One important

[2] A correlation between body weight and height.

reason for this is the lack of good nutrition. To produce heat, a body needs nutrition. Furthermore, Castellini et al. [45] explains that malnutrition can lead to hypoglycaemia, which can decrease the amount of shivering. Because shivering is a reaction of the body to produce more heat [8], if this is reduced, the risk of getting hypothermia increases. The amount of nutrition also influences the fat percentage. Biem et al. [6] argue that the fat percentage can even be a more determining factor than age. A high amount of body fat increases the insulation, as a result the core temperature is better maintained [6, 45].

Other factors that can increase the risks are alcohol, drugs and diseases. Tanaka and Todudome [41] found in more than 60% of the persons that died due to hypothermia were inebriated. Castellani et al. [45] mention that alcohol impairs the thermoregulation. Nixdorf-Miller et al. [7] and Ulrich and Rathlev [8] explain that this is because of the inhibition of the shivering response and because of vasodilation, which increases heat loss through radiation. McMahon and Howe [39] and Nixdorf-Miller et al. [7] also point out that alcohol intake can result in poor decision making. Drugs can have the same effect as alcohol, depending on which drug is used [7, 8, 45]. Some diseases can also increase the risk of hypothermia. Diabetes or peripheral vascular diseases, for example, are often mentioned as diseases that increase the risk, because they influences the heat production [39, 41, 45].

2.2.2.3. Deaths hypothermia in homeless population worldwide

Hypothermia is often mentioned as one of the mortality causes among the homeless population worldwide. Vuillermoz et al. [47] discovered in Paris that between 2008 and 2010 4% of the 693 mortality cases among homeless persons was directly related to hypothermia. They argue that this is probably an underestimation because there are more unspecific mortality causes that are related to cold. Bigé et al. [48] also looked at Paris and found from 2000 till 2012 a 3.1% of deaths that is directly related to hypothermia. In Philadelphia a 6% was found [9]. A study in New York City showed that from 2005 to 2007, 13 homeless people died due to hypothermia [49]. In Tokyo, Suzuki et al. [10] found that 9.1% of deaths in the homeless population is due to hypothermia in the years 1999-2010. Moscow has a very high amount of deaths through hypothermia cases. In four years the number was 1697, although it is not clear if this involves only homeless people, or all people living in Moscow [50]. Based on these findings, it is clear that hypothermia is indeed a problem among the homeless community.

2.2.3. Homeless people's perception of technology

This section covers how homeless people are perceiving technology. Because almost no articles could be found that looked at the perception of homeless people towards technology in general, the mobile phone is used to represent technology. The next part will first cover the distribution of mobile phones among homeless persons. Secondly it will look at how homeless people perceive owning a mobile phone. This is followed by a description of the reasons for using the mobile phone. In the end the challenges homeless people face when owning a mobile phone can be found.

2.2.3.1. Percentage of homeless people owning a mobile phone

The percentage of homeless people owning a mobile phone found in literature is not consistent and can range from 44% to 89%. Moczygemba et al. [51] and McInnes et al. [52] both observe that a percentage of 89% owns a mobile phone. Mocyzgemba et al. [51] looked at a sample of 290 homeless people, 18 years or older, in Virginia, that visited HCH centres for health related issues. McInnes et al. [53] looked at a sample of 106 homeless veterans in Massachusetts. Although the sample size in both studies is quite large, they only looked at subgroups of the homeless population. However, the study of Moczygemba et al. [51] is from 2017, and therefore it is likely that this percentage did not change much in the timeframe when the study was conducted till now. Asgary et al. [54] imply that 78% of 50 homeless people in New York City owns a mobile phone, but their sample size was limited. Rice et al. [55] conclude that 62% (n=169) use a mobile phone among homeless youth in Los Angeles. The sample size of 169 people is large, but they only looked at youth, which can cause a different outcome compared with looking at the whole homeless community. Eyrich-Garg [56] suggests that 44% of the homeless population owns a mobile phone. However, this was measured among 100 participants from one neighbourhood in Philadelphia and therefore it is unknown if this number can be generalised. This study is also the oldest, so the percentage can have changed over the years. Overall, if only the studies are used that are five years old or younger, then the percentage of homeless people owning a mobile phone is estimated at more than 78%.

2.2.3.2. Attitude toward privacy issues of the mobile phone.

Privacy is an important aspect when dealing with mobile phones. Jennings et al. [57] mention that some homeless persons distrust their level of privacy using a mobile phone and that they believe that their mobile phone could be used to trace them. Adkins et al. [58] also state that most people do not like the idea that they can be tracked. However, the resistance against sharing and receiving (personal) information over the mobile phone becomes less if the user knows more about what is done with the information and how it is protected against misuse [51, 58]. Both Le Dantec and Edwards [59] and Adkins et al. [58] point out that as long as sharing the information is useful and beneficial for the user, they are more willing to participate and to use their mobile phone.

2.2.3.3. Reasons for owning a mobile phone

There are five different reasons that could be found in literature why the homeless people own a mobile phone:

1. Stay connected with friends and families
2. Job related
3. Communication with support services
4. Entertainment
5. Making life easier

Stay connected

The first and most important reason for using a mobile phone is to stay connected with friends and families. McInnes et al. [53] looked at the reasons for mobile phone calls, texting and emailing among homeless veterans and they point out that in all three groups most communication was conducted with friends and families. Rice et al. [55] and Eyrich-Garg [56] also observe that most participants used their phone to keep in contact with family and friends. There are three arguments why the homeless population want to stay connected with friends and families. The first argument, pointed out by Rice et al. [55], is that having a cell phone makes it possible for the owner to contact their relatives or friends for support in times of need. Le Dantec and Edwards [59] elaborate on this by saying that often the phone is the only stable connection these people have with relatives or friends from home. Therefore, the second argument is that the cell phone is an important device that makes it possible to know if something bad is happing with their relatives or friends. Besides using the phone in emergency situations or knowing if something bad is happing with other people, Eyrich-Garg [56] states that also just 'catching up' or 'making plans to meet with one another' are an important argument when calling with relatives or friends.

Job related

Beside staying in contact with family or friends, job related use of the phone is another reason for owning a mobile phone. Calling with (potential) employers is often mentioned [53, 55, 56] . Eyrich-Garg [56] furthermore implies that it is even more important to receive calls from (potential) employers then to make them. If the subject cannot receive these calls, the changes are that the employer will give the job to someone else. However McInnes et al. [53] state that contact for jobs among homeless veterans was more often done over mail then over the phone. They also mention that the internet was often used to find jobs. This is also pointed out by Eyrich-Garg [56] and Adkins et al. [58], who state that searching for job applications on the internet was another reason for using the phone.

Communication with support services

Communication with support services is also a reason for using cell phones. Using the phone to keep in contact with case workers, social workers, physicians or other health related contacts was often observed [53, 55, 56]. McInnes et al. [53] observe that after social calls with friends and families, calls for health related reasons were the second reason why people called. Although this was not found in the study of Eyrich-Garg [56] and Rice et al. [55], both studies also concluded that it was an important reason for using the mobile phone. Rice et al. [55] argue that having a cell phone leads to more stable contacts which can have a positive effect on the (mental) health of the users. Eyrich-Garg [56] also implies that having instant access to services and support can help the owner of a mobile phone with staying clean or sober. However, this was only mentioned by one of the interviewed persons. She also points out that it can give a safe feeling, knowing that help is only a phone call away.

Entertainment

The mobile phone is also sometimes used as entertainment. Adkins et al. [58] suggest that besides communication, music and social media were mentioned the most as reasons for using mobile phones in homeless youth. Social media is indeed also mentioned by other studies. Woelfer and Hendry [60] conclude that the homeless youth also uses their phones for making video's and placing them on youtube [61] or MySpace [62]. However, music was not mentioned by other studies.

McInnes et al. [53] mention that using entertainment was the most important reason for using the internet on the phone among homeless veterans. They did not specify what kind of entertainment was meant by this. On the other hand, Moczygemba et al. [51] suggest that more than half of the participants of the study did not use mobile apps. What kind of apps was not clarified, but apps often can be used for entertainment.

Making life easier

Besides all the previous reasons, the mobile phone is also used to make the daily life of the homeless persons a bit easier. Both Moczygemba et al. [51] and Adkins et al. [58] state that the use of the alarm clock is used for waking up or an appointment reminder. Furthermore, use for navigation and transportation is pointed out by McInnes et al. [53] and Adkins et al. [58]. Le Dantec and Edwards [59] also add that having a mobile phone can be used as identity management. As long as the person has a mobile phone, others will think that they are doing all right.

2.2.3.4. Mobile phone problems

Although owning a mobile phone can have a lot of benefits, it also causes some problems. The most common problem is the access to power and power sockets [51, 52, 58, 59, 63]. It is not always easy the keep the phone charged. As a result some only use a phone until it is dead and then throw it away [59, 60]. Being out of money is another problem homeless people often face. As a consequence the phone cannot be used [52, 59] or is even sold to get quick money for other important needs or drugs [60, 63]. Furthermore, keeping the phone safe from the weather is another struggle [58, 63, 64], as is theft [51, 59], and not breaking the mobile phone [52, 58, 64]. Woelfer and Hendry [63] also suggest that cold weather can result in stiff fingers, making it almost impossible to use the mobile phone during these weather conditions. However, it is not clear if they researched this or if it is an assumption. For some, especially older people, it is also hard to use the phone because of poor eye sight [54].

2.2.4. Conclusion

There were two goals of this literature review. The first was to find more information about hypothermia and what the symptoms and risk factors are. The second goal was to find out how the perception towards technology is among the homeless community, based on their perception towards the mobile phone.

In this paper only the literally homeless were looked at, so people that are sleeping sometimes or always on the street or someplace else in the city that is not meant for sleeping. Among this group, hypothermia is the cause of death in 3 till 9 percent of the mortality cases and does happen world-wide.

To know if someone has hypothermia, the core temperature needs to be measured. However, this can only be done using invasive methods which are unsuitable for this project. Therefore an estimation of what the core temperature can be, needs to be derived from other factors, for example from the peripheral temperature, the symptoms and the risk factors of hypothermia. For this project, the symptoms of the mild stage are interesting, because the envisioned solution should prevent hypothermia as much as possible.

Note:

Hypothermia can be divided in multiple stages. During this project the mild stage is looked at and from now on when hypothermia is written, the mild stage of hypothermia is meant.

When looking at the measurable symptoms, the most interesting are heart rate, breathing and shivering. However, a Sheltersuit is often worn over a lot of other clothing, so close contact with the skin is not always possible, making it impossible to use sensors that need skin contact.

When looking at the risk factors, there are also several. Because it is such a diverse spectrum of factors, when someone gets hypothermia differs for each person and for each situation. This makes it very hard to predict with a high accuracy when someone is getting hypothermia. Therefore it is concluded that the envisioned system should only detect when the user has a risk of getting hypothermia.

Looking at technology, the literally homeless in the studies found, do often think that their phone is beneficial for them. Beside this, as long as they see the benefit they are willing to use new applications for them and give up some privacy. When looking at the studies from five years or younger, the percentage of homeless people owning a mobile phone is 78% or higher. So they are indeed willing to use technology. It is therefore not impossible to use technology in general, and a mobile phone specifically, in the envisioned solution. However it is important to understand that the mobile phone is not always usable, so the envisioned solution cannot be based solemnly on the mobile phone. Furthermore, the challenges faced when owning a mobile phone are also problems that can arise when using other technological devices. For the envisioned solution it is important to keep these challenges in mind.

Furthermore, it is important to note that there is a limited amount of articles used. There where almost no articles that focussed on the perception of technology in general among homeless people and when looking at the perception towards the mobile phone, this was still limited and only studies executed in the United States could be found. Therefore a recommendation for further study would be to investigate the mobile phone use in Europe and how homeless people perceive technology in general. Furthermore, it is also important to state that most samples used in the studies are not representative for the whole homeless community, because they only focussed on subgroups among the homeless community.

2.3. State of the art

This section covers products or services that focus on helping homeless people, contacting people in an emergency and measuring (symptoms of) hypothermia. This section will first cover apps that are available and then devices. In the end the conclusion can be found.

2.3.1. Apps

Winter survival kit

The winter survival kit [65] is an app that will help the user when they are stranded in cold weather conditions. The user can store important phone numbers and contact information of friends or family. The app can be used to call 911, or other emergency services that the user has provided, and determine the current location. Beside this, for car drivers, it can estimate how long the engine can keep running on the remaining fuel to provide warmth. It also gives every 30 minute a notification to turn of the engine periodically, so carbon monoxide poisoning is prevented.

OurCalling

OurCalling [66] is an app developed by the non-profit organisation, OurCalling. It provides homeless people in Dallas with information on all the available short and long term resources in the city that homeless people can use. The resources for homeless people can change quite often. Therefore, it can sometimes be hard for these people to know where they can find all the things that they need, for example food pantries or laundry places. The OurCalling app gathers all the resources and catalogue it in their own database.

Non homeless people can also use this app to report a homeless establishment, so people of the organisation can review it. They can also see the volunteer calendar of OurCalling, to see any opportunities for volunteering.

Beside this, the organisation also uses the data of this app to get a better understanding where all the homeless people are living on the street [67]. When using the app, GPS data is collected. It is unknown if this data is collected with informed consent. This data is then compared with collected data of 911 and 311 calls related to reporting homeless establishments and with their own internal data. This provides a map showing where the homeless people are. Which can then be used to provide resources.

WeShelter

WeShelter [68] is from the same organisation as OurCalling and has two functions. One is to let people dial 311 if they see a homeless person that needs help. The shelter organisation can then send a team to offer assistance. Beside this you can also tap a button that will donate a small amount of money to homeless organisations.

StreetLink

StreetLink [69] is an app that provides the opportunity to alert local authorities in England and Wales about homeless people sleeping on the street. Some people that are homeless do not know that there are services and support available for them. The local authorities also do not always know who is homeless and how many there are, because these people remain out of sight or are constantly on the move. With StreetLink, people can easily provide information of where and when they saw a homeless person sleeping on the street. The local authorities can then connect them to the local support and services they need.

DUSIB app

DUSIB stand for the Delhi Urban Shelter Improvement Board [70]. They developed an app that works in the same way as StreetLink, but then for Delhi. The user can use the app to inform the organisation that help for a homeless person is needed. The user of the app can do this by taking a picture of the situation and posting it on the app. The location is then automatically detected and a team is send to help the person in need. The user that called for help is afterwards updated over the situation. In winter, there are a total of 23 teams available to rescue homeless persons and move them to shelters.

GiveSafe

GiveSafe [71] is another app that focuses on helping the homeless community. It does this by providing homeless persons with a beacon, see figure 3. If the app is installed on a mobile phone, the owner of this phone will get a notification if they pass a homeless person with a beacon. Together with this notification, also the story behind the homeless person and how they ended up on the street is send. Money can then be donated to this person. The homeless person will receive it digitally on its beacon and can spent this money at partner retailers. This way, the donator always knows that the money is not spend on alcohol or drugs. The beacon turns of every month, and can only be activated again after the bearer has checked in with a counsellor that gives guidance. This counsellor can also provide a needed product, which cannot be obtained at one of the partner retailers.

Figure 3: Beacon of GiveSafe [71]

React mobile

React mobile [72] is an app in combination with a panic button. The app makes it possible to share your GPS location with friends or families, keeping them updated about your whereabouts. This will increase your own safety, because there is always someone that knows where you are. The button can be used in a dangerous situation and, if the phone is in a three meter radius, will immediately connect to your mobile phone. The app will then alert the contact persons you have entered.

2.3.2. Devices

SmartWatcher – emergency watch

The SmartWatcher [73] works the same as the React mobile, but the panic button is incorporated in a watch. If this button is pressed, up to 12 persons will be alerted. The watch also has a build in microphone and speaker, which makes it possible to be called on the watch. There is also an app that works the same as the React mobile app and shows where the SmartWatcher owner is at any time of the day.

Tcore™ Temperature Monitoring System

Tcore [74] calculates continuously the core body temperature of the user. For this it uses a dual-sensor heat flux technology. The sensor needs to be placed on the forehead of the user and the measured temperatures will +/- be within 0.3 C of rectal measurements, which is the standard way of measuring core temperature [75]. The sensor can be seen in figure 4.

Figure 4: Tcore [74]

Healthcare Thermometer Strips

The Healthcare Thermometer Strips [76], see figure 5, are strips that can be placed on the forehead. The strips use thermochromic liquid crystals, that change colour depending on the temperature. The temperature is measured from the temporal artery and it claims to be reliably reflecting core body temperature (accuracy of +/- 0.6 °C). The range of temperatures it can measure is 29 – 41 °C and it can be used with an ambient temperature range from -1 - 82 °C.

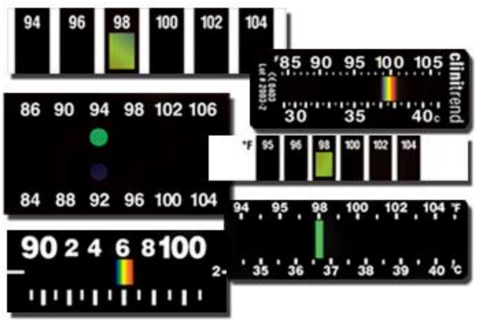

Figure 5: Healthcare thermometer strips [76]

ThermoSpot

The ThermoSpot [77] is also a sticker that uses liquid crystal technology to indicate constantly the current core temperature of the user. However, the places where this sticker can be placed are in the armpit, above the liver or on the great vessel in the neck. The ThermoSpot is a smiley sticker that is specifically developed for neonates, infants and children in developing countries and focuses mostly on indicating hypothermia, see figure 6. The smiley sticker is green when the baby is in de safe zone (36,5-37,5 °C). When the temperature drops, the smiley turns to light green (<36.5 °C), red (<35.5 °C) and black (<32 °C). If the temperature is higher than 37.5 °C the smiley is blue.

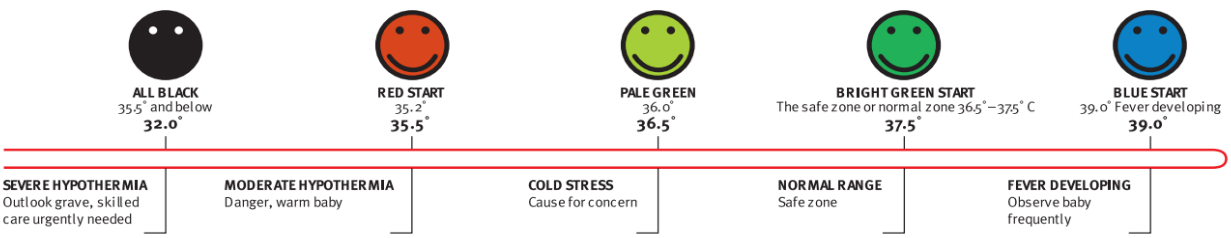

Figure 6: colours of the smiley sticker at different temperatures [77]

ThermoFocus

ThermoFocus [78] is a non-contact thermometer that measures the infrared emission the body diffuses, see figure 7. It takes the measurement on the forehead, from the temporal artery and calculates from this the core body temperature. ThermoFocus mainly focusses on detecting fever. It is usable best in temperatures from 16 to 40 °C but it can be used from 5 °C, although the accuracy is then not guaranteed.

Figure 7: ThermoFocus [78]

Bempu

Bempu [79, 80] is a bracelet for babies that is constantly measuring their temperature, see figure 8. It focusses especially on detecting hypothermia. It measures the temperature on the underside of the wrist and if this temperature is fluctuating too much, an alarm will go off, telling the caretaker(s) that something is wrong. Bempu is measuring the peripheral skin temperature, and not the core body temperature. When the body cannot produce enough heat, it will conserve the warm blood for the core. As a result the peripheries become colder before the core becomes too cold. So Bempu measures the peripheries because it can than detect a chance on getting hypothermia early, before the hypothermia can do any damage to the organs. An algorithm is used to calculate the temperature threshold for hypothermia. This threshold can differ for each user.

Figure 8: Bempu [79]

Cosinuss One

Cosinuss One [81] is a device developed for sports. It can measure the pulse, body temperature and heartrate variability of the user continuously. The device is worn in and around the ear, see figure 9. Because it is for sports, the temperature measurement focuses mainly on detecting a raise in body temperatures.

Figure 9: Cosinuss One [81]

TempTraq

TempTraq [82] is a thermometer patch that needs to be placed on the side of the body, under the arm. It will for 24 hours measure the temperature continuously and will send this, using Bluetooth, to a connected Android or iOS device that has the corresponding app installed, see figure 10. It mainly focusses on fever, but can measure temperatures between 30.5 and 43 °C. They claim that they measure the same temperature as oral readings do. TempTraq can be used for all ages.

Figure 10: TempTraq [82]

Check-my-temp

Check my temp [83] is a wearable thermometer in the form of an arm band, see figure 11. Besides temperature, it also measures movement, position and fall detection for elderly. The data is send to a corresponding device with the app installed. The thermometer is on the underside of the wrist. They claim that, with their Multi Temp Technology, the temperature readings are accurate, regardless of the body position.

Figure 11: Check-my-temp device around the upper arm [83]

Spire

Spire [84] is a device that monitors breathing. It does this by sensing the expansion and contraction of your torso when inhaling or exhaling. It therefore needs to be clipped to the top of your pants, see figure 12. By measuring your breathing, you can understand when you are tens or stressed and you can work on your breathing to become more relaxed again.

Figure 12: Spire clipped to the top of the pants [84]

Children's respiration monitor

The Children's respiration monitor (ChARM) [85, 86] is a belt that can be strapped around a child chest, see figure 13. It then measures the breathing rate by detecting converting chest movements, using accelerometers. The ChARM does not need direct skin contact. It is used in developing countries to help with the diagnosis of pneumonia in children less than five years old.

Figure 13: ChARM [85]

Contactless bed sensor (muRate)

The Contactless bed sensor [87] is a sensor that is places under the bed. It can measure the heart rate, respiration rate and heart rate variables. It uses an ultra-sensitive accelerometer to detect bed movements that are causes by the heart beat and by breathing. These movements are then translated to heart rate and respiration rate by a microcontroller with specific algorithms.

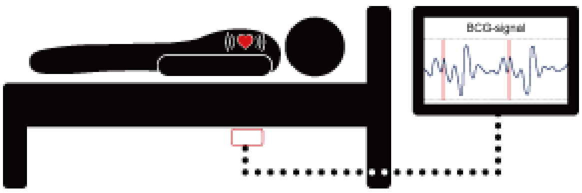

Figure 14: The contactless bed sensor from muRate [87]

CliMate

CliMate [88] is a small device that can measure humidity, UV rays and temperature of the environment of the user, see figure 15. Using Bluetooth, it will send the data to the mobile phone. Furthermore it can track the location and time of collection. By using the data the app on the phone will warn the user when the UV rays are too strong or when the temperature or humidity is too high or low. CliMate is small enough to be wearable, on clothing or as a keychain, or it can be placed somewhere. The measured values can also be send to the cloud server, which results in a crowdsourced real-time weather map.

Figure 15: CliMate, a small device that can measure the immediate environment of the user [88]

StormTag

StormTag [89] is a small Bluetooth weather station that can be worn as a keychain, see figure 16. It can measure the temperature, humidity, barometric pressure for weather mapping and UV rays. It focusses mainly on forecasting the local weather. The battery last one year and the device is completely waterproof. The data is send to a connected Android or iOS device that has the corresponding app installed. The app will then interpret the data and can send an alarm if there are sudden changes.

Figure 16: StormTag can easily be worn as a keychain [89]

Tempi

Tempi [90] is a device that will measure and track the temperature and humidity of the immediate surrounding of the user. It can be clipped easily to clothing or it can be placed somewhere, using the base, see figure 17. It uses Bluetooth to send the data to a connected iOS device that has the corresponding app installed. This phone needs to be in a range up to 30 meters. When the phone is not in this range, Tempi will store the data itself and send it to the phone when there is a connection. Multiple Tempis can be connected to the same phone. When the temperature or humidity level goes above or below a set limit, a notification is send to the user.

Figure 17: Tempi can measure the temperature and humidity of the immediate environment of the user [90]

SynapseWear

SynapseWear [91] is an open source device that can measure the motion and the immediate environment of the user. It has six sensors and with these sensors it can measure: CO2/TVOC, temperature, humidity, pressure, light, movement (nine degrees of freedom) and ambient sound level. It communicates with the users phone using Bluetooth. Because it is open source, the code used is available and it is possible to change it yourself. Arduino and update OTA can be used to program for the device. SynapseWear can be worn on clothing, see figure 18.

Figure 18: SynapseWear measures motion and the immediate environment of the user and can be attached to clothing [91]

Smart life jacket

The Smart life jacket [92] is a normal jacket but with some extra functions. It uses a GSM module to send GPS data of the current location of the owner to the rescue teams. Beside this it also has a pulse sensor that monitors the heartrate.

2.3.3. Conclusion

The findings in the state of the art show that there are already some apps that try to find the people on the street and get them of the street. However, these are mostly focussed on getting the citizen involved in helping a homeless person. There are also some emergency buttons, that can be used. The user has to press these button themselves and a mobile phone needs to be close by to send a call. The technology to non-invasively measure core temperature is also available, but these almost all require skin contact. The infrared temperature sensor on the forehead is the only one that does not require any contact, but this one is not usable with lower temperatures. There are devices that can measure breathing without direct skin contact, and there is also a heart rate monitoring device that does not need direct skin contact. However, that device is specific for lying in bed situations.

Furthermore, there are already some devices that can easily measure the immediate environment of the user, like temperature, humidity and UV rays. This is interesting because weather factors are risk factors for getting hypothermia. Nothing specifically focussed on hypothermia in combination with homelessness could be found.

2.4. Relevance of the research question

Based on the literature research it was found that hypothermia is indeed a mortality cause among homeless people world-wide. Therefore it is interesting to find a solution for this problem. Looking at the state of the art there are already apps that people can use to call local authorities if a homeless person is seen sleeping on the street. However, these apps all focus on the citizen seeing these homeless person, and not on the homeless person themselves calling for help. There are also emergency buttons that can be pushed to call for help. However, these can be used in all kind of situations and do not give any information to the user if there is a change of getting hypothermia. Beside this, they all use a mobile phone to notify that the person is in danger. Homeless people do not always have a (usable) mobile phone, making these buttons potentially useless for them. There are also already devices that can non-invasively detect hypothermia, but these require direct skin contact or are not usable with low temperatures. So, looking at the current state of the art and to the fact that hypothermia is indeed a mortality cause among homeless people, it can be concluded that the research question of this graduation project is relevant.

3. Ideation

During this project the 'Creative Technology Design process' is followed [93]. This design process is made for the Creative Technology bachelor program and can be used by students as a guideline. The process consist of four phases: Ideation, Specification, Realisation and Evaluation.

In this chapter, the ideation phase is discussed. The ideation phase is meant to go from the research question, stated in chapter 1, to an elaborated project idea and the envisioned solution requirements. The ideation phase starts with a stakeholder analysis, to get a better understanding about who the stakeholders are, how important their interests are and how much these interests should be taken into account when making decisions relating to this project [94]. Beside the stakeholder analysis, also an iPACT analysis is done, followed by a 'user perspective scenario'. This shows the envisioned system from the user point of view. Based on this a list of preliminary requirements is made and together with the 'user perspective scenario' these requirements are used to generate different concepts for the envisioned system. After all concepts are explained, the final concept is chosen. Based on this final project idea, the ideation phase ends with the additional requirement list.

3.1. Stakeholder analysis

A stakeholder analysis is done to get a better understanding about who the stakeholders are and how much their interests should be taken into account when making a decision [94]. Freeman defines stakeholders as follows:

'A stakeholder in an organisation is (by definition) any group or individual who can affect or is affected by the achievement of the organisation's objectives' [95].

Furthermore, Sharp et al. identify four roles a stakeholder can have: users, developers, legislators and decision makers [96].

Users

Users are people that interact with the system directly and who will use the products of the system. The envisioned system has one main user and, depending on the preferences of this main user, it can have two other types of users. The main users are the homeless people living on the street. The other two types of users are the contact persons/aid organisations (e.g. Humanitas [12], Salvation Army [13], Tactus [14]) that can be contacted when help is needed and, secondly, people, that are by chance nearby the user in the Sheltersuit, from now one addressed as passersby, that can be warned when the user of the Sheltersuit needs help. The influence of the homeless people is high, because they are the ones that are mainly using the product and if they do not like it, they will not use it. The preferences of the homeless person also influences if a contact person or passersby is notified in case there is a risk of getting hypothermia.

The influence of the contact persons/homeless shelter organisations is medium, because, if they are notified, they will only use a small part of the product and only if the homeless people are using it. Beside this, they will not use it as intensive as the homeless people do.

The influence of passersby is also medium, because they will not use the envisioned system intensively and they will only use a small part of the envisioned system. However, if they are notified by the Sheltersuit, the envisioned system should be able to encourage them to help and the passersby have to understand what to do in such a situation.

Developers

Developers are the people that are involved in the developing phase of the project. In this project the researcher has this role. Her influence is medium because she does make decisions, but these are mainly based on the interests of the users and the decision makers.

Legislators

These are often authorities, that have e.g. connections with the law or politics, that may produce guidelines or laws that influence the development of the system. The municipalities that have an influence in the policies of aid organisations are legislators for this project. Their influence is low.

Decision makers

Decision makers can be the ones that are responsible for commissioning the system. They can also be people that decide what processes or standards are identified in the beginning of the project. They are usually managers or financial controllers. In this project Sheltersuit Foundation is a decision maker with a high influence level. They are the ones commissioning the system and they have a final say in the decisions that are made relating this project. Beside the Sheltersuit Foundation, the supervisor from the Creative Technology program also is a decision maker with a high influence. His influence is mainly on the timeframe, documentation and project processes. In table 2 all the stakeholders, their roles and their influence level can be found.

Table 2: The stakeholders and their role and influence level

Stakeholder	Role	Influence level
Sheltersuit Foundation	Decision maker	High
Creative Technology supervisor	Decision maker	High
Homeless people living on the street	User	High
Contact persons/homeless shelter organisations	User	Medium
Passersby (people in the surrounding of the Sheltersuit when help is needed)	User	Medium
Researcher	Developer	Medium
Municipalities that influence policies of aid organisations	Legislation	Low

3.2. Contact with stakeholders

To get a clear understanding about the preferences and wishes of all the stakeholders, it is important to involve them during the design process. Therefore several meetings were conducted with the client, the Sheltersuit Foundation, to understand their wishes and preferences.

Furthermore, contact was tried to established with the homeless shelter organisations the Salvation Army and Humanitas onderdak. Unfortunately there is some disagreement between these organisations and the Sheltersuit Foundation. As explained in chapter 2 the homeless shelter organisations believe that the Sheltersuit will encourage people to sleep on the street, while they want to get as many people as possible of the street. Because they do not agree with the purpose of the Sheltersuit product, they also did not want to cooperate with this project. So, besides one meeting with the Salvation Army at the beginning of the project (see chapter 2), before the focus of the project was clear, no other meetings with the homeless shelter organisations could be conducted.

This also meant that the homeless shelter organisations could not be used as a gateway to come in contact with the homeless people themselves. The Sheltersuit Foundation also could not help with this. In the end Tactus (organisation specialized in addiction care), did manage to find two homeless people that were willing to cooperate with this project. However, organising a meeting with them was quite challenging and in the end no meeting could be established.

Besides the homeless people and the homeless shelter organisations also a meeting was conducted with the municipality of Enschede in the beginning of the project. This did result in some background information (see chapter 2).

In the end, most information came from the Sheltersuit Foundation themselves and based on the information obtained in the meetings with them the iPact analysis, user perspective scenario, requirements and concepts were generated.

3.3. iPACT analysis

A PACT analysis can be used to get a better understanding about the context the envisioned system is used in and to describe the envisioned system from the users perspective [97]. PACT is an acronym and stands for People, Activities, Context and Technologies. An iPACT analysis is based on the PACT analysis, but adds the 'i' of intention as a part of the analysis [98].

Intentions

The intention of this envisioned system is to make sleeping on the street a bit more safe by monitoring when the user has a high risk of getting hypothermia. If this happens, it will warn the user, a contact person/aid organisation or passersby, so they can take action.

People

Lisa is a 38 old woman. She became homeless five years ago after a divorce. She is an alcoholic and lives on the street together with a fellow homeless man named Hans. She does not like the homeless shelters and therefore she sleeps often on the street. She is physically all right, but very scrawny. She had some education and before she became homeless she worked at a post office. She knows how to use computers and she owns a mobile phone.

Activities

This section describes the activities and tasks the user needs to perform. When it is cold outside, the user will probably wear the Sheltersuit. The monitoring system that monitors if the user has a risk of getting hypothermia works autonomously. If the Sheltersuit gives an indication that there is a risk of getting hypothermia, the user has to tell the system that they have understood the warning. After this they have to change the circumstances such that the Sheltersuit will not send a notification again in a while. If the user is not capable of action, it will not respond to the notification, and by doing nothing they are telling the Sheltersuit that other people need to be notified.

Context

The environment in which the envisioned system is used, is on the street in urban areas. The envisioned system is embedded in the Sheltersuit. The Sheltersuit can be used in any weather condition, but will probably be used most often in winter conditions when the weather is cold and it can be wet and windy.

Because the nights are often the coldest part of the day, hypothermia is more likely to happen at these moments and therefore the notification will probably also be activated most often during this time. Depending on the social contact the user has, they can have company by fellow homeless people or are on their own.

Technologies

The technology used in the envisioned system consist of sensors that are capable of monitoring when a Sheltersuit user has a risk of getting hypothermia. The data of these sensors are translated to a risk of getting hypothermia. Based on the risk level, the notification system can be activated. Furthermore, if a contact person/aid organisation needs to be notified, a mobile phone can be used.

3.4. User perspective scenario

Based on the iPACT analysis an user perspective scenario is made. This scenario describes a concrete situation from the user's point of view and what the user does and wants [97]. It gives insight in the requirements the envisioned system should have and it is a good starting point for generating concepts.

This scenario describes a day in the life of the user. Because the main users are the homeless people, their perspective is used in the following scenario.

Lisa is a 38 year old women who became homeless five years ago after a divorce. The stress became too much and, together with a mental breakdown, she started drinking. In the end she lost her job and couldn't pay the rent anymore. She became homeless.

She is now living on the street, together with a fellow homeless man, named Hans. In the city where they live, there are shelters that are helping the homeless population. These shelters offer food, a place to sleep and daytime activities. However, what the shelters offer differs per location and not all shelters are always open.

Both Lisa and Hans do not like these shelters. They use them sporadically to collect food and refreshments, recharging phones and warming up on a cold day. But beside this, they think that the shelters are too crowded (especially in winter). They also do not trust the people who are staying there and that there is a big chance of stuff being stolen from them. Also because of their alcohol behaviour, they are sometimes refused in a shelter. So they often sleep on the street.

To make the sleeping on the street a bit more comfortable, they received two Sheltersuits. These suits consist of two parts. The top part is a jacket that can be worn independently from the bottom part. The bottom part is a bag for the legs, that can be zipped to the jacket, making it a sleeping bag. Unfortunately, one of their Sheltersuits got lost, so now they are sharing the remaining one.

On a cold winter day, Lisa and Hans wake up early in the morning. The weather is cold, wet and windy. Unfortunately for Lisa, it was Hans his turn to use the Sheltersuit. Lisa's blanket became very damp during the night, because of the humidity in the air and she is feeling very cold. The Sheltersuit would have protected her against the humidity, because of the water-resistant exterior. The Sheltersuit also retains the heat of her body better than her blanket. With the blanket she always has to be careful not to make a gap while turning, so cold air cannot reach her body. The Sheltersuit doesn't have this problem.

It takes Hans some time to get out of the bottom part of the Sheltersuit and to put it in the bag. This is due to the darkness, but also because he has to crawl out of the bottom part and it was packet with newspaper, which helped to increase the insulation. He keeps wearing the jacket, which will protect him against the winter weather.

At a shelter they have some breakfast and refreshments. They also want to charge their phones, but because it is very busy, all the power sockets are occupied all the time, so in the end they leave with dead phones. This shelter stays open till noon, but because the shelter is very crowded with this weather, Lisa doesn't like to be there, so they leave earlier. Before they go, a shelter volunteer tells them that it will get very cold this night and that they better stay in a night-shelter for the night. Lisa thinks that the women is exaggerating, it is not that cold at the moment and they have dealt with low temperatures before, so they will survive this night as well.

For the night they find a quiet spot under a bridge. Another men is already sleeping there. Lisa puts on the Sheltersuit and stuffs the Sheltersuit with newspapers. The temperature is dropping rapidly, more than Lisa had expected. They have some alcohol to keep themselves warm. However, the warmth of the alcohol doesn't work long, and soon Lisa is shivering extremely. Around midnight, the Sheltersuit sends a notification, indicating that Lisa has a risk of getting hypothermia. Both Lisa and Hans are too drunk to notice. The Sheltersuit keeps sending the notification for a while, keeping the level of notification such that it is only noticeable by Lisa (or other persons, like Hans, that are very nearby). When Lisa or Hans are not responding, the Sheltersuit will start to search for a mobile phone that is connected to the Sheltersuit. However, both the phones of Lisa and Hans are dead, so the Sheltersuit does not find a mobile phone it can use to send an alarm notification with GPS location to the contact persons Lisa and Hans have entered. Because it cannot send an alarm notification, it will now start to notify passersby. This attracts the other men that is sleeping under the bridge. He doesn't know what the notification means and is first hesitant to walk over to them. However, when the notification does not disappear, he approaches them. He first think that they do not respond because they are too drunk to notice anything. But then the notification tells him that the person suffers from hypothermia and that an ambulance is needed. He then calls for an ambulance and both Lisa and Hans are picked up and brought to a hospital.

3.5. Preliminary Requirements

As a result of the iPACT analysis, user scenario and meetings with the client, a preliminary list of requirements is worked out, see table 3. The requirements are divided in functional and non-functional requirements. The functional requirements are "the things the system does", the non-functional requirements are "the things the system is" [99]. To give a level of importance to the requirements, the MoSCoW method is used [100], which categorises the requirements in Must, Should, Could and Won't.

Because no contact was made with the end user, the homeless people, there are no 'must' requirements about how the user wants to get notified. Also, because it is unknown if they agree in contacting a contact person/aid organisation or passersby if needed, these requirements are classified as could.

Table 3: Preliminary requirements of the system

Functional requirements	Non-functional requirements
MUST	
The system must detect when there is a risk of getting hypothermia	The system must be integrated in the Sheltersuit
The system must notify the user if there is a risk of getting hypothermia	The system must be wearable
The system must be usable without other devices (such as a mobile phone)	The system must be usable with low temperatures
	The system must be usable in all weather conditions
	The system must be low cost
	The system must not hinder the user in their activities
SHOULD	
The system should have different settings for the notification that can be personalised	The system should be energy efficient
COULD	
The system could send a notification to a contact person if needed	
The system could notify passersby	
WON'T	
The system will not, on a clinical level, predict if the user gets hypothermia	The sensors of the system will not be placed directly on the skin of the user

3.6. Concepts

In this section, different concepts are described for the envisioned solution that can prevent hypothermia in a Sheltersuit user. The concepts are based on the user perspective scenario, described in section 3.4, and on the preliminary requirements, described in section 3.5. When looking at the research question:

How to develop a monitoring and notification system to prevent hypothermia of a Sheltersuit user?

the envisioned product can be divided in two parts, the monitoring system and the notification system. This section will cover them separately.

3.6.1. Monitoring system

The monitoring part will describe five different concepts about how an estimation for the risk of getting hypothermia can be made. This risk analysis can be based on monitoring the symptoms and risk factors of hypothermia that are described in chapter 2. A mind map is made with all the risk factors and symptoms of hypothermia that are assumed to be measurable, see figure 19. Because the goal is to prevent hypothermia, when looking at the symptoms, especially the symptoms that are linked to mild hypothermia are interesting to measure.

Note:

None of the concepts is capable of predicting accurately when someone gets hypothermia. All concepts only give an estimation of the risk of getting hypothermia.

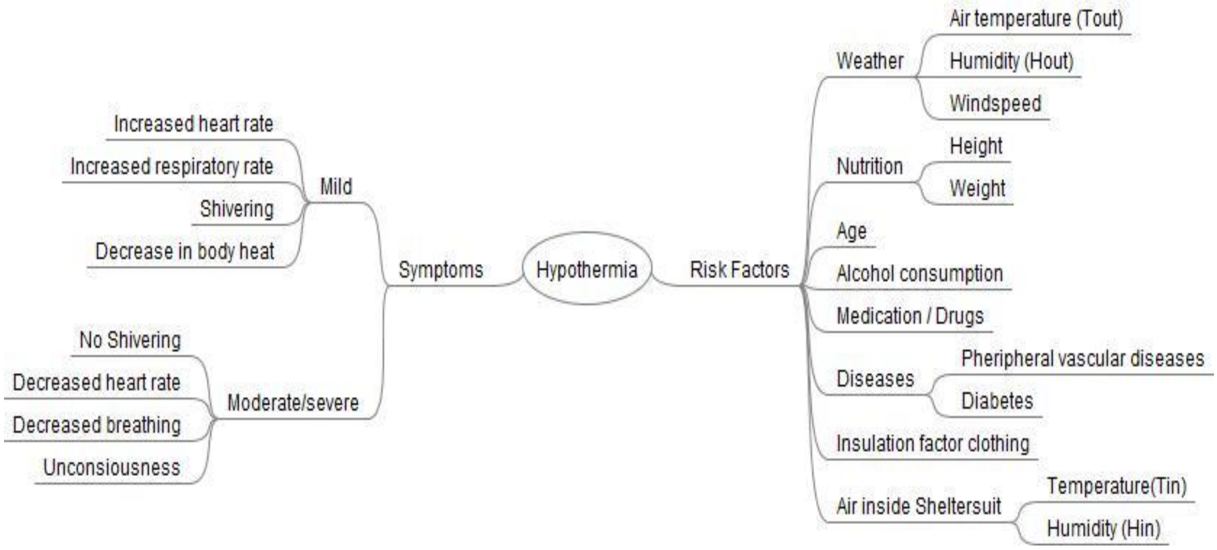

Figure 19: Symptoms and risk factors of hypothermia that can be measured or asked. For the symptoms, the symptoms in the mild stage are the most interesting.

3.6.1.1. Concept 1

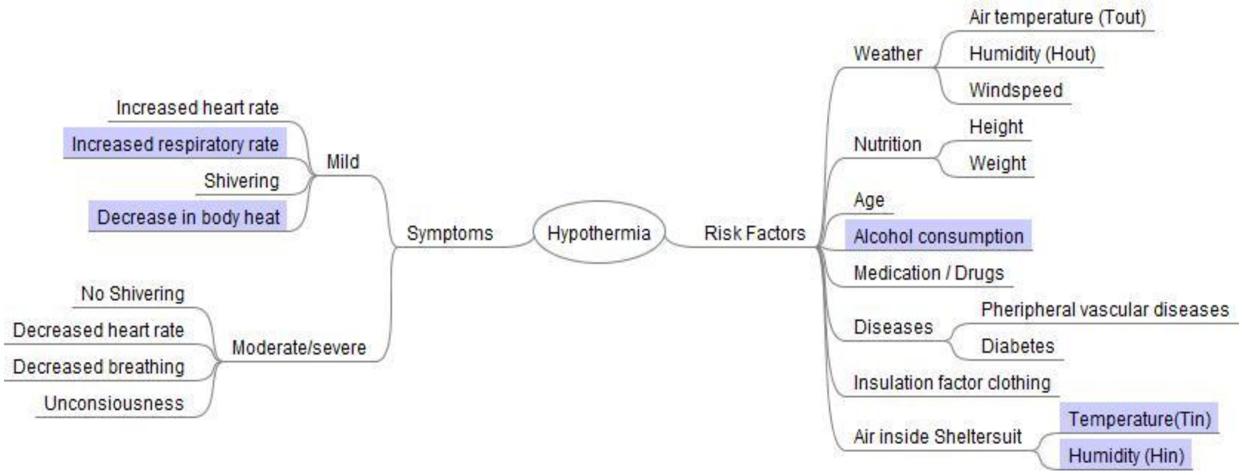

Figure 20: Symptoms and risk factors of hypothermia used in concept 1

In figure 20 the symptoms and risk factors that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.1. As explained in chapter 2, consumption of alcohol is an important risk factor and alcohol intoxication is often found in homeless people that died of hypothermia. Therefore it is interesting to measure the amount of alcohol the user has consumed. As can be seen in figure 21, this alcohol sensor is placed in the piece of the Sheltersuit that covers the lower part of the face. Alcohol sensors are sensitive for temperature and humidity, so the temperature and humidity need also be measured by a sensor to get a more accurate alcohol measurement. This temperature/humidity sensor can then also be used to measure the breathing of the user. The respiratory rate increases when the user suffers from mild hypothermia, and therefore, if the rapid breathing continues for some time, it can be used as an indication that the user has a risk of getting hypothermia. The temperature/humidity sensor can measure that the temperature and humidity increase when the user is breathing out, and decreases again if the user is breathing in. Because hypothermia often happens in low temperatures, it must be possible to measure the difference in temperature between the environmental air and the breathing.

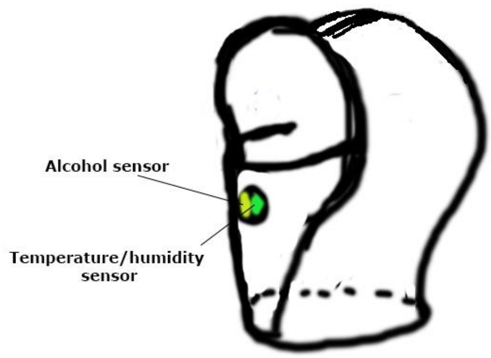

Figure 21: monitoring alcohol and breathing, concept 1

Because rapid breathing can also be linked to other activities, the temperature inside the Sheltersuit (Tin) is measured. Tin influences how much heat the body is losing. Therefore it can give an indication if the temperature is indeed low enough for a user to be at risk. When a low temperature makes the body loses too much heat, then the rapid breathing can be a result of hypothermia. Furthermore, Tin itself is influenced by how much heat the body is producing and when rapid breathing is due to physical strain, it is assumed that the Tin will increase due to an increase of heat production in the body of the user that is transported to the air surrounding the body. However, when someone is sitting/laying still, there is no increase of heat production, so no increase of Tin, which can indicate that the rapid breathing is not a result of physical strain. The temperature/humidity sensor to measure Tin/Hin is placed on the inside at the side of the jacket, below the arm, see figure 22.

The breathing measurement can also be used to indicate if the Sheltersuit is worn at the moment.

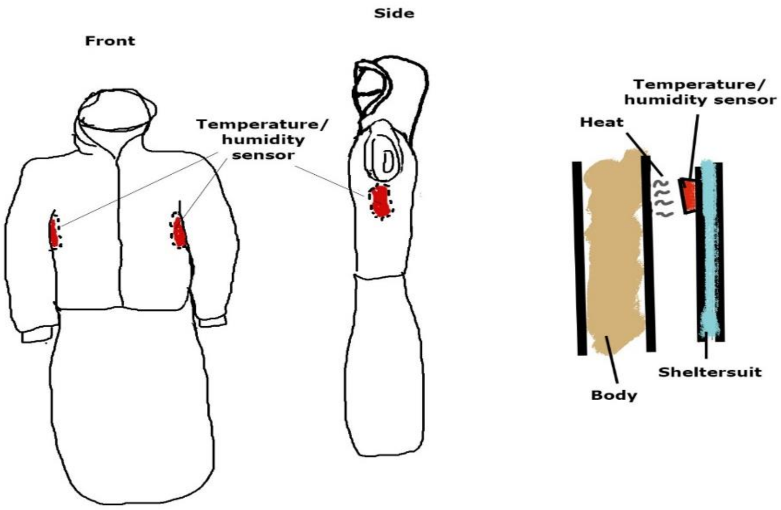

Figure 22: Placement sensors and variables that are measured in concept 1

3.6.1.2. Concept 2

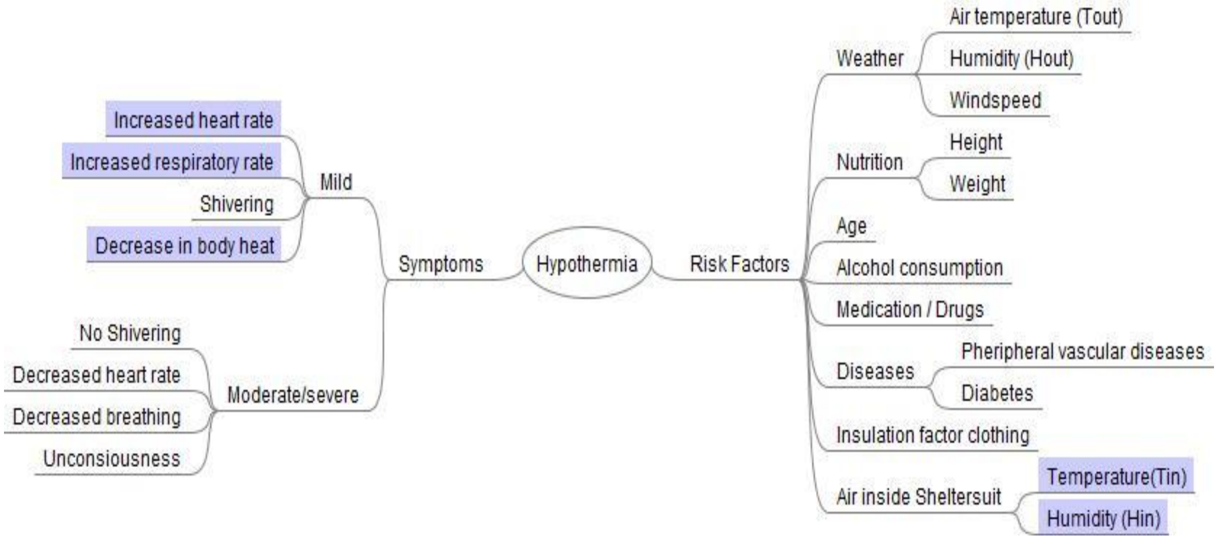

Figure 23: Symptoms and risk factors of hypothermia used in concept 2

In figure 23 the symptoms and risk factors that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.2. The 'contactless bed sensor' from MuRate [87] and the 'sleepace' from RestOn [101], see figure 24, are devices that can measure the vibrations a heartbeat or respiratory movements make on a matrass, by placing the sensor under or on the matrass. These sensors are interesting for the Sheltersuit, because they do not require immediate contact with the skin and they can measure two symptoms that are linked to mild hypothermia, namely increase in heartrate and increase in respiratory rate. When an increase in heartrate and respiratory rate is measured, this can be an indication that the user has a risk of getting hypothermia. The sensor is placed around the torso, see figure 25.

Figure 24: Sensors that measure heart beat and respiratory movements while sleeping. First is the 'Contactless bed sensor' from muRata [87], the second is 'Sleepace' from RestOn [101].

To get a better understanding if the increase in heart rate and respiratory rate is due to hypothermia, the Tin and Hin are measured with a temperature/humidity sensor. This data can be used to give context to the heart/respiratory rate. Tin is related to the body heat production and Tin and Hin both influence the speed in which heat is transported from the body to the surrounding air. If Tin is high and Hin low, it is unlikely that the increase in heart/respiratory rate is due to hypothermia. However, if Tin is low and Hin is high, it is possible that the increase in heart/respiratory rate is due to hypothermia. The temperature/humidity sensor to measure Tin/Hin is placed on the inside at the side of the jacket, below the arm, see figure 25.

Detection of heart beat and respiratory movements can also be used to determine if the Sheltersuit is worn at the moment.

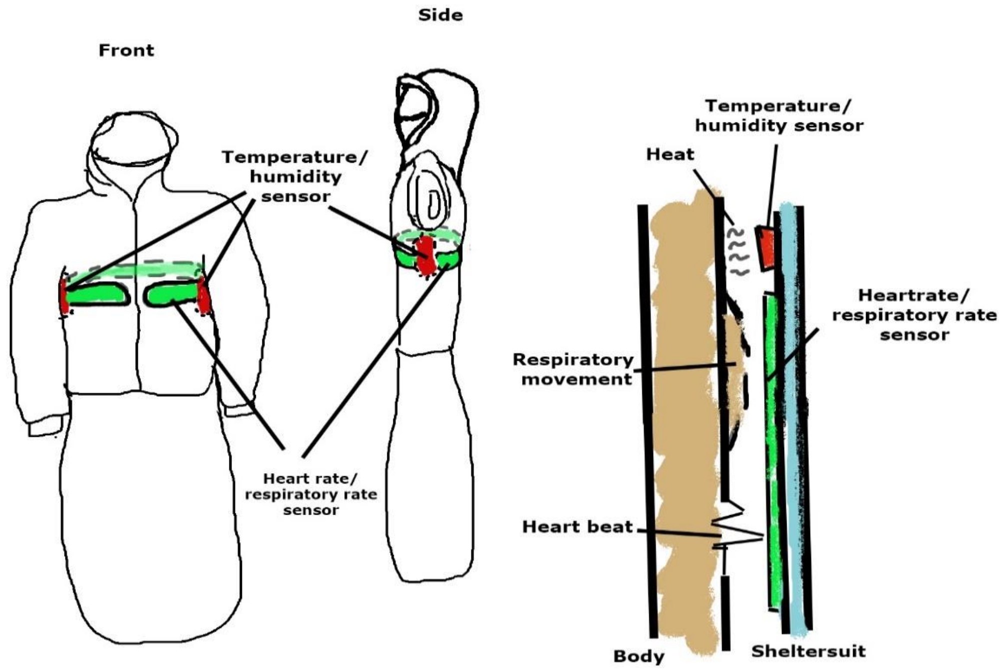

Figure 25: Placement sensors and variables that are measured in concept 2

3.6.1.3. Concept 3

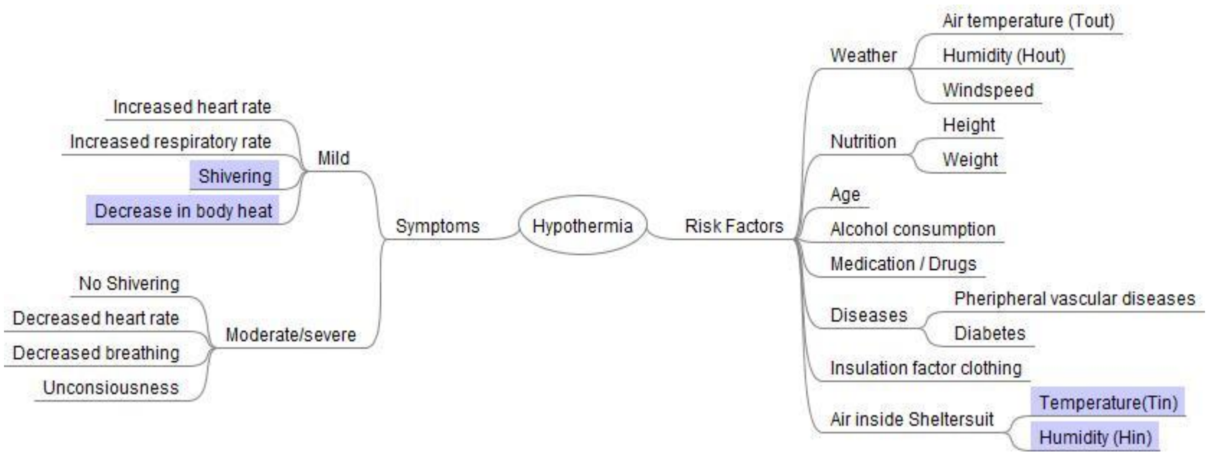

Figure 26: Symptoms and risk factors of hypothermia used in concept 3

In figure 26 the symptoms and risk factors that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.3. This concept will use vibration sensors to monitor the movement of the user, and especially the shivering movement. It is assumed that shivering can be separated from other movements, because it is a soft, repetitive movement. Shivering is a reaction of the body to produce more heat. Shivering for a short time is normal if you enter a colder environment and the body need to adjust. However, when this shivering happens for a longer duration, it can be a symptom of mild hypothermia. This shivering and the duration of the shivering can be measured and used to determine if the user has a risk of getting hypothermia. The motion sensors are located at the shoulders and on the arms, see figure 27, because it is assumed that there the respiratory movements are less present. Other movements can be present at these points, but these are often not soft, repetitive movements.

To give a better estimation if the movements are due to shivering, the Tin/Hin are measured with a temperature/humidity sensor. Tin is related to the body heat production and Tin and Hin both influence the speed in which heat is transported from the body to the surrounding air. If the movements are due to physical activity, it is likely that Tin is high, because of the increased body heat production due to physical activity. Besides, a high Tin, indicates that the body is capable of producing enough heat, making it unlikely that the movements are due to hypothermia. However, if Tin is low and Hin is high, it is possible that the movements are indeed due to shivering.

To know if the Sheltersuit is worn by the user at the moment, a button on the inside of the jacket needs to be pressed manually to activate/deactivate the Sheltersuit.

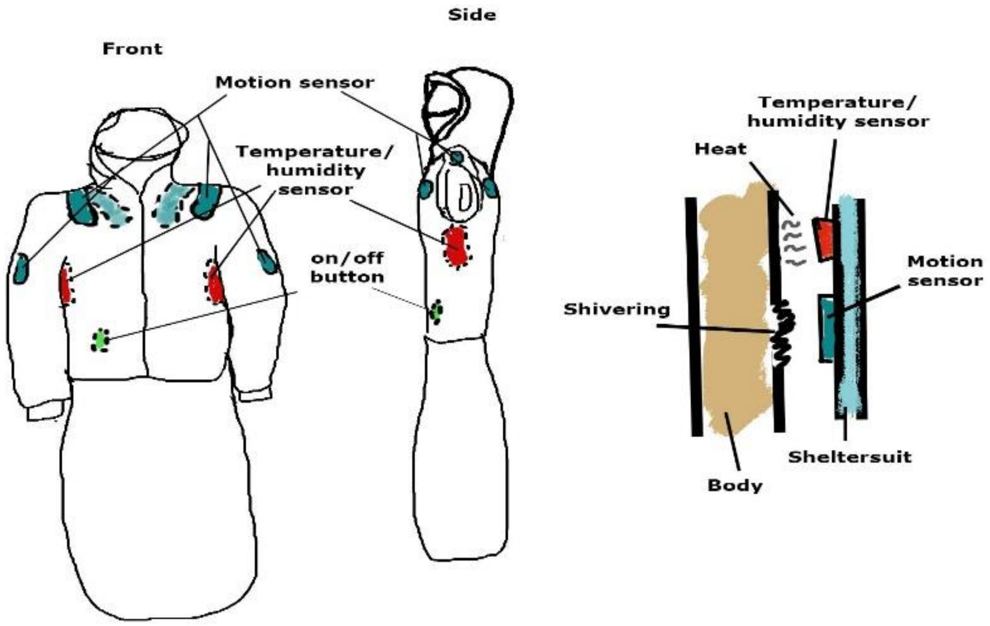

Figure 27: Placement sensors and variables that are measured in concept 3 and 4

3.6.1.4. Concept 4

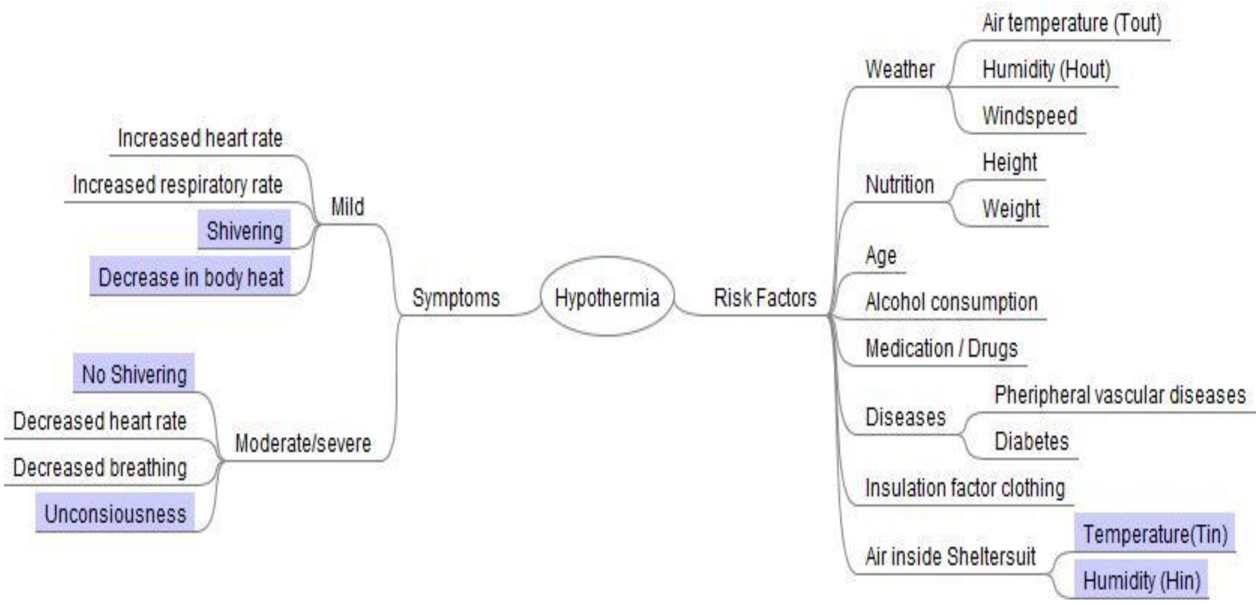

Figure 28: Symptoms and risk factors of hypothermia used in concept 4

In figure 28 the symptoms and risk factors that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.4. This concept is similar to concept 3, but it uses a symptom of later stages of hypothermia, namely unconsciousness. The same as in concept 3, the Sheltersuit measures the shivering and the Tin/Hin to estimate the risk of getting/having hypothermia. Only, instead of warning at this point, it will monitor if the user is still moving after the shivering stops. When the stopping of shivering is measured, the Sheltersuit will monitor for a while if the user will still move or not. Normally, if a person does not have hypothermia, the person will move ones in a while, even when sleeping. However, one of the symptoms for later stages of hypothermia is unconsciousness. If this happens, the user will not move anymore. So, when the sensors detect that the user was shivering and then detect that the user is not shivering anymore, but keeps moving, it assumes that nothing is wrong. However, when the sensors detect that, after the shivering stops, the user is at some point not moving anymore for a while, it can assume that something is wrong.

This detection of 'not moving' does not have to be immediately after the shivering stops, because the user does not have to be already unconscious at that point. However, when the state of hypothermia becomes worse, the movements do stop at some point. To be certain, when no movement is detected for a while, the Sheltersuit will start vibrating. If nothing is wrong, this vibration will prompt some kind of response in the user, making them move, which will then stop the vibration. If the user is unconscious however, there will be no response to this vibration. This can be an indication that something might be wrong. The vibration will be places in the top of the hood, see figure 29. At the hood there is a small chance that the vibration is muffled and on the top it is not uncomfortable while wearing the hood.

The data of the shivering and the Tin/Hin that is measured can give an indication if the stopping of movements can be due to hypothermia. If a person is only unconscious because of e.g. alcohol intoxication, no shivering or low Tin is detected. However, if it is indeed due to hypothermia, shivering and a low Tin is measured. The place of the sensors is the same as in concept 3, see figure 27.

To know if the Sheltersuit is worn by the user at the moment, a button on the inside of the jacket needs to be pressed manually to activate/deactivate the Sheltersuit.

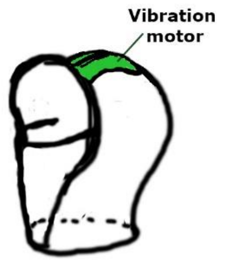

Figure 29: Place of the vibration motors in the hood of the Sheltersuit

3.6.1.5. Concept 5

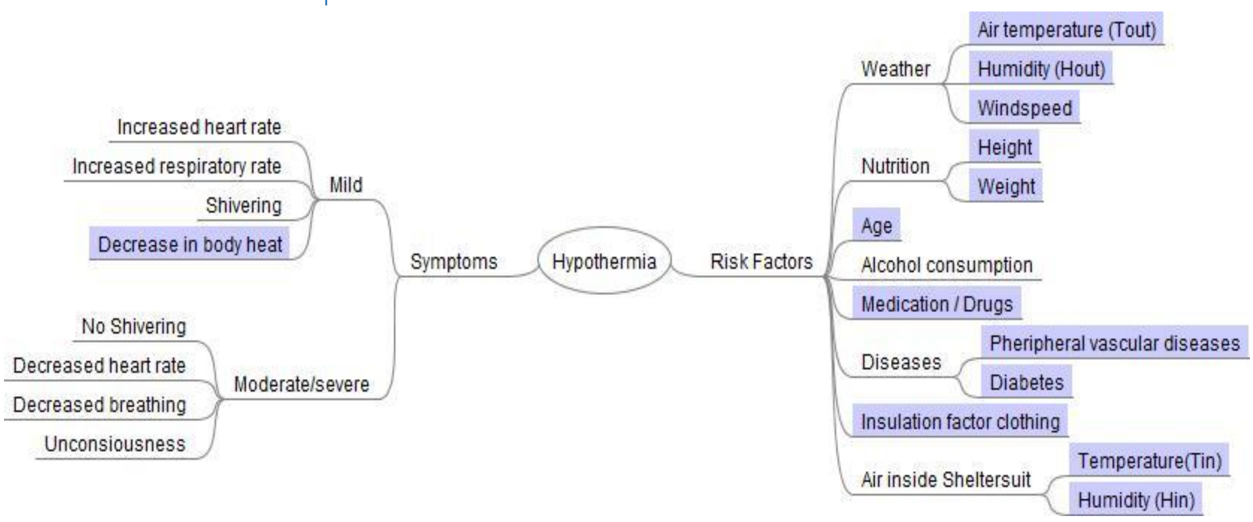

Figure 30: Symptoms and risk factors of hypothermia used in concept 5

In figure 30 the symptoms and risk factors that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.5. There are some risk factors for hypothermia that cannot be measured easily by the Sheltersuit, namely: age, height, weight, medication use, diseases or the amount of clothing the user is wearing, under cold circumstances, besides the Sheltersuit. These risk factors however can be useful when analysing what the risk of getting hypothermia is for a certain user. So, to know this data, the user is asked to fill it in, using an app. This data is then send to the Sheltersuit. The users are, depending on the data they fill in, divided over groups, each with their own risk level of getting hypothermia. For example, the group with a low risk level will be notified later that there is a risk of getting hypothermia then the group with a high risk level. The mobile phone, with which the data is collected, does not have to be linked to the Sheltersuit all times, therefore any mobile phone can be used to enter this data, making it also possible to use for people that do not own a mobile phone themselves. However, the data has to be kept up to date at a regular basis.

Knowing this data however is not enough to estimate if there is a risk of getting hypothermia at a certain moment. Therefore also the Tout/Hout, windspeed and the Tin/Hin are measured using temperature/humidity sensors and an anemometer based on the ‘hot-wire’ technique (a technique that makes it possible to measure wind speed without moving parts). The sensors are placed on the shoulders, because this part is not muffled that often, see figure 31. As explained in chapter 2, Tout, Hout and wind speed are important risk factors for getting hypothermia. They influence how fast the heat inside the Sheltersuit is transported to the outside air. Low Tout and high Hout or winds speed increases the transportation. Tin and Hin are also important risk factors, because they influence how fast the body heat is transported to the air inside the Sheltersuit.

However, Tin can also be used as an estimation of the body heat production. Tin depends on these factors: Hin, Tout, Hout, wind speed. But Tin also depends on the heat the body is producing. Monitoring Hin, Tout, Hout and the wind speed makes it possible to estimate if a decrease in Tin is due to a decrease/increase in one of these variables or due to a decrease in the body heat production. This latter can be an indication that the user is not capable anymore of producing enough heat to keep warm and therefore can be an indication that the user is suffering from hypothermia.

At which values the Sheltersuit determines that there is a risk of getting hypothermia depends on the group the user was put in. So a group with a high risk of getting hypothermia will be warned even when Tin is not that low, for not so long. However, someone that has a low risk of getting hypothermia will only be warned if Tin is already decreased to a lower value or Tin is low for a longer time.

To know if the Sheltersuit is worn at the moment, the difference between Tin and Tout is looked at. When Tin is higher than Tout, it assumes that the increase of temperature is due to body heat and that the Sheltersuit is worn at that moment.

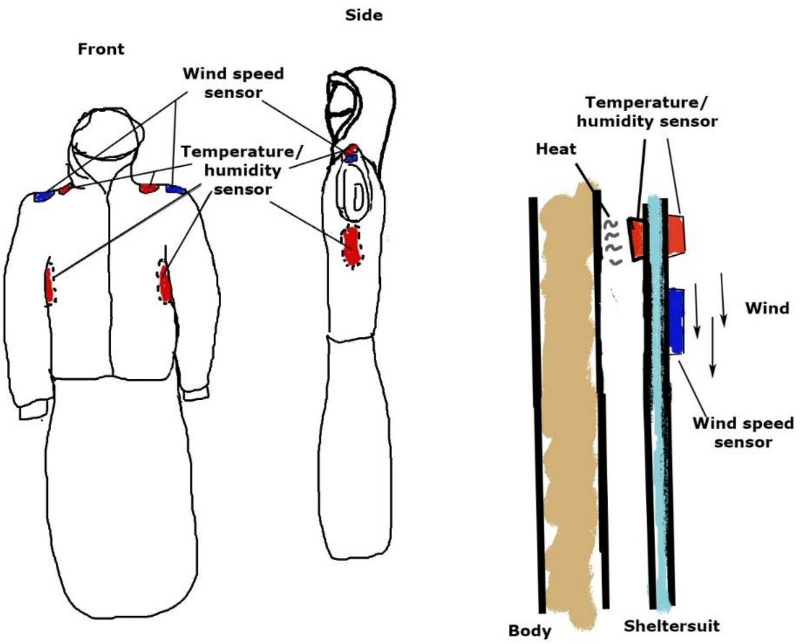

Figure 31: Placement sensors and variables that are measured in concept 5

3.6.2. Notification system

When the Sheltersuit has measured that there is a risk of getting hypothermia, the user need to be notified. However, it can be that the user is not capable anymore to respond to this notification. That is why also options are investigated that involve contacting other people that can help the user. In the concepts two types of 'other people' are used: passersby, and contact persons/aid organisations that are registered by the user.

Figure 32 shows a mind map of all the possible methods, that could be thought of, that can be used when notifying the user, contact person(s) or passersby. Not all these methods are useful for the Sheltersuit. In the concepts below, the ones that are useful are described.

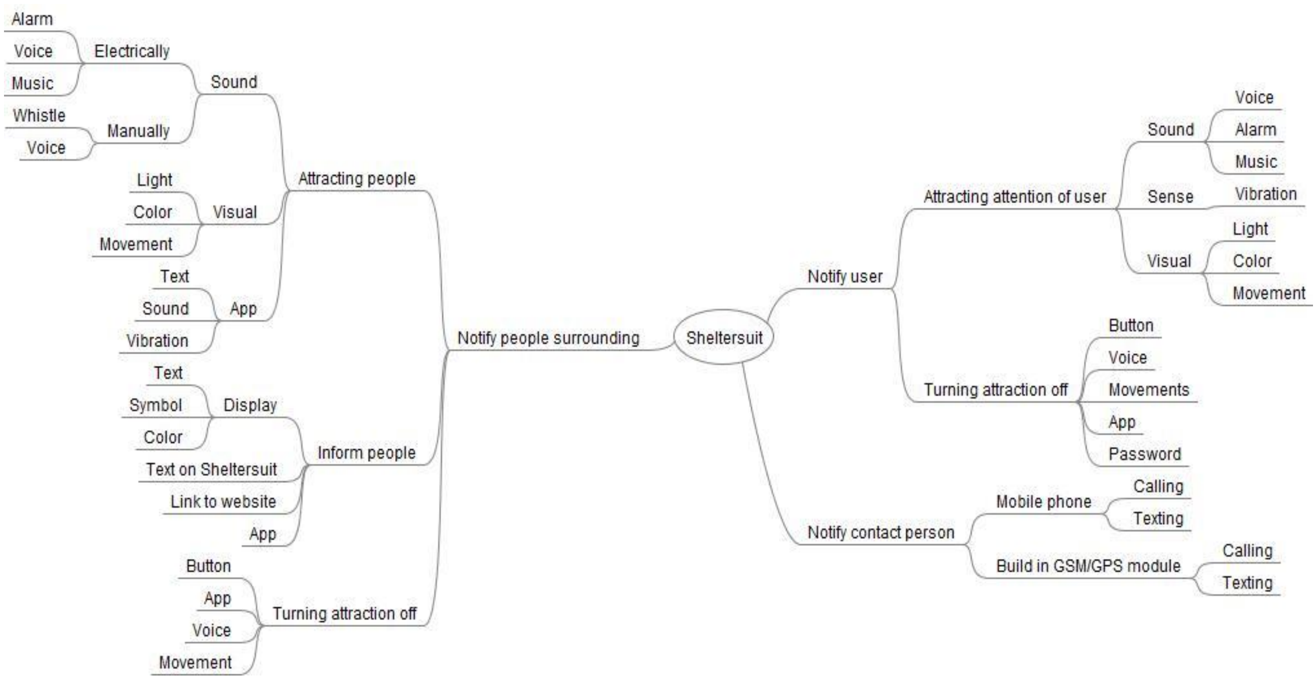

Figure 32: Overview of all the possible methods, that could be thought of, that can be used when notifying the user, contact person(s) or passersby.

3.6.2.1. Concept 6

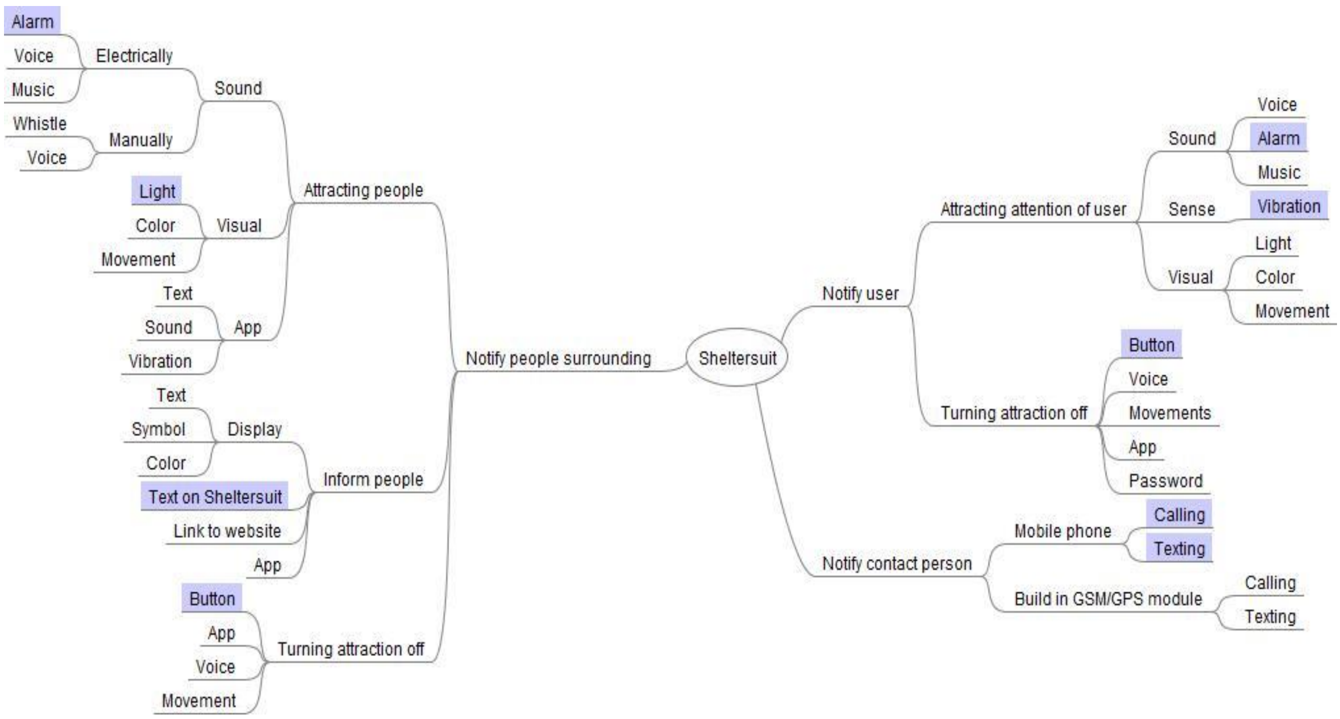

Figure 33: The methods used in concept 6

In figure 33 an overview of the methods that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.6. After the Sheltersuit has monitored that there is a risk of getting hypothermia, first the user themselves is notified. A soft vibration starts. If the user does not respond, also a soft beeping sound starts. The vibration is done first, because it is more discrete. To be sure the user can feel and hear the vibration/sound, both are placed in the hood of the Sheltersuit, because it is assumed that at this place the vibration/sound has a lesser possibility of being muffled. The actuators are placed at the top of the hood, where they do not be in the way while sleeping, see figure 34.

The user has to respond to this notification, by pushing a button to stop the vibration and sound. When the measured values do not change and after a certain amount of time there is still a risk of getting hypothermia, the sound/vibration will start again and the user has to respond to this again by pushing the button. If the notification is send three times in a short time period, the envisioned system assumes that the user is not capable in changing their situation themselves and the Sheltersuit will start to contact someone else. The user can opt out of this function by changing the settings. By default the user is opt in.

If the user does not respond or if the situation does not change after three times of warning, and this function is turned on, the Sheltersuit will search for a connected mobile phone. If this phone is found, the contact person is called, using a pre-programmed voice message. When the contact person has heard the message, also a text is send to the contact person with the location of the user obtained by the gps function on the mobile phone, if there is still enough money for texting left. When the first contact person on the list does not pick up the phone, and there are more contact persons, the next person is called. Calling has an advantage over texting, because it is immediately clear if the contact person has gotten the message.

If no connected mobile phone is found, or if the function is turned off, the Sheltersuit will try to attract and warn passersby. A loud sound and lights around the arms and chest are used to attract passersby. Text on the Sheltersuit, near the lights, will tell the passerby that if the lights are blinking and the alarm rings, it means that the user is at risk of having hypothermia and the emergency number needs to be called. A button needs to be pressed to turn the alarm off. The lights keep blinking for a while after pressing the button, and then are turned off automatically. See figure 34 for the placements of all the components. The user can opt out of the function that is attracting passersby, by changing the settings. By default this function is turned on and the user is opted in.

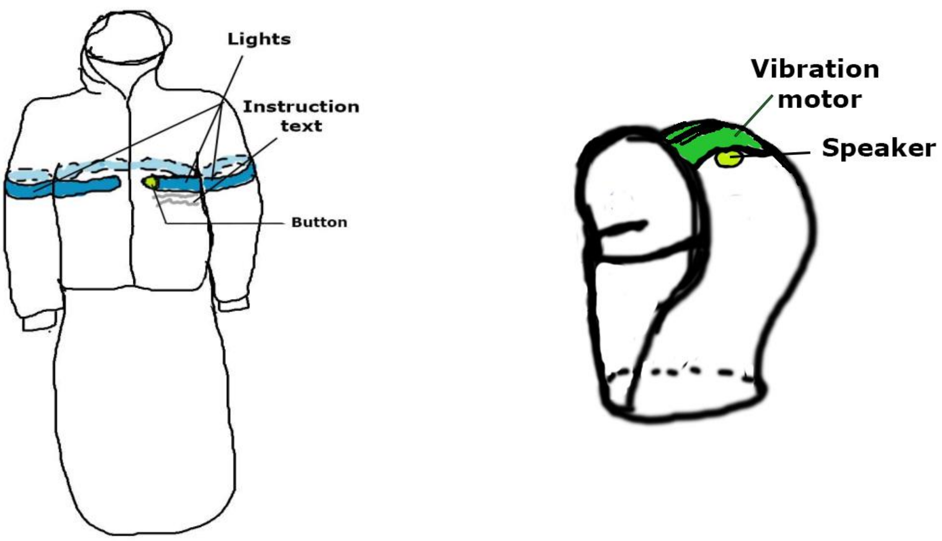

Figure 34: Place lights, instruction text, vibration motor and speaker on the Sheltersuit, concept 6

3.6.2.2. Concept 7

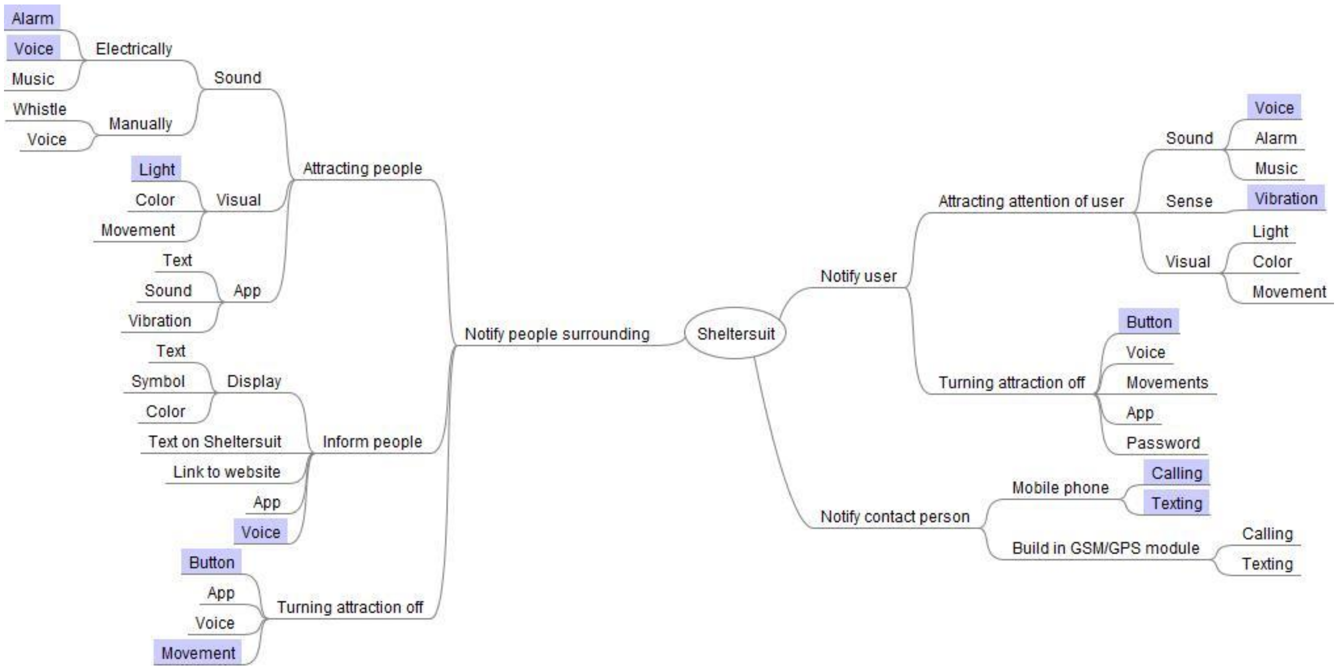

Figure 35: The methods used in concept 7

In figure 35 an overview of the methods that are used in this concept can be found. A schematic overview of this concept can be found in Appendix A, figure A.7. After the Sheltersuit has determined that there is a risk of getting hypothermia, first the user is notified. A soft vibration starts. In between the vibration, a voice tells the user that there is a risk of getting hypothermia and that action is needed. To be sure the user can feel and hear the vibration/voice, both are placed in the hood of the Sheltersuit, because it is assumed that at this place the vibration/sound has a lesser possibility of being muffled. The components are placed at the top of the hood, where they do not be in the way while sleeping, see figure 34.

The user has to respond to this notification, by pushing a button to stop the vibration and voice. This is the same as in concept 6. When the measured values do not change and after a certain amount of time there is still a risk of getting hypothermia, the sound/vibration will start again and the user has to respond to this again by pushing the button. If the notification is send three times in a short time period, the envisioned system assumes that the user is not capable in changing their situation themselves and the Sheltersuit will start to contact someone else. The user can opt out of this function by changing the settings. By default the user is opt in.

If the user does not respond or if the situation does not change after three times of warning, and this function is turned on, the Sheltersuit will try to attract and warn passersby. A loud sound and lights around the arms and chest are used to attract the passerby. This is the same as in concept 6. However, in this concept, motion sensors are used to detect if someone is close by, see figure 36. If this is detected, the loud sound will stop and a pre-programmed voice will tell the person that the user of the Sheltersuit is at risk of getting hypothermia and needs help. Using a voice makes it clear for the person what the problem is and how they can help. Knowing how to help and being talked to personally can reduce the risk of the bystander effect [102, 103]. The voice also tells the person that they have to press a button to 'tell' the Sheltersuit that they are willing to help. If this is done, the Sheltersuit will not start the loud sound again for a certain amount of time. However, if after this time the situation is not changed, which means that the monitoring part still measures a risk of getting hypothermia, the Sheltersuit will start again with attracting and warning passersby. If no movements are detected anymore, and the button was not pressed, the loud sound will start again immediately. The user can opt out of the function that is attracting passersby by changing the settings. By default the user is opted in.

When the Sheltersuit is trying to attract passersby for a certain amount of time, but no one has pressed the button, then the Sheltersuit will start to search for a connected mobile phone. If this phone is found, the contact person is called, using a pre-programmed voice message. When the contact person has heard the message, also a text is send to the contact person with the location of the user obtained by the GPS function on the mobile phone, if there is still enough money for texting left. When the first contact person on the list does not pick up the phone, and there are more contact persons, the next person is called. Calling has an advantage over texting, because it is immediately clear if the contact person has received the message. When no contact person can be reached, the Sheltersuit tries again to attract passersby. The user can opt out of the function that is contacting a contact person by changing the settings. By default the user is opted in.

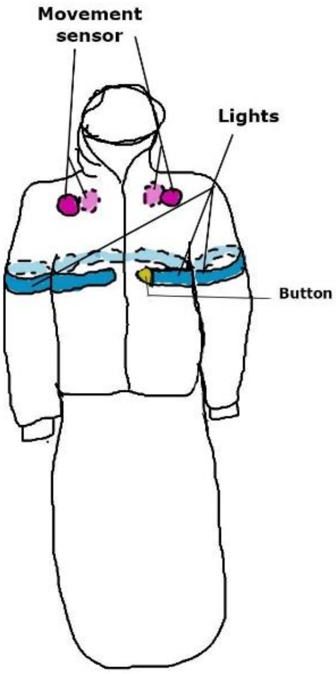

Figure 36: Place lights and movement sensors, concept 2

3.6.2.3. Concept 8

This concept is an addition to concept 6 and 7. Both concept 6 and 7 only start to notify the user when the Sheltersuit has detected a certain risk of getting hypothermia. However, before this, the Sheltersuit has already detected that the risk of getting hypothermia increases. This risk increase can also be shown to the user. The colour of a LED is used to indicate what the risk of getting hypothermia is, see figure 37. Because the user has to see the LED, it is placed on the front of the Sheltersuit. To save power, only one LED is used and this LED is blinking very slowly, only lighting up every minute or so for a couple of seconds.

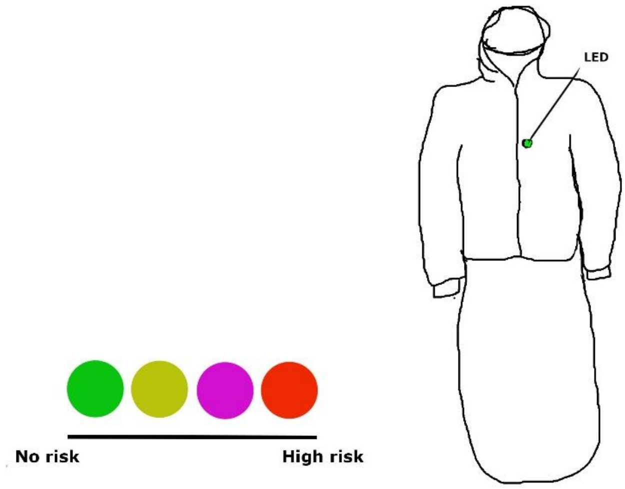

Figure 37: LED color shows increase risk of getting hypothermia. The LED is placed on the front of the jacket

3.6.2.4. Concept 9

This concept is also an addition to concept 6 and 7. When the user is notified that they are having a risk of getting hypothermia, the Sheltersuit will already search for a connected mobile phone. If this mobile phone is found, an alarm on the mobile phone will also go off and the user is asked, on the mobile phone, if they want to call or text a contact person, see figure 38. The user has to do the calling or texting themselves. When no mobile phone is found, this function is not operational.

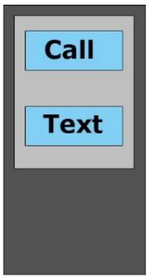

Figure 38: User is asked if they want to call or text the contact person

3.6.2.5. Concept 10

This concept is also an addition to concept 6 and 7. People can download an app and if the user of the Sheltersuit does not respond to the notification of the Sheltersuit, the Sheltersuit can search if a user of the app is close by. If this is the case, the Sheltersuit can notify this person via this app that the user of the Sheltersuit needs help. Besides this, the app user can give permission that the Sheltersuit is using their phone to call the contact person(s) of the Sheltersuit user if no other mobile phone is available.

3.6.2.6. Concept 11

This concept is an addition to concept 6. Besides having text on the Sheltersuit, there is also a QR code placed under the text that links to a website with more information what the helping person can do best at that moment, see figure 39.

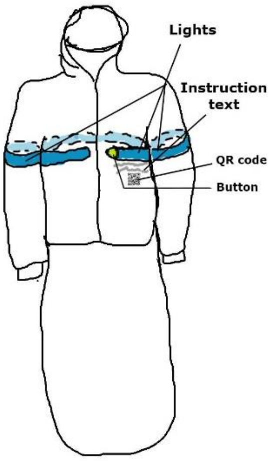

Figure 39: QR code can be used to tell passersby what they need to do. It is placed near the info text on the Sheltersuit

3.6.2.7. Concept 12

This concept is an addition to concept 6 or 7. Instead of using only a mobile phone, also a build in gsm/gps module is implemented as a back-up for the mobile phone, see figure 40. The mobile phone is the first choice of use when contacting the contact person(s), because this one is also used for all other kinds of things and is therefore not reliable as a back-up. The gsm/GPS module in the Sheltersuit will only be used when the user has a risk of getting hypothermia and the mobile phone cannot be used. It is therefore more likely that the gsm/GPS has enough money to send a text. Beside this, the Sheltersuit does have power at that moment, because otherwise it could not detect the risk of getting hypothermia or notify the user.

Figure 40: gsm/gps module can be used instead or together with a mobile phone

3.6.3. Choosing final concept and additional requirements

Based on a meeting with the client, monitoring concept 2 and 3 where chosen as the most promising. These concepts focus on heart rate and respiratory rate (concept 2) and on shivering (concept 3). Both concepts also look at the temperature and humidity inside the Sheltersuit. To get to know if the data analysis of these concepts are feasible, an interview was done with Oresti Banos, an expert in biomedical signal analysis from the University of Twente [104]. He assumes that measuring heart rate without skin contact can become quite challenging. A requirement is that the sensor has to be placed in the Sheltersuit, instead of on the skin of the user, and he assumes that the heart rate signal will disappear in all the noise that will be present due to other movements of the Sheltersuit. The same goes for measuring the respiratory rate, although this signal will probably be better measurable because the movement of breathing is bigger. However, shivering is probably the most feasible to measure, because it is quite a distinctive movement. It was therefore decided that monitoring concept 3 is the most feasible, which consist of measuring shivering and the temperature and humidity inside the Sheltersuit.

While discussing the concepts, one other requirement became clear, namely that all components of the system must be easily integrated in the Sheltersuit. The idea at this moment is that a belt is made with all the components on it. This belt can then easily be sawn into the Sheltersuit. Requirements, based on the chosen monitoring concept, are added to the preliminary requirement list and all the additional requirements can be found in table 4.

Because no interviews have been conducted with the homeless people, and their opinion and preferences is important for the notification system, the final notification system is not determined at this moment. However, to have some kind of notification system in the end prototype, an audio notification system will be implemented. The reason to choose audio is because audio can also be heard when the user is sleeping. Furthermore, audio can be changed in volume, duration and frequency, making it possible to represent different risk levels for getting hypothermia. Therefore audio in this stage looked like a suitable notification. Audio is part of concept 6.

Table 4: Additional requirements

Functional requirements	Non-functional requirements
MUST	
The system must detect when there is a risk of getting hypothermia	The system must be integrated in the Sheltersuit
The system must detect when the user is shivering	The components of the system must be placed on a belt, which can be easily sawn into the Sheltersuit
The system must measure the duration of the shivering	The system must be wearable
The system must measure the temperature inside the Sheltersuit (Tin)	The system must not hinder the user in their activities
The system must measure the humidity inside the Sheltersuit (Hin)	The system must be usable with low temperatures
The system must base the risk of getting hypothermia on the Tin, Hin, shivering, sensitivity level of the system and duration of shivering	The system must be usable in all weather conditions
The system must notify the user if there is a risk of getting hypothermia	The system must be low cost
The system must be usable without other devices (such as a mobile phone)	
SHOULD	
	The system should be energy efficient
	The system should have different settings for the notification that can be personalised
COULD	
The system could send a notification to a contact person if the user does not respond to the notification for three times and if the user is opted in for this function	
The system could notify passersby if the user does not respond to the notification for three times and if the user is opted in for this function	
WON'T	
The system will not, on a clinical level, predict if the user gets hypothermia	The sensors of the system will not be placed directly on the skin of the user

4. Specification

The specification phase is the second phase of the 'Creative Technology Design process'. The ideation phase ended with a specific product idea and the goal of the specification phase is to specify and describe the different functionalities this envisioned system and its subsystems will have. Furthermore, additional requirements are obtained. A functional system architecture is used to describe the overall system, the subsystems and the interaction between the subsystems.

4.1. Functional system architecture

The system is described using decomposition, going from a 'black-box' view of the total system in level 0, to a more detailed description of the subsystems in level 1 and level 2.

4.1.1. Level 0

This level gives a 'black-box' view of the system. As can be seen in figure 41, the system consist of the 'hypothermia detection and notification system' (HDNS). The signals that go into the HDNS are the temperature (Tin) and humidity (Hin) inside the Sheltersuit and the movements the Sheltersuit makes due to movements of the user. Beside these signals, also the time is an input and the sensitivity level. The sensitivity level is how long the user has to shiver before a risk of hypothermia is detected and this level is set manually by the user. Based on the input values, the HDNS determines if audio should be generated, which will then come out of the HDNS.

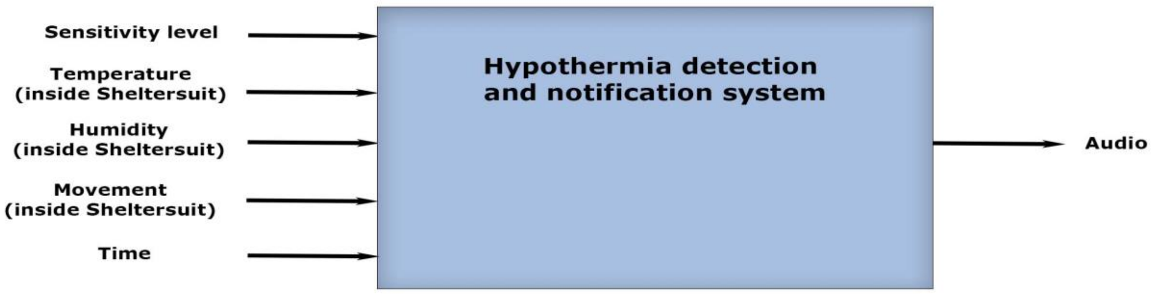

Figure 41: Level 0, the 'black-box' view of the system.

4.1.2. Level 1

Zooming in on the black box, different functionalities of the HDNS can be distinguished, see figure 42. The HDNS needs to sense the Tin and Hin. These functions are captured in the functions Temperature sensing and Humidity sensing. Because the Hin depends on the temperature of the air, the measured temperature is also an input value of the 'Humidity sensing' function. Beside the Tin and Hin the HDNS has to detect when the user inside the Sheltersuit is moving and if these movements look like shivering movements of the user. This is captured with the function Shivering detection. The temperature, humidity, shivering data, the sensitivity level of the system and time need to be processed to detect if there is a risk of getting hypothermia. This is done in the 'Hypothermia risk detection' function. This function will then generate a risk level. Based on this risk level the 'Feedback generation' function will produce the notification, in this case an audio sound, when a risk is detected.

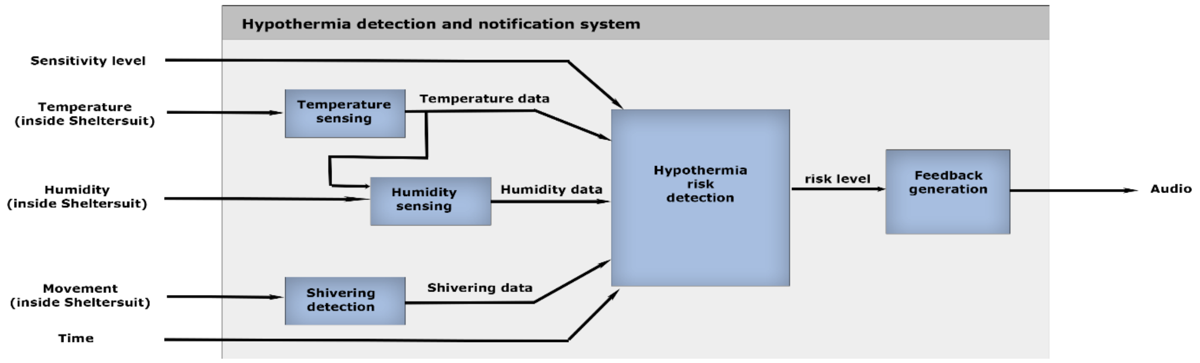

Figure 42: Different functionalities of the HDNS

4.1.3. Level 2

In this level all the different functionalities that are described in level 1 are decomposed further.

4.1.3.1. Temperature sensing

Figure 43 shows the functional block diagram of the Temperature sensing function. The Tin is sensed, then converted to voltage and after this converted to bits. These bits are then calculated back to temperature data.

Looking at the environmental conditions the envisioned system is used in, the temperature sensing function needs to work at temperatures between -20 to 50 °C, because this is around the outside temperature range in which the Sheltersuit is used, and it also needs to be able to measure this range of temperatures. Furthermore, the sensing has to be accurate and the error should not exceed the +/- 1 °C, because a drop of one degree can already have an effect on the risk of getting hypothermia.

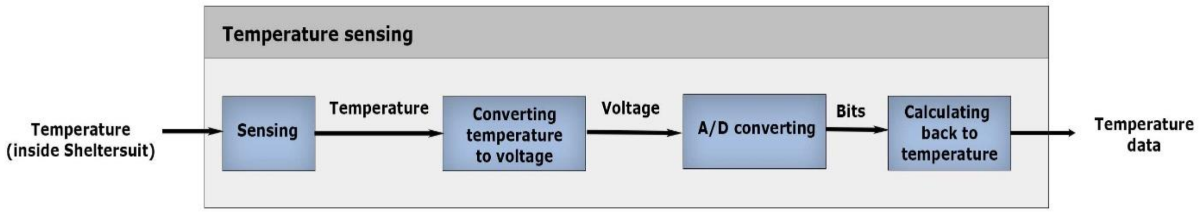

Figure 43: Functional block diagram Temperature sensing

4.1.3.2. Humidity sensing

Figure 44 shows the functional block diagram of the Humidity sensing function. The humidity sensing goes the same as the temperature sensing. The Hin is sensed and then converted to voltage, which is then converted to bits. These bits are then calculated back to humidity data. For this calculation also temperature data is needed, because the humidity level depends on the temperature of the air [105], see figure 45. When the air temperature is lower, the capacity to hold water decreases [38], see figure 46. Therefore, with the same amount of water in the air, air with a low temperature has a relative higher humidity level then air with a high temperature.

Because the humidity level is influenced by the temperature of the air, during this function the amount of heat that is generated should nog exceed 0.2 °C. Furthermore, the humidity sensing function needs to work in temperatures that can range from -20 to 50 °C and it should be able to detect the humidity level from 0% till 100%. Also, the sensing has to be accurate and the error should not exceed the +/- 4%.

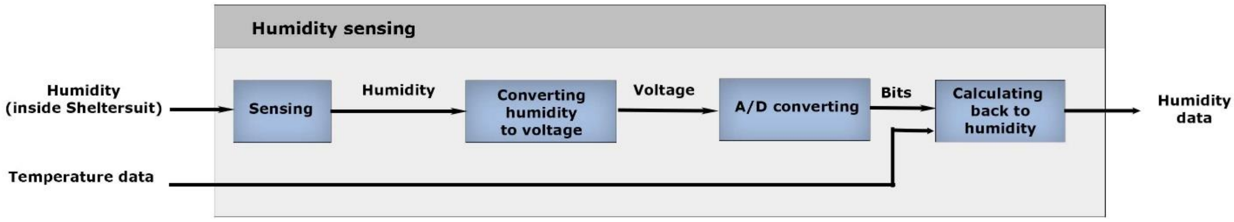

Figure 44: Functional block diagram Humidity sensing

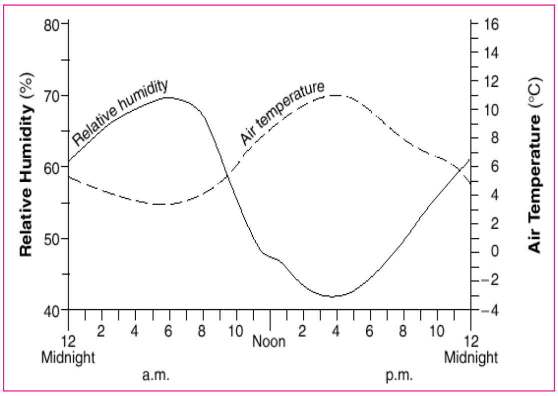

Figure 45: relation humidity level and air temperature [105]

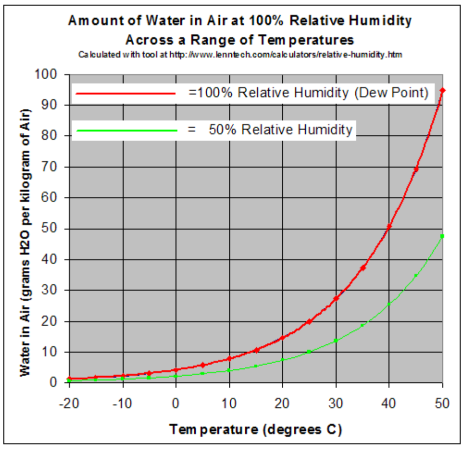

Figure 46: Amount of water in air at 100% humidity [38]

4.1.3.3. Shivering detection

Figure 47 shows the functional block diagram of the Shivering detection function. The HDNS can sense movement in a 3 dimensional space. This movement is converted to voltage, which is then converted to bits. Based on the incoming bits the G-force of the x, y and z axis are calculated. This data is then composed to one vector. To get the magnitude of this vector, the following function is used:

$$magnitude = \sqrt{x^2 + y^2 + z^2}$$

For the next section, all parameters mentioned are obtained through data analysis. How this process was done can be found in Chapter 5, section 5.3 and 5.4.

After the magnitude of the vector is obtained, this value is entered in the 'signal filtering' function, together with the value of the x-axis. Sung et al. found that shivering has a frequency of around 10 Hz [106]. Because of this, it is assumed that frequency can be used as a classification feature to determine if the user is shivering or not. Because the parameters used for the classification depend on the posture of the user, the parameters mentioned here are specified for two different postures: the 'sitting straight' posture and the 'laying on the left side straight' posture. To determine which posture the user has, the x-axis values are used. Only if the x-axis values correspond to one of the two postures, which means above 300 mg for the 'sitting straight' posture and below -200 mg for the 'laying on the left side straight' posture, the signal can be classified as shivering movements. The frequencies related to shivering for these two postures lay in the range of 8 till 11 Hz. To capture frequencies up to 11 Hz, the sample frequency should at least be 22 Hz, due to the nyquist theory[3]. To get rid of all frequencies that are not related to shivering, the signals are filtered. This is done with a 2nd order band pass Butterworth filter. The cut off frequencies for the 'sitting straight' posture are 8 and 10 Hz. The cut off frequencies for the 'laying on the left side straight' posture are 9 and 11 Hz. After this the absolute value is taken from all values, making the whole signal positive. To smoothen this signal, the envelope is extracted, using a 2nd order low pass Butterworth filter with a cut off frequency of 0.7 Hz for both postures.

After the filtering, the signal has to be classified as shivering movement or as other movements of the user. This is done with the 'signal classification' function. To classify the signal, the filtered signal is used together with a signal obtained by a rectangle windowed FFT. Due to using a windowed FFT, the signal is divided in sections of 64 values of which the FFT is calculated. If in such a section the amplitude of the filtered signal passes the threshold of 12 mg (sitting straight) or 5 mg (laying on the left side straight) and the FFT amplitude passes the threshold of 250 (sitting straight) or 125 (laying on the left side straight), then this section is classified as a movement that looks like shivering. If this happens at least 4 times in 20 seconds, the signal is classified as shivering. So the output of the Shivering detection is a boolean: shivering is detected or not.

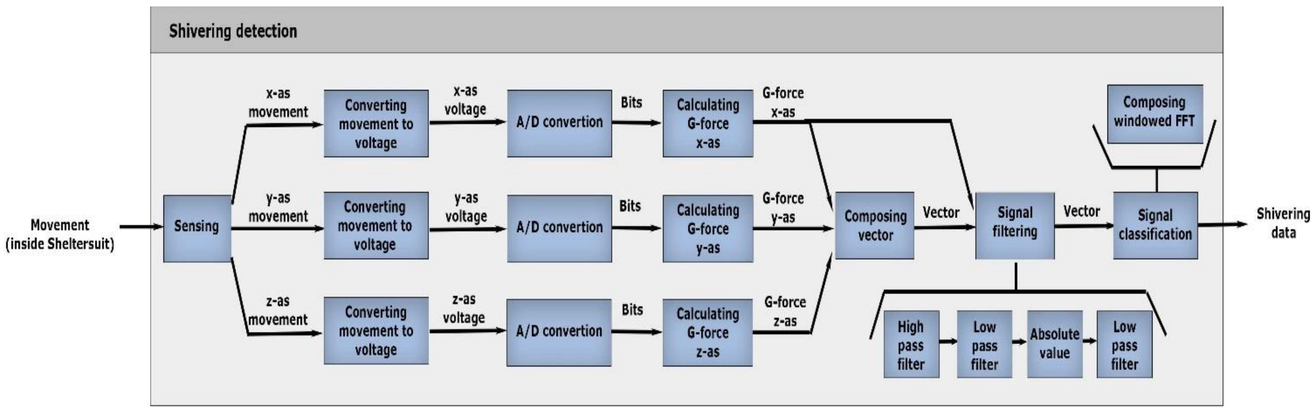

Figure 47: Functional block diagram Shivering detection

[3] To avoid aliasing, the sample frequency should at least be 2 times the maximum frequency present in the signal

4.1.3.4. Hypothermia risk detection

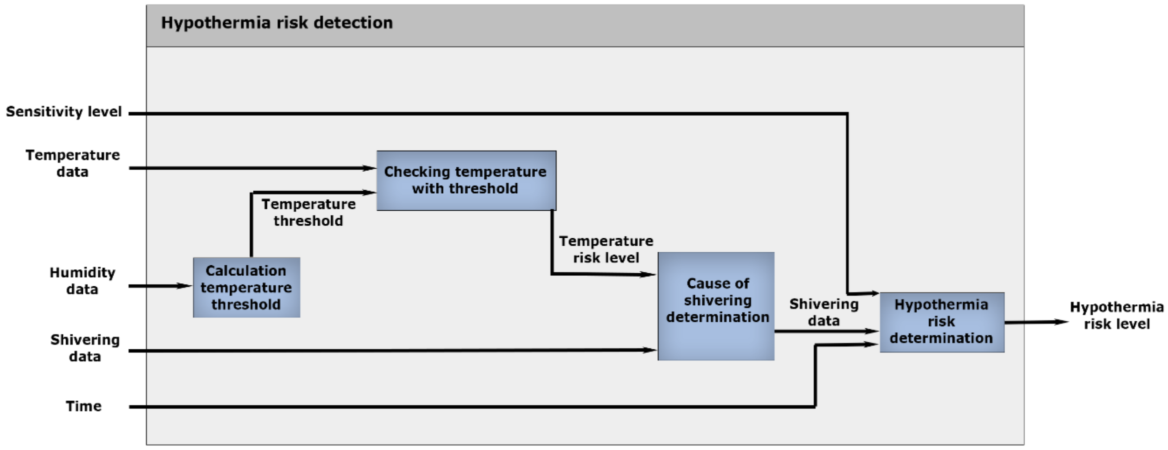

Figure 48: Functional block diagram Hypothermia risk detection

Figure 48 shows the functional block diagram of the 'Hypothermia risk detection' function. As can be seen the input is the temperature data, the humidity data, the shivering data, the sensitivity level and time.

As explained in chapter 2, the humidity level of the air influences how fast body heat can be transported from the body to its environement through evaporation and conduction [7, 32, 33]. Both processes have an opposite reponse to the humidity level in the air. Heat loss through evaporation decreases if the humidity level is high, while heat loss through conduction increases if the humidity level is high. Because heat loss through evaporation is mainly used to cool the body, this process is less present in a cold environment. Therfore, the HDNS system assumes that a high humidity level always increases the speed of heat transportation from the body to the environment.

The environmental temperature also influences how fast body heat can be transported from the body to its environment through conduction and radiation [7, 32, 33]. If the temperature is low, more heat is transported from the body to its environement.

So when combining both the influence of the temperature and the humidity level, if the temperature is low and the humidity level is high more heat is transported from the body compared to a relative high temperature and low humidity level, see figure 49.

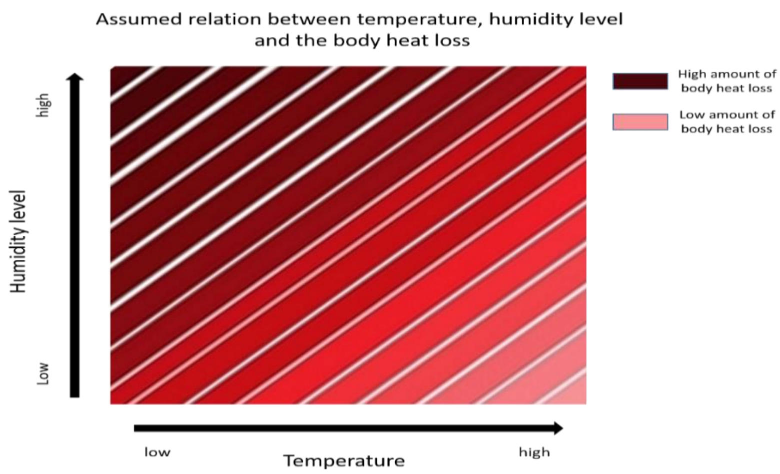

Figure 49: An assumed relation between temperature, humidity and the body heat loss.

Because both humidity level and the temperature inside the Sheltersuit influences how fast body heat is tranported from the body to its environment, the humidity data can be used to determine a temperature threshold. If the Tin comes below this threshold, the Tin and Hin conditions are such that there is a possibility that the body is losing enough heat that the shivering of the user is due to having a risk of getting hypothermia. Deteriming the temperature threshold is done with the 'calculating temperature threshold' function.

Unfortunately, no literature could be found that describes the specific relation between humidity, temperature and body heat loss for cold environments. The only relation that is found is the heat index, which is based on the evaporation process when temperatures are high [107], and is therefore not suitable for this system. Because no information could be found, only an educated guess could be made. This educated guess assumes that there is a liniear relation between humidity and temperature and that a high humidity needs to have a high temperature to have the same amount of body heat loss as in a situation where the humidity and temperature are lower.

Furthermore, the educated guess assumes that for a humidity level of 100% all temperatures inside the Sheltersuit from 32 °C and lower can result in a risk of getting hypothermia. The threshold of 32 °C is chosen because, knowing that the body temperature is around 37 °C and taking into account that there is always some heat loss to the environment, it is assumed that there will be an equilibrium around 32 °C. Using measurements with a thermal imagine camera, it was found that a temperature of 26 °C was measured with a humidity of 84%, see figure 50. So it is assumed that for a 84% humidity level the temperature should be below 26 °C to have a possibility that the combination of Hin and Tin can cause a risk of getting hypothermia. The 100%-32 °C and the 84%-26 °C pairs were then used to come up with a liniear formula that describes what the minimal temperature is (the temperature threshold) that is needed to not catogorische the shivering data as real shivering data, see figure 51. The formula is:

tempThreshold = 0,375*Hin-5,5

The measured Tin is then compared with the calculated temperature threshold and if the Tin is higher then this threshold, it is assumed that there is no risk of getting hypothermia, even if the 'shivering detection' function did detect shivering. However, when the Tin is lower then the threshold and the 'shivering detection' function did detect shivering, then it is assumed that the detected shivering is due to a risk of getting hypothermia. Determining if shivering is due to Hin and Tin values is done with the 'cause of shivering determination' function.

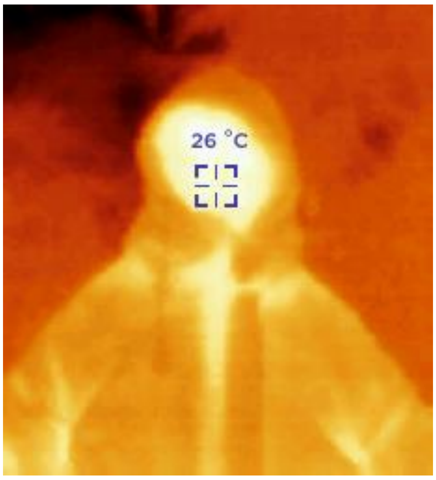

Figure 50: Thermal image made with a humidity of 84% showing a body temperature of 26 °C

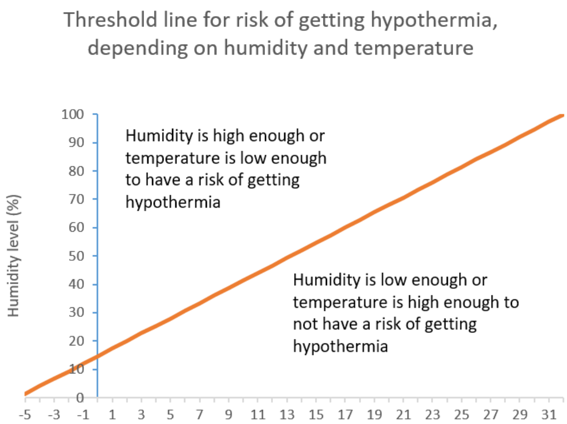

Figure 51: The assumed threshold line that can be used to determine what the temperature needs to be, based on a given humidity level, such that the shivering movement that is detected can be due to getting at a risk of having hypothermia. The formula is: tempThreshold=0.375Hin-5.5

Shivering for a short time, when Tin and Hin values are such that hypothermia can occure, does not immediately have to mean that there is a high risk of getting hypothermia. Therefore a duration can be set that determines how long the user has to shiver before the system will send a notification. This is the sensitivity of the system. Because how long someone has to shiver before there is a risk of getting hypothermia is user dependent, the user can manually set the sensitivity level beforehand. There are 7 levels: 0, 5, 10, 15, 20, 25 and 30 minutes. Zero minutes means that the system will immediately notify the user when shivering is detected, 30 minutes means that the user has to shiver for 30 minutes before a notification is send. Because no literature could be found about how long someone shiveres before hypothermia is detected, these duration values are educated guesses.

The 'hypothermia risk determination' function measures the duration of shivering and compares this with the set sensitivity level. When the duration of shivering crosses the sensitivity duration threshold, it is determined that the user has a risk of getting hypothermia. The risk level at this moment is still low. However, when the user does not respond to the notification within one minute, but they keep shivering, the risk level rises. There are 11 levels, ranging from 0, which mean there is no risk of getting hypothermia, to 10, which means that there is a very high risk of getting hypothermia, based on the fact that the user did not respond to previous notifications. This 'hypothermia risk level' is the output of the total 'hypothermia risk detection' function.

4.1.3.5. Feedback generation

The 'feedback generation' function is the only function that belongs to the notification sub system, and can be seen in figure 52. The hypothermia risk level, the output of the last 'Hypothermia risk detection' function, is used as an input for this function. Based on the hypothermia risk level the volume and the duration of the audio is determined. This is then translated to voltage and based on the voltage the audio sound is composed and an audio signal is the output of this function.

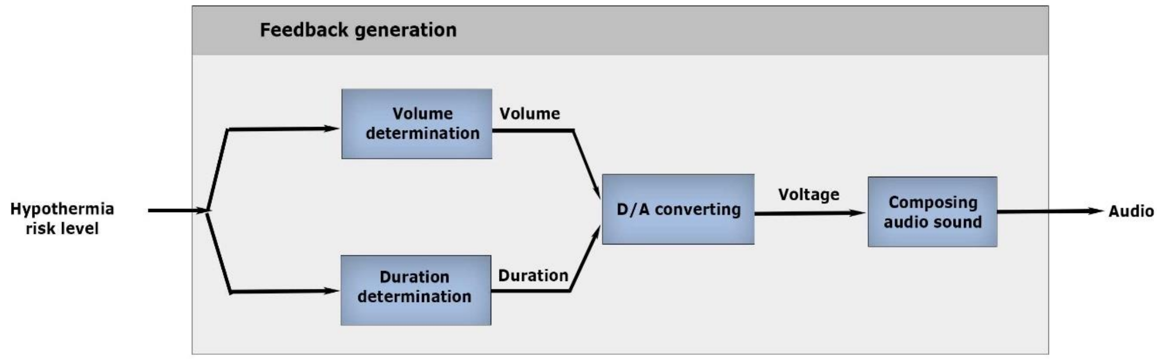

Figure 52:Functional block diagram Feedback generation.

5. Realisation

During the realisation phase a prototype is made based on the findings of the specification phase. The goal of this phase is to investigate if the shivering concept 3, the chosen monitoring concept of chapter 3, would work in reality. In this chapter first the hardware/software components that are used are described, followed by a description of how the necessary data is collected and analysed. In the end everything is put together, which results in a prototype that is ready to be evaluated.

5.1. Hardware and software

In this section the chosen hardware for the different functions of the system is listed. Furthermore, also the software that is used to control this hardware and for analysing the shivering and moving data is described.

5.1.1. Hardware

5.1.1.1. Accelerometer

To detect when the user is moving or shivering, an accelerometer is used. An accelerometer is a sensor that can detect acceleration forces. The measured force can be static or dynamic and this data can be used to determine the tilt and movement of the accelerometer [108]. Accelerometers are often used in studies to measure movements and tremor of a test person [109-111], and one study was found in which the accelerometer was used to measure shivering of the test person [106]. Although in this case the accelerometer was attached to the body of the test person, it gave positive results in using shivering as a detection for hypothermia. Because no other examples of sensors could be found that would be capable of measuring shivering without skin contact, it was decided to use the accelerometer.

The used accelerometer is the mma7361l, a three axis analog accelerometer with a selectable sensitivity of 1.5g or 6g. During this project, 1.5g was selected. This accelerometer has a temperature operating range from -40 till +85 °C, therefore it is suitable for winter conditions. See appendix B for the datasheet of this accelerometer.

5.1.1.2. Temperature and humidity sensor

To measure the temperature and humidity inside the Sheltersuit, the digital SHT15 temperature/humidity sensor is used. The reason this model is used is that it was easily accessible. However, it is a relative expensive sensor, and therefore in contrast to the requirement that the system should be as cheap as possible. For a proof of concept, this is not a problem, but for the end product, alternatives should be looked at.

The datasheet of the SHT15 can be found in appendix C. The SHT15 has a humidity level operation range from 0 till 100% and a temperature operating range from -40 °C till +123,8 °C.

Furthermore, the sensor has a temperature accuracy of +/- 0.3 °C if the environmental temperature is around 20 °C. However, the accuracy decreases with lower temperatures, going to +/- 1.5 °C accuracy if the environmental temperature is -40 °C. At -20 °C it is around +/- 1 °C and therefore accurate enough for this system. The humidity accuracy is more stable and is, in the range of 10% till 90% humidity, +/- 2%. Only below and above this range, the accuracy will decrease to +/-4%. Taking measurements with the sensor can cause self-heating of the sensor. To keep this below 0.1°C, only one measurement per second at 12 bit accuracy should be made.

5.1.1.3. Arduino

For the microcontroller an Arduino Uno is used. The Arduino Uno is used during the Creative Technology curriculum and therefore it was easily accessible and familiar to the researcher. It has analog and digital input and output pins, making it easy to connect sensors and actuators. The Arduino Uno is suitable for prototyping, however, for the final product, the microcontroller has to be sized down.

5.1.1.4. Piezo buzzer

For the notification system, a piezo buzzer is used. This buzzer can produce tones with different frequency and volume. The piezo buzzer was chosen, because it is an easy, cheap and available actuators. Because the current notification system is only a 'dummy' system, the actuator used didn't have to have advanced functions.

5.1.2. Software

The software necessary to control the hardware is programmed using the Arduino language, which is based on C/C++. For analysing the data both Matlab R2017a and Excel 2016 is used. All code used can be found in appendix D, E, H, I, J and L?

5.2. Collecting data freezer test

To investigate if the chosen monitoring concept would work, data needed to be collected. The monitoring concept works with three types of data: shivering data, temperature data from inside the Sheltersuit and the humidity data from inside the Sheltersuit. Collected data can be used to see how to distinguish between shivering data and other movements and to know how the temperature and humidity level inside the Sheltersuit will behave over time when someone is getting at risk of having hypothermia. Unfortunately, due to time limits the temperature and humidity data could not be obtained and only shivering data was collected. In this section the goals, material used and set up is described for collecting the shivering data.

5.2.1. Goals collecting shivering data

When a user of the Sheltersuit shivers, this shivering motion can be transported to the Sheltersuit, resulting in movement of the Sheltersuit. This movement of the Sheltersuit can then be measured by an accelerometer and this data can be used to determine if the user is shivering or not. For this test there are three goals:

1. To investigate if it is possible to use the movements of the Sheltersuit as an indication for when the user is shivering.
2. To investigate what the best place is to put the accelerometer sensor on the Sheltersuit
3. To investigate if the data that is obtained depends on the body posture of the user.

5.2.2. Material used

For collecting the data, the following materials are used:

- 2 MMA7361L accelerometers (sensitivity set to 1.5g), soldered to +/- 5 meter cables
- Arduino Uno (code can be found in appendix D)
- Laptop
- Sheltersuit (only jacket part)
- Walk in freezer with a temperature of -20 °C.
- Adhesive tape to attach accelerometers to clothing/Sheltersuit
- Excel 2016

5.2.3. Set up

Because it is not possible to get shivering data from a real situation, the situation needs to be emulated. This is done by using a walk in freezer with a temperature of -20 °C.

Data is collected using one test person. Two accelerometers were available and they are used to collect data. These accelerometers are soldered to five meter cables. The cables are connected to the Arduino, which is connected to a laptop. The five meter cables make it possible to leave the Arduino and laptop outside the freezer. See figure 53 for the schematics.

Four places were chosen to attach the accelerometer on the Sheltersuit: left shoulder, right side, sternum and back, see figure 54. These places were chosen because it is assumed that shivering movements will be most around the shoulders, torso and arms. However, no accelerometer is placed on the sleeves, because there is a possibility that, in cold conditions, the Sheltersuit user will pull their arms in, leaving the sleeves empty.

Sung et al. found that the shivering frequency lays around 10 Hz [106]. Therefore it is assumed that the movements of the Sheltersuit, due to shivering of the user, lay also around 10 Hz. Looking at the same study, they used a sample frequency of 50 Hz and because this can easily measure frequencies of 10 Hz, this sample frequency is taken over. The Arduino code that is used for collecting the data can be found in appendix D. The data is displayed on the serial monitor and after each test, this data is copy-pasted in an excel document.

First a control test is done. This control test is to get shivering data of the test person without a Sheltersuit. After the control test, the test person puts on the Sheltersuit and motion data of the Sheltersuit is collected under different circumstances.

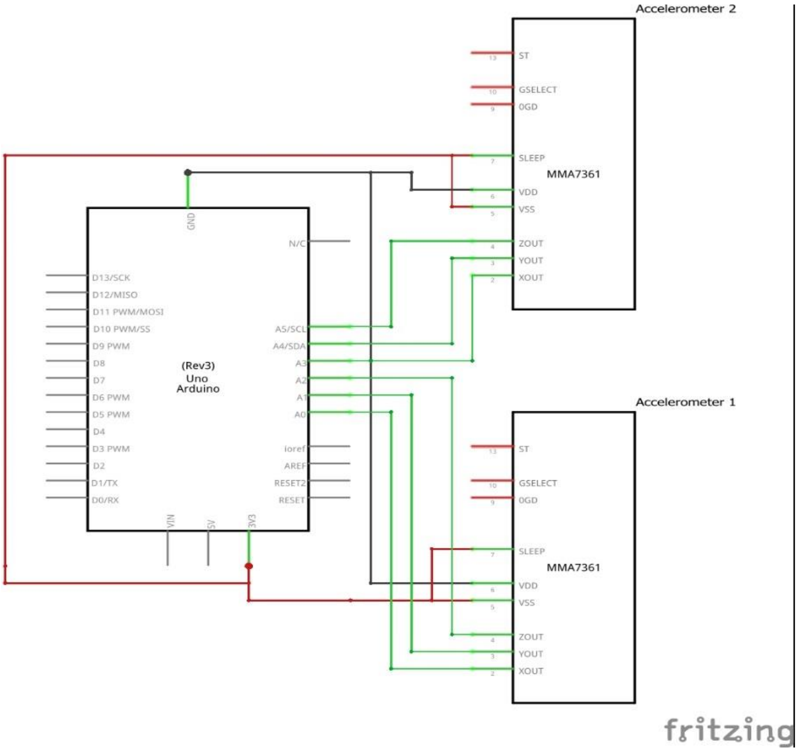

Figure 53: Schematic overview of the components used for collecting data, made in Fritzing

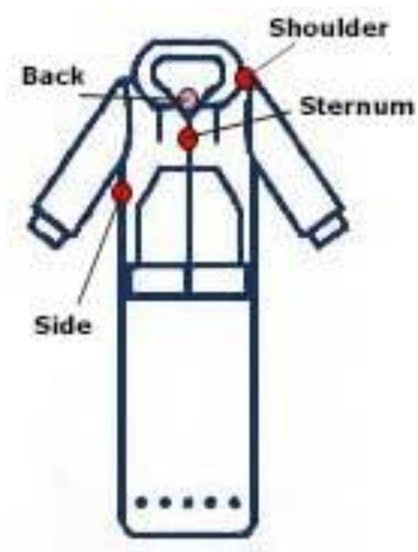

Figure 54: Places accelerometer: left shoulder, right side, sternum, back (between shoulder blades)

Control

During the control test, the test person is wearing their normal clothing, without the Sheltersuit. One accelerometer is attached to the clothing at the left shoulder, another one is attached to the right side. First data is collected for 20 seconds while standing as still as possible outside the freezer. After this, the test person goes inside the freezer and waits until shivering occurs. From this moment, data of the accelerometers is collected again for 20 seconds while the test person is shivering. After this, the accelerometers are placed on the sternum and the back and the test (outside and inside the freezer) is repeated.

Sheltersuit

During the tests with the Sheltersuit, the motion data of the Sheltersuit is collected under different circumstances. To make sure that it does not take too long before the test person is shivering, only the jacket part of the Sheltersuit is worn. The circumstances differ in body posture of the test person, see figure 55, type of movement of the test person and position of the accelerometers. See figure 56 for all the different variables tested. During each test one of these variables is changed. When the test person has to make movements, these movements consist of ordinary calm movements (e.g. moving the arms, moving the legs, shift position) while keeping the same body posture.

Figure 55: Different body postures used while collecting data

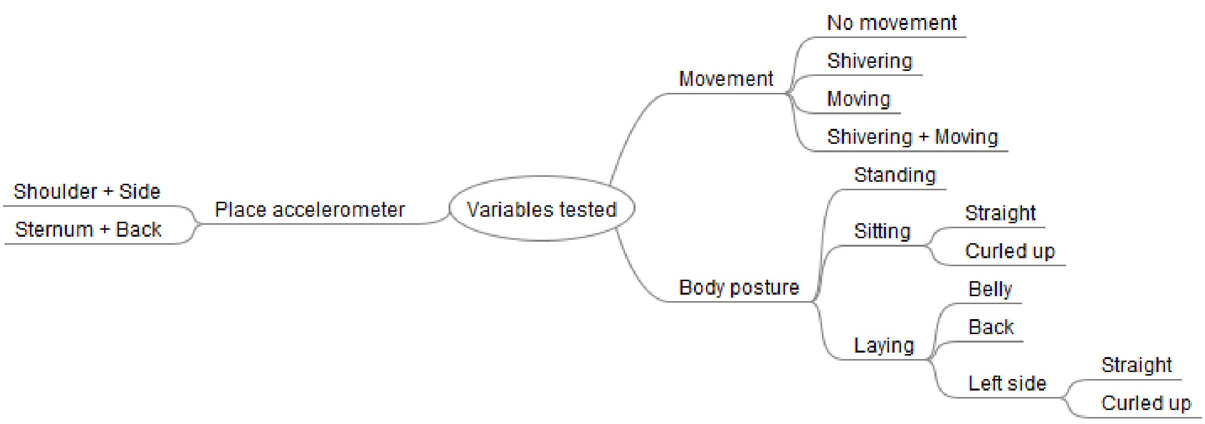

Figure 56: Variables tested

Based on the different variables, the tests in table 5 are conducted. Test 1 till 14 are first conducted outside the freezer, when the person is not shivering. For each test, data is collected for 20 seconds. When the tests are done, the person enters the freezer. When the person is shivering, test 1 till 14 are repeated. Again data is collected for 20 seconds for each test. This results in the end that each of the seven body postures has data of four types of movement: no movement, shivering, moving and shivering and moving.

When test 1 till 14 are done inside the freezer, the position of the accelerometers are changed for test 15 till 28. Test 15 till 28 are first again conducted outside the freezer, when the test person is not shivering, and are then repeated inside the freezer, when the test person is shivering.

Both times, data is collected for 20 seconds for each test. This again results in the end that each of the seven body postures has data of four types of movement.

Note:

The laptop is not charging at the moment of measuring. Having the laptop connected to a power socket can interfere with the measurements, resulting in a difference in data.

Table 5: Tests collecting data under different circumstances

Test	Position	Movement	Place accel. meter
1	Standing	No	Shoulder + side torso
2	Standing	Yes	Shoulder + side torso
3	Sitting – straight	No	Shoulder + side torso
4	Sitting – straight	Yes	Shoulder + side torso
5	Sitting – curled up	No	Shoulder + side torso
6	Sitting – curled up	Yes	Shoulder + side torso
7	Laying – belly	No	Shoulder + side torso
8	Laying – belly	Yes	Shoulder + side torso
9	Laying – back	No	Shoulder + side torso
10	Laying – back	Yes	Shoulder + side torso
11	Laying – left side, straight	No	Shoulder + side torso
12	Laying – left side, straight	Yes	Shoulder + side torso
13	Laying – left side, curled up	No	Shoulder + side torso
14	Laying – left side, curled up	Yes	Shoulder + side torso
15	Standing	No	Sternum + back
16	Standing	Yes	Sternum + back
17	Sitting – straight	No	Sternum + back
18	Sitting – straight	Yes	Sternum + back
19	Sitting – curled up	No	Sternum + back
20	Sitting – curled up	Yes	Sternum + back
21	Laying – belly	No	Sternum + back
22	Laying – belly	Yes	Sternum + back
23	Laying – back	No	Sternum + back
24	Laying – back	Yes	Sternum + back
25	Laying – left side, straight	No	Sternum + back
26	Laying – left side, straight	Yes	Sternum + back
27	Laying – left side, curled up	No	Sternum + back
28	Laying – left side, curled up	Yes	Sternum + back

5.3. Data analysis freezer test

In this section the methods used to analyse the data and the findings are described. This section focusses on three parts: the difference in data obtained by positioning the accelerometers on different places, the differences in data obtained while having different body postures and analysing the data obtained while doing different types of movements and finding a way to detect when shivering occurs.

The data was obtained from 3-axis accelerometers, meaning that it gives acceleration data of the x-axis, y-axis and z-axis. To make the dataset a bit easier to work with, the data of the x, y and z-axis are combined in a vector and the magnitude of this vector is used during the analysis. To get the magnitude of the vector the following formula is used:

$$magnitude = \sqrt{x^2 + y^2 + z^2}$$

Analysing the data and generating the graphs was done in Matlab. The Matlab code can be found in appendix E and H. The data that is analysed comes from an emulation. Therefore it is important to keep in mind that it can differ from data that is obtained in a real situation.

5.3.1. Location accelerometer

Due to time limits, only test 1 till 14, see table 5, could be conducted. This means that only data was obtained while having the accelerometer attached to the left shoulder and to the right side. To determine which location gives better data to detect shivering, the two shivering datasets, obtained by the shoulder and side accelerometer, were compared with each other for each body posture. Because the signals displayed in the time domain already gave a good view of which position of the accelerometer would be favourable, it was determined to compare the signals only in the time domain. The Matlab code to generate the graphs of the signals can be found in appendix E.

The shivering motions are indicated by the increase in amplitude of the signal, so this is the factor that is looked at while comparing both signals. The difference in offset between the signals is due to the position of the accelerometers and is not important in this case. The graphs of the shivering signals of the shoulder and side accelerometer for each body posture can be found in appendix F.

The results show that in in the case of standing, there is not a clear difference between the amplitude of both signals when there is a shiver episode and the shiver episodes are equally noticeable for both signals. However, in the case of sitting straight/curled up and laying on the belly and back the episodes of shivering are clearer to determine in the data gotten from the shoulder accelerometer. Only in the cases while laying on the left side straight, the shivering episodes were clearer to distinguish from noise in the signal obtained by the side accelerometer then from the shoulder accelerometer. This can be due to the fact that the accelerometer was placed on the shoulder that was laid on. Therefore the Sheltersuit could not move freely at that place, restricting the shivering movement of the Sheltersuit. The side accelerometer, however, was on the side that was not laid on, and had therefore room to move. Although the side accelerometer in this case does clearer show the shivering episodes, also in the data of the shoulder accelerometer the shivering episodes can be detected (after some filtering), see figure 71. In the case while laying on the side curled up, the signals of both accelerometers do not show the shivering episodes clearly.

Conclusion

Because the shivering movements were often more distinct in the data of the shoulder accelerometer, it was decided to use this data for analysing the differences in signal between shivering and other types of movements.

5.3.2. Difference in data body posture

The second goal of the test was to see if there is a difference in data when the test person has a different body posture. To answer this question, the shivering data obtained by the shoulder accelerometer, while having different body postures, was compared with each other. The data was compared both in the time and frequency domain. In the time domain, the difference in amplitude of the envelope of the shivering signal was looked at. For the frequency domain, a FFT (fast fourier transform) was used. A FFT shows which frequencies are present in the signal and with what magnitude. The frequency domain is interesting to look at because shivering is a repetitive movement with a frequency of around 10 Hz [106]. Therefore it is likely that frequency can be used as a classification feature to distinguish shivering from other common movements, because the latter will probably have a lower frequency. So, the difference in the frequencies present and their magnitude was looked at for the different body postures. The graphs of the shivering data of the shoulder accelerometer of appendix F are used to compare in the time domain. Appendix G shows the FFT of the shivering data, for all body postures, obtained by the shoulder accelerometer.

Conclusion

Looking at the signals, in both the time and frequency domain, of the different body postures, there are between certain body postures indeed some differences. In the time domain, the amplitude of the envelope and the offset can differ between signals. In the frequency domain, the frequencies that are mostly present can differ between the signals, as well as the amplitude of these frequencies. Therefore, it was determined that the data of each body posture was analysed separately, to find the optimal method, for each body posture, to distinguish between shivering and other types of movements

5.3.3. Analysis data different types of movement

5.3.3.1. Choosing body posture

The most important aspect of the monitoring system is to distinguish between shivering movements and other types of movements. To find the optimal method, the data of each body posture needed to be analysed separately. Due to time limits only the data of two different postures could be analysed. It is assumed that at the first stages of feeling cold, the user will try to keep themselves warm by laying curling up. Therefore the 'laying on the left side curled up' body posture is assumed to be the body posture most often used by the user in situations when there is a risk of getting hypothermia. Unfortunately the signal obtained while having this posture did not show clear shivering episodes, see appendix F and G. Therefore the body posture, that came closest to this posture, was looked at, which is the 'laying on the left side straight' posture. Beside this posture, the 'sitting straight' signal was chosen, because it is assumed that homeless people also sleep while sitting (based on talks with Sheltersuit Foundation). Looking at both signals of the sitting postures, the 'sitting straight' signal was more promising.

Sitting straight

Figure 57 shows the signal of all movements of the 'sitting straight' body posture. In the shivering and the shivering+moving signal the shivering episodes can be distinguished by the increase in amplitude but also because the signal is more compact at these places, indicating the presence of higher frequencies. A frequency of around 10 Hz is expected, based on literature [106]. When looking at the FFT of the signals, which can be found in figure 58, it shows indeed that both the shivering and shivering+moving signal have higher amplitudes around 10 Hz. For the shivering signal the peak lays around 8 till 11 Hz, while the shivering+moving signal has a peak around 8 till 12 Hz. The moving signal does not have a peak around 10 Hz. The frequencies of this signal are more in the range of 0 till 5 Hz.

Laying on the left side straight

Also in the 'laying on the left side straight' signal there are differences between the shivering signal and the moving signal, although these differences are less clear then in the 'sitting straight' signal. When looking closely at figure 59, the shivering episodes of the shivering and shivering+moving signal, look more compact, indicating higher frequencies. Furthermore, Both the moving signal and the shivering+moving signal show some low frequencies, which are caused probably by the movements, which are not present in the shivering signal. This can also be seen in the FFT, see figure 60. The moving signal has most frequencies in the range of 0 till 3 Hz, while the shivering signal has a peak between 8 and 12 Hz. The shivering+moving signal has some frequencies between 0 and 2 Hz, but also a small peak between 8 and 12 Hz. However, the amplitude of both the peaks of the shivering and the shivering+moving signal between 8 and 12 Hz is not large and the amplitude of the frequencies of the moving signal at this frequency range, is only a tiny bit lower, which is caused by a dip at around 10 Hz.

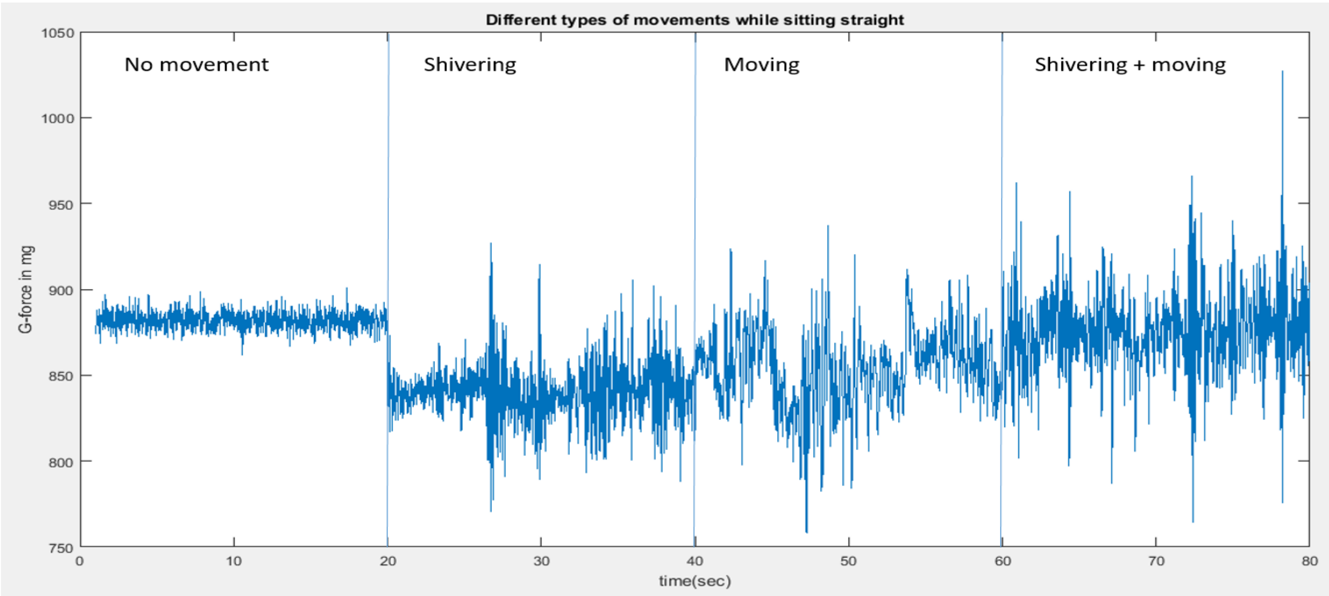

Figure 57: Accelerometer signal while sitting straight doing different types of movements

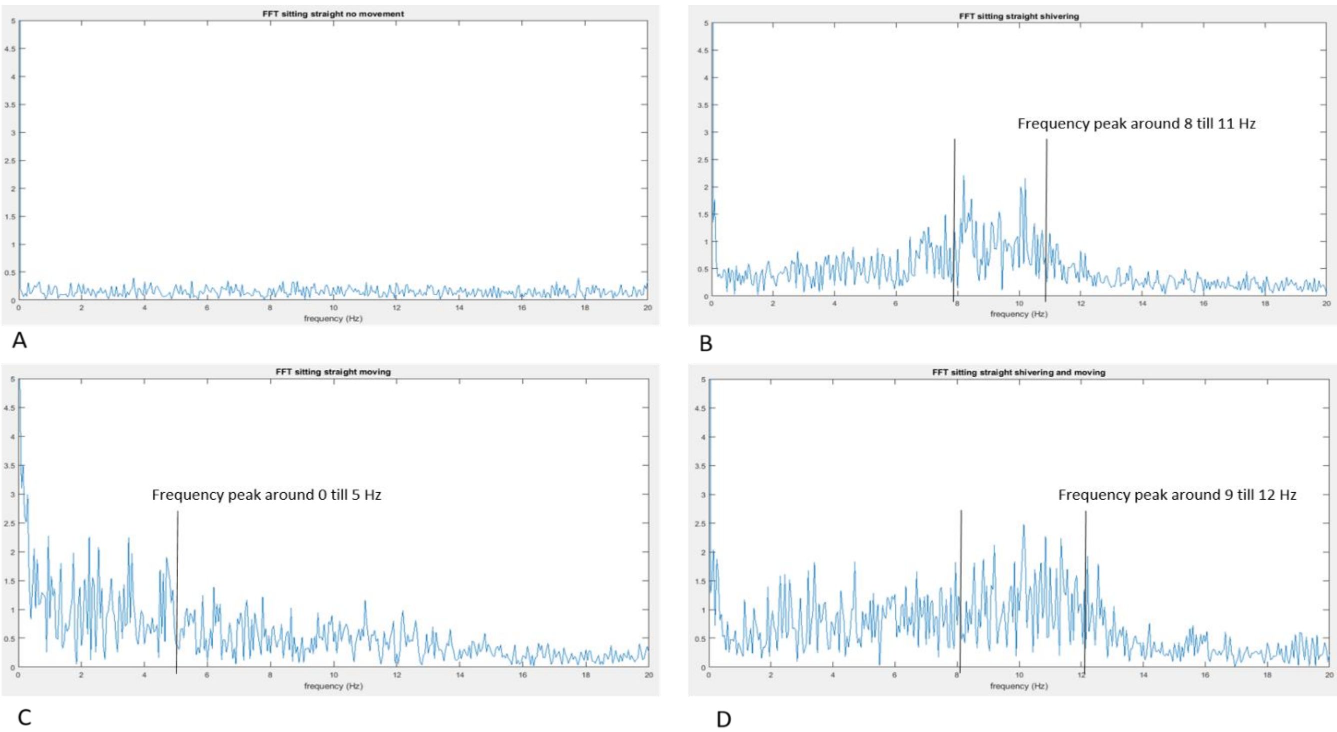

Figure 58: FFT signals of the sitting straight posture, A: no movement, B: shivering, C: moving, D: shivering+moving

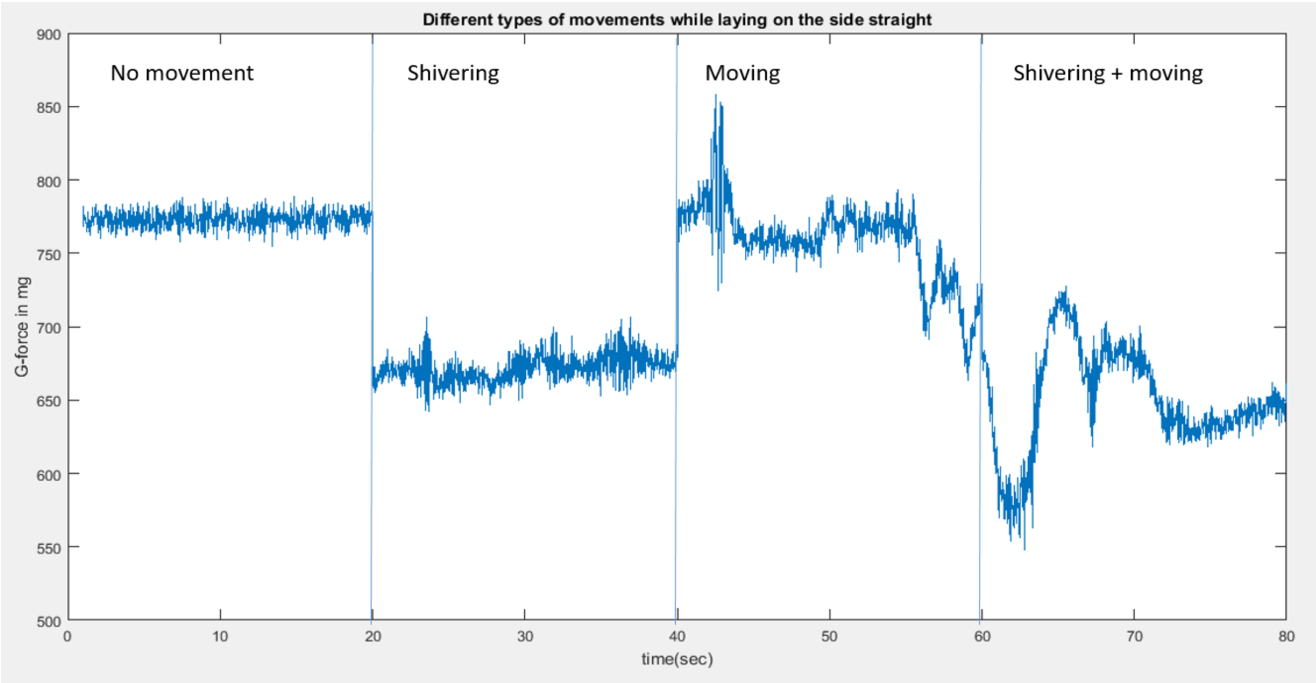

Figure 59: Accelerometer signal while laying on the left side straight doing different types of movements

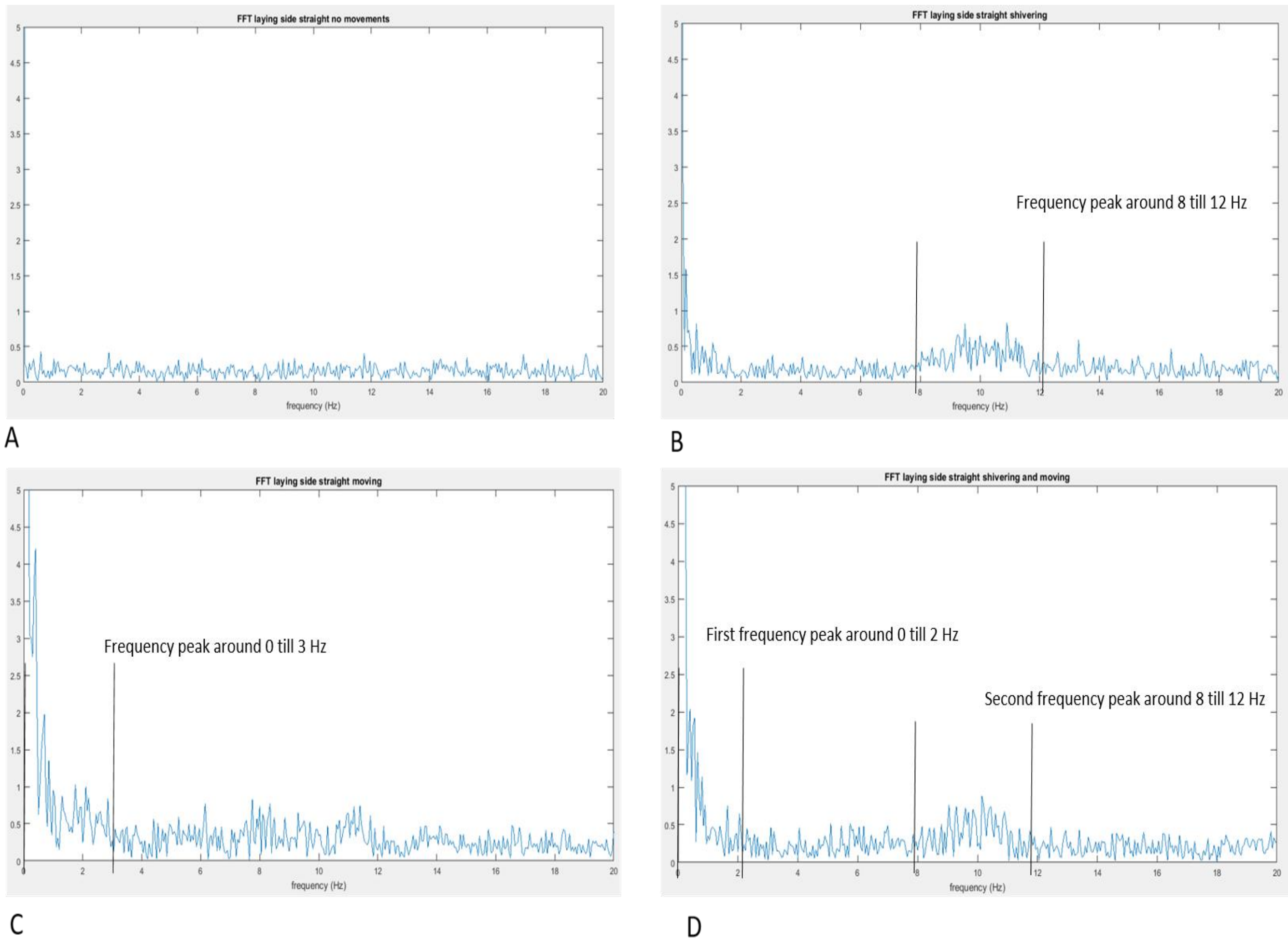

Figure 60: FFT signals of the 'laying on the left side straight' posture, A: no movement, B: shivering, C: moving, D: shivering+moving

5.3.3.2. Classification techniques

Based on the found information in the previous sections, a classification technique, that has to distinguish between shivering and other types of movements, had to be generated. Looking at literature, a study that also wanted to distinguish between shivering and other types of movements used FFT as the main classification feature [106]. However, they placed the accelerometer directly on the body and therefore probably would have a clearer signal with less noise. Preece et al. also looked at classifying dynamic activities from accelerometer data [109]. They found that using a FFT outperforms wavelet features (another classification technique often used) [112]. They also found that using features from the time domain (e.g. mean dc, mean rectified ac and SDs) already could give good levels of classification accuracy. Although they did not look at activities like shivering, looking at both studies it was decided to use a combination of time domain features and frequency domain features to try to classify shivering movements from other types of movements.

5.3.3.3. Filtering

If only certain frequencies need to be present in a signal, filtering can be applied. Filtering will attenuate the unwanted frequencies. In this case the unwanted frequencies are frequencies due to movements not related to shivering and due to noise. The frequencies that are wanted are the frequencies that determine shivering, and they lay in the range of 8 till 12 Hz, depending on posture, as can be seen in figures 58 and 60. Therefore, when the signal is filtered, which means in this case attenuating all frequencies below and above the frequency range of shivering, this will result in a signal where the moving signal and noise is filtered out and only the shivering signal is present.

Filtering during this phase is done digitally in Matlab, using high and low pass filters. The code can be found in appendix H. A Butterworth filter [113] is used during this analysis phase. A Butterworth filter was chosen, because this type of filter has a flat response in the pass-band, leaving the wanted signal untouched [113, 114]. Furthermore, it has a higher roll off rate then the Bessel filter [114], see figure 61. The Butterworth filter has two variable parameters: the cut off frequency and the order. The order of the Butterworth filter determines the width of the transition band, see figure 62. In this case it was found, after some trial and error, that for all filters a 4th order was good enough, which results in a roll off rate of 80dB/decade [115].

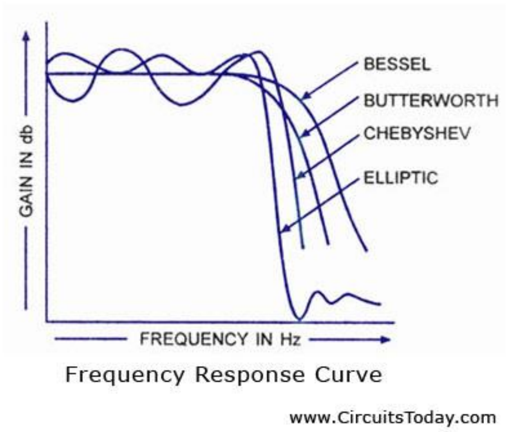

Figure 61: Different filter types [113]

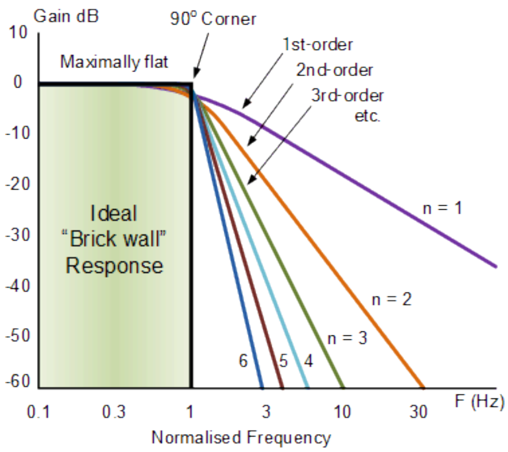

Figure 62: Signal behaviour with different orders [114]

Sitting straight

After some trial and error and looking at the FFT of the shivering signal, the following steps worked best:

- Butterworth 4^{th} order high pass filter, with cut off frequency of 8 Hz
- Butterworth 4^{th} order low pass filter, with cut off frequency of 10 Hz
- Absolute values
- Butterworth 4^{th} order low pass filter, with cut off frequency of 0.7 Hz

The high pass filter gets rid of the low frequencies and therefore also the offset of the signal. The first low pass filter gets rid of the noise and the high frequencies that are present. After this filter, the absolute values are taken, changing the negative values to positive values, to get the signal only above the x-axis. The second low pass filter is added to get the envelope of the signal. See figure 63 till 67 for the graphs of all the steps.

The filters used are causing a delay in the end signal. However, for this project this is not a problem. The system only has to detect if someone is shivering, and it does not matter if this detection happens, for example, 5 seconds after the user shivered.

For the signal after the second low pass filter an amplitude threshold value can be set to determine when something is shivering and when not. If this threshold is set at 10 mg, then all peaks that fall in the moving period (40 till 60 sec) will fall below this, and most peaks during the shivering and shivering+moving period (20 till 40 and 60 till 80 sec) will pass this amplitude threshold, see figure 68. This makes it possible to use the amplitude of the peaks as a classification feature to determine shivering.

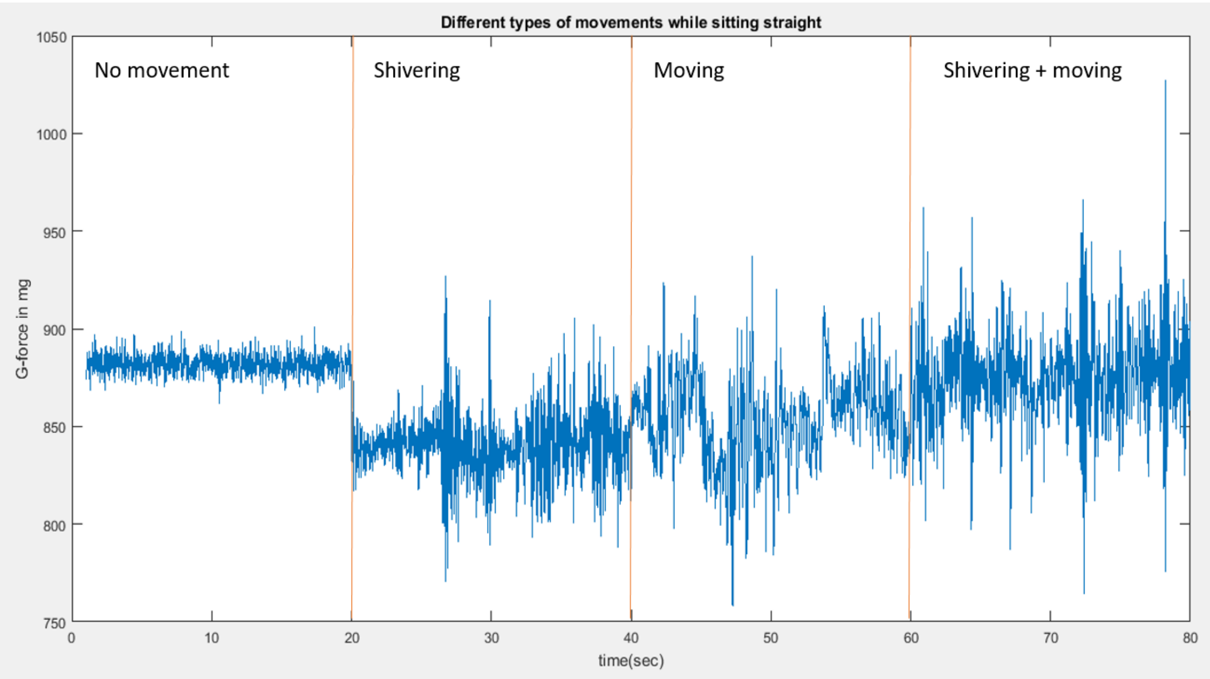

Figure 63: Original signal of the sitting straight body posture

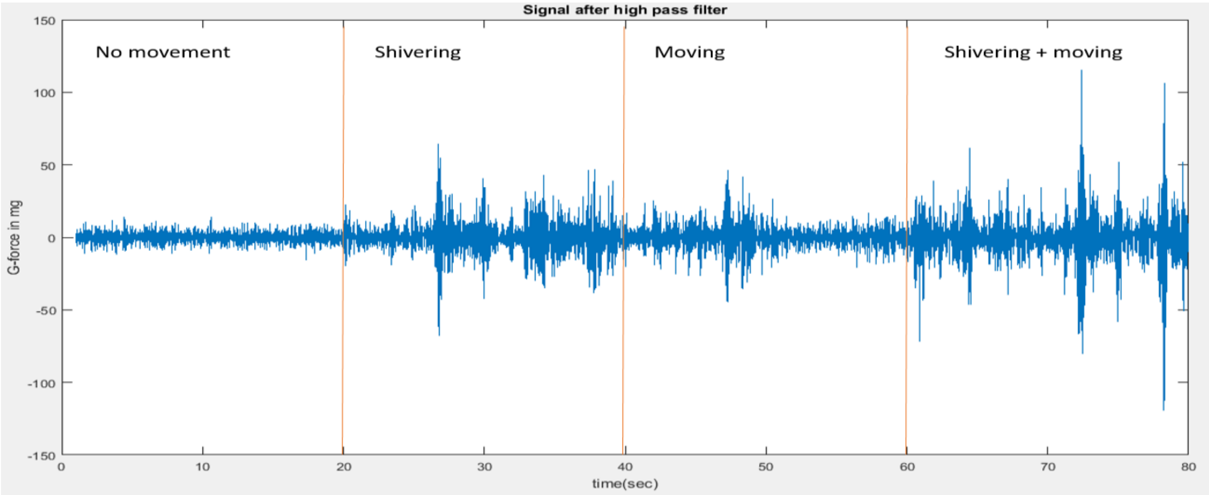

Figure 64: Signal after Butterworth 4th order high pass filter with cut off frequency of 8 Hz

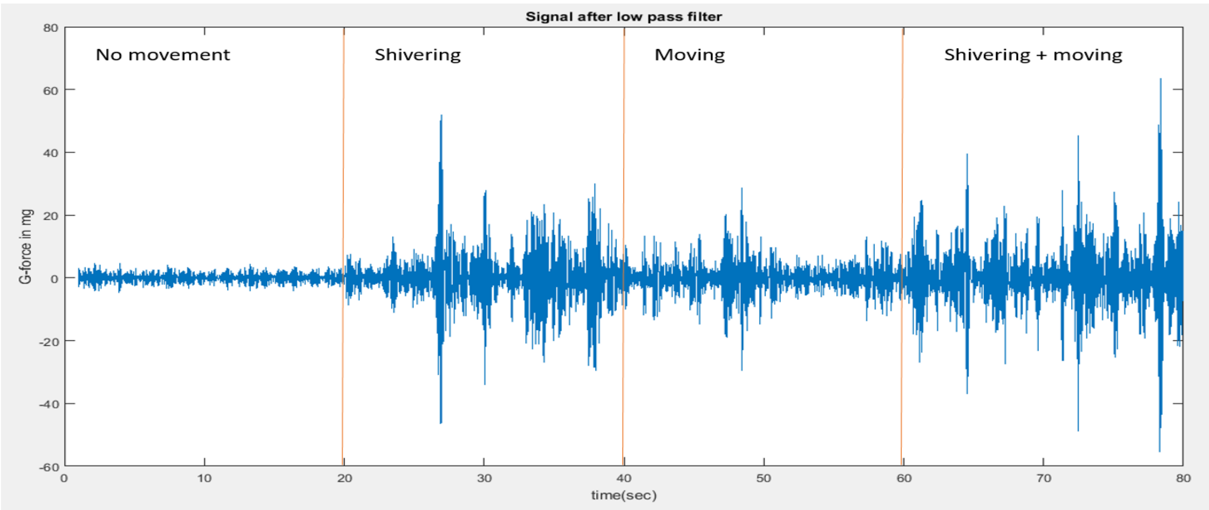

Figure 65: Signal after Butterworth 4th order low pass filter with cut off frequency of 10 Hz

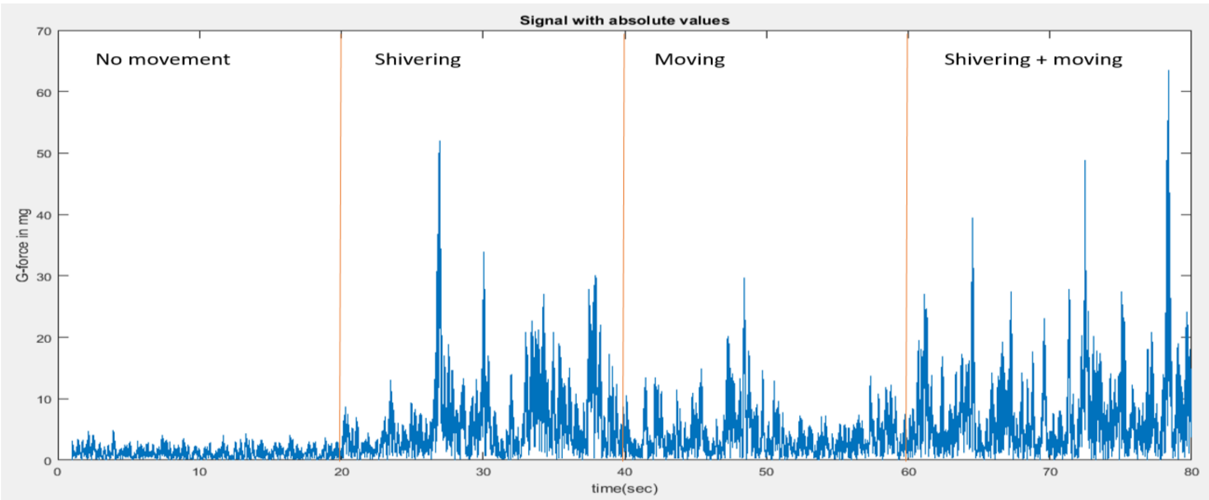

Figure 66: Signal with only absolute values

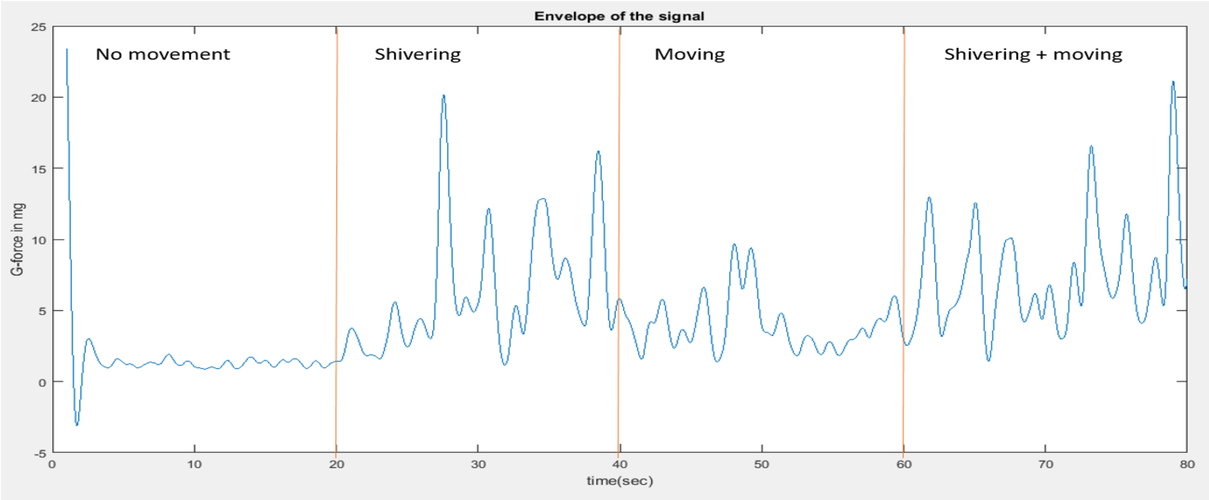

Figure 67: The envelope of the 'absolute value' signal, obtained using a Butterworth 4th order low pass filter with cut off frequency of 0.7 Hz.

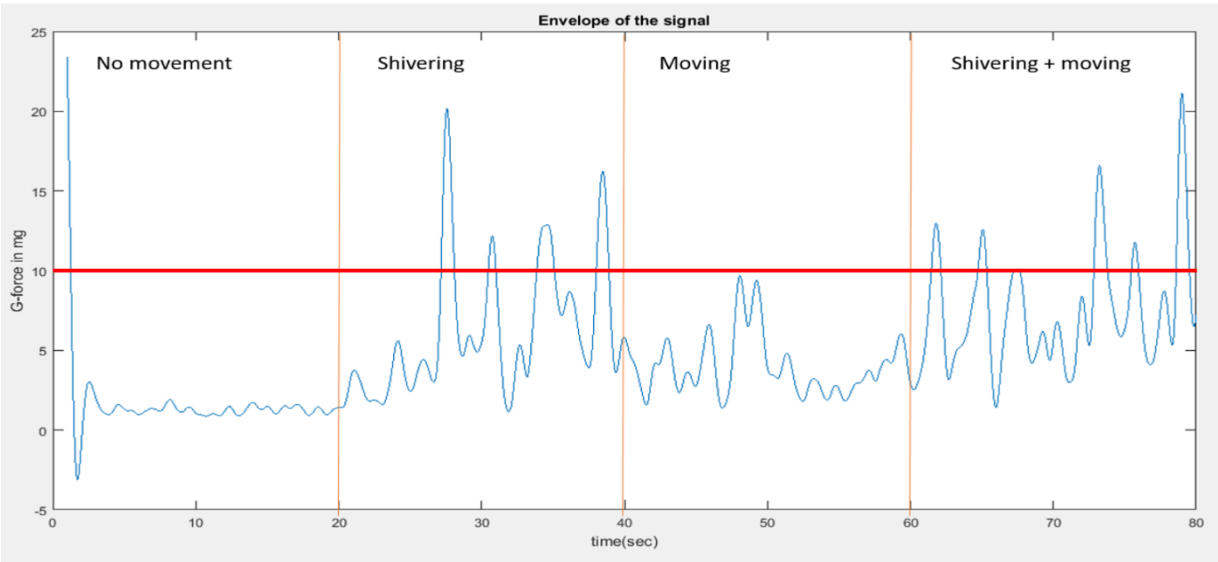

Figure 68: A amplitude threshold value of 10 mg can be used to classify between shivering and other types of movements for the 'sitting straight' posture.

Laying on the left side straight

For the 'laying on the left side straight' posture the same steps were conducted, but with different cut off frequencies:

- Butterworth 4th order high pass filter, with cut off frequency of 9 Hz
- Butterworth 4th order low pass filter, with cut off frequency of 11 Hz
- Absolute values
- Butterworth 4th order low pass filter, with cut off frequency of 0.7 Hz

All the steps can be seen in figure 69 till 73. As can be seen in the end signal, no amplitude threshold value can be chosen that is passed by the shivering peaks but not by the moving peaks. So if a amplitude threshold value is chosen that can be passed by the shivering peaks, there will always be a false positive due to the high peak in the movement data. In the end a threshold value of 4 mg is chosen, which result in one false positive in the moving period and three peaks that pass the threshold value in the shivering and shivering+moving period, see figure 74. That there is a false positive is not a big problem, and can be solved in the implementation by letting the signal pass the threshold a couple of times before it is classified as shivering. In this case, when a false positive happens ones in a while, it is not immediately classified as shivering.

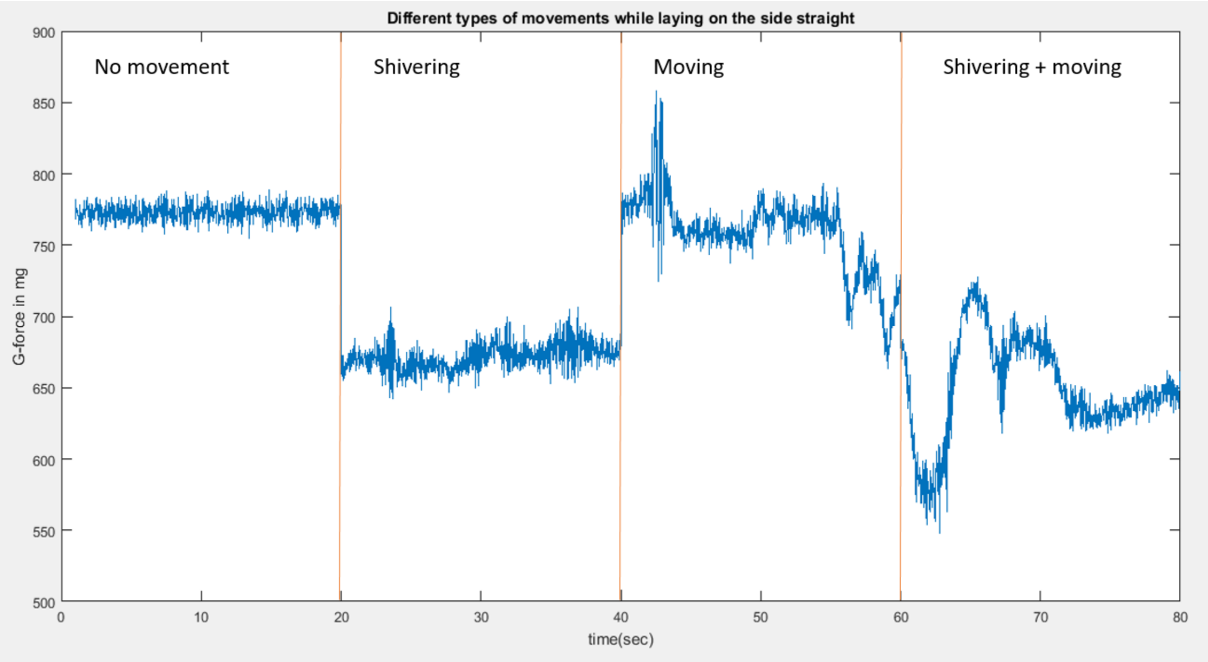

Figure 69: Original signal of the 'laying on the left side straight' body posture

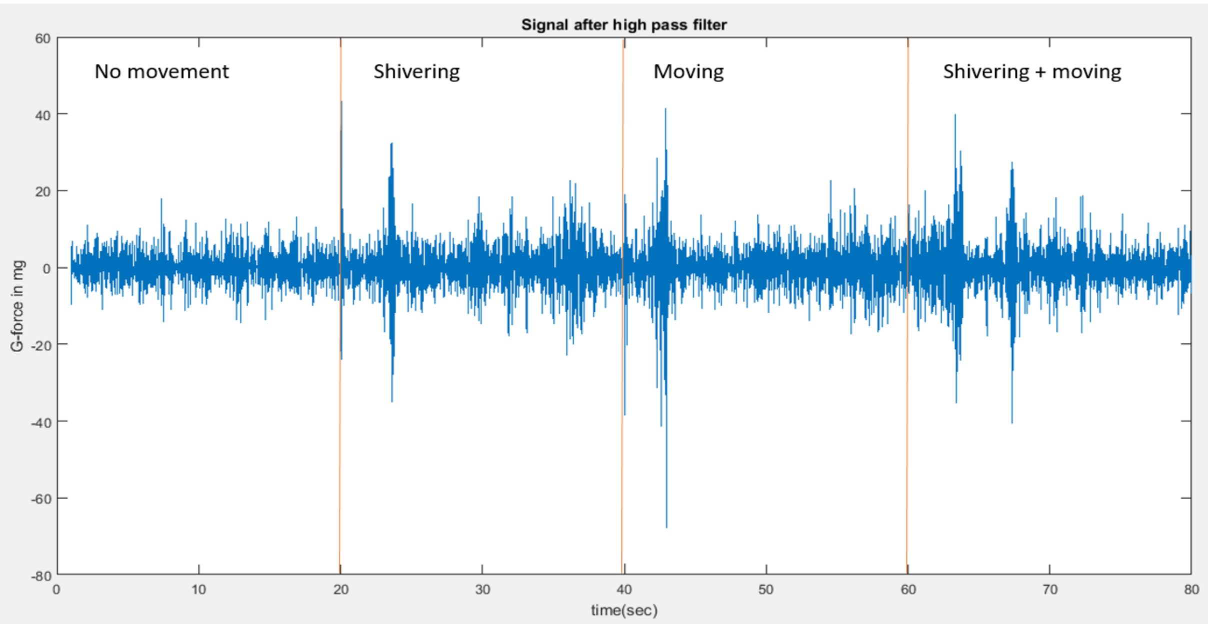

Figure 70: Signal after Butterworth 4th order high pass filter with cut off frequency of 9 Hz

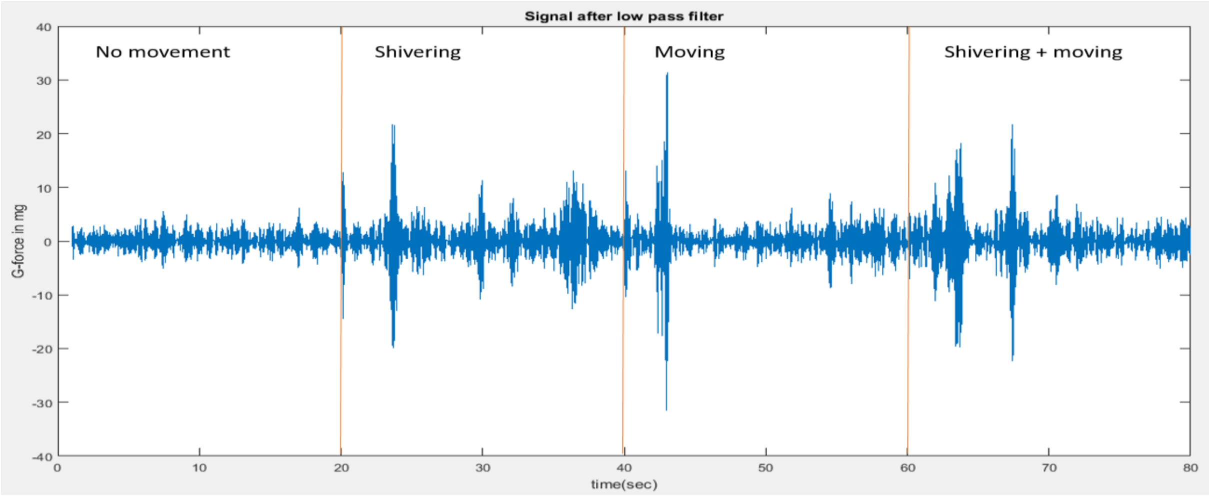

Figure 71: Signal after Butterworth 4th order low pass filter with cut off frequency of 11 Hz

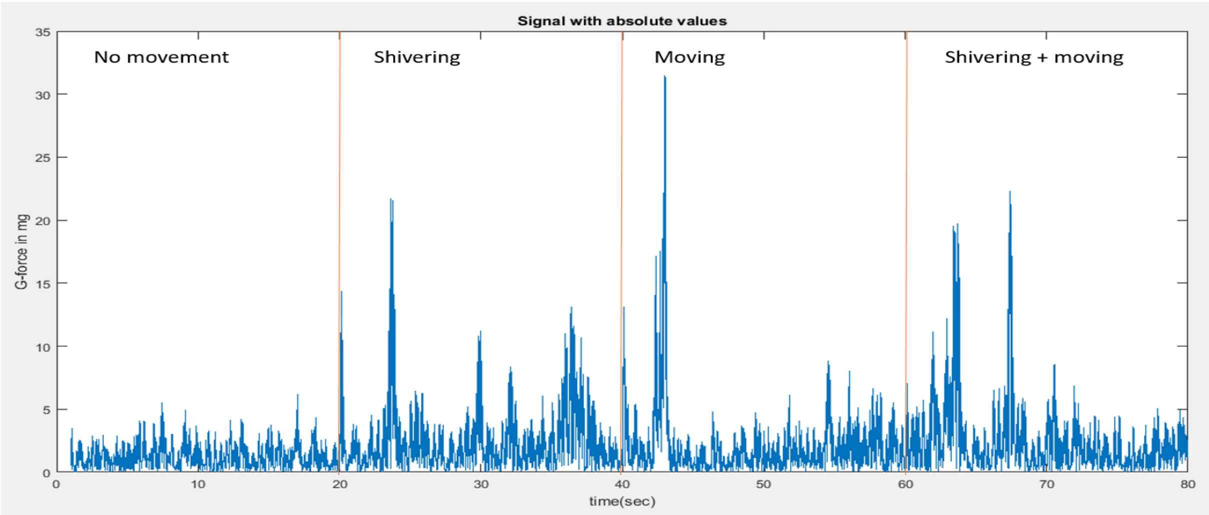

Figure 72: Signal with only the absolute values

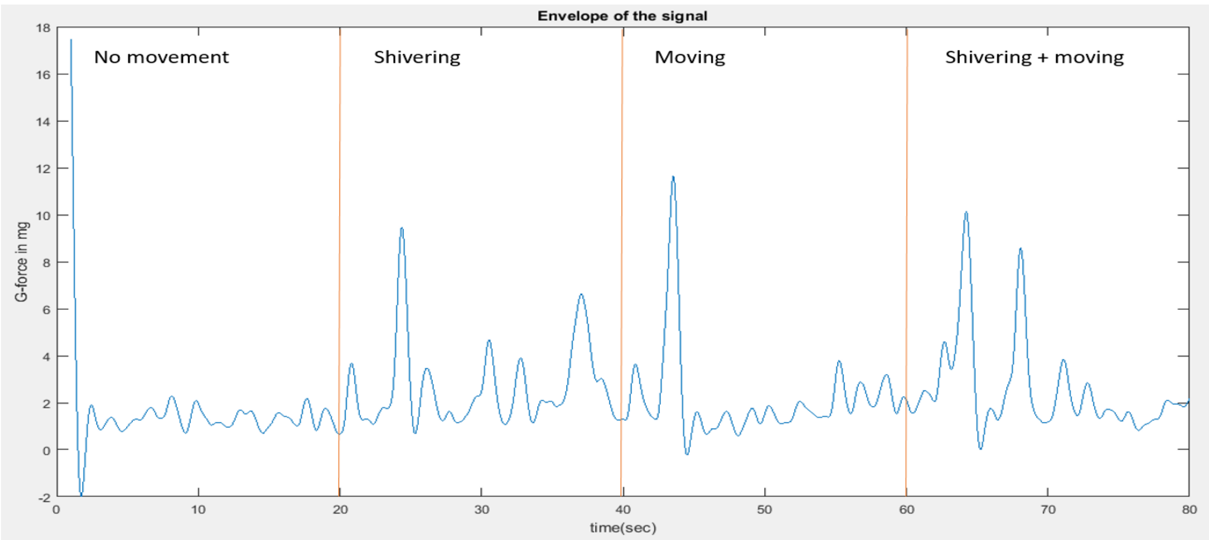

Figure 73: The envelope of the 'absolute value' signal, obtained using a Butterworth 4th order low pass filter with cut off frequency of 0.7 Hz.

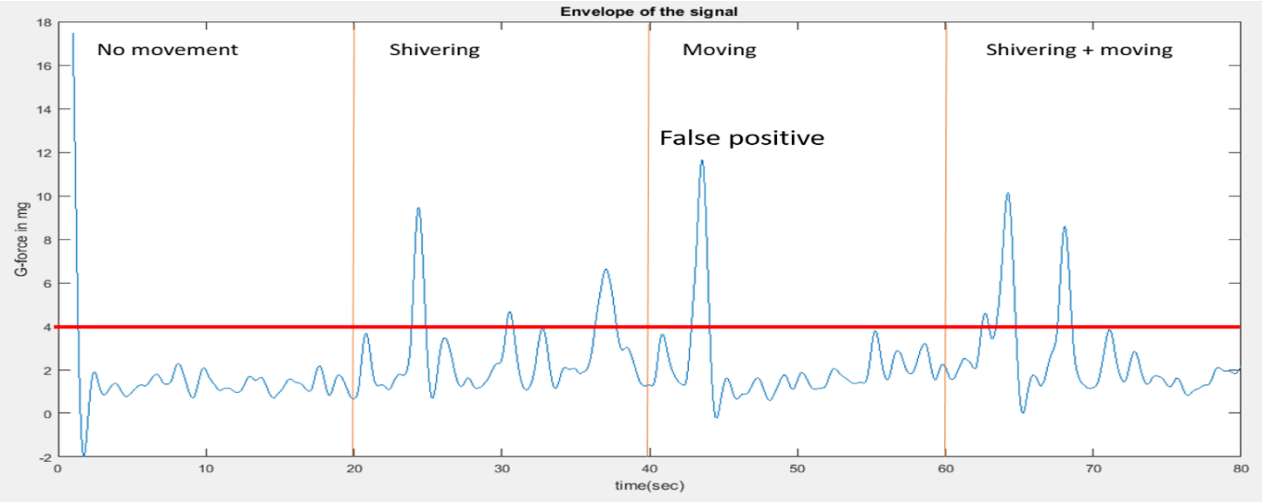

Figure 74: An amplitude threshold value of 4 mg will still result in a false positive of the moving signal for the 'laying on the left side straight' body posture.

5.4. Implementation Arduino

After the data analysis in Matlab, all the steps have to be implemented in the Arduino such that the Arduino would, in real time, perform these steps on the incoming accelerometer data. This implementation is described in the following section. Beside this, it is explained that testing is done using simulated data, that in the end a FFT classification feature is added to the classification steps to make distinguishing between shivering and other movements more accurate and that the x-axis signal of the accelerometer can be used to determine the current posture of the user.

5.4.1. Filter implementation Arduino

First of all, the filters needed to be implemented in the Arduino. To do this, an online program [116] was used that automatically generated Arduino code for a filter, based on the chosen type of filter, order, sampling frequency and cut off frequency.

Unfortunately, only a 2nd order filter could be made with this program. To check how much difference there would be between this Arduino code, using a 2nd order filter, and the Matlab results, the Arduino code was translated to an excel function and all steps done in Matlab (high pass, low pass, absolute values, second low pass) were now executed in excel using the Arduino code, with the only difference that now a 2nd order filter was used instead of a 4th order. The data that was filtered in excel was the data obtained during the emulation in the freezer for the 'sitting straight' posture and the 'laying on the left side straight' posture. This way, the graphs made in Excel could be compared with the Matlab graphs (figure 68 and 74).

Sitting straight

The values entered into the program for the high pass filter and both low pass filters can be found in table 6 and the corresponding code in appendix I-1. The result can be seen in figure 75. When comparing this to the Matlab graph in figure 68, it can be seen that there is now also a peak in the 'moving' signal that passes the amplitude threshold of 10 mg. Therefore, having a 2nd order filter does decrease the differences in the signal between shivering and other types of movements, increasing the possibility of false positives.

Table 6: Values entered for different filter types

	Filter type	Character	Frequency
Sitting straight	**High pass**	Butterworth, high pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 8Hz
	Low pass 1	Butterworth, low pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 10Hz
	Low pass 2 (envelope)	Butterworth, low pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 0.7Hz
	Band pass	Butterworth, band pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 8Hz, upper corner 10Hz
Laying side straight	**High pass**	Butterworth, high pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 9Hz
	Low pass 1	Butterworth, low pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 11Hz
	Low pass 2 (envelope)	Butterworth, low pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 0.7Hz
	Band pass	Butterworth, band pass, 2nd order	Samplerate checked, sample rate 50Hz, lower corner 9Hz, upper corner 11Hz

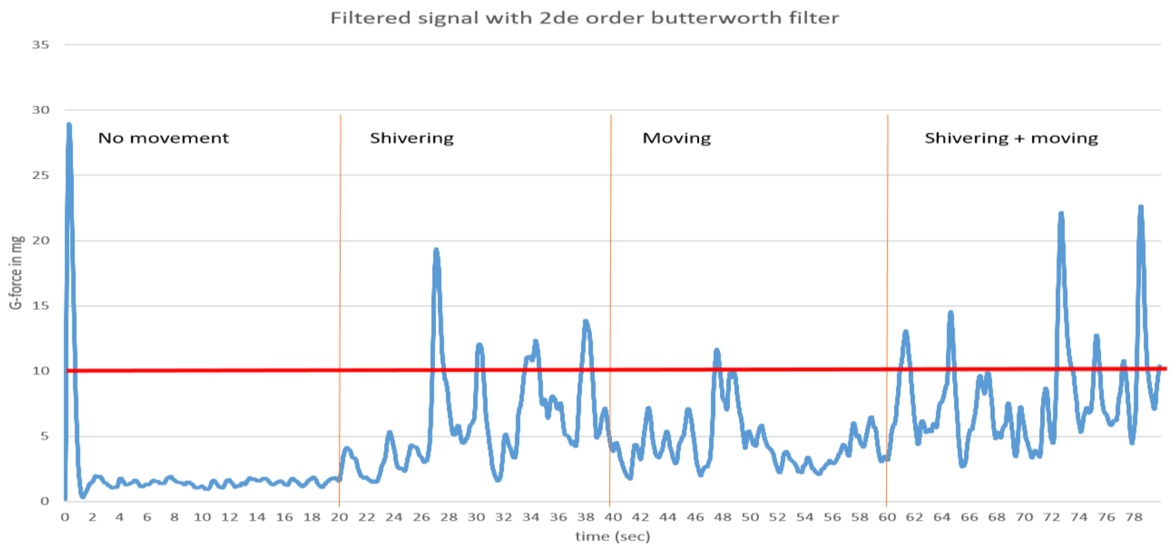

Figure 75: 'Sitting straight' signal obtained by using 2nd order Butterworth filters. There is now a false positive in the moving signal.

The program also gave as an option to use a 2nd order band pass filter, instead of using a high pass filter followed by a low pas filter. Therefore the filtered signal using this option, with the same cut off frequencies of 8 and 10 Hz, was also looked at and compared with the filtered signal using a high pass filter followed by a low pass filter. The values entered for the band pass filter can be found in table 6 and the corresponding code in appendix I-1. The results can be seen in figure 76. Based on these results, it was decided to continue with the band pass filter, because the amplitude of the peaks of the shivering movements became in general larger, while the amplitude of the peaks of the moving signal became a bit lower with this filter.

Furthermore it was decided to change the threshold value from 10 mg to 12 mg, such that, when using a band pass filter, no false positives are measured in the moving signal.

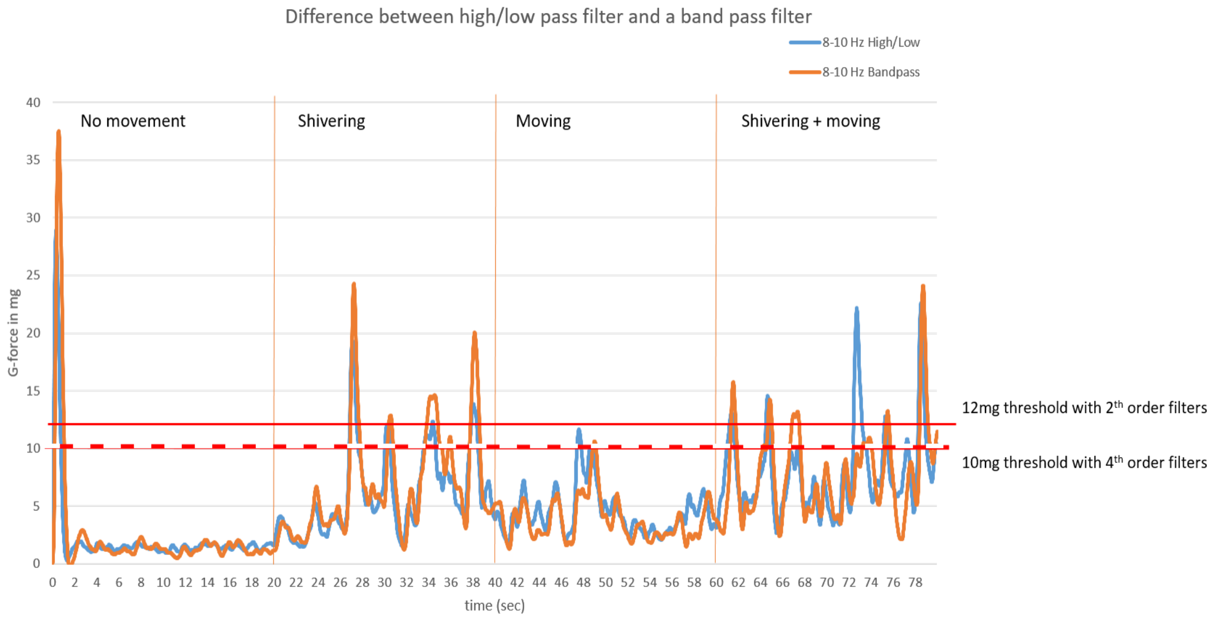

Figure 76: Difference in 'sitting straight' signal between Butterworth 2nd order band pass filter and a combination of Butterworth 2nd order high pass and low pass filter. When the amplitude threshold is moved from 10 mg to 12 mg and the band pass filter is used, no more false positives are measured in the moving signal.

Laying on the left side straight

The values entered into the program for the high pass filter and both low pass filters can be found in table 6, the corresponding code can be found in appendix I-2. The result can be seen in figure 77. When comparing this with figure 74, in this case also the peak just after 40 seconds touches the threshold line and the peak at around 55 seconds does pass the threshold of 4 mg, resulting in at least two peaks of the moving signal that are passing the threshold. Therefore, having a 2nd order filter will also decrease the differences in the 'laying on the left side straight' signal between shivering and other types of movements, increasing the possibility of false positives.

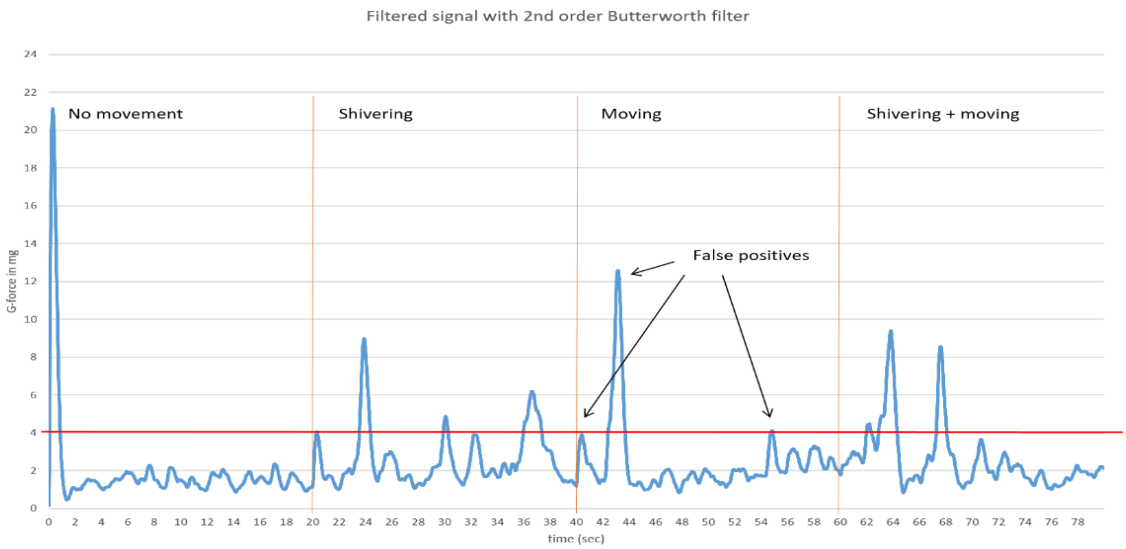

Figure 77: 'Laying on the left side straight' signal obtained by using 2nd order Butterworth filters

When looking at the difference between the combination of a high pass filter and a low pass filter and a band pass filter, the peaks in the shivering signals are higher with the band pass filter, see figure 78. Therefore this filter was chosen to be implemented into the Arduino code. The values entered into the program for the band pass filter can be found in table 6, the corresponding code can be found in appendix I-2. Furthermore, it was decided to change the threshold value from 4 mg to 5 mg. Doing this will get rid of two of the false positives in the moving signal, while still three peaks in the shivering and the shivering+moving signal passes the threshold.

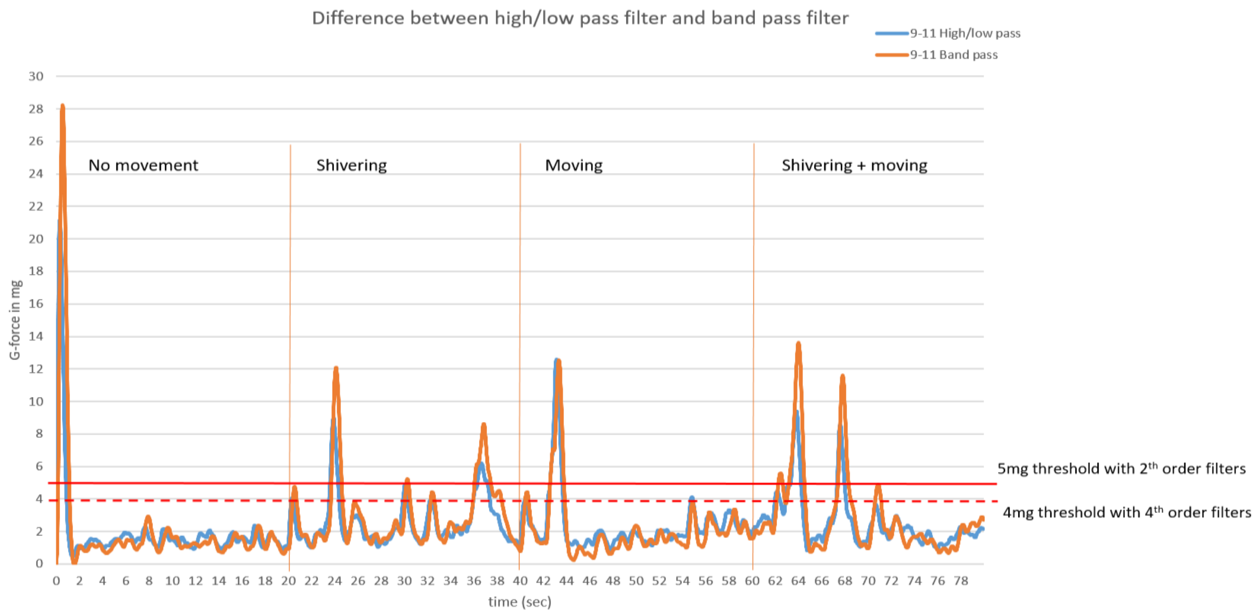

Figure 78: Difference in 'laying on the left side straight' signal between Butterworth 2nd order band pass filter and a combination of Butterworth 2nd order high pass and low pass filter. When the amplitude threshold is moved from 4 mg to 5 mg and the band pass filter is used, only one false positive is measured in the moving signal.

5.4.2. Shivering simulation

To see if filtering the incoming accelerometer data worked using the Arduino, data needed to be generated. Unfortunately, due to time limits, it was not possible to use a freezer again to get emulated shivering data, therefore shivering needed to be simulated. However, before this simulated data could be used for testing purposes, it was important to know if the simulated signal corresponded with the emulated signal obtained using the freezer.

5.4.2.1. Comparing emulated shivering with simulated shivering signal using Matlab

To compare the simulated data with the emulated data, simulated shivering data needed to be obtained. This was done while simulating shivering for 20 seconds and having the body posture 'sitting straight' or 'laying on the left side straight'. To collect the data, the same Arduino code was used as with the emulation, see appendix D. The only difference is that in this case only the accelerometer on the left shoulder was attached. The obtained data was then compared with the emulated shivering signals of the corresponding posture. Multiple tests were executed, using different types of shivering, before a signal could be produced that came relatively close to the shivering signal obtained from the emulation data using the freezer.

Figure 79 and 80 compare the filtered emulated shivering signal with the final filtered simulated shivering signal of both the ‘sitting straight’ posture and the ‘laying on the left side straight’ posture. The signals were filtered using Matlab and therefore the 4th order filter could be used, having an amplitude threshold of 10 mg for ‘sitting straight’ and 4 mg for ‘laying on the left side straight’. So, for ‘sitting straight’, looking at the maximum values of the peaks and the amount of peaks that cross the 10 mg threshold, the first is higher in the emulated signal and the latter is higher in the simulated signal. For ‘laying on the left side straight’, the values are higher in the simulated data causing the signal to cross the 4 mg threshold more often.

Although there are still some differences between the emulated and simulated signal of both body postures, it was decided that in both cases the differences were small enough to continue with simulating the shivering, also because no other options were available. It is unclear how close this simulated signal is to a signal obtained from a real situation, because no data is available from such a situation.

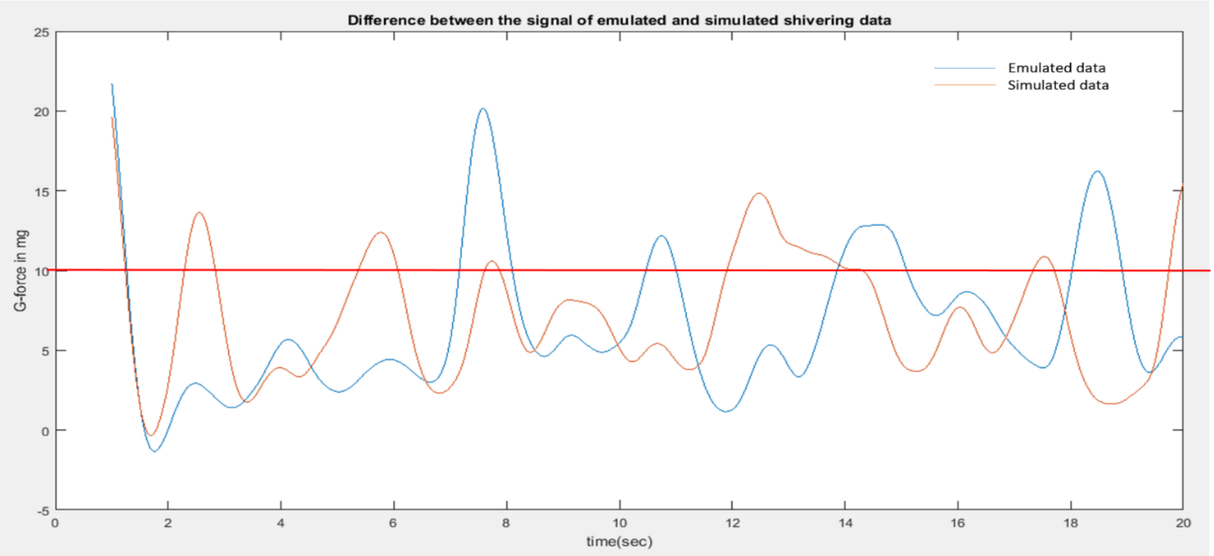

Figure 79: Difference between the signal of emulated and simulated shivering data for the ‘sitting straight’ posture

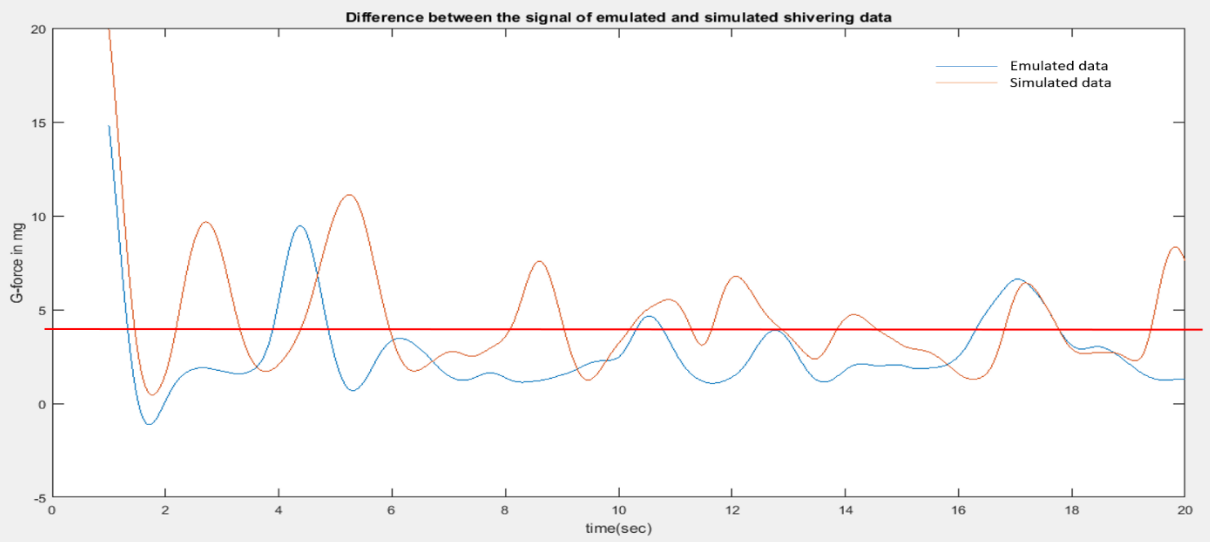

Figure 80: Difference between the signal of emulated and simulated shivering data for the ‘laying on the left side straight’ posture

5.4.2.2. Comparing simulated shivering signal with moving signal using Arduino

After determining that simulated data could be used, filtering a signal with the Arduino could be tested using simulated data. For both body postures a simulated shivering and moving signal was obtained for a duration of around 20 seconds, see figure 81 for 'sitting straight' and figure 82 for 'laying on the left side straight'. The Arduino code used can be found in appendix J. The filtered values are copied to an excel file, in which the graphs are generated.

Sitting straight

Looking at figure 81 both signals start with a high peak, this peak is due to the movement to get in position and can be ignored at this stage. When using the threshold value of 12 mg, because 2nd order filters are used, the shivering peaks do pass this threshold, but there are also some false positives when the movement signal pass this threshold. When ignoring the first three seconds, the shivering peaks pass the threshold four times, while the moving peaks pass it two times.

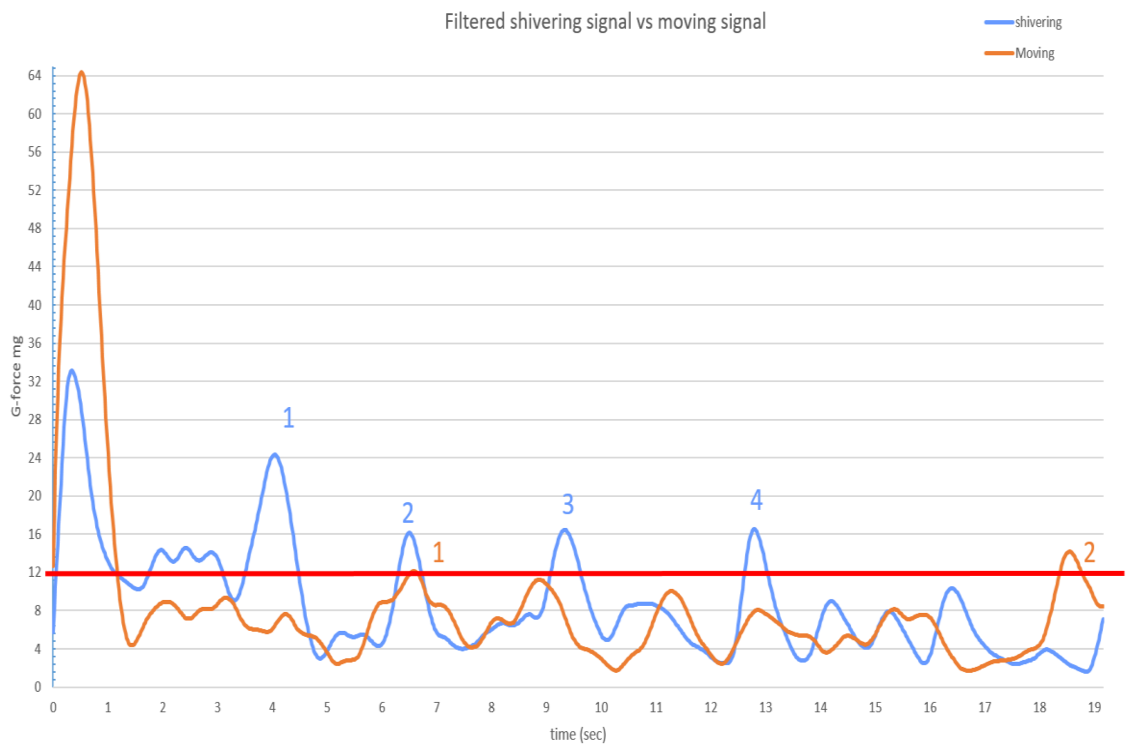

Figure 81: Comparing the simulated shivering signal with the moving signal obtained while sitting straight.

Laying on the left side straight

Looking at figure 82, both signals start again with a high peak, which is due to movements to get in position. When ignoring the first 2.5 seconds, the shivering peak does pass the threshold of 5 mg, because 2nd order filters are used, 8 times, while the moving signal passes the threshold 2 times.

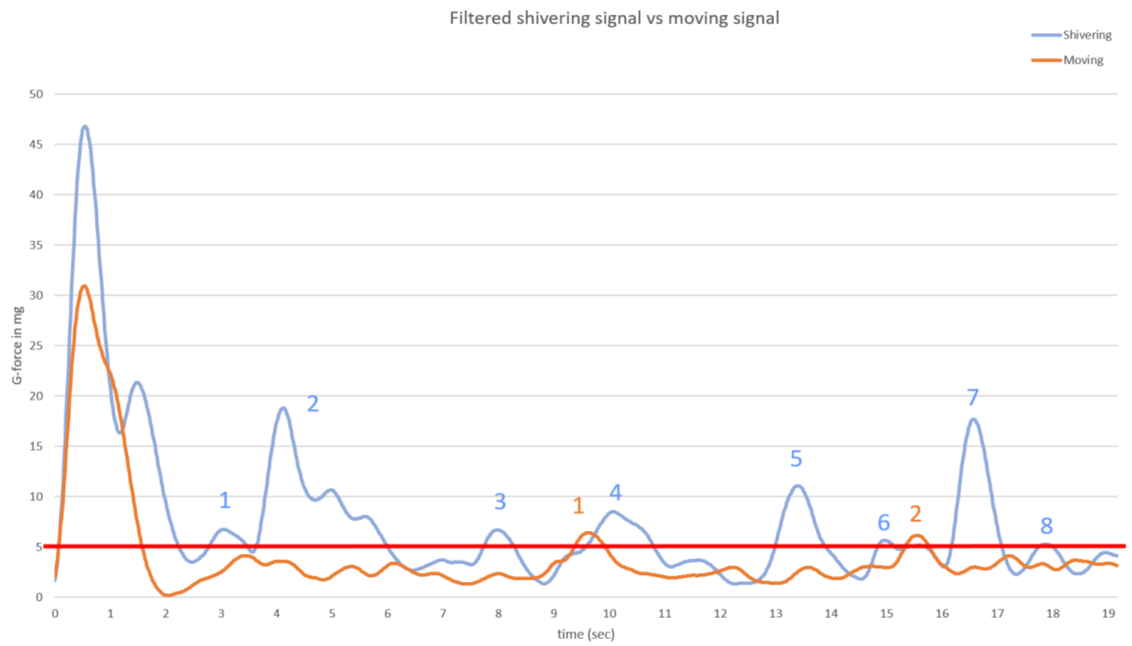

Figure 82: Comparing the simulated shivering signal with the moving signal obtained while laying on the left side straight

5.4.3. Windowed FFT as classification feature

At this stage, looking at the findings of the previous sections, the classification between the shivering and moving signal can be based on the height of the peaks and on the amount of peaks that passes the amplitude threshold. However, to decrease the possibility of false positives in the moving signal, another classification feature was looked at: the windowed FFT.

During the Matlab analysis it was found that for both body postures the height of the FFT signal in the frequency range related to shivering was higher for the shivering signal then for the moving signal, see figure 58 and 60. So, based on these findings, the height of the FFT for this specific frequency range could possibly also be used as a classification feature.

The windowed FFT was implemented in the Arduino using the Arduino FFT library. This feature looks at the FFT obtained from, in this case, a sample of 64 values. The Arduino FFT library lets the user chose between the Rectangle, Hamming, Hann, Triangle, Blackman, Flat top and Welch window. A window is used because the FFT assumes that the signal is repetitive [117]. When this is not the case, the FFT will measure frequencies that are not present, due to the discontinuity of the signal. This is called spectral leakage. This spectral leakage can be reduced using windowing. There are different window functions with each their own characteristics. Figure 83 shows the differences between five popular window types. As can be seen, there is a trade-off between the attenuation of the side lobs and the spreading of the main lob over the frequency bins. For example, ‘No window’ has a very narrow main lob, which is useful if high frequency resolution is needed. However, there is almost no attenuation in the side lobs. The Seven-term Blackman-Harris on the other hand has a very wide main lob, decreasing the frequency resolution, but the side lobs are also attenuated a lot.

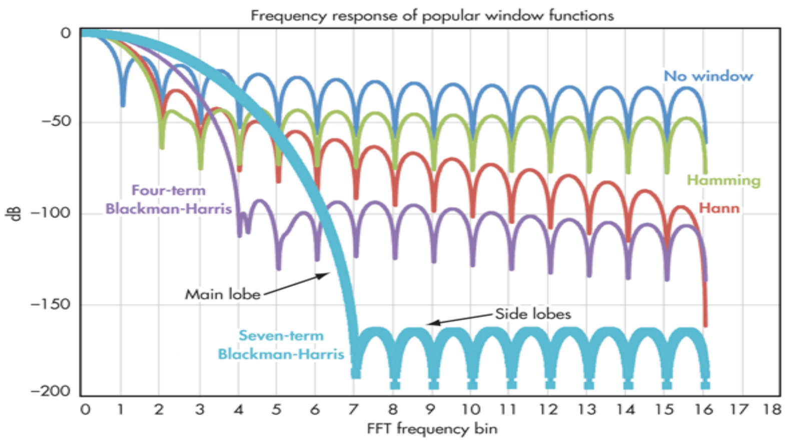

Figure 83: Characteristics of five popular window types [117]

To know which window type would be best, simulated shivering data and moving data was obtained, while having the ‘sitting straight’ posture, and a windowed FFT was executed with the different window types that were available in the FFT library. The Arduino code can be found in appendix J. All graphs, made in Excel, of the FFT with different window types can be found in appendix K. Which window would be best was only looked at only for the ‘sitting straight’ posture, due to time limits, and it was assumed that this window would also work for the ‘laying on the left side straight’ posture. The input values are the values of the filtered signal. Therefore the FFT will mostly have frequencies in the range of 8-10Hz in case of the ‘sitting straight’ posture and 9-11 in the case of the ‘laying on the left side straight’ posture. Looking at the graphs of appendix K, it was found that the simple rectangle window showed the biggest difference in amplitude between the shivering signal and the moving signal, therefore this window was implemented for both body postures.

Figure 84 shows the windowed FFT of the ‘sitting straight’ posture for 15 episodes of 64 samples (which is around 20 seconds) and figure 85 shows the windowed FFT of the ‘laying on the left side straight’ posture. The first two peaks of both figures should be ignored, because that time was used to get in position. Based on the results, an amplitude threshold could be set that most shivering peaks would pass and most moving peaks will stay below this value. In the case of the ‘sitting straight’ this amplitude threshold is set on 250, in case of the ‘laying on the left side straight’ it is set on 125.

Figure 86 compares, for the moving signal of the ‘laying on the left side straight’ posture, the obtained windowed FFT with the moving signal. Using both classification features will not delete all false positives, because a high amplitude of the signal often also result in a high FFT. However, some false positives are deleted, because the FFT signal does not reach the threshold value. To get rid of the last false positives, in a time period of 13 samples (20 seconds), the threshold values have to be passed at least 4 times before the Arduino will categorise the signal as shivering.

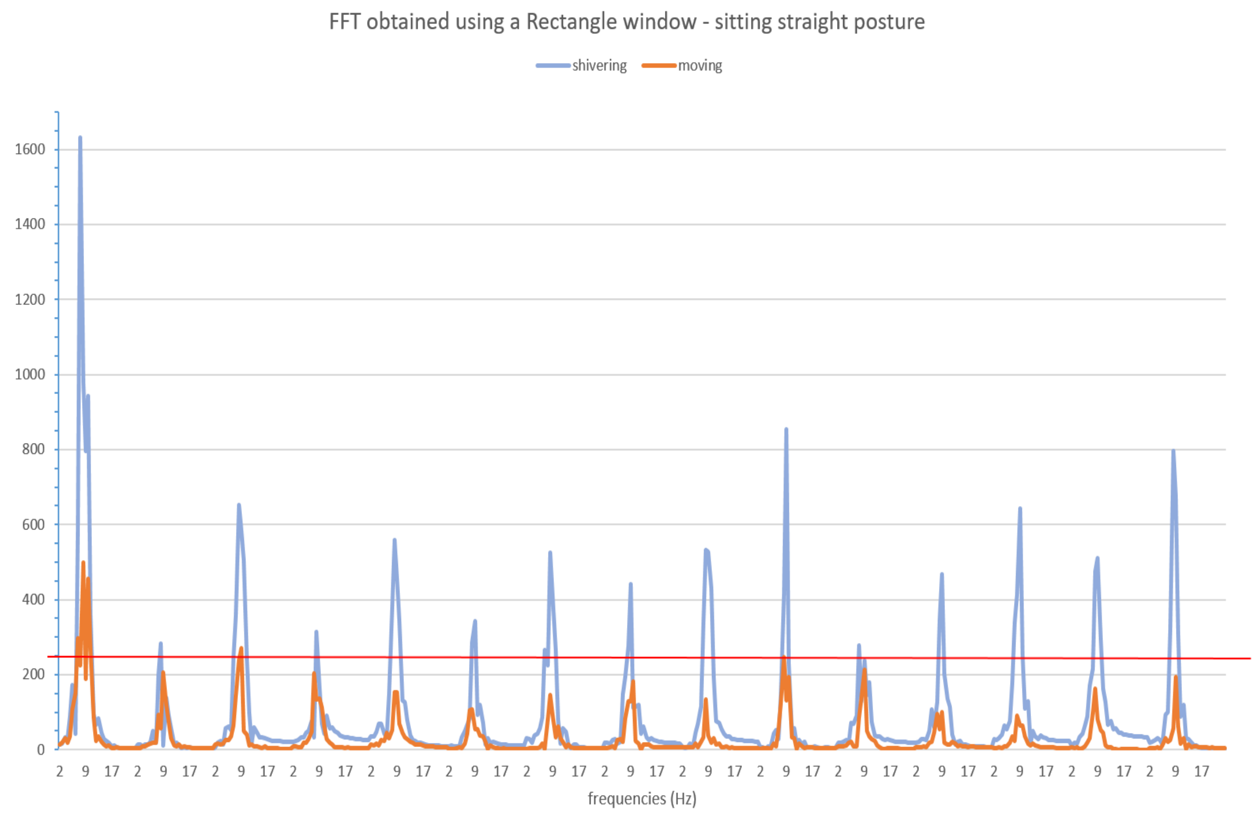

Figure 84: Windowed FFT signal from the filtered shivering and moving signal while having the sitting straight body posture. The FFT was made over 64 samples, using the rectangle window type.

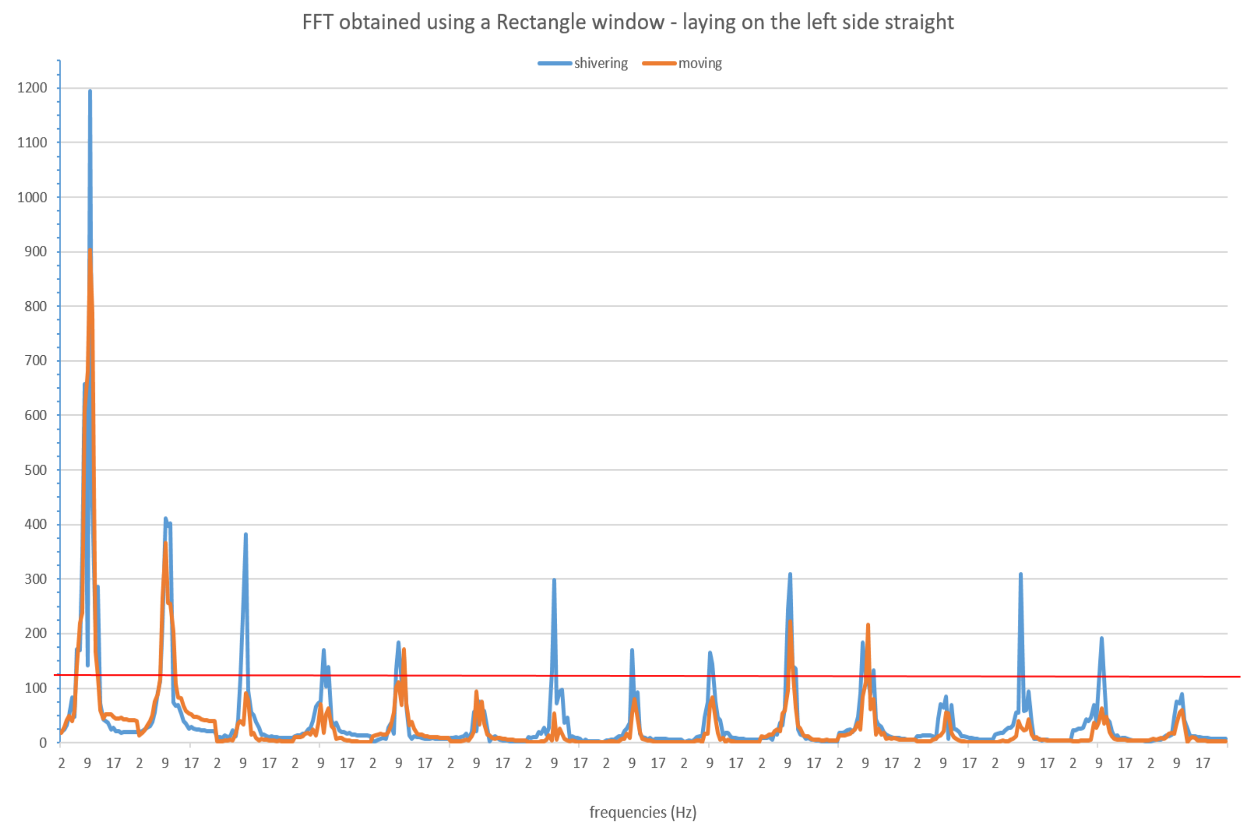

Figure 85: Windowed FFT signal from the filtered shivering and moving signal while having the 'laying on the left side straight' body posture. The FFT was made over 64 samples, using the rectangle window type.

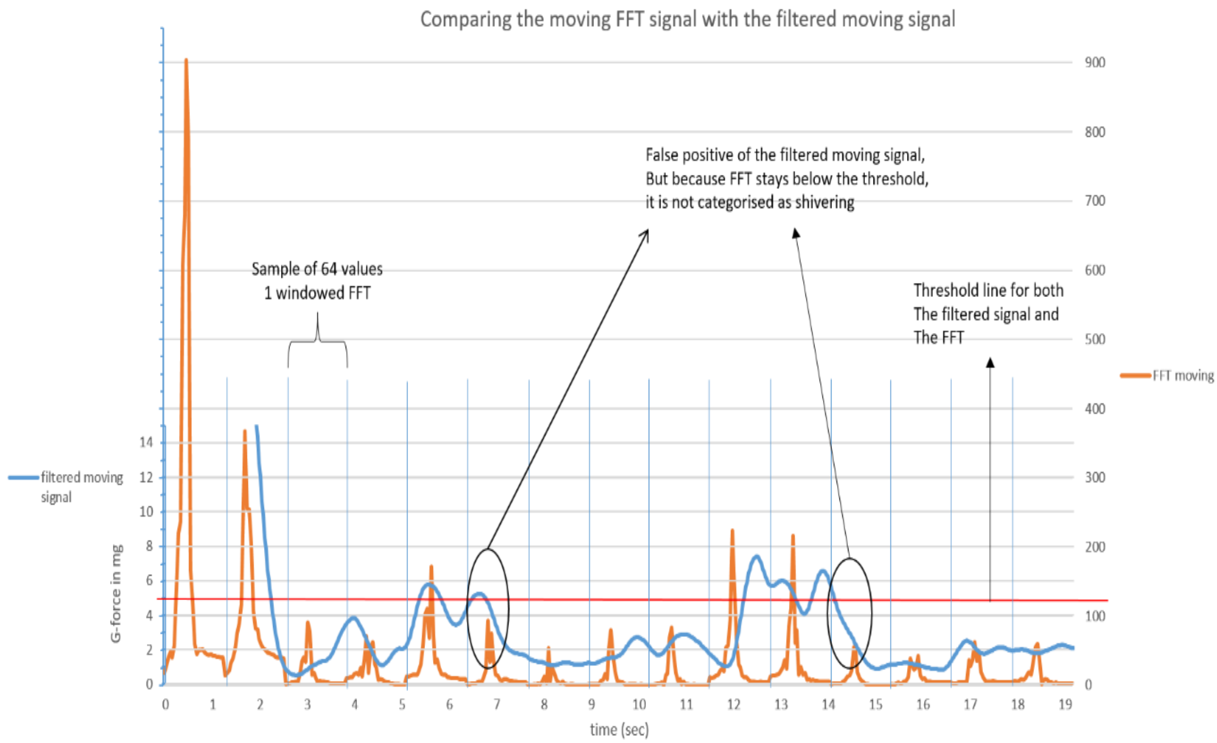

Figure 86: A comparison between the FFT signal and the filtered moving signal of the 'laying on the left side straight' posture. The red line is the threshold value for both the FFT signal (125) and the filtered moving signal (5mg). The black circles show were the false positives of the filtered moving signal are no longer measured due to the low FFT values.

5.4.4. Using accelerometer data to determine body posture

The offset of the raw x, y and z signal of the accelerometer can be used to determine the tilt of the accelerometer with respect to the earth [118]. When no movement is detected the accelerometer still measures the acceleration due to gravity. When the accelerometer is placed such that the z-axis is pointing straight down, all g forces is measured by the z-axis, and the x and y axis will have a value of 0. However, when there is a tilt, the g force due to gravity can be decomposed over the axis, giving also the x and/or y axis a value other then 0.

Figure 87 shows the x values of both the 'sitting straight' posture and the 'laying on the left side straight' posture. The first two seconds are used to get into position, but after that, the x values between both postures are different, due to the different tilt the accelerometer has for each posture. Knowing the effect the tilt has on the x-axis of the accelerometer can therefore be used to distinguishing between the 'sitting straight' posture and the 'laying on the left side straight' posture. This can be useful to make the program automatically change all parameters to the right values, depending on the posture it measures. For this system, when the x-axis values are above 300 mg, it assumes that the user has a 'sitting straight' posture and when the values are below -200 mg, it assumes that the user has a 'laying on the left side straight' posture. When the values are between 300 or -200 mg it is assumed that the user has another posture then 'sitting straight' or 'laying on the left side straight' and as a result none of the measured movements is classified as shivering.

To use the tilt of the accelerometer, it is important that the accelerometer is always attached to the shoulder in the same way, otherwise the axis values can change due to a difference in tilt. See figure 88 for photos of how the accelerometer was attached to the shoulder throughout this project.

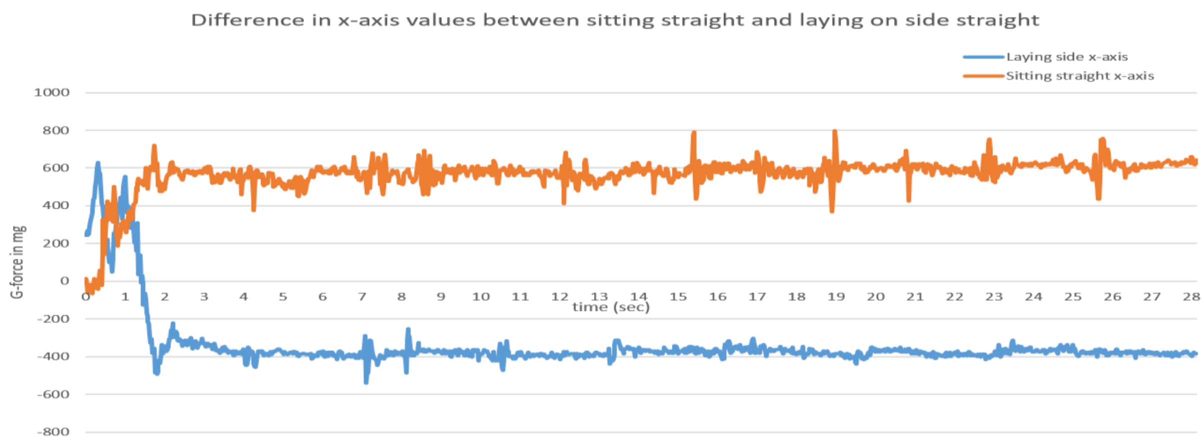

Figure 87: The difference in value of the x axis between the 'sitting straight' and 'laying on the left side straight' body postures can be used to determine which body posture the user has

Figure 88: Position of the accelerometer at the left shoulder of the Sheltersuit

5.5. End prototype

This section will give a description of the set-up of the end prototype. After this a walkthrough can be found about how this prototype is functioning.

5.5.1. Set-up

The end prototype consist of a Sheltersuit, one mma7361l analog accelerometer, attached to the left shoulder on the inside of the Sheltersuit, one SHT15 temperature/humidity sensor and a piezo buzzer. The sensors are connected to an Arduino Uno, which is connected to a laptop. To connect the accelerometer from the Sheltersuit to the Arduino, a +/- 5 meter cable is used. Both the SHT15 sensor and the piezo buzzer is not incorporated in the Sheltersuit, but are placed on a breadboard. See figure 89 for a photo of the set-up and figure 90 for a schematic overview of the hardware used.

Note:

Having the laptop connected to a power socket can interfere with the measurements of the accelerometer, therefore all measurements and tests were done without connecting the laptop to the power socket.

Figure 89: Photos of the set-up of the end prototype

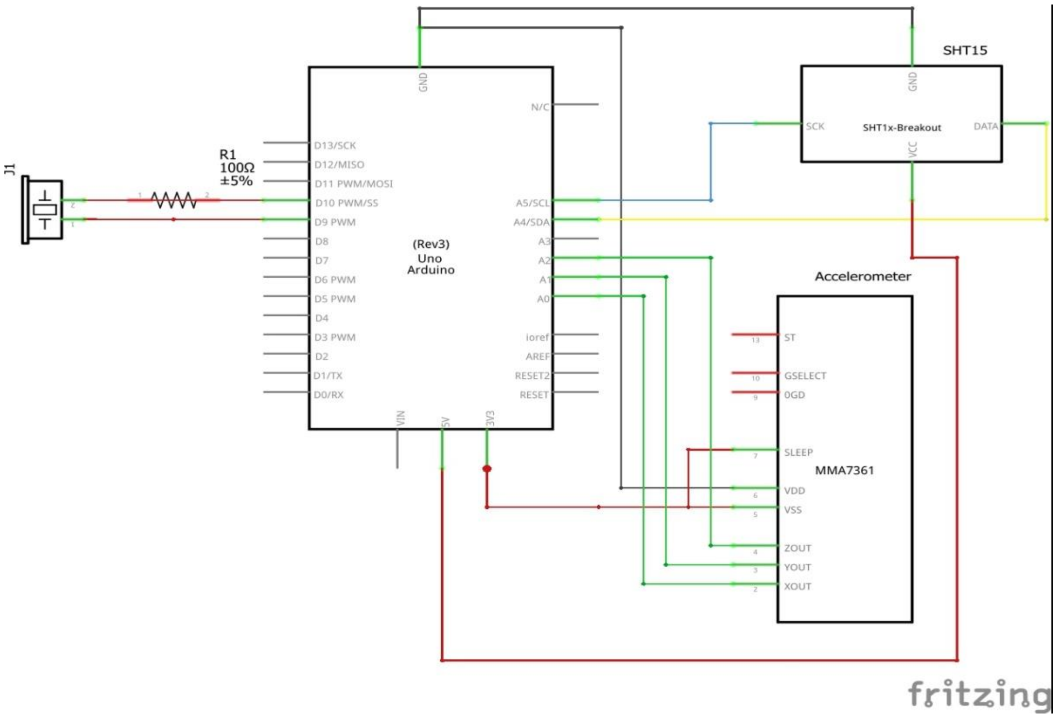

Figure 90: Hardware schematics of the end prototype, made with fritzing

5.5.2. Functionality

The end prototype works as follows: Based on the values of the x-axis of the accelerometer, the body posture is determined. This can be 'sitting', 'laying', or 'none'. Depending on the posture, the parameters are changed. When the Sheltersuit moves, due to movement of the user inside it, this movement is detected by the accelerometer and send to the Arduino. The Arduino will take samples of 64 values. When during one sample the threshold of the filtered signal and the threshold of the FFT is passed, the Arduino determines that the movement looks like shivering. After 13 samples (around 20 seconds), the Arduino will look at the amount of times the movement looks like shivering and at the temperature and humidity. When the movements look like shivering for at least four times in +/- 20 seconds, and the temperature is below the calculated temperature threshold, the Arduino assumes that it has detected shivering. The sensitivity level of the system is in the prototype always 0. Therefore detecting shivering means immediately that the user has a risk of getting hypothermia and the buzzer will start beeping with short beeps and a low volume. If in the next +/- 20 seconds shivering is not detected, the beeping will stop. However, when shivering is detected again in the next 20 seconds, the beeps will become longer and the volume will increase. The Arduino code used can be found in appendix L.

6. Evaluation

This chapter describes the testing of the end prototype. In this stage only a functional test could be conducted, due to the state of the prototype and because no contact was made with the end users. This section will describe the functional tests, conducted to evaluate the end prototype, and the results obtained.

6.1. Functional tests

The functional test evaluates if all functional requirements, classified as ‘must’ and stated in section 3.6.3, were implemented in the prototype and if the functions fulfilling the functional requirements were working properly. All tests were conducted with the same test person that was used during the realisation phase.

The system must detect when the user is shivering

Test

To test if the system could distinguish between shivering and other movements of the user, a test person, wearing the Sheltersuit, had to sit straight and shiver during 5 sessions of 20 seconds, and during 5 sessions of 20 seconds while performing ordinary movements while keeping the sitting posture. The order in which these sessions were performed is:

shivering – shivering – moving – moving – moving – shivering – shivering - shivering – moving – moving

These 10 sessions were repeated for the laying on the left side straight posture.

Result

For the sitting straight posture all 5 shivering sessions were categorised as shivering and all 5 movement sessions were categorised as not shivering. For the laying on the left side straight posture, 4 of the 5 shivering sessions were categorised as shivering and 5 of the 5 movement sessions were categorised as not shivering.

Conclusion

The prototype can distinguish between shivering sessions and non-shivering sessions for the sitting straight posture. For the laying on the left side straight also almost all sessions were categorised correctly. The one shivering session that was not categorised as shivering was the last session of the shivering sessions. The reason that this session is not categorised as shivering can be because it is hard to simulate shivering for a longer amount of time. However, more tests need to be conducted to see if this is the case or if the parameters are not set correctly. In a real situation, having a false positive is less dangerous then having a false negative, because in the latter case, help can become too late.

The system must measure the duration of the shivering

Test

The results of the previous test were used

Results

For the sitting straight posture it counted respectively 2 and 3 sessions, while for the laying on the left side straight posture it counted 2 and 2 (due to categorising one shivering session as not shivering). When the shivering is interrupted by a sample with no shivering, the counting will start at 0 again.

Conclusion

The system can measure how much sessions in a row it detects shivering. However, this is not based on time, but on sessions, and although a session is around 20 seconds, in this stage the system is not capable of telling accurately how long in seconds or minutes the user is shivering. Furthermore, it does not take into account previous sessions of shivering. Therefore the user has to constantly shiver for the system to keep counting. If, for whatever reason, one session was categorised as non-shivering, the counting will start over. This can make the results unreliable, because it can result in a user that is shivering for 10 minutes, but because some sessions are not categorised as shivering, the system will assume a shorter shivering duration. Better ways to keep track of the duration of shivering, that will also look at previous shivering sessions, need to be investigated to get a more reliable view of the real duration the user is shivering.

The system must measure the temperature inside the Sheltersuit (Tin)

Test

To test if the temperature measured by the prototype was correct, the temperature was compared with the temperature of the thermostat. To test if the sensor would respond to temperature changes, the temperature was measured while holding the temperature in a fist.

Results

The system can measure temperature, however the temperature sensor is not integrated in the Sheltersuit and therefore does not measure the Tin.

The temperature measured by the prototype started around 20.4 °C, however it increased to 20.5 and then decreased over time to around 20.2 °C, see figure 91. The thermostat gave a value of 20.0 °C. Which result in an end difference of 0.2 °C.

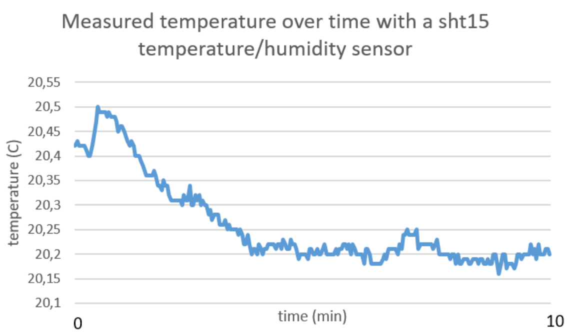

Figure 91: Measured temperature over time with a sht15 temperature/humidity sensor

When the sensor was hold in a fist, the temperature increased from around 20.5 to 23.5 and when the sensor was released, the temperature dropped again, see figure 92.

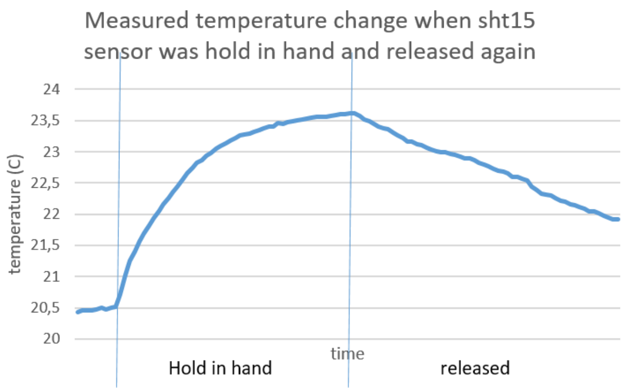

Figure 92: Measured temperature change when sht15 temperature/humidity sensor was hold in hand and released again

Conclusion

This requirement is not met because the Tin cannot be measured. However, the sensor itself could be tested.

The temperature did need some time to get a stable value. However, when this stable value was reached is correlated closely with the thermostat value. A difference of 0.2 °C can be expected with this sensor at this temperature. However, the difference can also be because of the resolution of the thermostat, which is 0.5 °C, and therefore less precise.

The temperature increased immediately when the sensor was hold in the hand. This was expected because of the body heat. It was not tested how long it would take before a stable value was reached again. The decrease of the temperature, when the sensor is released, goes more slowly in comparison with the increase of temperature. For this it was also not measured how long it would take before a stable value was reached again.

The system must measure the humidity inside the Sheltersuit (Hin)

Test

Because the humidity is measured with the same sensor as the temperature, the results of the previous test are used.

Results

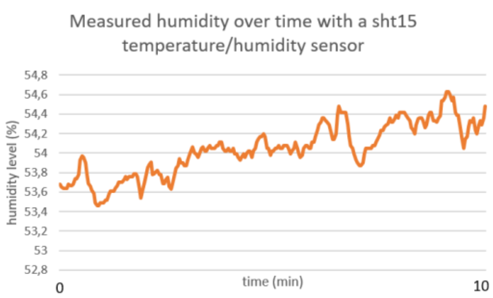

Figure 93: Measured humidity over time with a sht15 temperature/humidity sensor

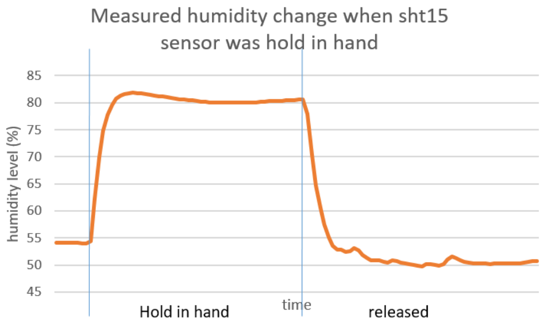

Figure 94: Measured humidity change when sht15 sensor was hold in hand

Conclusion

The requirement is not met, because Hin cannot be measure. But the sensor does work.

The system must base the risk of getting hypothermia on the Tin, Hin, shivering and duration of shivering

Test

To test if the system bases the risk of getting hypothermia on the Tin, Hin, shivering and duration of shivering, the threshold values of these features were, after each other, changed.

Test 1: Set the measured temperature manually on 50 °C.

Test 2: Set the measured humidity level manually to 100%.

Test 3: Set the accelerometer values to 0, meaning no shivering can be detected

Test 4: Keep the duration the user is shivering on 0 from the start.

For each test conduct a shivering session in the sitting straight posture and record if the prototype would detect if there is a risk of getting hypothermia.

Results

The system cannot measure the Tin and Hin, so therefore this requirement is not met. However, using the outside temperature and humidity level instead, they can also give an indication if temperature and humidity are used to base the risk of getting hypothermia on.

During test 1, 2, 3 and 4 no risk of getting hypothermia was detected because the criteria values were not reached. This means that the temperature, humidity, shivering and shivering duration are used to determine the risk of getting hypothermia.

Conclusion

All four parameters are used to determine the risk of getting hypothermia. However, this does not mean that the values of these parameter are also set to the correct ones to detect a risk of getting hypothermia. The temperature threshold for example can be set on 40 degrees, which will almost always result that the measured temperature is cold enough for the user to be able to have a risk of getting hypothermia. To test if the right values are used, a test needs to be conducted in a real situation, which was not possible at this moment.

The system must notify the user if there is a risk of getting hypothermia

Test

The results of the test of requirement 1 are used

Result

After detecting a shivering session, a buzzer sound could be heard. The volume, duration and frequency of the buzzer was increased for each session that was detected following another shivering session. When a non-shivering session was detected, the buzzer sound stopped.

Conclusion

In the end prototype, when the system detects shivering, this immediately means that there is a risk of getting hypothermia. Because this notification system works without the user has to shiver for a certain duration, it is assumed that the notification system will also work when this duration threshold is implemented. Therefore activating a buzzer when a shivering session is detected does mean that the system notifies the user if there is a risk of getting hypothermia. The volume, duration and frequency of the buzzer is then used to indicate to the user how high the risk of getting hypothermia is, based on the detected shivering duration of the user.

The system must be usable without other devices (such as a mobile phone)

At this stage the system still needs a computer for power. This has to be changed to a battery to fulfil this requirement.

7. Conclusion and recommendations

This chapter will give an answer to the research questions and it will conclude if the goal of the project is reached. Beside this it will discuss other conclusions that were found during the project. In the end the recommendations for further work are discussed.

7.1. Conclusion

The focus of this graduation project lay on developing a system that could protect the user of the Sheltersuit against hypothermia. At the start of the project the main research question was formulated:

How to develop a monitoring and notification system to prevent hypothermia of a Sheltersuit user?

Because it is possible that the end user is not capable to react on the notification system themselves, the following sub-question was also formulated:

What are the possibilities of using the Sheltersuit user's mobile phone as a notification gateway to aid organisations?

From the start it became clear that coming in contact with the main stakeholder, the homeless people, was challenging. The homeless shelter organisations also did not want to cooperate because they do not agree with purpose of the Sheltersuit product. As a result no information, that could have been useful for the ideation, specification and realisation phase of this project, was obtained from the homeless people and from the shelter organisations.

Because no information could be obtained from the end users, and because of time limits, the sub question is only answered using the information found during the literature research. This information showed that it is possible to use the mobile phone in the notification system. However, due to the challenges the homeless people that own a mobile phone face (e.g. charging or keeping it safe from breaking/weather), and because not all homeless people own a mobile phone, the notification system should not fully depend on a mobile phone. Furthermore, it is not clear at this stage if the homeless people are also willing to involve others by sending a notification to the aid organisations or a contact person, or if aid organisations are willing to participate with such a kind of system. More research on this subject needs to be done.

The main research question was answered through literature research, brainstorming, meetings with the client and data analysis. Based on the literature research, it was found that measuring the core body temperature, the way hypothermia is normally measured, is too invasive to be suitable for the envisioned system. Therefore it was concluded that only an estimation of the core temperature could be derived by looking at the symptoms and risk factors of hypothermia. Furthermore, because core body temperature could not be measured and because there are a lot of factors involved that determine if someone is getting hypothermia, it was also concluded that it is not possible during this project to predict with a high accuracy when someone is getting hypothermia. Instead, the focus was laid on determining when the user has a risk of getting hypothermia.

The final prototype focussed on the mild hypothermia symptom shivering and on the risk factors temperature and humidity inside the Sheltersuit to determine the risk of getting hypothermia. Shivering was measured using an accelerometer on the shoulder. The classification between shivering and other types of movements of the user was accomplished using filters to filter the signal, using a windowed FFT and counting the amount of times the signal would pass the determined amplitude threshold. The results showed that it is indeed possible to distinguish between simulated shivering and other calm types of movements of the user. At this stage it is still unclear if the shivering data obtained during the emulation and simulations is representative for a real situation. Therefore it is unknown how successful the prototype would be, in a real situation, to distinguish between shivering and other types of movements of the user. Furthermore, all tests were done with only one test person, making it impossible to predict how the system would behave with other users. However, the results obtained so far are promising and do suspect that measuring shivering movements with an accelerometer on the shoulder can be used to determine when a person is shivering.

To determine the risk of getting hypothermia, the shivering data needed to be combined with the temperature and humidity level inside the Sheltersuit. Unfortunately, no data was obtained about how the temperature and humidity level do behave over time inside the Sheltersuit when the user is getting at a risk of having hypothermia. Therefore, the determination of the threshold for the temperature and the duration for the sensitivity level of the system is only based on an educated guess. More information is needed to verify the accuracy of these guesses. Because of this, and because the prototype could not be tested in a real situation, it is unclear at this stage if it can accurately determine the risk of getting hypothermia. However, first steps are taken in the right direction.

The notification system depends strongly on the preferences and wishes of the end user and because they are not known, the notification concepts could only be made using own assumptions and information gathered while talking with the client. As a result, the chosen notification concept was kept simple and is based on the fact that sound can be noticed while sleeping, which can be the case if the user has a risk of getting hypothermia. However, more information about the end user preferences is needed to produce a notification system that is more adapt to the end user.

7.2. Recommendations

The prototype at this moment is still in the developing phase and more research needs to be done before it is capable of determining with some accuracy if there is a risk of getting hypothermia and to find a notification system that is adapted to the end user. In this section the recommendations for further studies are discussed

First of all, it is especially for the notification system important to find a way to involve the end user into the designing process. Their preferences and wishes should be taken into account when developing the notification system further. It is especially interesting to know what they would think about contacting other people if they themselves cannot react to the notification. At this stage only the homeless shelter organisations active in Enschede were contacted. To get a higher possibility to come in contact with homeless people, also shelter organisations in other cities can be contacted to see if they can be a gateway to them. Patience, flexibility and persistence is important when dealing with homeless people as a target group.

Besides the homeless people as a target group, is the Sheltersuit Foundation, at this moment, also looking for other target groups that could benefit from the Sheltersuit, like refugees in refugee camps. It could therefore be interesting to investigate who these target groups can be and how the hypothermia risk detection system needs to be adapted to be usable by and useful for these other target groups.

When looking at the monitoring system, at this stage, the hypothermia risk determination only depends on shivering of the user. The temperature threshold can also be calculated using Hin. However, how temperature and humidity relate to each other and to the body heat loss is still only a guess. Therefore, before the temperature and humidity data could be relied on for the system, it is important to understand how these two variables behave over time when the user is getting hypothermia. This will hopefully give a better understanding how they relate to each other, to the loss of body heat and to the duration of shivering that needs to be performed before it becomes dangerous for the user. As long as it is not clear how these relations work, only shivering data can be used to detect if someone is getting hypothermia, which decreases the accuracy of the system a lot.

The end prototype can distinguish between shivering and calm ordinary movements while the user keeps having the same posture. However all tests are done using one test person, making the results unreliable. Also because the data analysis is also done with data obtained using this test person. It is therefore unclear how the data can differ between users. Chapter 2 explains that there are different factors that can influence the shivering behaviour of a person. For example: amount of body fat, hypoglycaemia and alcohol or drug use. Therefore more data needs to be collected from multiple test persons to get a reliable dataset that can then be analysed.

For the laying on the left side positions the shoulder accelerometer was placed on the shoulder closest to the ground. It is assumed that this location influenced the obtained signals because the Sheltersuit at this location has little room to move. It is therefore interesting to investigate how the signal will look if the accelerometer was placed on the other shoulder, the farthest from the ground.

Also other locations to put the accelerometer can be researched to see which would work best. Furthermore, it is also interesting to investigate if multiple accelerometers will give more accurate results. Or if multiple accelerometer can be used to determine the posture of the user. To determine the difference between sitting straight or laying on the left side, the x-axis values of one accelerometer was enough. However, when multiple postures need to be distinguished from each other, it is possible that some postures that look like each other would have almost the same x, y and z values if only one accelerometer attached to one specific location is used.

Besides multiple accelerometers, there are also other options that can be investigated to see if they can be helpful in determining the posture of the user, like pressure sensors for example. Which options and how they should be implemented need to be researched further.

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Appendix A

Schematic overview of the concepts

Figure A.1: Schematic overview of concept 1

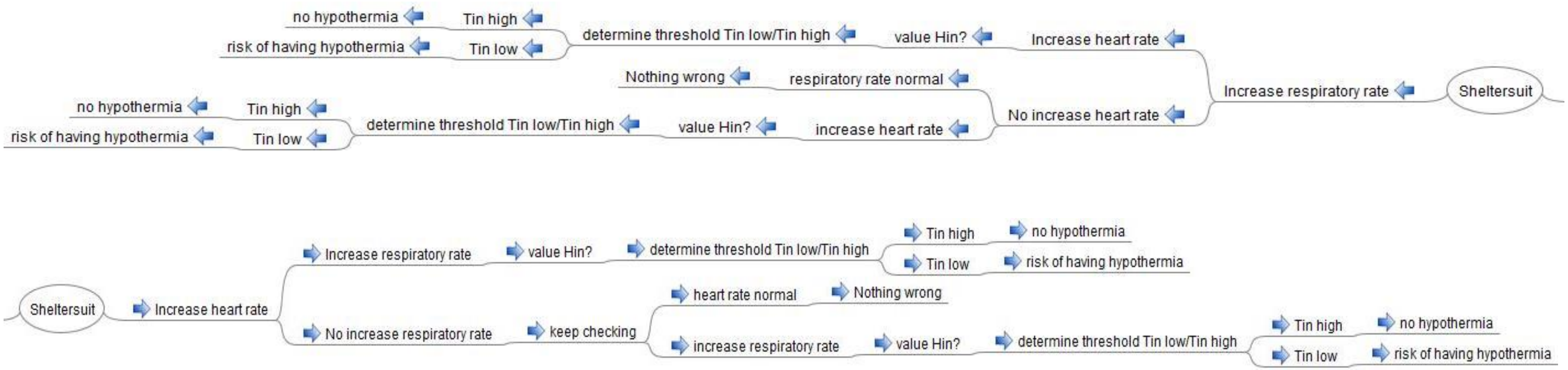


Figure A.2: Schematic overview of concept 2

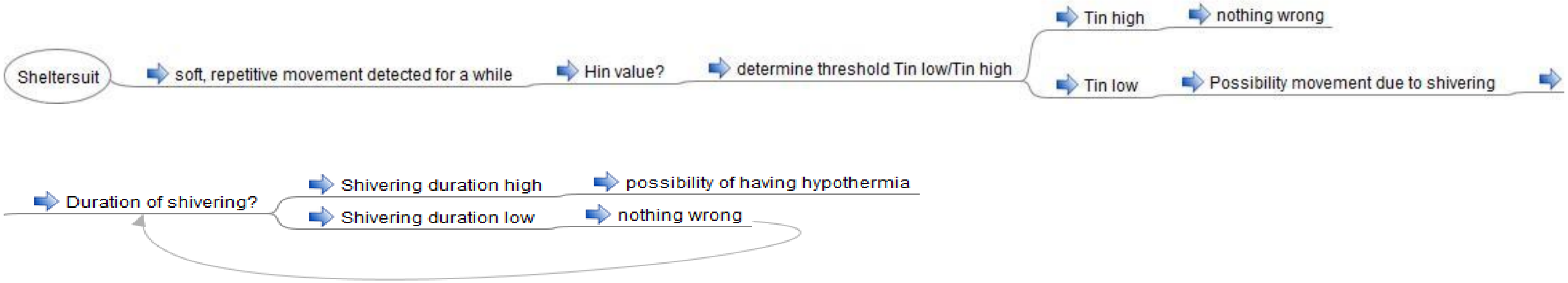


Figure A.3: Schematic overview of concept 3

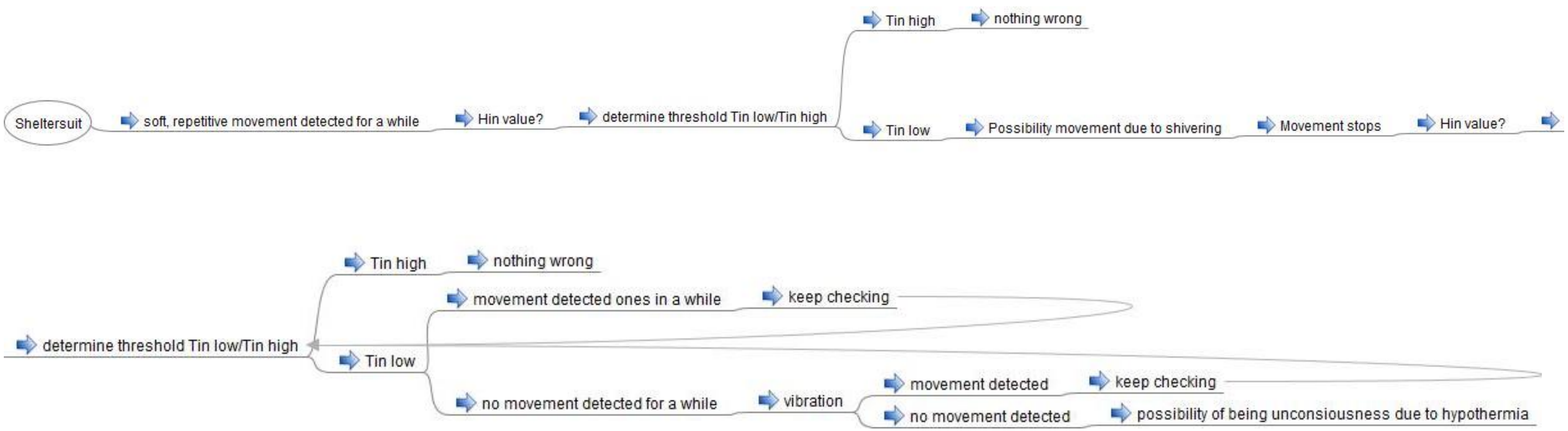


Figure A.4: Schematic overview of concept 4

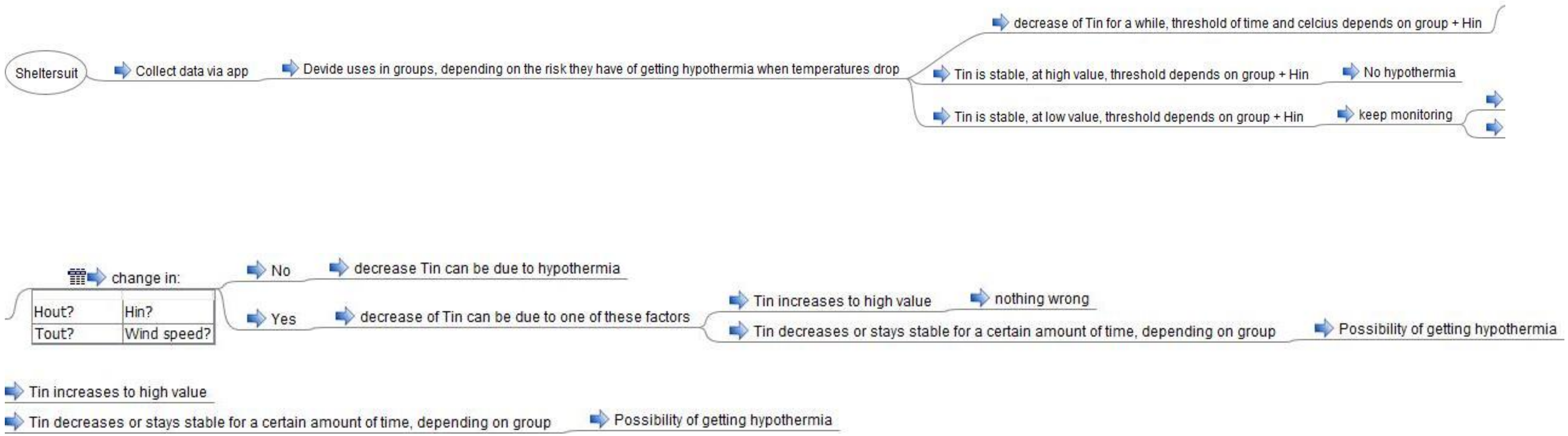


Figure A.5: Schematic overview of concept 5

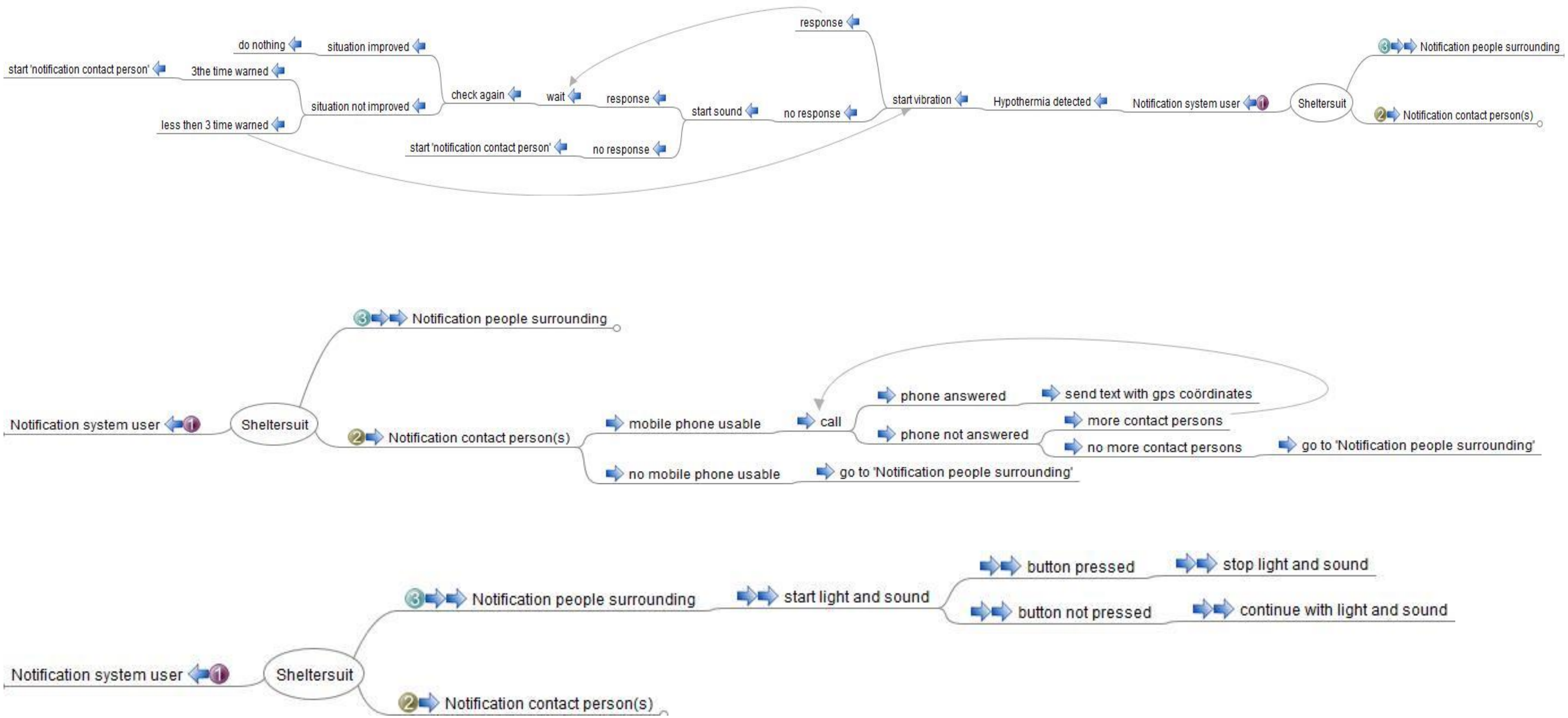
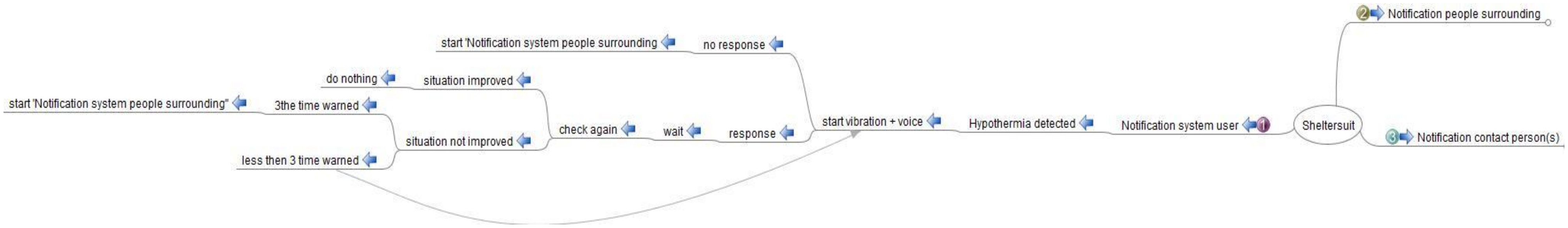
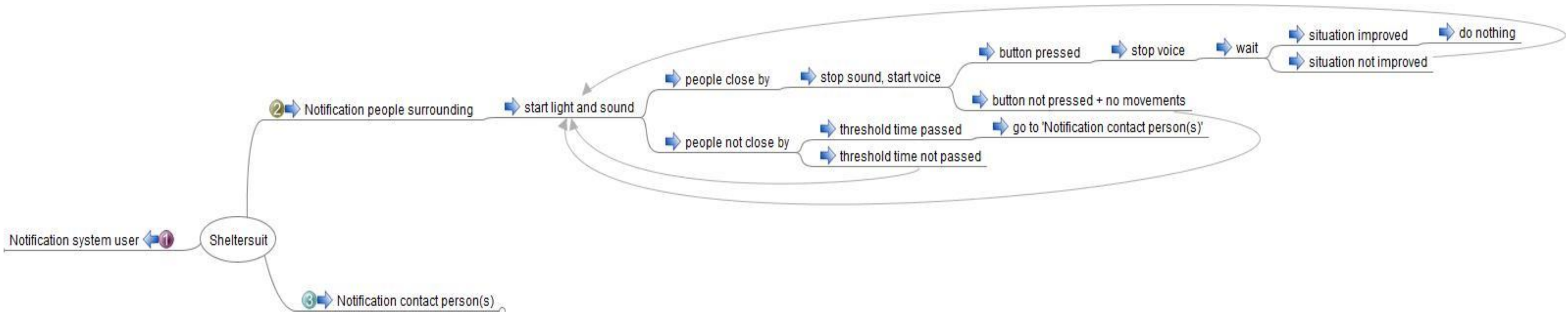


Figure A.6: Schematic overview notification system concept 6





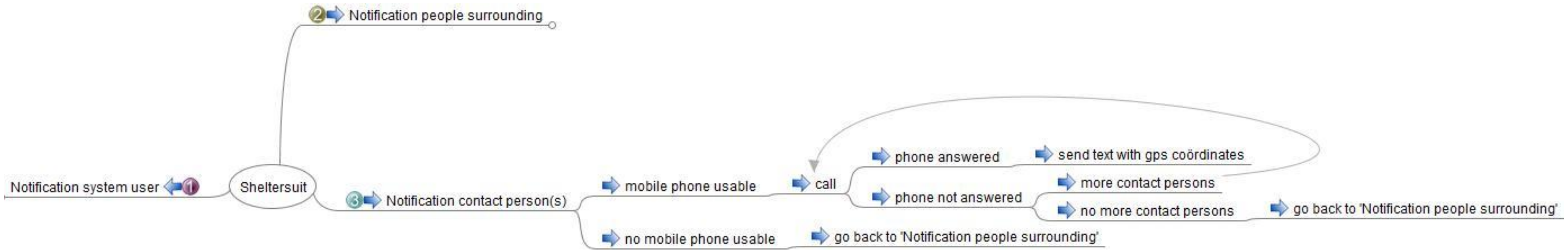


Figure A.7: Schematic overview notification system concept 7

Appendix B

Datasheet mma7361l accelerometer

Freescale Semiconductor
Technical Data

Document Number: MMA7361L
Rev 0, 04/2008

RoHS

±1.5g, ±6g Three Axis Low-g Micromachined Accelerometer

MMA7361L

MMA7361L: XYZ AXIS ACCELEROMETER ±1.5g, ±6g

The MMA7361L is a low power, low profile capacitive micromachined accelerometer featuring signal conditioning, a 1-pole low pass filter, temperature compensation, self test, 0g-Detect which detects linear freefall, and g-Select which allows for the selection between 2 sensitivities. Zero-g offset and sensitivity are factory set and require no external devices. The MMA7361L includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

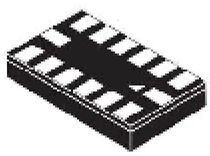
Features

- 3mm x 5mm x 1.0mm LGA-14 Package
- Low Current Consumption: 400 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- High Sensitivity (800 mV/g @ 1.5g)
- Selectable Sensitivity (±1.5g, ±6g)
- Fast Turn On Time (0.5 ms Enable Response Time)
- Self Test for Freefall Detect Diagnosis
- 0g-Detect for Freefall Protection
- Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- RoHS Compliant
- Environmentally Preferred Product
- Low Cost

Typical Applications

- 3D Gaming: Tilt and Motion Sensing, Event Recorder
- HDD MP3 Player: Freefall Detection
- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Robotics: Motion Sensing

Bottom View



14 LEAD LGA CASE 1977-01

Top View

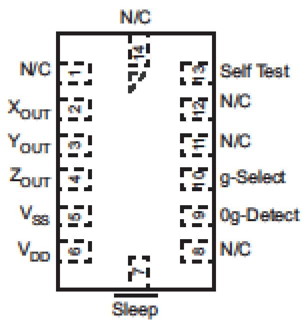


Figure 1. Pin Connections

ORDERING INFORMATION				
Part Number	**Temperature Range**	**Package Drawing**	**Package**	**Shipping**
MMA7361LT	–40 to +85°C	1977-01	LGA-14	Tray
MMA7361LR1	–40 to +85°C	1977-01	LGA-14	7" Tape & Reel
MMA7361LR2	–40 to +85°C	1977-01	LGA-14	13" Tape & Reel

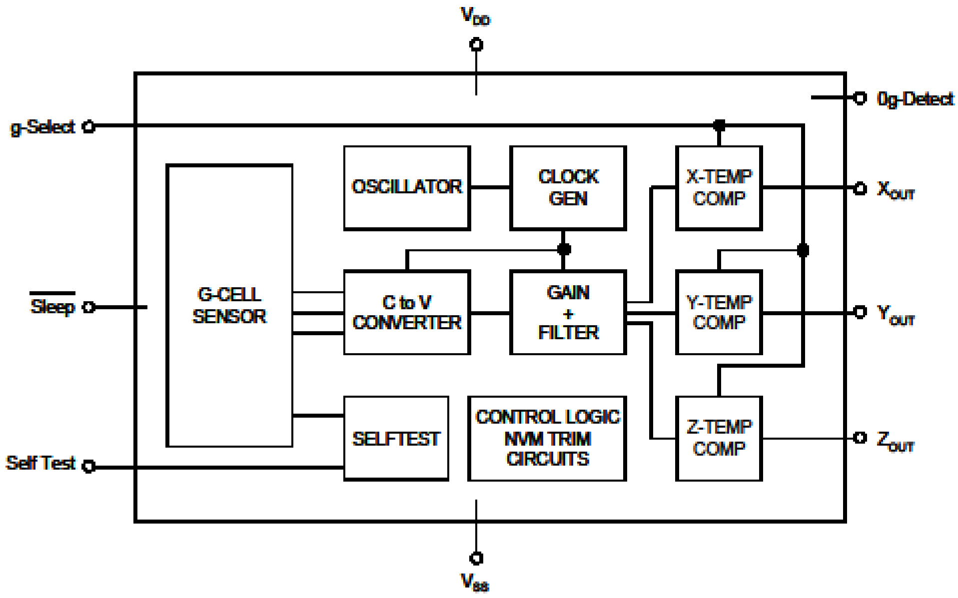


Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±5000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test[1]	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 2. Operating Characteristics
Unless otherwise noted: $-40°C \le T_A \le 85°C$, $2.2\ V \le V_{DD} \le 3.6\ V$, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current[4]	I_{DD}	—	400	600	µA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	µA
Operating Temperature Range	T_A	-40	—	+85	°C
Acceleration Range, X-Axis, Y-Axis, Z-Axis					
g-Select: 0	g_{FS}	—	±1.5	—	g
g-Select: 1	g_{FS}	—	±6.0	—	g
Output Signal					
Zero-g (T_A = 25°C, V_{DD} = 3.3 V)[5], [6]	V_{OFF}	1.485	1.65	1.815	V
Zero-g[4]	V_{OFF}, T_A	-2.0	±0.5	+2.0	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
1.5g	$S_{1.5g}$	740	800	860	mV/g
6g	S_{6g}	190.6	206	221.5	mV/g
Sensitivity[4]	S,T_A	-0.0075	±0.002	+0.0075	%/°C
Bandwidth Response					
XY	f_{-3dBXY}	—	400	—	Hz
Z	f_{-3dBZ}	—	300	—	Hz
Output Impedance	Z_O	—	32	—	kΩ
0g-Detect	$0g_{detect}$	-0.4	0	+0.4	g
Self Test					
Output Response					
X_{OUT}, Y_{OUT}	Δg_{STXY}	+0.05	-0.1	—	g
Z_{OUT}	Δg_{STZ}	+0.8	+1.0	+1.2	g
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Noise					
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[7]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[8]	t_{ENABLE}	—	0.5	2.0	ms
Self Test Response Time[9]	t_{ST}	—	2.0	5.0	ms
Sensing Element Resonant Frequency					
XY	$f_{GCELLXY}$	—	6.0	—	kHz
Z	f_{GCELLZ}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 3 µA)	V_{FSO}	V_{SS}+0.1	—	V_{DD}–0.1	V
Nonlinearity, X_{OUT}, Y_{OUT}, Z_{OUT}	NL_{OUT}	-1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[10]	$V_{XY, XZ, YZ}$	-5.0	—	+5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of an internal 32kΩ resistor and an external 3.3nF capacitor (recommended as a minimum to filter clock noise) on the analog output for each axis and a 0.1µF capacitor on V_{DD} - GND. The output sensor bandwidth is determined by the Capacitor added on the output. $f = 1/2\pi * (32 \times 10^3) * C$. C = 3.3 nF corresponds to BW = 1507HZ, which is the minimum to filter out internal clock noise.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 1.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$. For negative acceleration, the output will decrease below $V_{DD}/2$.
6. For optimal 0g offset performance, adhere to AN3484 and AN3447
7. The response time between 10% of full scale V_{DD} input voltage and 90% of the final operating output voltage.
8. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
9. The response time between 10% of the full scale self test input voltage and 90% of the self test output voltage.
10. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a signal conditioning ASIC contained in a single package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

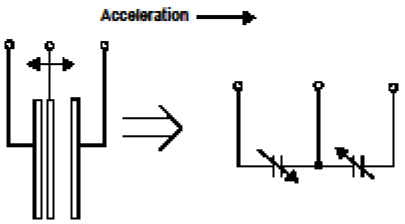


Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

0g-Detect

The sensor offers a 0g-Detect feature that provides a logic high signal when all three axes are at 0g. This feature enables the application of Linear Freefall protection if the signal is connected to an interrupt pin or a poled I/O pin on a microcontroller.

Self Test

The sensor provides a self test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as hard disk drive protection where system integrity must be ensured over the life of the product. Customers can use self test to verify the solderability to confirm that the part was mounted to the PCB correctly. To use this feature to verify the 0g-Detect function, the accelerometer should be held upside down so that the z-axis experiences -1g. When the self test function is initiated, an electrostatic force is applied to each axis to cause it to deflect. The x- and y-axis are deflected slightly while the z-axis is trimmed to deflect 1g. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

g-Select

The g-Select feature allows for the selection between two sensitivities. Depending on the logic input placed on pin 10, the device internal gain will be changed allowing it to function with a 1.5g or 6g sensitivity (Table 3). This feature is ideal when a product has applications requiring two different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select pin can be left unconnected for applications requiring only a 1.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (800mV/g)).

Table 3. g-Select Pin Description

g-Select	g-Range	Sensitivity
0	1.5g	800 mV/g
1	6g	206 mV/g

Sleep Mode

The 3 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 7 (Sleep Mode) will place the device in this mode and reduce the current to 3 μA typ. For lower power consumption, it is recommended to set g-Select to 1.5g mode. By placing a high input signal on pin 7, the device will resume to normal mode of operation.

Filtering

The 3 axis accelerometer contains an onboard single-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

BASIC CONNECTIONS

Pin Descriptions

Top View

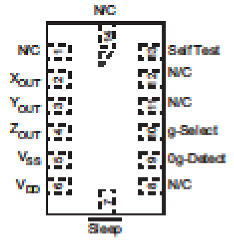


Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	N/C	No internal connection Leave unconnected
2	X_{OUT}	X direction output voltage
3	Y_{OUT}	Y direction output voltage
4	Z_{OUT}	Z direction output voltage
5	V_{SS}	Power Supply Ground
6	V_{DD}	Power Supply Input
7	$\overline{\text{Sleep}}$	Logic input pin to enable product or Sleep Mode
8	NC	No internal connection Leave unconnected
9	0g-Detect	Linear Freefall digital logic output signal
10	g-Select	Logic input pin to select g level
11	N/C	Unused for factory trim Leave unconnected
12	N/C	Unused for factory trim Leave unconnected
13	Self Test	Input pin to initiate Self Test
14	N/C	Unused for factory trim Leave unconnected

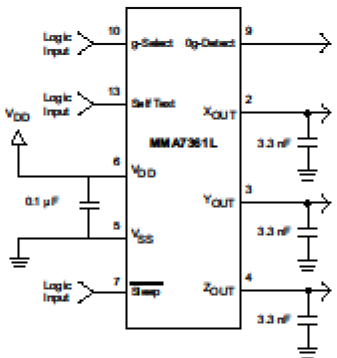


Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

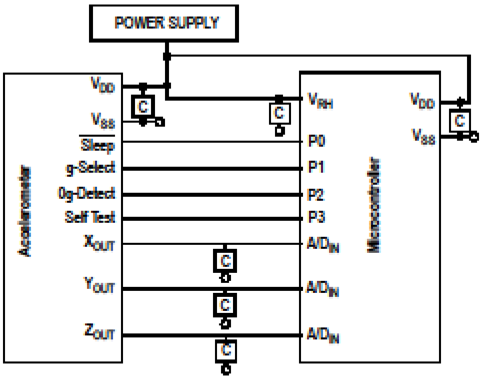
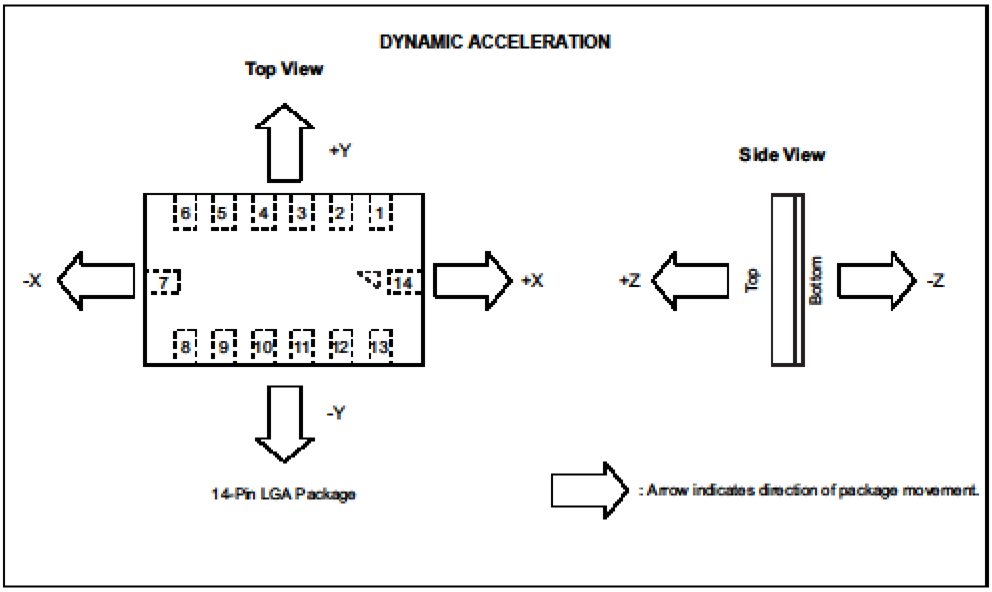
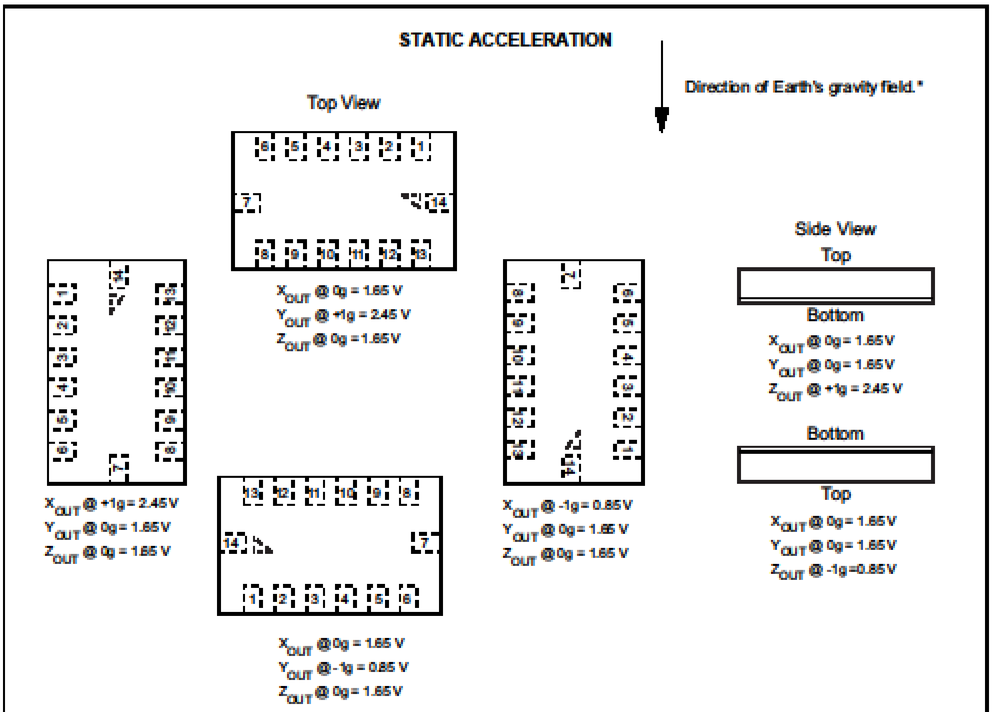


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use a 3.3nF capacitor on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.
8. 10MΩ or higher is recommended on X_{OUT}, Y_{OUT} and Z_{OUT} to prevent loss due to the voltage divider relationship between the internal 32 kΩ resistor and the measurement input impedance.





* When positioned as shown, the Earth's gravity will result in a positive 1g output.

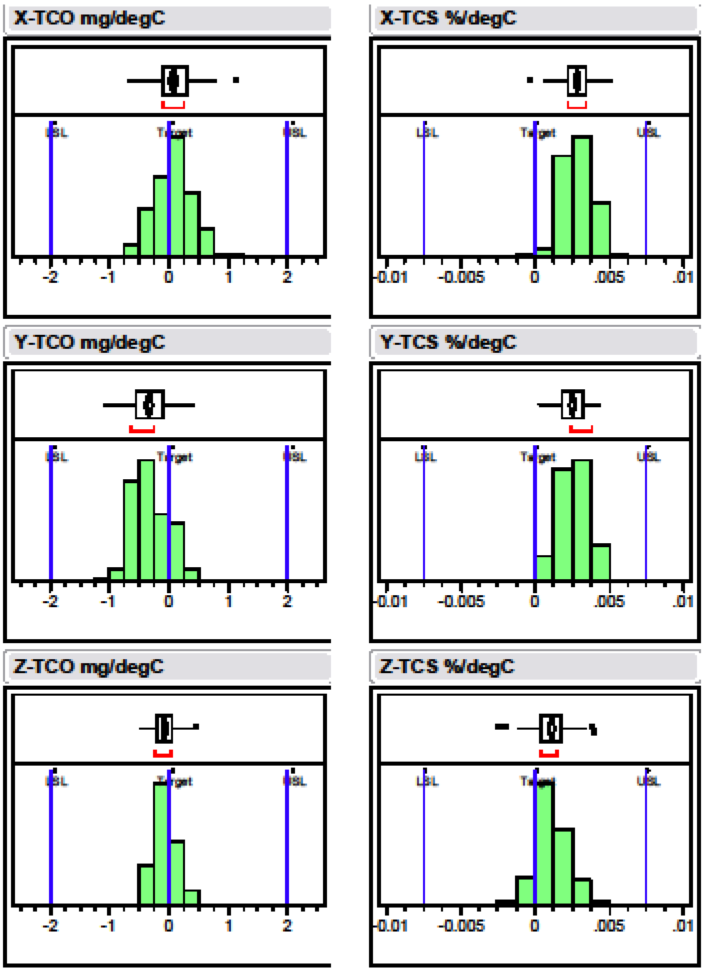


Figure 7. MMA7361L Temperature Coefficient of Offset (TCO) and Temperature Coefficient of Sensitivity (TCS) Distribution Charts

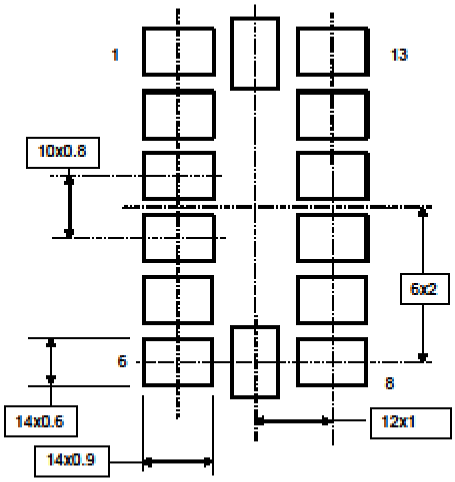
MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

PCB Mounting Recommendations

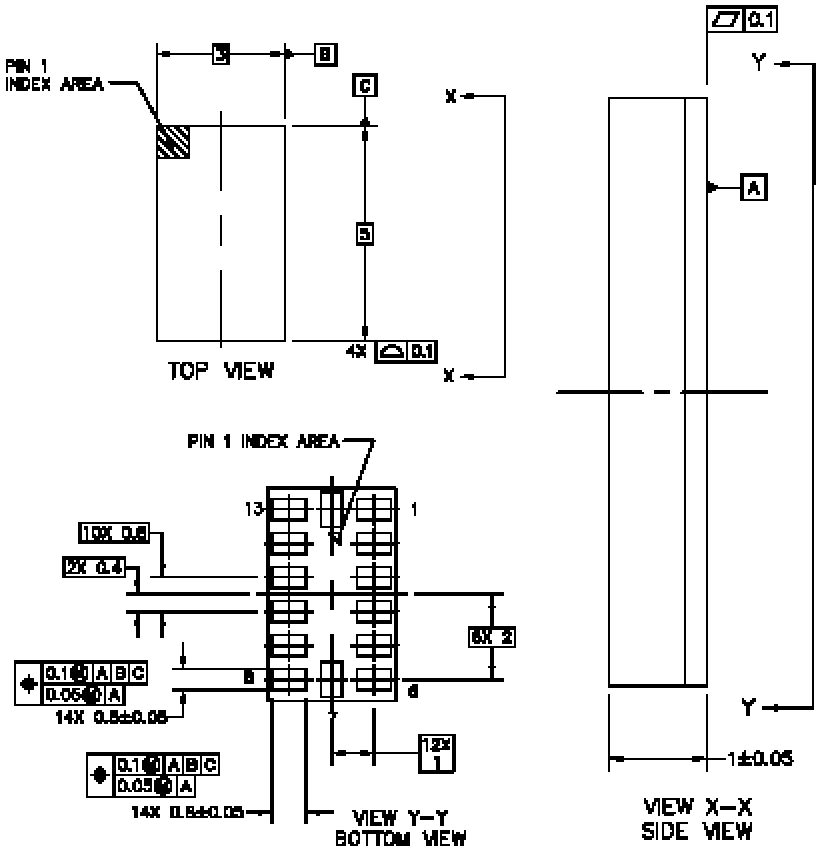
MEMS based sensors are sensitive to Printed Circuit Board (PCB) reflow processes. For optimal zero-g offset after PCB mounting, care must be taken to PCB layout and reflow conditions. Reference application note AN3484 for best practices to minimize the zero-g offset shift after PCB mounting.

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.



PACKAGE DIMENSIONS



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	CASE NUMBER: 1977–01	09 JAN 2008
	STANDARD: NON–JEDEC	

CASE 1977-01
ISSUE A
14-LEAD LGA

PACKAGE DIMENSIONS

NOTES:

1. ALL DIMENSIONS IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994.

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CASE 1977-01
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Rev. 0
04/2008

Appendix C

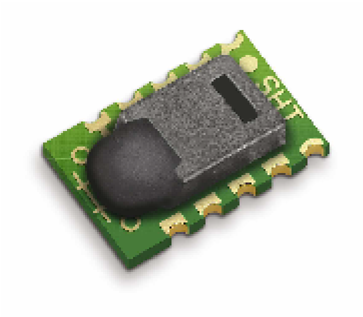
Datasheet SHT1x humidity/temperature sensor

SENSIRION
THE SENSOR COMPANY

Datasheet SHT1x (SHT10, SHT11, SHT15)

Humidity and Temperature Sensor

- Fully calibrated
- Digital output
- Low power consumption
- Excellent long term stability
- SMD type package – reflow solderable



Product Summary

SHT1x (including SHT10, SHT11 and SHT15) is Sensirion's family of surface mountable relative humidity and temperature sensors. The sensors integrate sensor elements plus signal processing on a tiny foot print and provide a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. The applied CMOSens® technology guarantees excellent reliability and long term stability. Both sensors are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit. This results in superior signal quality, a fast response time and insensitivity to external disturbances (EMC).

Each SHT1x is individually calibrated in a precision humidity chamber. The calibration coefficients are programmed into an OTP memory on the chip. These coefficients are used to internally calibrate the signals from the sensors. The 2-wire serial interface and internal voltage regulation allows for easy and fast system integration. The tiny size and low power consumption makes SHT1x the ultimate choice for even the most demanding applications.

SHT1x is supplied in a surface-mountable LCC (Leadless Chip Carrier) which is approved for standard reflow soldering processes. The same sensor is also available with pins (SHT7x) or on flex print (SHTA1).

Dimensions

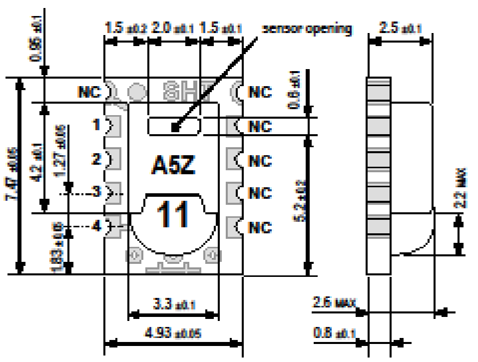


Figure 1: Drawing of SHT1x sensor packaging, dimensions in mm (1mm = 0.039inch). Sensor label gives "11" for SHT11 as an example. Contacts are assigned as follows: 1:GND, 2:DATA, 3:SCK, 4:VDD.

Sensor Chip

SHT1x V4 – for which this datasheet applies – features a version 4 Silicon sensor chip. Besides a humidity and a temperature sensor the chip contains an amplifier, A/D converter, OTP memory and a digital interface. V4 sensors can be identified by the alpha-numeric traceability code on the sensor cap – see example "A5Z" code on Figure 1.

Material Contents

While the sensor is made of a CMOS chip the sensor housing consists of an LCP cap with epoxy glob top on an FR4 substrate. The device is fully RoHS and WEEE compliant, thus it is free of Pb, Cd, Hg, Cr(6+), PBB and PBDE.

Evaluation Kits

For sensor trial measurements, for qualification of the sensor or even experimental application of the sensor there is an evaluation kit *EK-H2* available including sensor, hard and software to interface with a computer.

For more sophisticated and demanding measurements a multi port evaluation kit *EK-H3* is available which allows for parallel application of up to 20 sensors.

Version 4.0 – July 2008

Sensor Performance

Relative Humidity

Parameter	Condition	min	typ	max	Units
Resolution 1		0.4	0.05	0.05	%RH
		8	12	12	bit
Accuracy 2 SHT10	typical		±4.5		%RH
	maximal	see Figure 2			
Accuracy 2 SHT11	typical		±3.0		%RH
	maximal	see Figure 2			
Accuracy 2 SHT15	typical		±2.0		%RH
	maximal	see Figure 2			
Repeatability			±0.1		%RH
Replacement		fully interchangeable			
Hysteresis			±1		%RH
Nonlinearity	raw data		±3		%RH
	linearized		<<1		%RH
Response time 3	τ (63%)		8		s
Operating Range		0		100	%RH
Long term drift 4	normal		< 0.5		%RH/yr

Temperature

Parameter	Condition	min	typ	max	Units
Resolution 1		0.04	0.01	0.01	°C
		12	14	14	bit
Accuracy 2 SHT10	typical		±0.5		°C
	maximal	see Figure 3			
Accuracy 2 SHT11	typical		±0.4		°C
	maximal	see Figure 3			
Accuracy 2 SHT15	typical		±0.3		°C
	maximal	see Figure 3			
Repeatability			±0.1		°C
Replacement		fully interchangeable			
Operating Range		-40		123.8	°C
		-40		254.9	°F
Response Time 6	τ (63%)	5		30	s
Long term drift			< 0.04		°C/yr

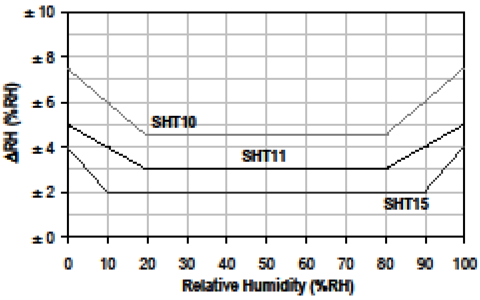


Figure 2: Maximal RH-accuracy at 25°C per sensor type.

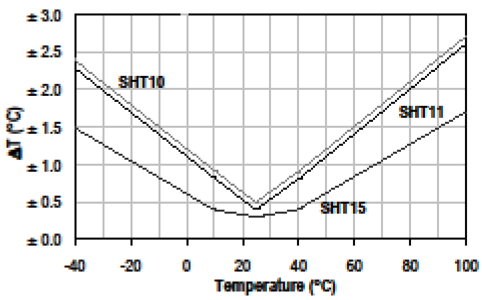


Figure 3: Maximal T-accuracy per sensor type.

Electrical and General Items

Parameter	Condition	min	typ	max	Units
Source Voltage		2.4	3.3	5.5	V
Power Consumption 5	sleep		2	5	µW
	measuring		3		mW
	average		150		µW
Communication	digital 2-wire interface, see Communication				
Storage	10 – 50°C (0 – 125°C peak), 20 – 60%RH				

Packaging Information

Sensor Type	Packaging	Quantity	Order Number
SHT10	Tape & Reel	2000	1-100218-04
SHT11	Tape & Reel	100	1-100051-04
	Tape & Reel	400	1-100098-04
	Tape & Reel	2000	1-100524-04
SHT15	Tape & Reel	100	1-100085-04
	Tape & Reel	400	1-100093-04

1 The default measurement resolution of is 14bit for temperature and 12bit for humidity. It can be reduced to 12/8bit by command to status register.
2 Accuracies are tested at Outgoing Quality Control at 25°C (77°F) and 3.3V. Values exclude hysteresis and non-linearity.
3 Time for reaching 63% of a step function, valid at 25°C and 1 m/s airflow.
4 Value may be higher in environments with high contents of volatile organic compounds. See Section 1.3 of Users Guide.
5 Values for VDD=5.5V at 25°C, average value at one 12bit measurement per second.
6 Response time depends on heat capacity of and thermal resistance to sensor substrate.

1 Application Information

1.1 Operating Conditions

Sensor works stable within recommended normal range – see Figure 4. Long term exposures to conditions outside normal range may temporarily offset the RH signal (+3 %RH after 60h). After return to normal range it will slowly return towards calibration state by itself. See Section 1.4. "Reconditioning Procedure" to accelerate eliminating the offset. Prolonged exposure to extreme conditions may accelerate ageing.

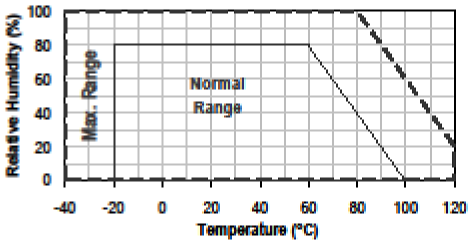


Figure 4: Operating Conditions

1.2 Soldering instructions

For soldering SHT1x standard reflow soldering ovens may be used. The sensor is qualified to withstand soldering profile according to IPC/JEDEC J-STD-020C with peak temperatures at 260°C during up to 40sec including Pb-free assembly in IR/Convection reflow ovens.

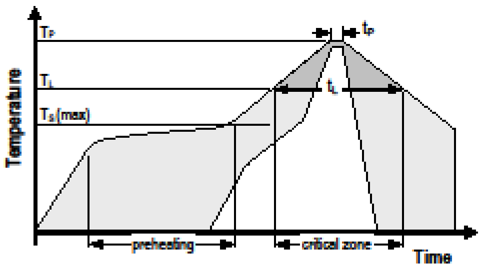


Figure 5: Soldering profile according to JEDEC standard. T_P <= 260°C and t_P < 40sec for Pb-free assembly. T_L < 220°C and t_L < 150sec. Ramp-up/down speeds shall be < 5°C/sec.

For soldering in Vapor Phase Reflow (VPR) ovens the peak conditions are limited to T_P < 233°C during t_P < 60sec and ramp-up/down speeds shall be limited to 10°C/sec. For manual soldering contact time must be limited to 5 seconds at up to 350°C[7].

IMPORTANT: After soldering the devices should be stored at >75%RH for at least 12h to allow the polymer to re-hydrate. Otherwise the sensor may read an offset that slowly disappears if exposed to ambient conditions.

In no case, neither after manual nor reflow soldering, a board wash shall be applied. Therefore it is strongly recommended to use "no-clean" solder paste. In case of application with exposure of the sensor to corrosive gases the soldering pads shall be sealed to prevent loose contacts or short cuts.

For the design of the SHT1x footprint it is recommended to use dimensions according to Figure 7. Sensor pads are coated with 35µm Cu, 5µm Ni and 0.1µm Au.

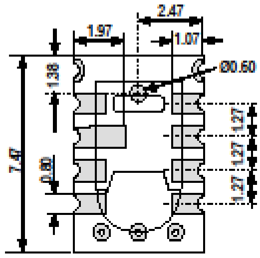


Figure 6: Rear side electrodes of sensor, view from top side.

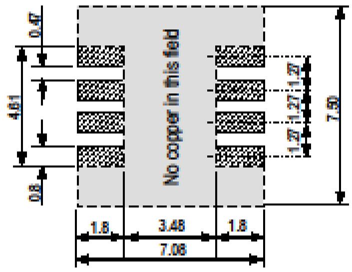


Figure 7: Recommended footprint for SHT1x. Values in mm.

1.3 Storage Conditions and Handling Instructions

It is of great importance to understand that a humidity sensor is not a normal electronic component and needs to be handled with care. Chemical vapors at high concentration in combination with long exposure times may offset the sensor reading.

For these reasons it is recommended to store the sensors in original packaging including the sealed ESD bag at following conditions: Temperature shall be in the range of 10°C – 50°C (0 – 125°C for limited time) and humidity at 20 – 60%RH (sensors that are not stored in ESD bags).

[7] 233°C = 451°F, 260°C = 500°F, 350°C = 662°F

For sensors that have been removed from the original packaging we recommend to stored them in ESD bags made of PE-HD[8].

In manufacturing and transport the sensors shall be prevented of high concentration of chemical solvents and long exposure times. Out-gassing of glues, adhesive tapes and stickers or out-gassing packaging material such as bubble foils, foams, etc. shall be avoided. Manufacturing area shall be well ventilated.

For more detailed information please consult the document *"Handling Instructions"* or contact Sensirion.

1.4 Reconditioning Procedure

As stated above extreme conditions or exposure to solvent vapors may offset the sensor. The following reconditioning procedure may bring the sensor back to calibration state:

Baking: 100 – 105°C at < 5%RH for 10h
Re-Hydration: 20 – 30°C at ~ 75%RH for 12h [9].

1.5 Temperature Effects

Relative humidity reading strongly depends on temperature. Therefore, it is essential to keep humidity sensors at the same temperature as the air of which the relative humidity is to be measured. In case of testing or qualification the reference sensor and test sensor must show equal temperature to allow for comparing humidity readings.

If the SHT1x shares a PCB with electronic components that produce heat it should be mounted in a way that prevents heat transfer or keeps it as low as possible. Measures to reduce heat transfer can be ventilation, reduction of copper layers between the SHT1x and the rest of the PCB or milling a slit into the PCB around the sensor (see Figure 8).

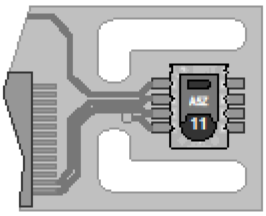


Figure 8: Top view of example of mounted SHT1x with slits milled into PCB to minimize heat transfer.

Furthermore, there are self-heating effects in case the measurement frequency is too high. Please refer to Section 3.3 for detailed information.

[8] For example, please check www.sirel.ch
[9] 75%RH can conveniently be generated with saturated NaCl solution. 100 – 105°C correspond to 212 – 221°F, 20 – 30°C correspond to 68 – 86°F

1.6 Light

The SHT1x is not light sensitive. Prolonged direct exposure to sunshine or strong UV radiation may age the housing.

1.7 Membranes

SHT1x does not contain a membrane at the sensor opening. However, a membrane may be added to prevent dirt and droplets from entering the housing and to protect the sensor. It will also reduce peak concentrations of chemical vapors. For optimal response times the air volume behind the membrane must be kept minimal. Sensirion recommends and supplies the SF1 filter cap for optimal IP54 protection (for higher protection – i.e. IP67 - SF1 must be sealed to the PCB with epoxy). Please compare Figure 9.

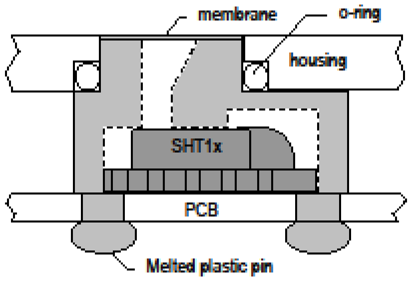


Figure 9: Side view of SF1 filter cap mounted between PCB and housing wall. Volume below membrane is kept minimal.

1.8 Materials Used for Sealing / Mounting

Many materials absorb humidity and will act as a buffer increasing response times and hysteresis. Materials in the vicinity of the sensor must therefore be carefully chosen. Recommended materials are: Any metals, LCP, POM (Delrin), PTFE (Teflon), PE, PEEK, PP, PB, PPS, PSU, PVDF, PVF.

For sealing and gluing (use sparingly): High filled epoxy for electronic packaging (e.g. glob top, underfill), and Silicone. Out-gassing of these materials may also contaminate the SHT1x (see Section 1.3). Therefore try to add the sensor as a last manufacturing step to the assembly, store the assembly well ventilated after manufacturing or bake at >50°C for 24h to outgas contaminants before packing.

1.9 Wiring Considerations and Signal Integrity

Carrying the SCK and DATA signal parallel and in close proximity (e.g. in wires) for more than 10cm may result in cross talk and loss of communication. This may be resolved by routing VDD and/or GND between the two data signals and/or using shielded cables. Furthermore, slowing down SCK frequency will possibly improve signal integrity. Power supply pins (VDD, GND) must be decoupled with a 100nF capacitor if wires are used.

Capacitor should be placed as close to the sensor as possible. Please see the Application Note "ESD, Latchup and EMC" for more information.

1.10 ESD (Electrostatic Discharge)

ESD immunity is qualified according to MIL STD 883E, method 3015 (Human Body Model at ±2 kV).

Latch-up immunity is provided at a force current of ±100mA with T_{amb} = 80°C according to JEDEC78A. See Application Note "ESD, Latchup and EMC" for more information.

2 Interface Specifications

Pin	Name	Comment
1	GND	Ground
2	DATA	Serial Data, bidirectional
3	SCK	Serial Clock, input only
4	VDD	Source Voltage
NC	NC	Must be left unconnected

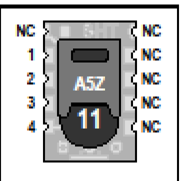


Table 1: SHT1x pin assignment, NC remain floating.

2.1 Power Pins (VDD, GND)

The supply voltage of SHT1x must be in the range of 2.4 – 5.5V, recommended supply voltage is 3.3V. Power supply pins Supply Voltage (VDD) and Ground (GND) must be decoupled with a 100 nF capacitor – see Figure 10.

The serial interface of the SHT1x is optimized for sensor readout and effective power consumption. The sensor cannot be addressed by I²C protocol, however, the sensor can be connected to an I²C bus without interference with other devices connected to the bus. The controller must switch between the protocols.

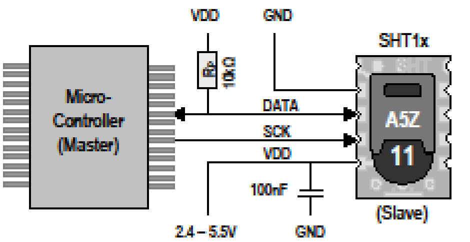


Figure 10: Typical application circuit, including pull up resistor R_P and decoupling of VDD and GND by a capacitor.

2.2 Serial clock input (SCK)

SCK is used to synchronize the communication between microcontroller and SHT1x. Since the interface consists of fully static logic there is no minimum SCK frequency.

2.3 Serial data (DATA)

The DATA tri-state pin is used to transfer data in and out of the sensor. For sending a command to the sensor, DATA is valid on the rising edge of the serial clock (SCK) and must remain stable while SCK is high. After the falling edge of SCK DATA may be changed. For safe communication DATA valid shall be extended T_{SU} and T_{HO} before the rising and after the falling edge of SCK, respectively – see Figure 11. For reading data from the sensor, DATA is valid T_V after SCK has gone low and remains valid until the next falling edge of SCK.

To avoid signal contention the microcontroller must only drive DATA low. An external pull-up resistor (e.g. 10kΩ) is required to pull the signal high – it should be noted that pull-up resistors may be included in I/O circuits of microcontrollers. See Table 2 for detailed I/O characteristic of the sensor.

2.4 Electrical Characteristics

The electrical characteristics such as power consumption, low and high level, input and output voltages depend on the supply voltage. Table 2 gives electrical characteristics of SHT1x with the assumption of 5V supply voltage if not stated otherwise. For proper communication with the sensor it is essential to make sure that signal design is strictly within the limits given in Table 3 and Figure 11.

Parameter	Conditions	min	typ	max	Units
Power supply DC[10]		2.4	3.3	5.5	V
Supply current	measuring		0.55	1	mA
	average[11]	2	28		µA
	sleep		0.3	1.5	µA
Low level output voltage	I_{OL} < 4 mA	0		250	mV
High level output voltage	R_P < 25 kΩ	90%		100%	VDD
Low level input voltage	Negative going	0%		20%	VDD
High level input voltage	Positive going	80%		100%	VDD
Input current on pads				1	µA
Output current	on			4	mA
	Tri-stated (off)		10	20	µA

Table 2: SHT1x DC characteristics. R_P stands for pull up resistor, while I_{OL} is low level output current.

[10] Recommended voltage supply for highest accuracy is 3.3V, due to sensor calibration.

[11] Minimum value with one measurement of 8 bit accuracy without OTP reload per second, typical value with one measurement of 12bit accuracy per second.

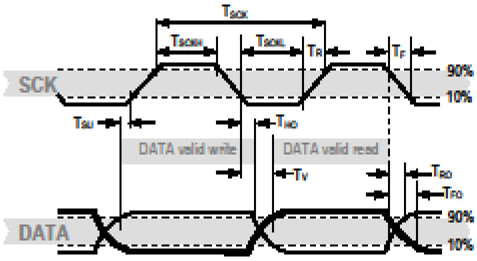


Figure 11: Timing Diagram, abbreviations are explained in Table 3. Bold DATA line is controlled by the sensor, plain DATA line is controlled by the micro-controller. Both valid times refer to the left SCK toggle.

	Parameter	Conditions	min	typ	max	Units
F_{SCK}	SCK Frequency	VDD > 4.5V	0	0.1	5	MHz
		VDD < 4.5V	0	0.1	1	MHz
T_{SCKx}	SCK hi/low time		100			ns
T_R/T_F	SCK rise/fall time		1	200	*	ns
T_{FO}	DATA fall time	OL = 5pF	3.5	10	20	ns
		OL = 100pF	30	40	200	ns
T_{RO}	DATA rise time		**	**	**	ns
T_V	DATA valid time		200	250	***	ns
T_{SU}	DATA setup time		100	150	***	ns
T_{HO}	DATA hold time		10	15	****	ns

* $T_{R\_max} + T_{F\_max} = (F_{SCK})^{-1} - T_{SCKH} - T_{SCKL}$

** T_{RO} is determined by the R_P*C_{bus} time-constant at DATA line

*** T_{V_max} and T_{SU_max} depend on external pull-up resistor (R_P) and total bus line capacitance (Cbus) at DATA line

**** $T_{HO\_max} < T_V - \max(T_{RO}, T_{FO})$

Table 3: SHT1x I/O signal characteristics, OL stands for Output Load, entities are displayed in Figure 11.

3 Communication with Sensor

3.1 Start up Sensor

As a first step the sensor is powered up to chosen supply voltage VDD. The slew rate during power up shall not fall below 1V/ms. After power-up the sensor needs 11ms to get to Sleep State. No commands must be sent before that time.

3.2 Sending a Command

To initiate a transmission, a Transmission Start sequence has to be issued. It consists of a lowering of the DATA line while SCK is high, followed by a low pulse on SCK and raising DATA again while SCK is still high – see Figure 12.

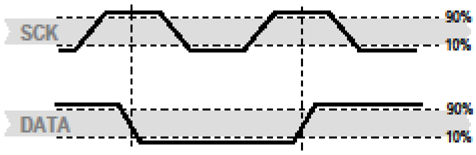


Figure 12: "Transmission Start" sequence

The subsequent command consists of three address bits (only '000' is supported) and five command bits. The SHT1x indicates the proper reception of a command by pulling the DATA pin low (ACK bit) after the falling edge of the 8th SCK clock. The DATA line is released (and goes high) after the falling edge of the 9th SCK clock.

Command	Code
Reserved	0000x
Measure Temperature	**00011**
Measure Relative Humidity	**00101**
Read Status Register	00111
Write Status Register	00110
Reserved	0101x-1110x
Soft reset, resets the interface, clears the status register to default values. Wait minimum 11 ms before next command	**11110**

Table 4: SHT1x list of commands

3.3 Measurement of RH and T

After issuing a measurement command ('00000101' for relative humidity, '00000011' for temperature) the controller has to wait for the measurement to complete. This takes a maximum of 20/80/320 ms for a 8/12/14bit measurement. The time varies with the speed of the internal oscillator and can be lower by up to 30%. To signal the completion of a measurement, the SHT1x pulls data line low and enters Idle Mode. The controller must wait for this Data Ready signal before restarting SCK to readout the data. Measurement data is stored until readout, therefore the controller can continue with other tasks and readout at its convenience.

Two bytes of measurement data and one byte of CRC checksum (optional) will then be transmitted. The micro controller must acknowledge each byte by pulling the DATA line low. All values are MSB first, right justified (e.g. the 5th SCK is MSB for a 12bit value, for a 8bit result the first byte is not used).

Communication terminates after the acknowledge bit of the CRC data. If CRC-8 checksum is not used the controller may terminate the communication after the measurement data LSB by keeping ACK high. The device automatically returns to Sleep Mode after measurement and communication are completed.

Important: To keep self heating below 0.1°C, SHT1x should not be active for more than 10% of the time – e.g. maximum one measurement per second at 12bit accuracy shall be made.

3.4 Connection reset sequence

If communication with the device is lost the following signal sequence will reset the serial interface: While leaving DATA high, toggle SCK nine or more times – see Figure 13. This must be followed by a Transmission Start sequence preceding the next command. This sequence resets the interface only. The status register preserves its content.

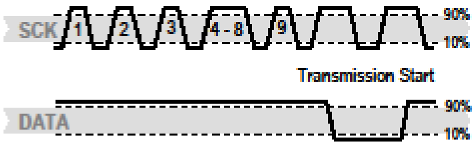


Figure 13: Connection Reset Sequence

3.5 CRC-8 Checksum calculation

The whole digital transmission is secured by an 8bit checksum. It ensures that any wrong data can be detected and eliminated. As described above this is an additional feature of which may be used or abandoned.

Please consult Application Note "CRC-8 Checksum Calculation" for information on how to calculate the CRC.

Status Register

Some of the advanced functions of the SHT1x such as selecting measurement resolution, end of battery notice or using the heater may be activated by sending a command to the status register. The following section gives a brief overview of these features. A more detailed description is available in the Application Note "Status Register".

After the command Status Register Read or Status Register Write – see Table 4 – the content of 8 bits of the status register may be read out or written. For the communication compare Figures 16 and 17 – the assignation of the bits is displayed in Table 5.

Figure 14: Status Register Write

Figure 15: Status Register Read

Examples of full communication cycle are displayed in Figures 15 and 16.

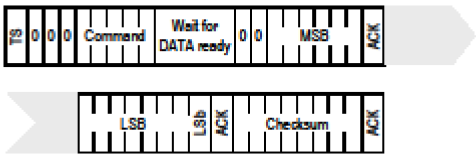


Figure 16: Overview of Measurement Sequence. TS = Transmission Start, MSB = Most Significant Byte, LSB = Last Significant Byte, LSb = Last Significant Bit.

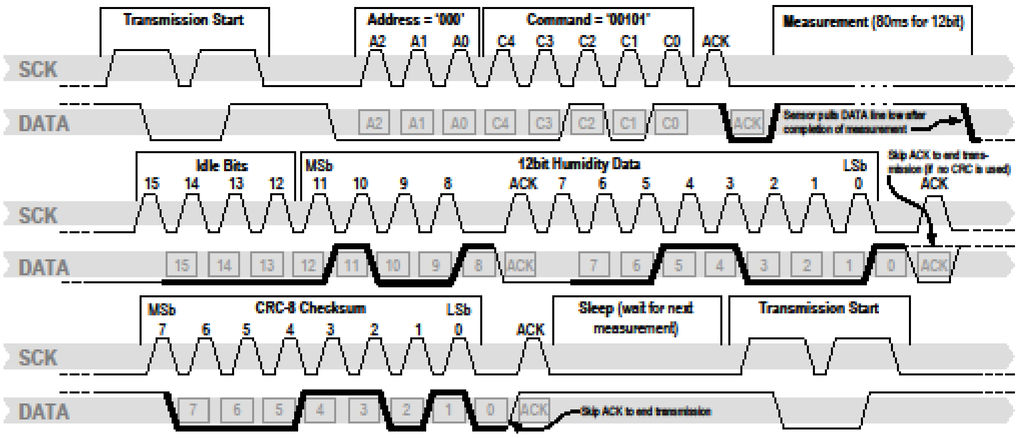


Figure 17: Example RH measurement sequence for value "0000'1001'0011'0001" = 2353 = 75.79 %RH (without temperature compensation). DATA valid times are given and referenced in boxes on DATA line. Bold DATA lines are controlled by sensor while plain lines are controlled by the micro-controller.

Bit	Type	Description	Default	
7		reserved	0	
6	R	End of Battery (low voltage detection) '0' for VDD > 2.47 '1' for VDD < 2.47	X	No default value, bit is only updated after a measurement
5		reserved	0	
4		reserved	0	
3		For Testing only, do not use	0	
2	R/W	Heater	0	off
1	R/W	no reload from OTP	0	reload
0	R/W	'1' = 8bit RH / 12bit Temp. resolution '0' = 12bit RH / 14bit Temp. resolution	0	12bit RH 14bit Temp.

Table 5: Status Register Bits

<u>Measurement resolution:</u> The default measurement resolution of 14bit (temperature) and 12bit (humidity) can be reduced to 12 and 8bit. This is especially useful in high speed or extreme low power applications.

<u>End of Battery</u> function detects and notifies VDD voltages below 2.47 V. Accuracy is ±0.05 V.

<u>Heater:</u> An on chip heating element can be addressed by writing a command into status register. The heater may increase the temperature of the sensor by 5 – 10°C[12] beyond ambient temperature. The heater draws roughly 8mA @ 5V supply voltage.

For example the heater can be helpful for functionality analysis: Humidity and temperature readings before and after applying the heater are compared. Temperature shall increase while relative humidity decreases at the same time. Dew point shall remain the same.

Please note: The temperature reading will display the temperature of the heated sensor element and not ambient temperature. Furthermore, the sensor is not qualified for continuous application of the heater.

4 Conversion of Signal Output

4.1 Relative Humidity

For compensating non-linearity of the humidity sensor – see Figure 18 – and for obtaining the full accuracy of the sensor it is recommended to convert the humidity readout (SO_{RH}) with the following formula with coefficients given in Table 6:

$$RH_{linear} = c_1 + c_2 \cdot SO_{RH} + c_3 \cdot SO_{RH}^{\ 2} \ (\%RH)$$

[12] Corresponds to 9 – 18°F

SO_{RH}	c_1	c_2	c_3
12 bit	-2.0468	0.0367	-1.5955E-6
8 bit	-2.0468	0.5872	-4.0845E-4

Table 6: Optimized V4 humidity conversion coefficients

The values given in Table 6 are newly introduced and provide optimized accuracy for V4 sensors along the full measurement range. The parameter set c_x*, which has been proposed in earlier datasheets, which was optimized for V3 sensors, still applies to V4 sensors and is given in Table 7 for reference.

SO_{RH}	c_1*	c_2*	c_3*
12 bit	-4.0000	0.0405	-2.8000E-6
8 bit	-4.0000	0.6480	-7.2000E-4

Table 7: V3 humidity conversion coefficients, which also apply to V4.

For simplified, less computation intense conversion formulas see Application Note "RH and Temperature Non-Linearity Compensation". Values higher than 99% RH indicate fully saturated air and must be processed and displayed as 100%RH[13]. Please note that the humidity sensor has no significant voltage dependency.

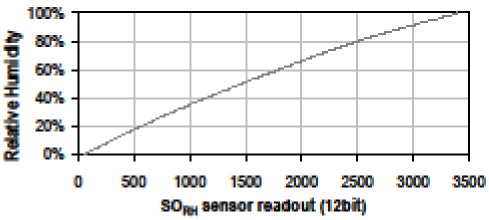


Figure 18: Conversion from SO_{RH} to relative humidity

4.2 Temperature compensation of Humidity Signal

For temperatures significantly different from 25°C (~77°F) the humidity signal requires a temperature compensation. The temperature correction corresponds roughly to 0.12%RH/°C @ 50%RH. Coefficients for the temperature compensation are given in Table 8.

$$RH_{true} = (T_{°C} - 25) \cdot (t_1 + t_2 \cdot SO_{RH}) + RH_{linear}$$

SO_{RH}	t_1	t_2
12 bit	0.01	0.00008
8 bit	0.01	0.00128

Table 8: Temperature compensation coefficients[14]

[13] If wetted excessively (strong condensation of water on sensor surface), sensor output signal can drop below 100%RH (even below 0%RH in some cases), but the sensor will recover completely when water droplets evaporate. The sensor is not damaged by water immersion or condensation.

[14] Coefficients apply both to V3 as well as to V4 sensors.

4.3 Temperature

The band-gap PTAT (Proportional To Absolute Temperature) temperature sensor is very linear by design. Use the following formula to convert digital readout (SO_T) to temperature value, with coefficients given in Table 9:

$$T = d_1 + d_2 \cdot SO_T$$

VDD	d_1 (°C)	d_1 (°F)
5V	-40.1	-40.2
4V	-39.8	-39.6
3.5V	-39.7	-39.5
3V	-39.6	-39.3
2.5V	-39.4	-38.9

SO_T	d_2 (°C)	d_2 (°F)
14bit	0.01	0.018
12bit	0.04	0.072

Table 9: Temperature conversion coefficients[15].

4.4 Dew Point

SHT1x is not measuring dew point directly, however dew point can be derived from humidity and temperature readings. Since humidity and temperature are both measured on the same monolithic chip, the SHT1x allows superb dew point measurements.

For dew point (T_d) calculations there are various formulas to be applied, most of them quite complicated. For the temperature range of -40 – 50°C the following approximation provides good accuracy with parameters given in Table 10:

$$T_d(RH,T) = T_n \cdot \frac{\ln\left(\frac{RH}{100\%}\right) + \frac{m \cdot T}{T_n + T}}{m - \ln\left(\frac{RH}{100\%}\right) - \frac{m \cdot T}{T_n + T}}$$

Temperature Range	Tn (°C)	m
Above water, 0 – 50°C	243.12	17.62
Above ice, -40 – 0°C	272.62	22.46

Table 10: Parameters for dew point (T_d) calculation.

Please note that "ln(…)" denotes the natural logarithm. For RH and T the linearized and compensated values for relative humidity and temperature shall be applied.

For more information on dew point calculation see Application Note "Dew point calculation".

5 Environmental Stability

If sensors are qualified for assemblies or devices, please make sure that they experience same conditions as the reference sensor. It should be taken into account that response times in assemblies may be longer, hence enough dwell time for the measurement shall be granted. For detailed information please consult Application Note "Qualification Guide".

The SHT1x sensor series were tested according to AEC-Q100 Rev. F qualification test method. Sensor specifications are tested to prevail under the AEC-Q100 temperature grade 2 test conditions listed in Table 11[16]. Sensor performance under other test conditions cannot be guaranteed and is not part of the sensor specifications. Especially, no guarantee can be given for sensor performance in the field or for customer's specific application.

Please contact Sensirion for detailed information.

Environment	Standard	Results[17]
HTSL	125°C, 1000 hours	Within specifications
TC	-50°C - 125°C, 1000 cycles Acc. JESD22-A104-C	Within specifications
UHST	130°C / 85%RH, 96h	Within specifications
THU	85°C / 85%RH, 1000h	Within specifications
ESD immunity	MIL STD 883E, method 3015 (Human Body Model at ±2kV)	Qualified
Latch-up	force current of ±100mA with T_{amb} = 80°C, acc. JEDEC 17	Qualified

Table 11: Qualification tests: HTSL = High Temperature Storage Lifetime, TC = Temperature Cycles, UHST = Unbiased Highly accelerated temperature and humidity Test, THU = Temperature humidity unbiased

6 Packaging

6.1 Packaging type

SHT1x are supplied in a surface mountable LCC (Leadless Chip Carrier) type package. The sensor housing consists of a Liquid Crystal Polymer (LCP) cap with epoxy glob top on a standard 0.8mm FR4 substrate. The device is fully RoHS and WEEE compliant – it is free of of Pb, Cd, Hg, Cr(6+), PBB and PBDE.

[15] Temperature coefficients have slightly been adjusted compared to datasheet SHTxx version 3.01. Coefficients apply to V3 as well as V4 sensors.

[16] Sensor operation temperature range is -40 to 105°C according to AEC-Q100 temperature grade 2.

[17] According to accuracy and long term drift specification given on Page 2.

Device size is 7.47 x 4.93 x 2.5 mm (0.29 x 0.19 x 0.1 inch), see Figure 1, weight is 100 mg.

6.2 Traceability Information

All SHT1x are marked with an alphanumeric, three digit code on the chip cap (for reference: V3 sensors were labeled with numeric codes) – see "A5Z" on Figure 1. The lot numbers allow full traceability through production, calibration and testing. No information can be derived from the code directly, respective data is stored at Sensirion and is provided upon request.

Labels on the reels are displayed in Figures 19 and 20, they both give traceability information.

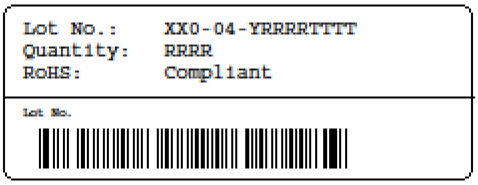


Figure 19: First label on reel: XX = Sensor Type (11 for SHT11), 04 = Chip Version (V4), Y = last digit of year, RRRR = number of sensors on reel, TTTT = Traceability Code.

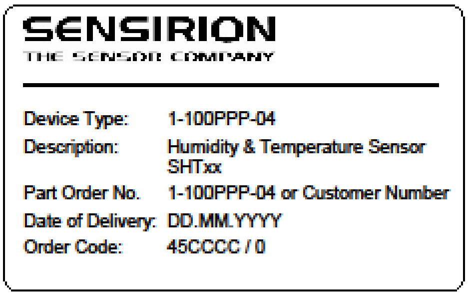


Figure 20: Second label on reel: For Device Type and Part Order Number please refer to Table 12, Delivery Date (also Date Code) is date of packaging of sensors (DD = day, MM = month, YYYY = year), CCCC = Sensirion order number.

6.3 Shipping Package

SHT1x are shipped in 12mm tape at 100pcs, 400pcs and 2000pcs – for details see Figure 21 and Table 12. Reels are individually labeled with barcode and human readable labels.

Sensor Type	Packaging	Quantity	Order Number
SHT10	Tape & Reel	2000	1-100218-04
SHT11	Tape & Reel	100	1-100051-04
	Tape & Reel	400	1-100098-04
	Tape & Reel	2000	1-100524-04
SHT15	Tape & Reel	100	1-100085-04
	Tape & Reel	400	1-100093-04

Table 12: Packaging types per sensor type.

Dimensions of packaging tape is given in Figure 21. All tapes have a minimum of 480mm empty leader tape (first pockets of the tape) and a minimum of 300mm empty trailer tape (last pockets of the tape).

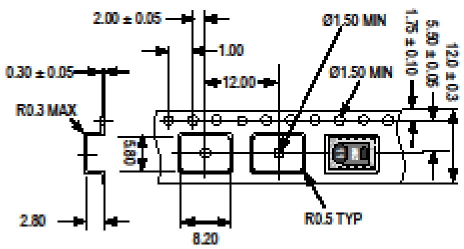


Figure 21: Tape configuration and unit orientation within tape, dimensions in mm (1mm = 0.039inch). The leader tape is at the right side of the figure while the trailer tape is to the left (direction of unreeling).

Revision History

Date	Version	Page(s)	Changes
March 2007	3.0	1 – 10	Data sheet valid for SHTxx-V4 and SHTxx-V3
August 2007	3.01	1 – 10	Electrical characteristics added, measurement time corrected
July 2008	4.0	1 – 10	New release, rework of datasheet

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product.
See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

This warranty does not apply to any equipment which has not been installed and used within the specifications recommended by SENSIRION for the intended and proper use of the equipment. EXCEPT FOR THE WARRANTIES EXPRESSLY SET FORTH HEREIN, SENSIRION MAKES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THE PRODUCT. ANY AND ALL WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSLY EXCLUDED AND DECLINED.
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Appendix D

Arduino code - collecting emulated shivering data

```
/*
  This code is used to collect data from 2 different accelerometers. The data is displayed on the serial
monitor and from there it can be copied to excel or another document.
  Parts of the code are based on the 'Sleeping Arduino - unless you joslte it!' code, made by Ed Halley

  Adjusted by Hinke Bosch, december 2017

*/

#include <math.h>


/* Accelerometer:
   Receive input from 2 3-axis devices.

   Specify the three axis pins, using analog pin
   numbers.  These are usually adjacent on the common breakout boards.

   Call the accelerometer's update() method occasionally to update the
   current values from the hardware.
*/

class Accelerometer
{
    int p[6]; // which analog pins
    int a[6]; // incoming data
    float b[6]; // acceleration, mapped
    int scale; // scaling factor between ADC and gravity
    float vector1; // vector magnitude
    float vector2;

  public:
    Accelerometer(int pinX, int pinY, int pinZ, int pinX2, int pinY2, int pinZ2)
    {
      pinMode((p[0] = pinX), INPUT);
      pinMode((p[1] = pinY), INPUT);
      pinMode((p[2] = pinZ), INPUT);
      pinMode((p[3] = pinX2), INPUT);
      pinMode((p[4] = pinY2), INPUT);
      pinMode((p[5] = pinZ2), INPUT);
      for (int i = 0; i < 6; i++) {
```

```
      a[i] = 0; // incoming data
      b[i] = 0; // scaled data to mg
    }
    scale = 1500; // sensitivity of the accelerometers, can be changed to 6000
    vector1 = 0;
    vector2 = 0;
  }

 // read incoming data from accelerometers and calculates the mg from the voltage.
  void update()
  {
    for (int i = 0; i < 6; i++) {
      a[i] = analogRead(p[i]);
      b[i] = mapf(a[i], 0, 675.84, -scale, scale); // for 3.3V
    }
// calculate magnitude vector of the incoming accelerometer data for both accelerometers
    vector1 =  sqrt(sq(b[0]) + sq(b[1]) + sq(b[2]));
    vector2 = sqrt(sq(b[3]) + sq(b[4]) + sq(b[5]));
  }

 // map data
  float mapf(float x, float in_min, float in_max, float out_min, float out_max)
  {
    return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
  }

 // display data on serial monitor
  void dump()
  {
    Serial.print(b[0]); // mapped data x as
    Serial.print("\t"); Serial.print(b[1]); // y as
    Serial.print("\t"); Serial.print(b[2]); // z as
    Serial.print("\t"); Serial.print(vector1); // vector magnitude

    Serial.print ("\t");
    Serial.print("\t"); Serial.print(b[3]); // mapped data x2 as
    Serial.print("\t"); Serial.print(b[4]); // y2 as
    Serial.print("\t"); Serial.print(b[5]); // z2 as
    Serial.print("\t"); Serial.print(vector2); // vector magnitude

    Serial.println();
  }

  void loop()
  {
    update();
  }
};
```

```
/*


*/
int count; // how often data needs to be collected
bool collecting;

void loop() {
  ;  // we do our own loop below
}

void setup()
{
  Serial.begin(115200);

  Accelerometer accel1 = Accelerometer(A0, A1, A2, A3, A4, A5); // making 1 accelerometer object for
2 accelerometers
  count = 0;
  collecting = true;

  //collecting data for 20 seconds
  while (collecting == true)
  {
    if (count > 150 && count <= 1150) { // 20 seconds
      accel1.loop(); // read and calculate mg from incoming accelerometers data
      accel1.dump(); // display data
    }
    if (count > 1150) {
      // Serial.println(millis());
      //     Serial.println("DONE");
      collecting = false;
    }
    count ++;
    delay(16); // because of serial.print this result in sample frequency of 50 Hz
  }
}
```

Appendix E

Matlab code - to compare location accelerometer and body posture

```
%%
% © Thomas Plaisier 02-02-2016.
% Aangepast door    Hinke Bosch january 2018
% Adaptatie van originele   script  van 'K.S.' aangezien    PortiLab2 niet
meer
% gebruikt  zal worden.
% Versie 1.02

%% Script


clear   variables
close   all
clc

filename = '1 binnen'; % fill in name of excel file where shivering data
for one body posture is stored

vectorSide=xlsread(filename, 'D:D'); % fill in column where vector can be
found of side accelerometer

vectorShoulder=xlsread(filename, 'H:H'); % vector of shoulder accelerometer

filter=1;
sample_time=1/50; %sample frequency of 50 Hz
time=[sample_time   : sample_time   : length(vectorSide)*sample_time]';


vectorSide=vectorSide(:,1);
vectorShoulder=vectorShoulder(:,1);

figure(1) % original signal side and shoulder
plot(time(1/sample_time:end), vectorSide(1/sample_time:end),
time(1/sample_time:end), vectorShoulder(1/sample_time:end));
title('Shivering signals while standing');
xlabel('time(sec)');
ylabel('G-force in mg');
legend('Side', 'Shoulder');

%composing FFT of the shoulder vector
[vectorShoulderSf, vectorShoulderSym, vectorShoulderSyp] = myfft( time,
vectorShoulder); % fft  original    signal

figure(2) % fft original signal shoulder
plot(vectorShoulderSf, vectorShoulderSym);
axis ([0 20 0 10]);
title('FFT standing');
xlabel ('frequency (Hz)');
```

```
legend('Shivering');

%
```

myfft function

```
function [ f, ym, yp ] = myfft( t, x )
%MYFFT Computes the FFT according to Shiavi (basically double sided DFT).
%For this to happen, we need to divide the fft by the length of the signal
%array (i.e. length of x).
%This function strips the second half of the FFT result (redundant part).

% t: time array
% x: signal value array
% f: frquency array
% ym: magnitude of fft(x)
% yp: phase of fft(x)

s = ceil(length(x)/2);
y = fft(x)/ length(x);
y = y(1:s);
ym = abs(y);
yp = angle(y);
f = 0:(s-1);
fspacing = 1 / ( length(t) * (t(2)-t(1)));
f = fspacing .* f;

end
```

Appendix F

Signals obtained with different location accelerometer

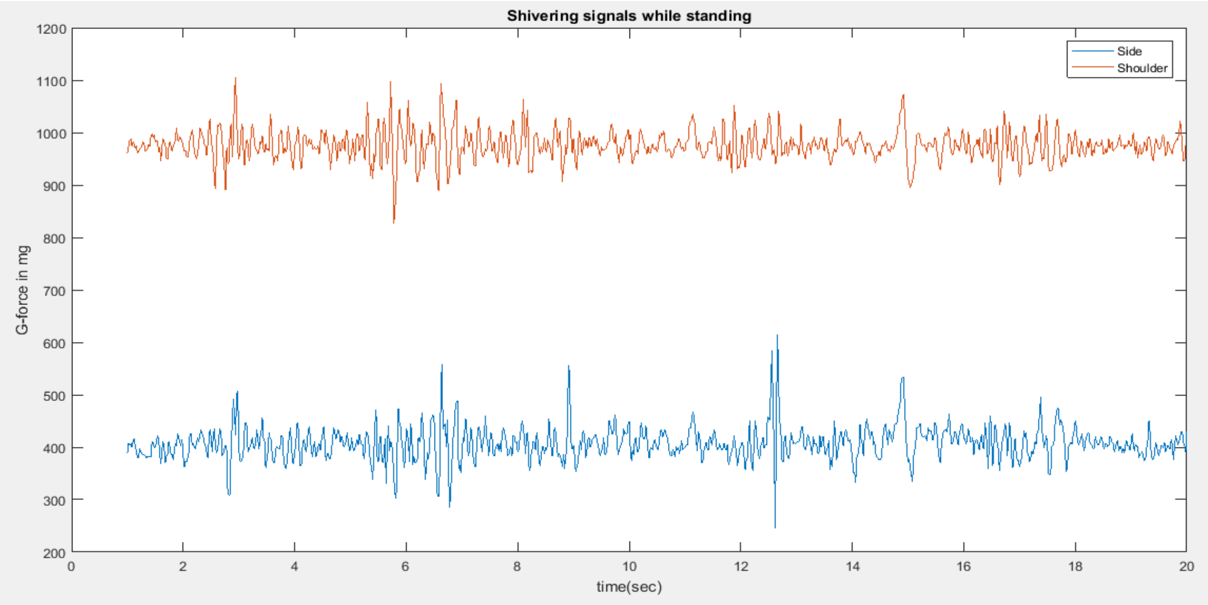

Figure F.1: Difference between shoulder signal and side signal while standing

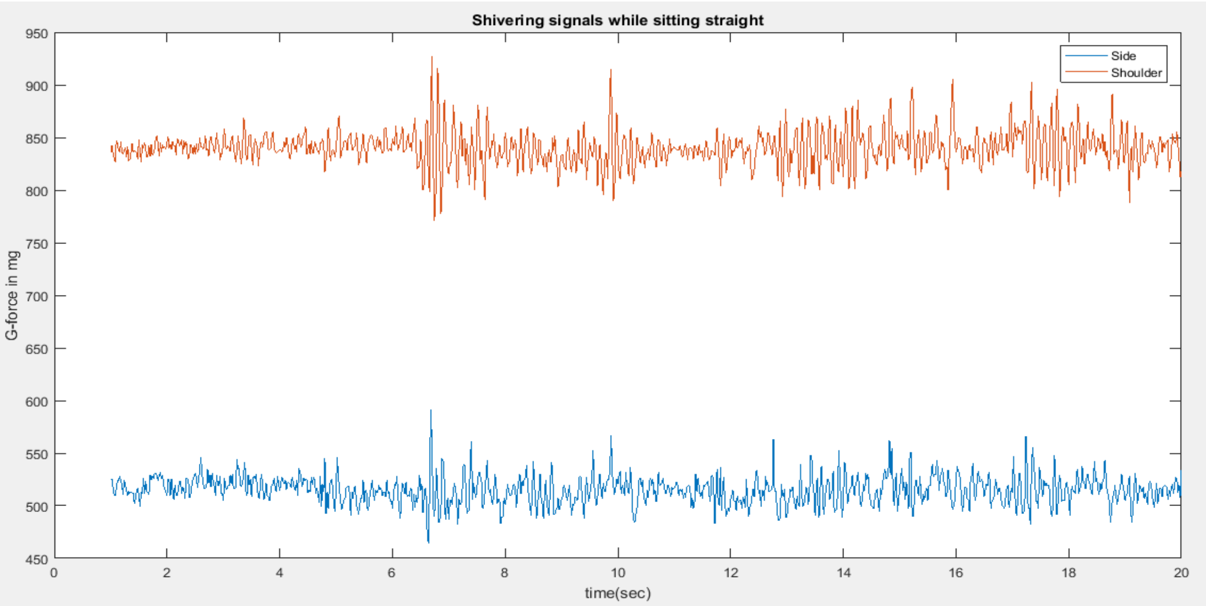

Figure F.2: Difference between shoulder signal and side signal while sitting straight

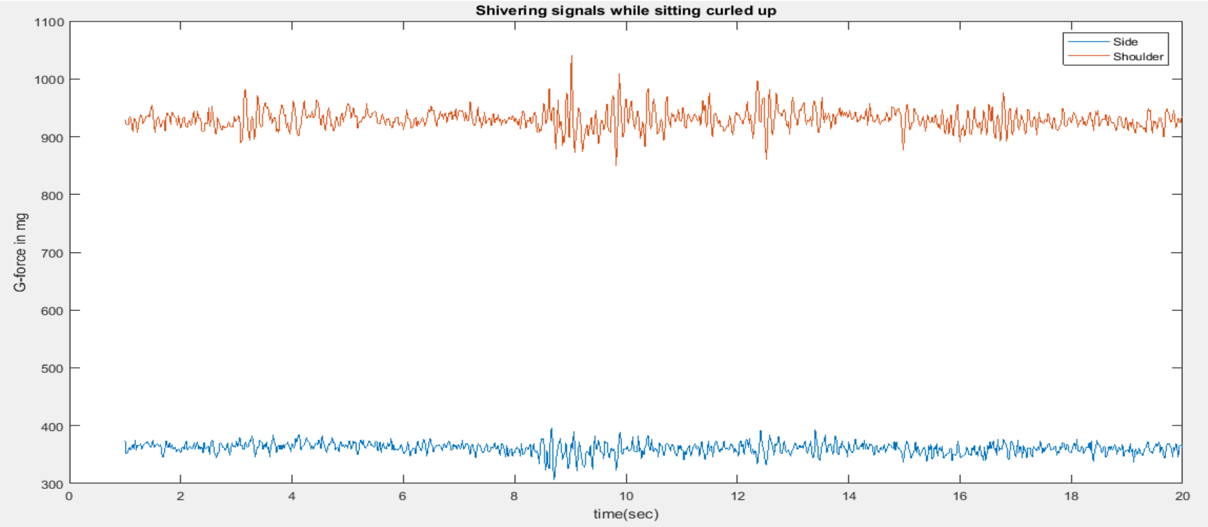

Figure F.3: Difference between shoulder signal and side signal while sitting curled up

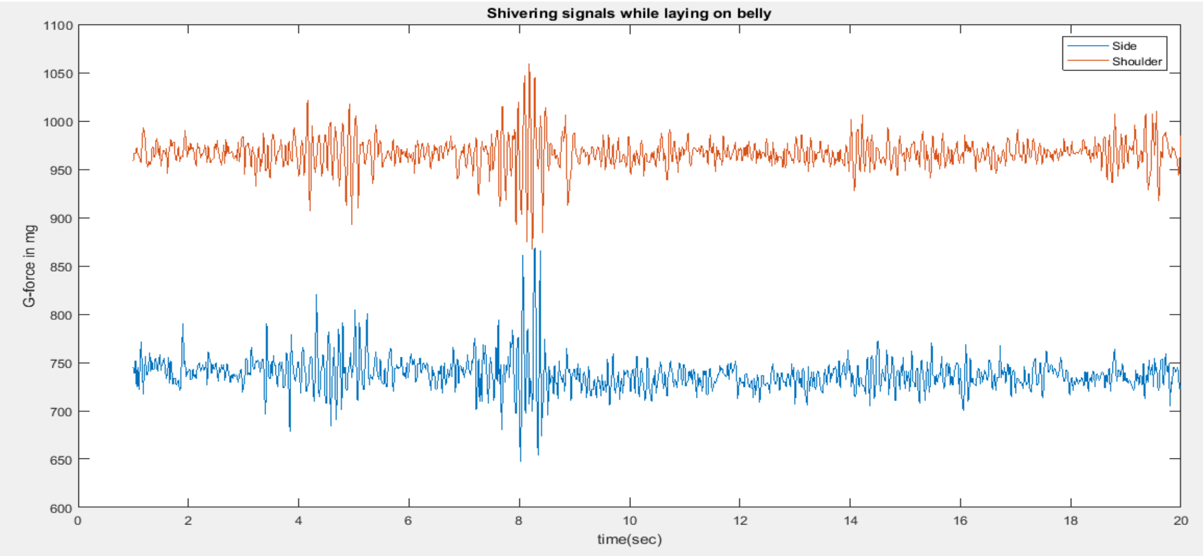

Figure F.4: Difference between shoulder signal and side signal while laying on belly

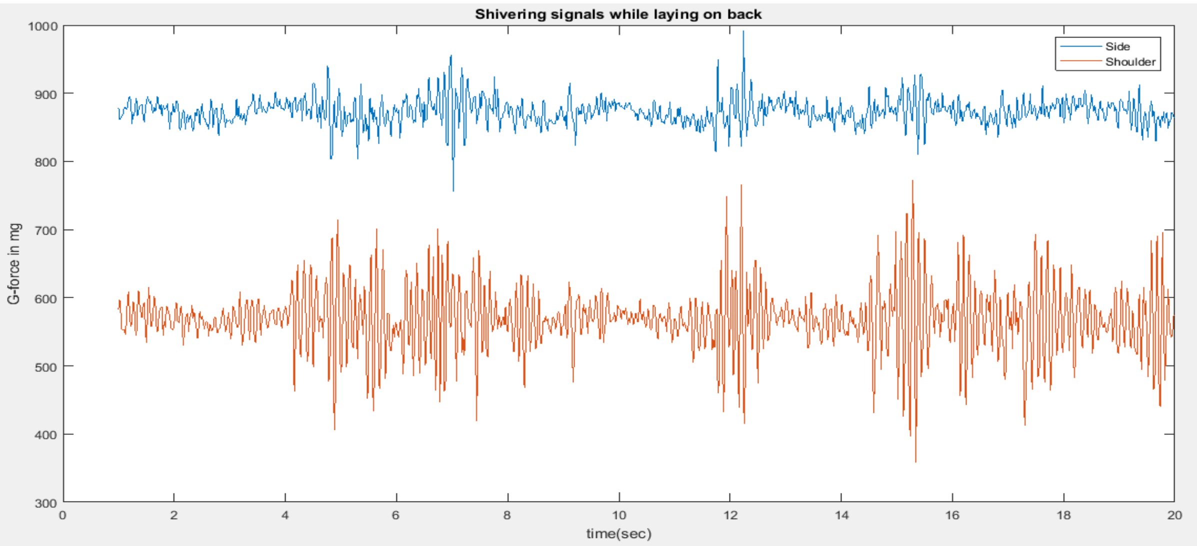

Figure F.5: Difference between shoulder signal and side signal while laying on back

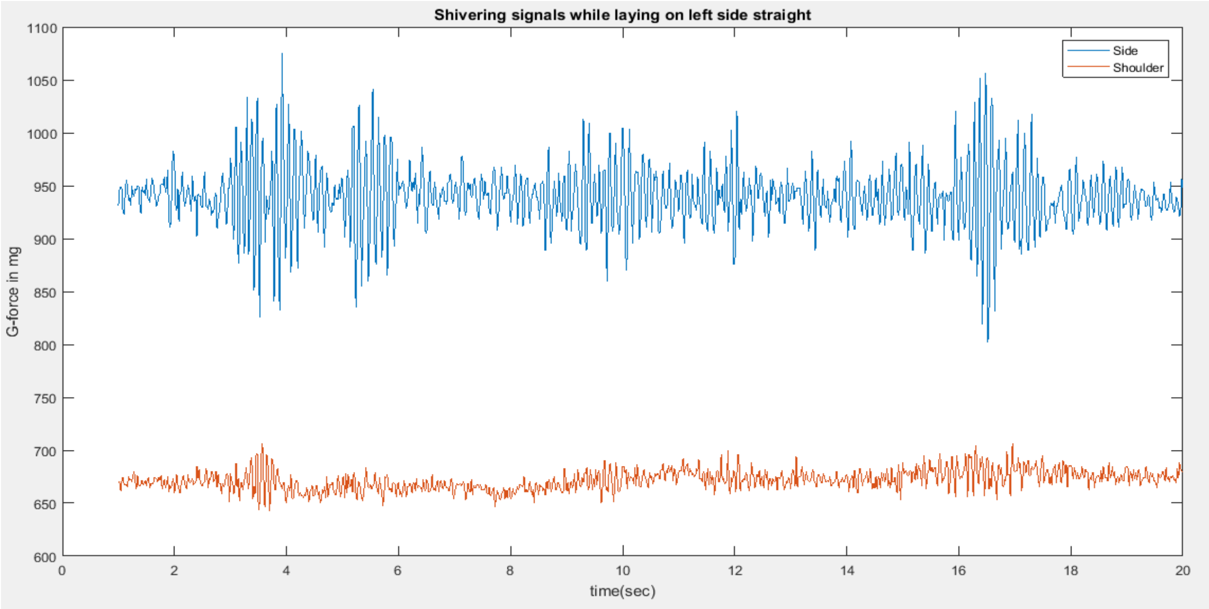

Figure F.6: Difference between shoulder signal and side signal while laying on left side straight

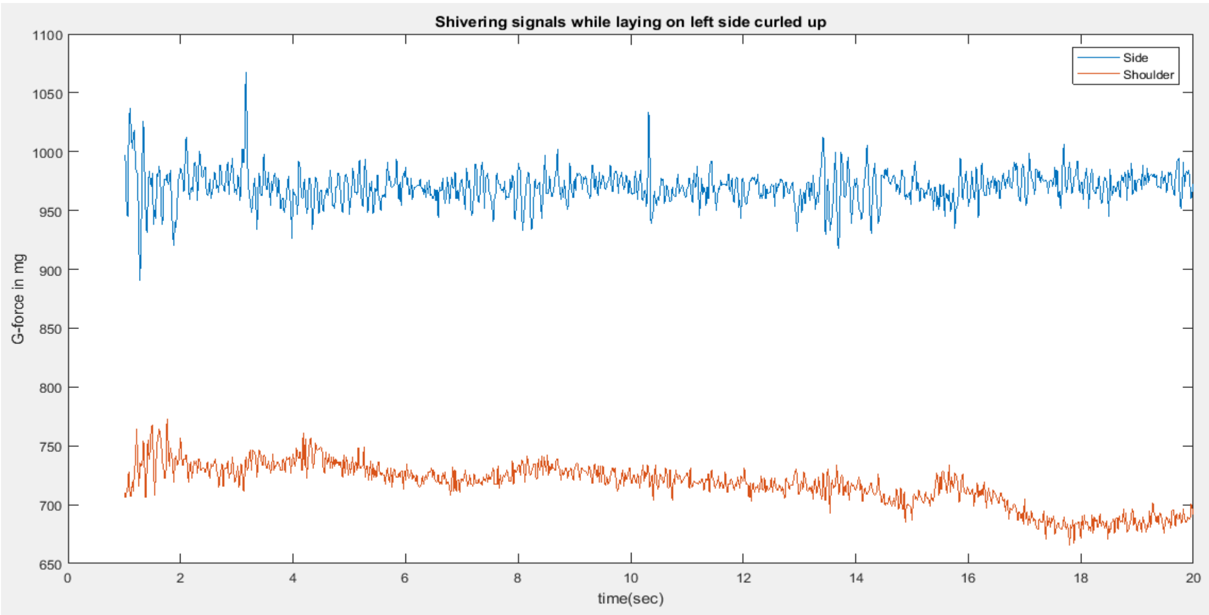

Figure F.795: Difference between shoulder signal and side signal while laying on left side curled up

Appendix G

FFT signals obtained from the emulated shivering data

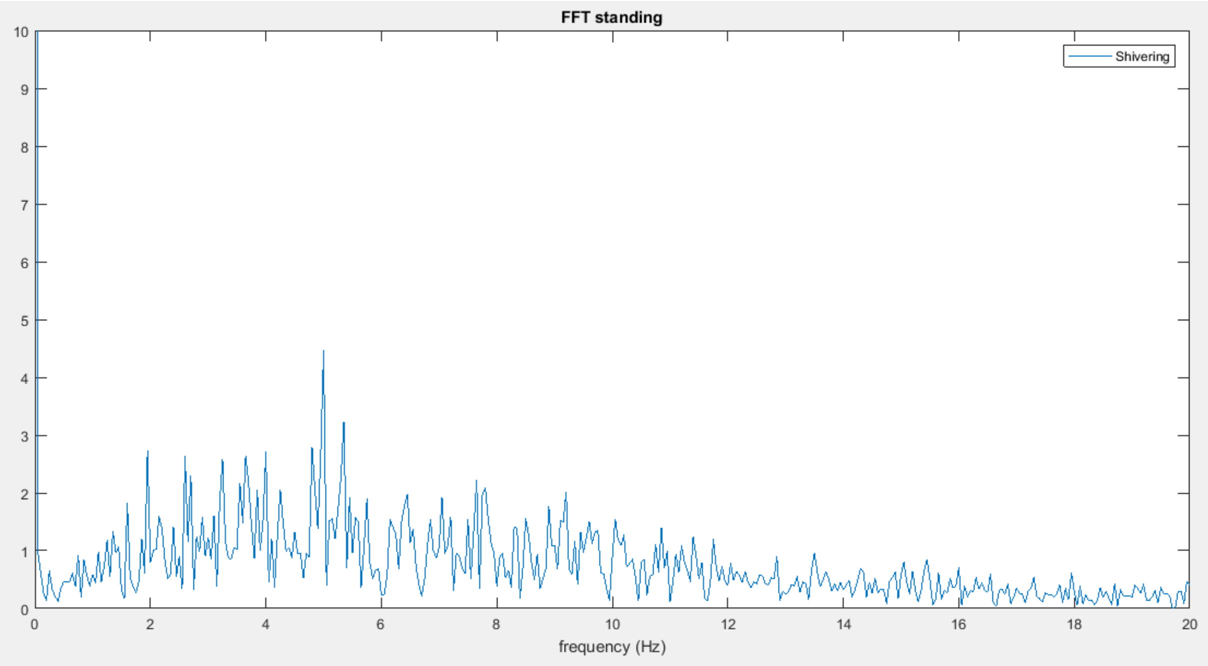

Figure G.1: FFT signal, for the standing posture, obtained from the accelerometer located at the shoulder

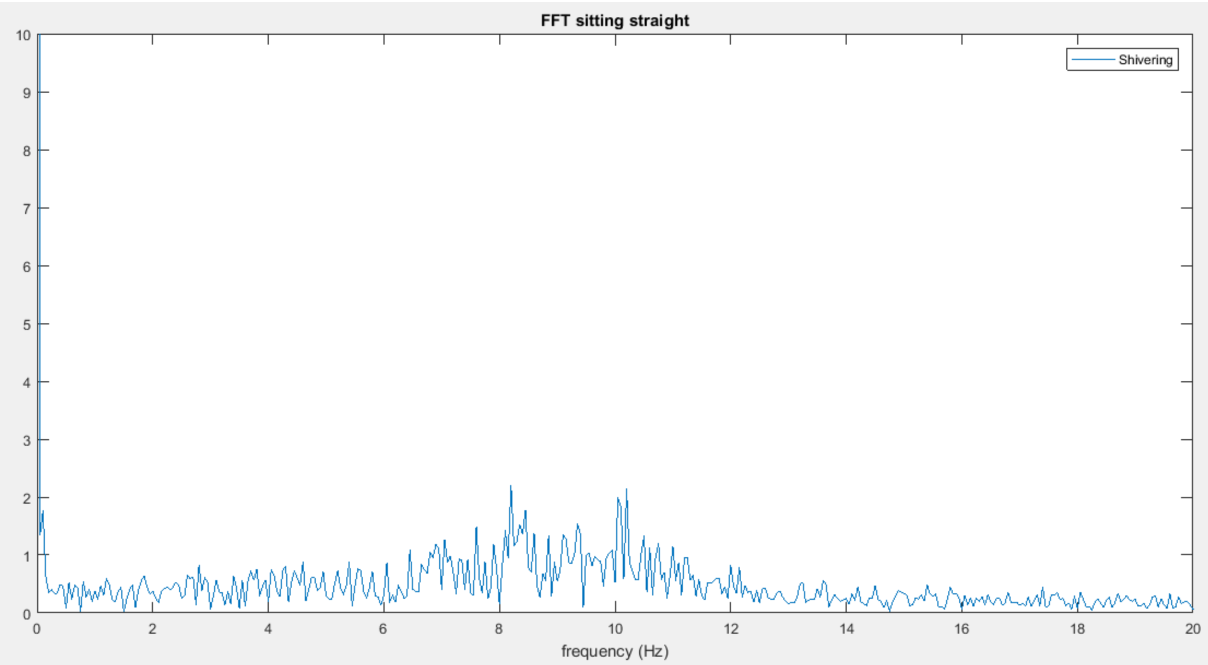

Figure G.2: FFT signal, for the sitting straight posture, obtained from the accelerometer located at the shoulder

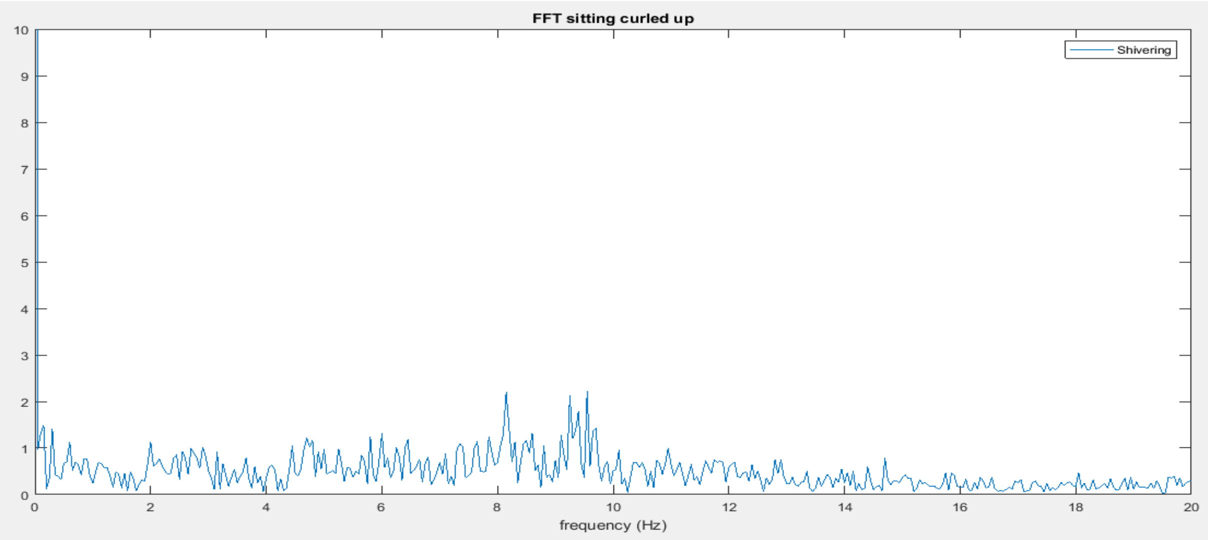

Figure G.3: FFT signal, for the sitting curled up posture, obtained from the accelerometer located at the shoulder

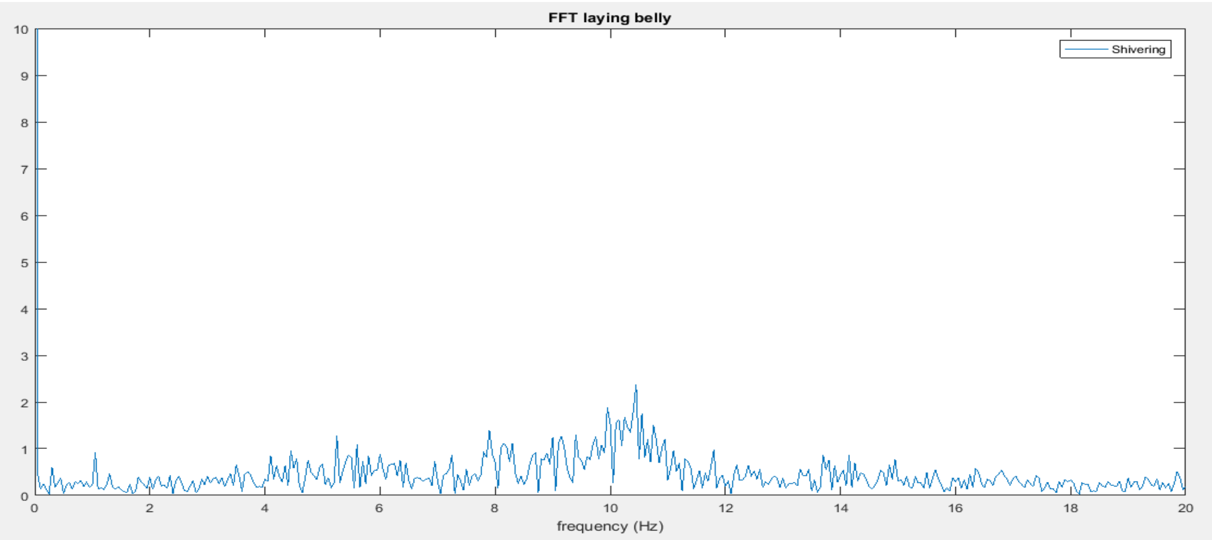

Figure G.4: FFT signal, for the laying on belly posture, obtained from the accelerometer located at the shoulder

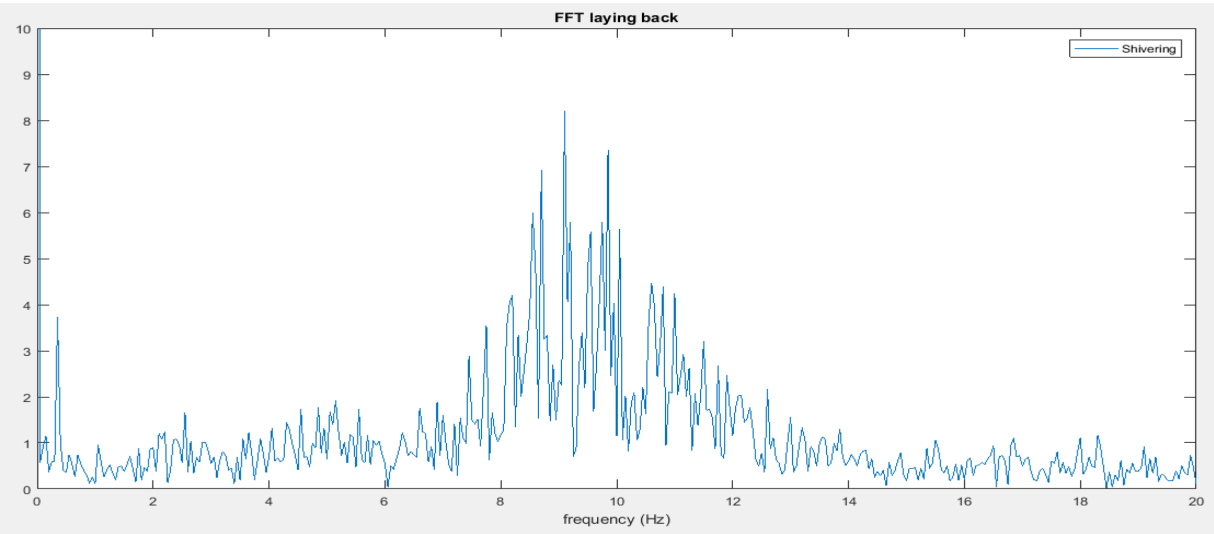

Figure G.5: FFT signal, for the laying on back posture, obtained from the accelerometer located at the shoulder

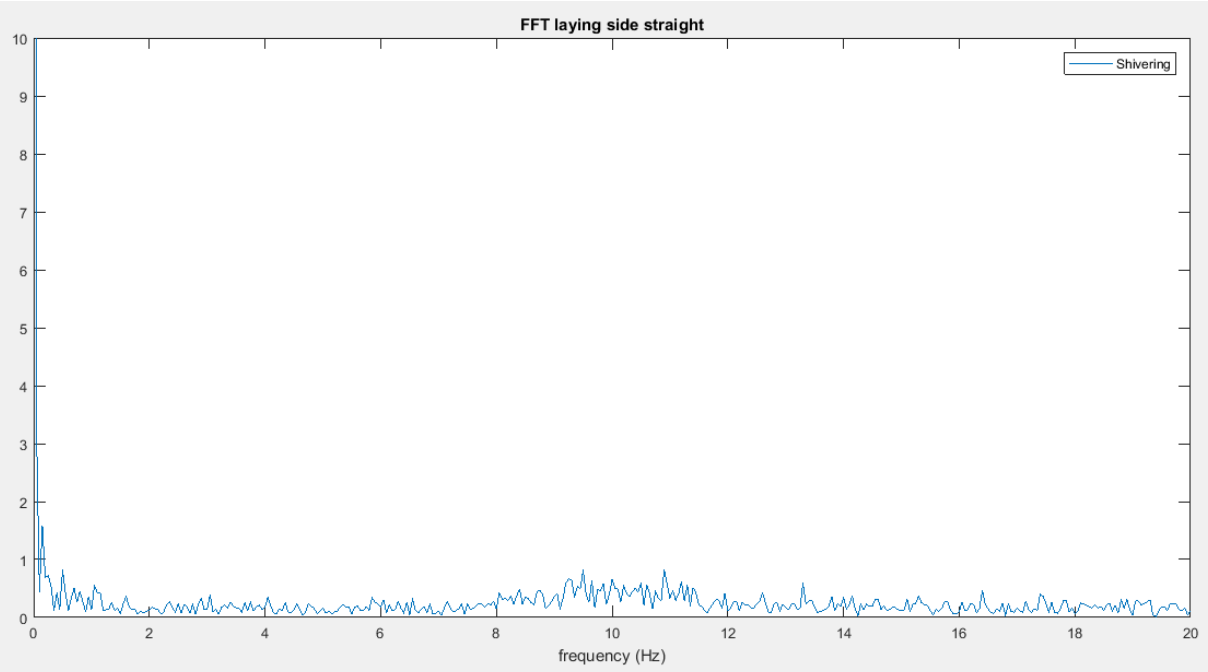

Figure G.6: FFT signal, for the laying on left side straight posture, obtained from the accelerometer located at the shoulder

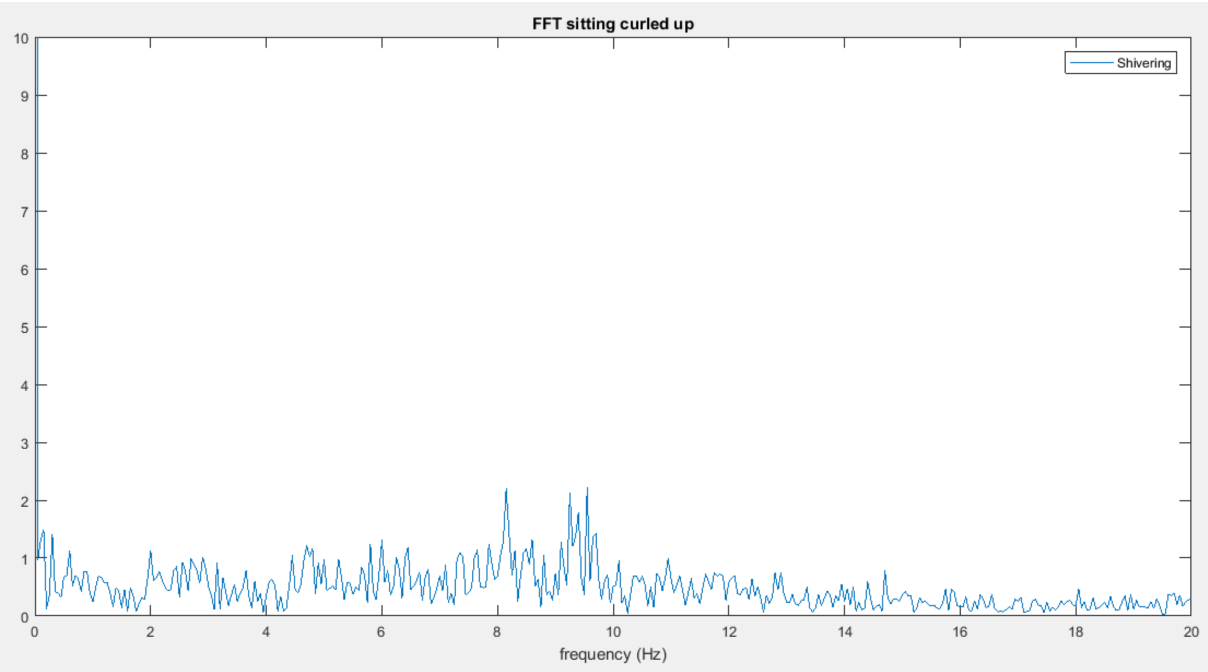

Figure G.7: FFT signal, for the laying on left side curled up posture, obtained from the accelerometer located at the shoulder

Appendix H

Matlab code - filtering accelerometer signals

```
%%
% Based on code from © Thomas Plaisier 02-02-2016.
% Aangepast door    Hinke Bosch january 2018
% Filters signal using butterworth filter and plot the results

%% Script


clear   variables
close   all
clc

filename = '3BuitenBinnen4BuitenBinnen'; % fill in name of excel file where
all data for one body posture can be found

vectorShoulder=xlsread(filename, 'H:H'); % import shoulder vector from
excel file

filter=1;
sample_time=1/50; %sample frequency of 50 Hz
time=[sample_time   : sample_time   : length(vectorShoulder)*sample_time]';

vectorShoulder=vectorShoulder(:,1);

figure(1) % orignal signal side and shoulder
plot(time(1/sample_time:end), vectorShoulder(1/sample_time:end));
title('Different types of movements while sitting straight');
xlabel('time(sec)');
ylabel('G-force in mg');


vectorShoulderHP=butfilter_highpass(vectorShoulder,1/sample_time); %High
pass filter
vectorShoulderLP=butfilter_lowpass(vectorShoulderHP,1/sample_time); %Low
pass filter
abVShoulder=abs(vectorShoulderLP); % Absolute values
vectorShoulderLP2=butfilter_lowpass2(abVShoulder,1/sample_time); % Envelope
of signal

figure(2) % after HP filter signal
plot(time(1/sample_time:end), vectorShoulderHP(1/sample_time:end));
title('Signal after high pass filter');
xlabel('time(sec)');
ylabel('G-force in mg');

figure(3) % after LP filter signal
plot(time(1/sample_time:end), vectorShoulderLP(1/sample_time:end));
title('Signal after low pass filter');
xlabel('time(sec)');
ylabel('G-force in mg');
```

```
figure(4) % after absolute values
plot(time(1/sample_time:end), abVShoulder(1/sample_time:end));
title('Signal with absolute values');
xlabel('time(sec)');
ylabel('G-force in mg');

figure(5) % after HP filter signal
plot(time(1/sample_time:end), vectorShoulderLP2(1/sample_time:end));
title('Envelope of the signal');
xlabel('time(sec)');
ylabel('G-force in mg');

%
```

butfilter_highpass function

```
function [y_filt]=butfilter_highpass(y,fs)
fkmotion = 8; % cutoff frequency, depends on posture
order = 4; % order
[b,a]=butter(order,fkmotion/(0.5*fs),'high');
y_filt=filter(b,a,y);
```

butfilter_lowpass function

```
function [y_filt]=butfilter_lowpass(y,fs)
fkmotion = 10; % cutoff frequency, depends on posture
order = 4; % order
[b,a]=butter(order, fkmotion/(0.5*fs),'low');
y_filt=filter(b,a,y);
```

butfilter_lowpass2 function

```
function [y_filt]=butfilter_lowpass2(y,fs)
fkmotion = 0.7; % cutoff frequency
order = 4; % order
[b,a]=butter(order, fkmotion/(0.5*fs),'low');
y_filt=filter(b,a,y);
```

Appendix I

Arduino code - filters

Here the Arduino code used to filter the signal can be found. The program that is used to generate the code can be found here:

http://www.schwietering.com/jayduino/filtuino/

1. Sitting straight

High pass filter

```
//High pass butterworth filter order=2, alpha1=0.16, cut off frequency=8
class  FilterBuHp2
{
	public:
		FilterBuHp2()
		{
			v[0]=0.0;
			v[1]=0.0;
		}
	private:
		float v[3];
	public:
		float step(float x) //class II
		{
			v[0] = v[1];
			v[1] = v[2];
			v[2] = (4.808384292640904278e-1 * x)
				 + (-0.25232462628226592916 * v[0])
				 + (0.67102909077409622629 * v[1]);
			return
				 (v[0] + v[2])
				- 2 * v[1];
		}
};
```

First low pass filter

```
//Low pass butterworth filter order=2, alpha1=0.2, cut off frequency=10
class  FilterBuLp2
{
	public:
		FilterBuLp2()
		{
			v[0]=0.0;
			v[1]=0.0;
		}
	private:
		float v[3];
```

```
	public:
		float step(float x) //class II
		{
			v[0] = v[1];
			v[1] = v[2];
			v[2] = (2.065720838261479730e-1 * x)
				 + (-0.19581571265583305741 * v[0])
				 + (0.36952737735124130403 * v[1]);
			return
				 (v[0] + v[2])
				+2 * v[1];
		}
};
```

Second low pass filter (envelope)

```
//Low pass butterworth filter order=2, alpha1=0.014, cut off frequency=0.7
class  FilterBuLp2
{
	public:
		FilterBuLp2()
		{
			v[0]=0.0;
			v[1]=0.0;
		}
	private:
		float v[3];
	public:
		float step(float x) //class II
		{
			v[0] = v[1];
			v[1] = v[2];
			v[2] = (1.820128711054497250e-3 * x)
				 + (-0.88302608655343883814 * v[0])
				 + (1.87574557170922084914 * v[1]);
			return
				 (v[0] + v[2])
				+2 * v[1];
		}
};
```

Band pass filter

```
//Band pass butterworth filter order=2, alpha1=0.16, alpha2=0.2, cut off
frequency1=8, cut off frequency2=10
class  FilterBuBp2
{
	public:
		FilterBuBp2()
		{
			for(int i=0; i <= 4; i++)
				v[i]=0.0;
		}
	private:
		float v[5];
	public:
		float step(float x) //class II
		{
			v[0] = v[1];
```

```
                        v[1] = v[2];
                        v[2] = v[3];
                        v[3] = v[4];
                        v[4] = (1.335920515923225659e-2 * x)
                                 + (-0.70089678118840248455 * v[0])
                                 + (1.30862793567505475423 * v[1])
                                 + (-2.26416434984956360665 * v[2])
                                 + (1.56535622816321762230 * v[3]);
                        return
                                 (v[0] + v[4])
                                - 2 * v[2];
                }
};
```

2. Laying on the left side straight

High pass filter

```
//High pass butterworth filter order=2, alpha1=0.18, cut off frequency=9
class  FilterBuHp2
{
        public:
                FilterBuHp2()
                {
                        v[0]=0.0;
                        v[1]=0.0;
                }
        private:
                float v[3];
        public:
                float step(float x) //class II
                {
                        v[0] = v[1];
                        v[1] = v[2];
                        v[2] = (4.347393482847464741e-1 * x)
                                 + (-0.21965398391369461706 * v[0])
                                 + (0.51930340922529127923 * v[1]);
                        return
                                 (v[0] + v[2])
                                - 2 * v[1];
                }
};
```

First low pass filter

```
//Low pass butterworth filter order=2, alpha1=0.22, cut off frequency=11
class  FilterBuLp2
{
        public:
                FilterBuLp2()
                {
                        v[0]=0.0;
                        v[1]=0.0;
                }
        private:
                float v[3];
```

```
        public:
                float step(float x) //class II
                {
                        v[0] = v[1];
                        v[1] = v[2];
                        v[2] = (2.397696590937593575e-1 * x)
                                 + (-0.18023207389834572378 * v[0])
                                 + (0.22115343752330818283 * v[1]);
                        return
                                 (v[0] + v[2])
                                +2 * v[1];
                }
};
```

Second low pass filter (envelope)

```
//Low pass butterworth filter order=2, alpha1=0.014, cut off frequency=0.7
class  FilterBuLp2
{
        public:
                FilterBuLp2()
                {
                        v[0]=0.0;
                        v[1]=0.0;
                }
        private:
                float v[3];
        public:
                float step(float x) //class II
                {
                        v[0] = v[1];
                        v[1] = v[2];
                        v[2] = (1.820128711054497250e-3 * x)
                                 + (-0.88302608655343883814 * v[0])
                                 + (1.87574557170922084914 * v[1]);
                        return
                                 (v[0] + v[2])
                                +2 * v[1];
                }
};
```

Band pass filter

```
//Band pass butterworth filter order=2 alpha1=0.18 alpha2=0.22
class  FilterBuBp2
{
        public:
                FilterBuBp2()
                {
                        for(int i=0; i <= 4; i++)
                                v[i]=0.0;
                }
        private:
                float v[5];
        public:
```

```
                float step(float x) //class II
                {
                        v[0] = v[1];
                        v[1] = v[2];
                        v[2] = v[3];
                        v[3] = v[4];
                        v[4] = (1.335920119429599012e-2 * x)
                                 + (-0.70089678118840237353 * v[0])
                                 + (0.94976030879978579069 * v[1])
                                 + (-1.97230236060631503037 * v[2])
                                 + (1.13608549390705593218 * v[3]);
                        return
                                 (v[0] + v[4])
                                - 2 * v[2];
                }
};
```

Appendix J

Arduino code - to collect and filter data and to generate windowed FFTs

```
/*
  This code is used to collect and filter data from an accelerometer. The data is displayed on the serial monitor and from there it can be copied to excel or another document.
  Parts of the code are based on the 'Sleeping Arduino - unless you joslte it!' code, made by Ed Halley

  Furthermore, a windowed FFT is made. The FFT code is based on the FFT_03 example, that is included with the arduinoFFT library. Copyright (C) 2017 Enrique Condes

  All code is adjusted by Hinke Bosch, January 2018
*/

#include <math.h>
#include "arduinoFFT.h"


//Sitting straight band pass butterworth filter 8-10Hz order=2 alpha1=0.14 alpha2=0.18
class  FilterBuBp2Sitting
{
  public:
    FilterBuBp2Sitting()
    {
      for (int i = 0; i <= 4; i++)
        v[i] = 0.0;
    }
  private:
    float v[5];
  public:
    float step(float x) //class II
    {
      v[0] = v[1];
      v[1] = v[2];
      v[2] = v[3];
      v[3] = v[4];
      v[4] = (1.335920515923225659e-2 * x)
             + (-0.70089678118840248455 * v[0])
             + (1.30862793567505475423 * v[1])
             + (-2.26416434984956360665 * v[2])
             + (1.56535622816321762230 * v[3]);
```

```
      float f = (v[0] + v[4]) - 2 * v[2];
      return f;
    }
};


//Laying left side straight band pass butterworth filter 9-11Hz order=2 alpha1=0.14 alpha2=0.18
class  FilterBuBp2Laying
{

  public:
    FilterBuBp2Laying()
    {
      for (int i = 0; i <= 4; i++)
        v[i] = 0.0;
    }
  private:
    float v[5];
  public:
    float step(float x) //class II
    {
      v[0] = v[1];
      v[1] = v[2];
      v[2] = v[3];
      v[3] = v[4];
      v[4] = (1.335920119429599012e-2 * x)
           + (-0.70089678118840237353 * v[0])
           + (0.94976030879978579069 * v[1])
           + (-1.97230236060631503037 * v[2])
           + (1.13608549390705593218 * v[3]);
      float f = (v[0] + v[4]) - 2 * v[2];
      return f;
    }
};

//Low pass butterworth filter 0.7 Hz order=2 alpha1=0.014
class  FilterBuLp2
{
  public:
    FilterBuLp2()
    {
      v[0] = 0.0;
      v[1] = 0.0;
    }
  private:
    float v[3];
  public:
    float step(float x) //class II
```

```
  {
    v[0] = v[1];
    v[1] = v[2];
    v[2] = (1.820128711054497250e-3 * x)
       + (-0.88302608655343883814 * v[0])
       + (1.87574557170922084914 * v[1]);
    float f = (v[0] + v[2]) + 2 * v[1];
    return f;
  }
};

/* Accelerometer:
  Receive input from a 3-axis device.

  Specify the three axis pins, using analog pin
  numbers.  These are usually adjacent on the common breakout boards.

  Call the accelerometer's update() method occasionally to update the
  current values from the hardware.
*/
class Accelerometer
{
  int p[3]; // which analog pins
  int a[3]; // incoming data
  float b[3]; // acceleration, mapped
  float vector;
  int scale; // scaling factor between ADC and gravity, can be set on 1500 or 6000
  float vectorFiltBP;
  float vectorFiltLP;
  float absVector;
  // FilterBuBp2Sitting filterBP = FilterBuBp2Sitting(); //filter for sitting straight posture
  FilterBuBp2Laying filterBP = FilterBuBp2Laying(); //filter for laying on the left side straight posture
  FilterBuLp2 filterLP = FilterBuLp2();

 public:
  Accelerometer(int pinX, int pinY, int pinZ)
  {
    pinMode((p[0] = pinX), INPUT);
    pinMode((p[1] = pinY), INPUT);
    pinMode((p[2] = pinZ), INPUT);
    for (int i = 0; i < 3; i++) {
      a[i] = 0; // incoming data
      b[i] = 0; // values in mg
    }
    vector = 0;
    vectorFiltBP = 0;
    vectorFiltLP = 0;
    absVector = 0;
```

```
  scale = 1500; // or 6000 depending on sensitivity of accelerometer
}

//Read incoming data from accelerometer, translate data from voltage to mg and filters the signal
void update()
{
  for (int i = 0; i < 3; i++) {
    a[i] = analogRead(p[i]);    // read data from accelerometer
    b[i] = mapf(a[i], 0, 675.84, -scale, scale);  // translate voltage to mg values, for 3.3V
  }
  vector = sqrt(sq(b[0]) + sq(b[1]) + sq(b[2])); // calculate vector magnitude
  vectorFiltBP = filterBP.step(vector); //bandpass filter
  absVector = abs(vectorFiltBP); //absolute values
  vectorFiltLP = filterLP.step(absVector);  //envelope signal
}

float getVector() {
  return vector;
}

float getVectorLP2() {
  return vectorFiltLP;
}

float getVectorBP() {
  return vectorFiltBP;
}

float mapf(float x, float in_min, float in_max, float out_min, float out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}

//Display data on serial monitor
void dump()
{
  Serial.println();
  Serial.print(b[0]); // mapped data x axis
  Serial.print("\t"); Serial.print(b[1]); // y axis
  Serial.print("\t"); Serial.print(b[2]); // z axis
  Serial.print("\t"); Serial.print(vector); // vector
  Serial.print("\t"); Serial.print(vectorFiltBP); //vector after bandpass
  Serial.print("\t"); Serial.print(absVector);  //vector after absolute values
  Serial.print("\t"); Serial.print(vectorFiltLP); //envelope of vector
  Serial.print ("\t");
}

void loop()
```

```
    {
      update();
    }
};


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

int count; // amount of time samples are taken
int t;  //used for printing 2 different fft windows
bool collecting;
float signalVBP; //signal after band pass
arduinoFFT FFT = arduinoFFT();
const uint16_t samples = 64; //This value MUST ALWAYS be a power of 2
const double samplingFrequency = 50;

/*
  These are the input and output vectors
  Input vectors receive computed results from FFT
  two times, to try two different window types at ones
*/
double vRealWType1[samples]; //for FFT window type 1
double vRealWType2[samples]; //for FFT window type 2
double vImagWType1[samples];
double vImagWType2[samples];

#define SCL_INDEX 0x00
#define SCL_TIME 0x01
#define SCL_FREQUENCY 0x02


void loop() {
  ;  // we do our own loop below
}

void setup()
{
  Serial.begin(115200); // high to get the right sample frequency
  Accelerometer accel1 = Accelerometer(A0, A1, A2);
  count = 0; // times the loop is done
  signalVBP = 0;
  collecting = true;
  t = 0;
  printColumnNames();

  while (collecting == true)
  {
```

```
    if (count == 14) {  //collect data for around 20 seconds
      collecting = false; // stops the loop
    }

    // activates functions from the accelerometer class to get the data and put 64 values in array for
making the FFT
    for (uint16_t i = 0; i < samples; i++) {
      accel1.loop(); // read data from accelerometer and filter the data
      accel1.dump(); // print data to serial monitor
      signalVBP = accel1.getVectorBP(); //get band passed filtered signal to use for the FFT

      vRealWType1[i] = double(signalVBP); //fill array for FFT1 with samples after band pass filter
      vImagWType1[i] = 0; // after band pass
      vRealWType2[i] = double(signalVBP); //fill array for FFT2 with samples after band pass filter
      vImagWType2[i] = 0; // after band pass
      delay(16); // +/- 50Hz with accel1.dump on, 19 will give +/- 50Hz when values are not printed to
the serial monitor.
    }

    // Create two windowed FFT with different window types

    // create windowed FFT 1, window types are: Rectangle, Hamming, Han, Triangle, Blackmann, Flat
top and Welch
    FFT.Windowing(vRealWType1, samples, FFT_WIN_TYP_RECTANGLE, FFT_FORWARD);  /* Weigh
data, RECTANGLE in FFT_WIN_TYPE_RECTANGE can be changed to one of the other window types*/
    FFT.Compute(vRealWType1, vImagWType1, samples, FFT_FORWARD); /* Compute FFT */
    FFT.ComplexToMagnitude(vRealWType1, vImagWType1, samples); /* Compute magnitudes */
    PrintVector(vRealWType1, (samples >> 1), SCL_FREQUENCY); //print values to serial monitor

    // create windowed FFT 2
    FFT.Windowing(vRealWType2, samples, FFT_WIN_TYP_BLACKMAN, FFT_FORWARD);  /* Weigh
data */
    FFT.Compute(vRealWType2, vImagWType2, samples, FFT_FORWARD); /* Compute FFT */
    FFT.ComplexToMagnitude(vRealWType2, vImagWType2, samples); /* Compute magnitudes */
    PrintVector(vRealWType2, (samples >> 1), SCL_FREQUENCY); //print values to serial monitor

    count++;
  }
}

void printColumnNames()
{
  Serial.print("x");
  Serial.print("\t"); Serial.print("y");
  Serial.print("\t"); Serial.print("z");
  Serial.print("\t"); Serial.print("vector");
  Serial.print("\t"); Serial.print("BP");
  Serial.print("\t"); Serial.print("abs");
```

```
  Serial.print("\t"); Serial.print("envelope");
  Serial.print("\t"); Serial.print("\t"); Serial.print("FFT1");
  Serial.print("\t"); Serial.print("\t"); Serial.print("\t"); Serial.print("FFT2");
  Serial.println();
}

// serial print FFT for both window types
void PrintVector(double *vData, uint16_t bufferSize, uint8_t scaleType)
{
  for (uint16_t i = 0; i < bufferSize; i++)
  {
    double abscissa;
    /* Print abscissa value */
    switch (scaleType)
    {
      case SCL_INDEX:
        abscissa = (i * 1.0);
        break;
      case SCL_TIME:
        abscissa = ((i * 1.0) / samplingFrequency);
        break;
      case SCL_FREQUENCY:
        abscissa = ((i * 1.0 * samplingFrequency) / samples);
        break;
    }
    if (abscissa > 1) {
      Serial.println();
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      Serial.print("\t");
      if (t == 1) {
        Serial.print("\t");
        Serial.print("\t");
        Serial.print("\t");
      }
      Serial.print(abscissa, 2);
      Serial.print("\t");
      Serial.print(vData[i], 2);
      Serial.println();
    }
  }
  Serial.println();
  if (t == 0) {
```

```
    t = 1;
  }
  else {
    t = 0;
  }
}
```

Appendix K

Windowed FFTs for different window types

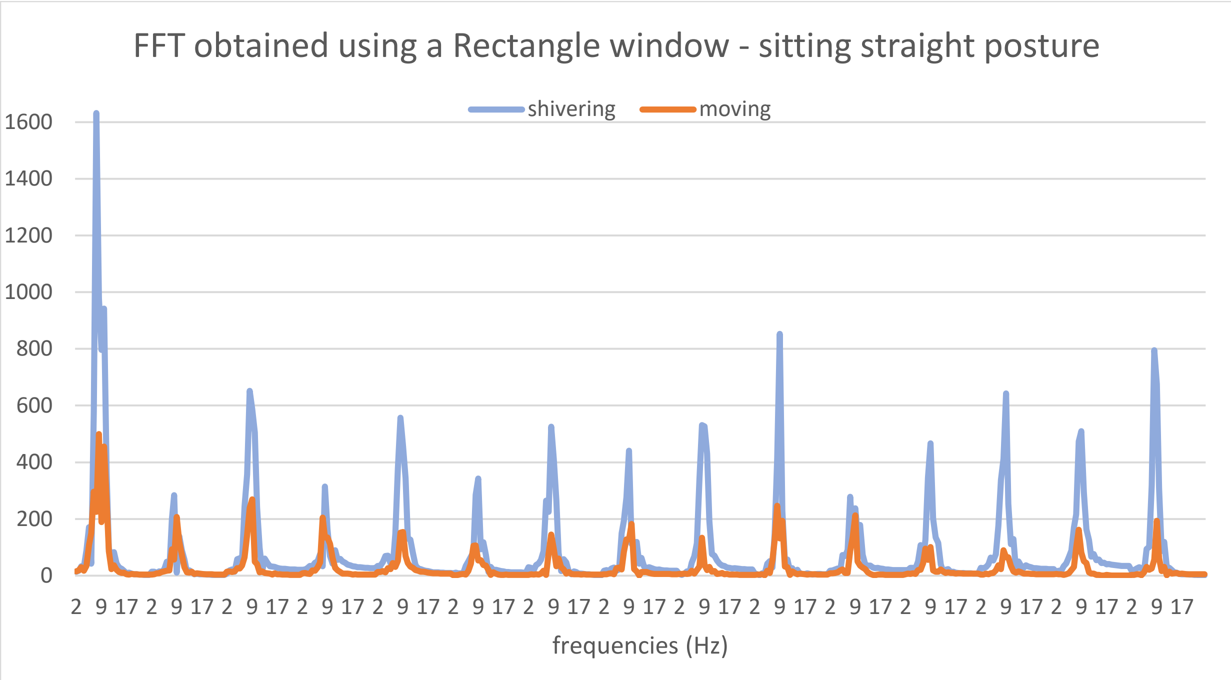

Figure K.1: Difference between the shivering windowed FFT and the moving windowed FFT with a Rectangle window for the 'sitting straight' posture

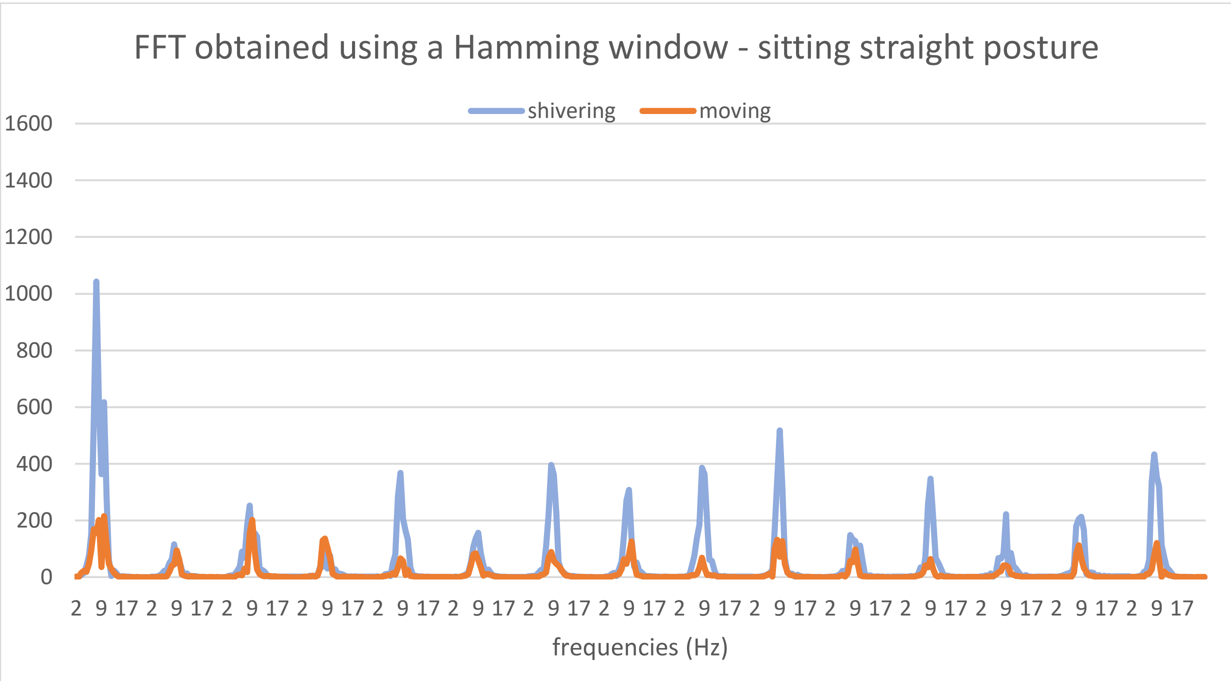

Figure K.2: Difference between the shivering windowed FFT and the moving windowed FFT with a Hamming window for the 'sitting straight' posture

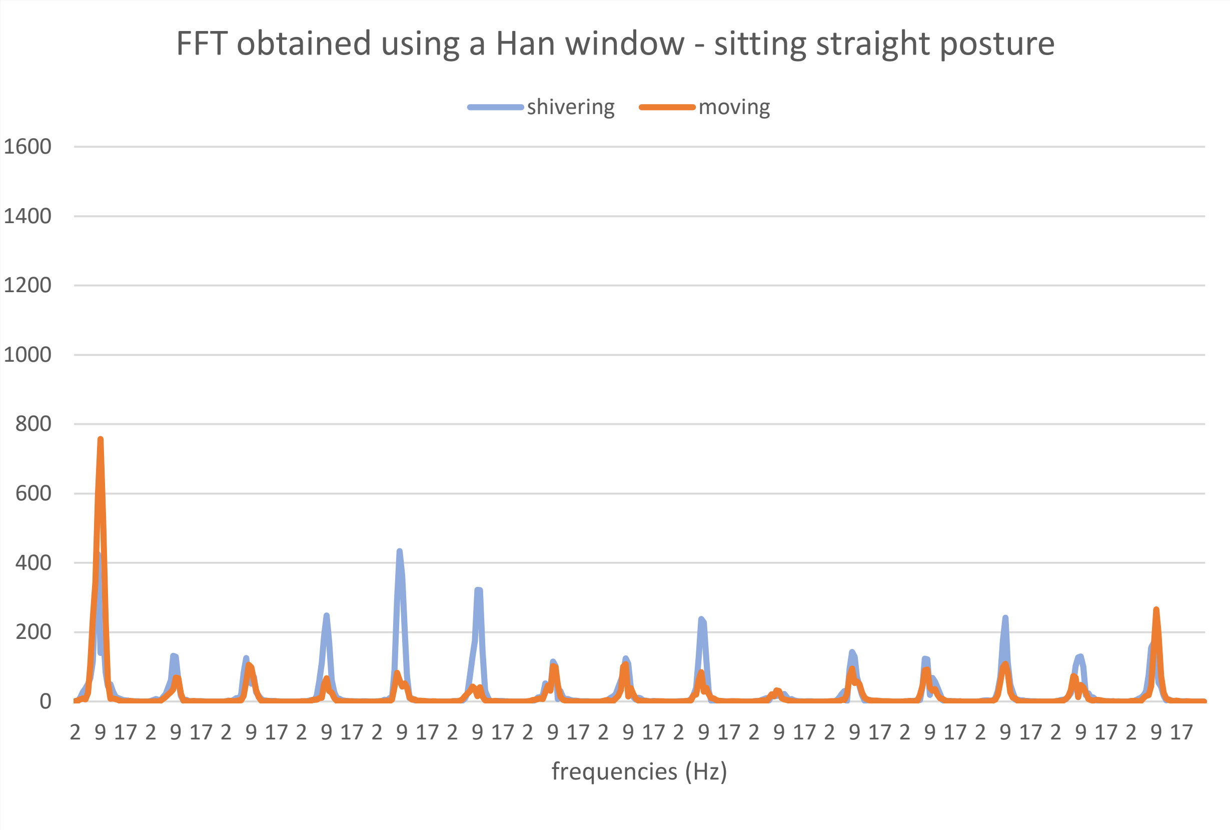

Figure K.3: Difference between the shivering windowed FFT and the moving windowed FFT with a Han window for the 'sitting straight' posture

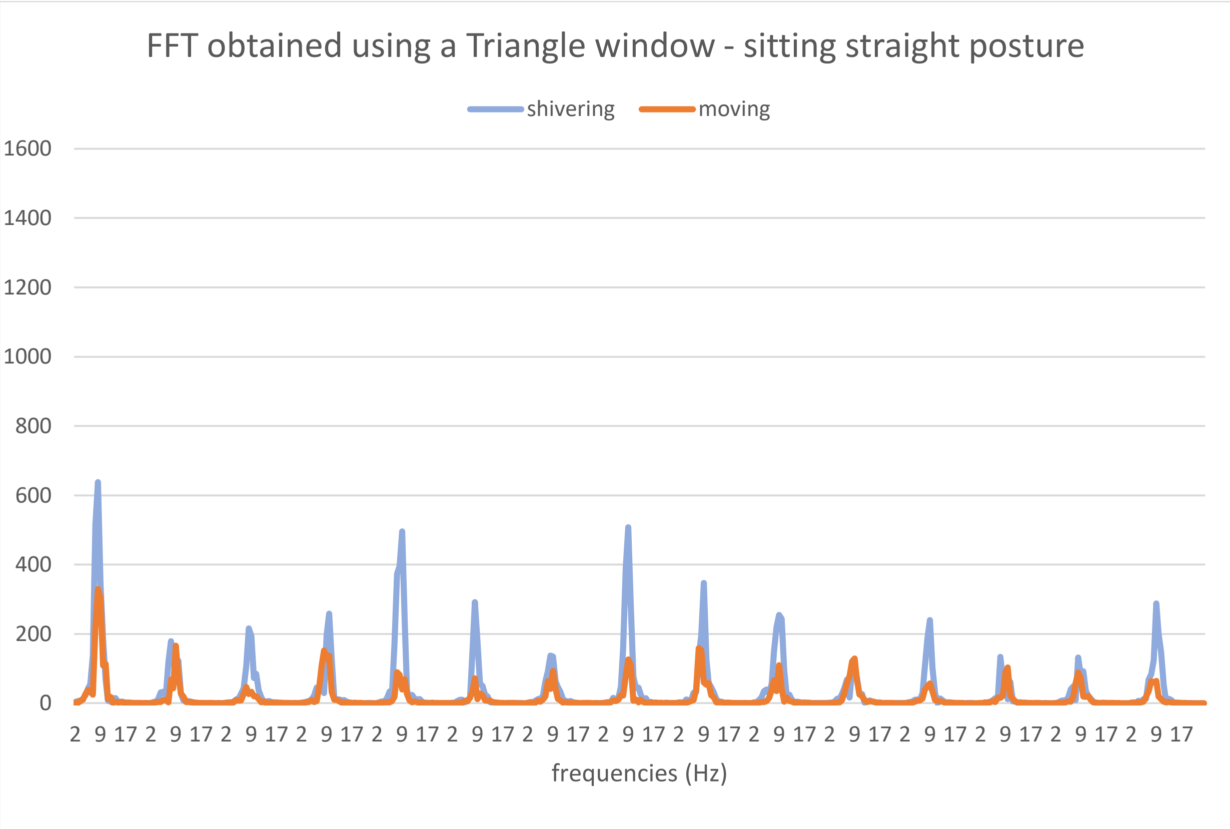

Figure K.4: Difference between the shivering windowed FFT and the moving windowed FFT with a Triangle window for the 'sitting straight' posture

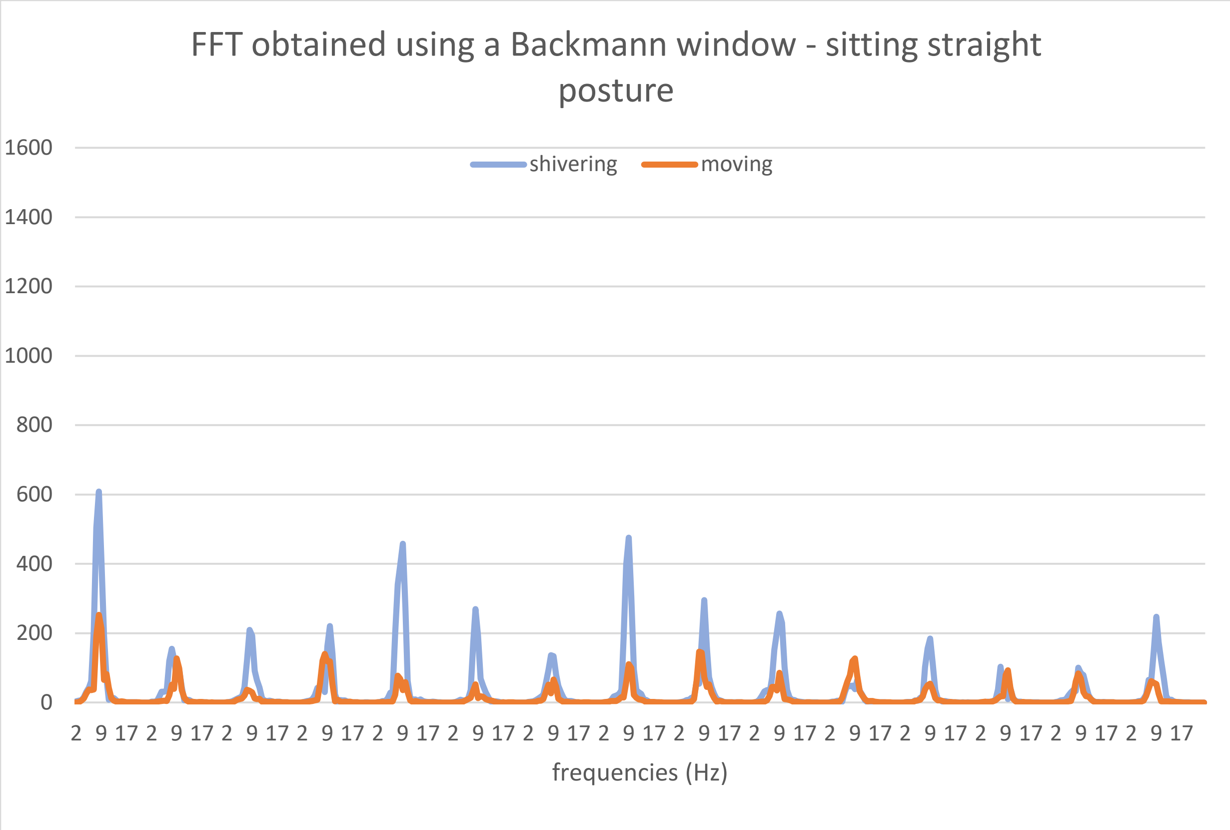

Figure K.5: Difference between the shivering windowed FFT and the moving windowed FFT with a Backmann window for the 'sitting straight' posture

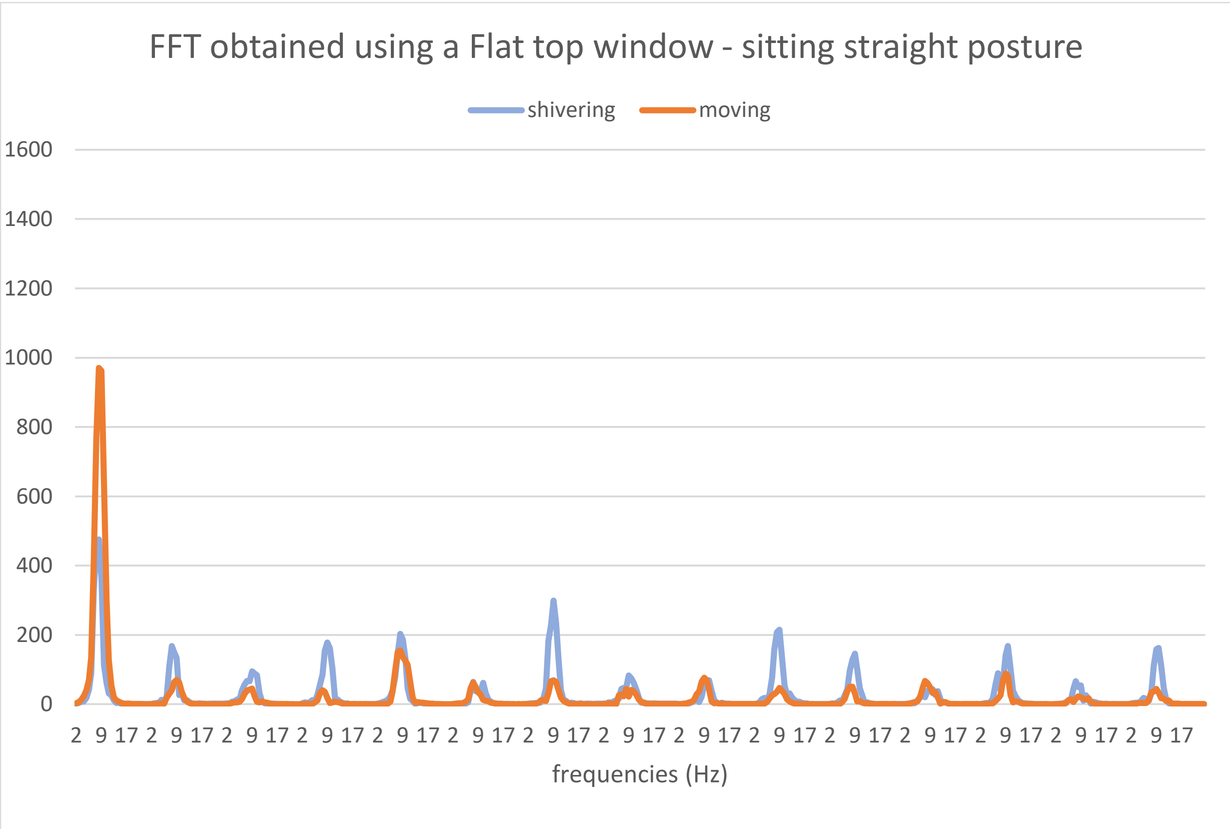

Figure K.6: Difference between the shivering windowed FFT and the moving windowed FFT with a Flat top window for the 'sitting straight' posture

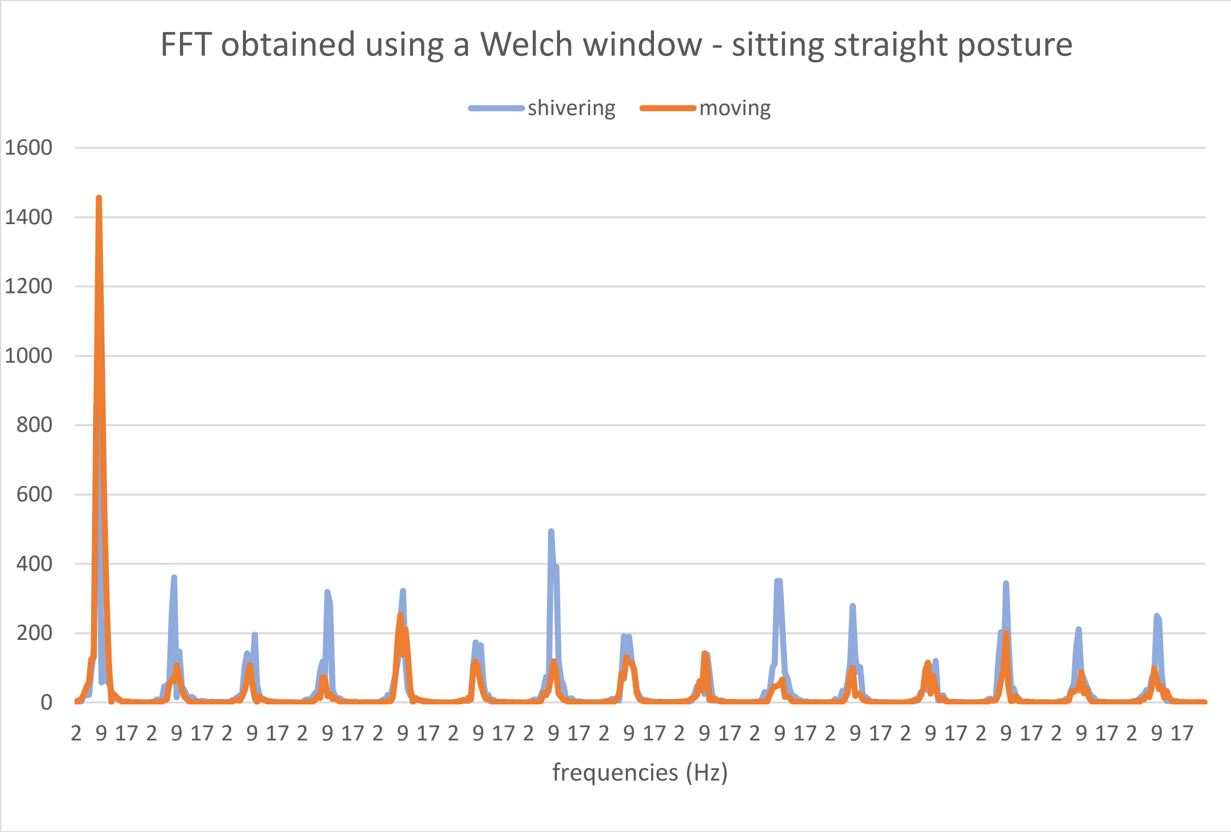

Figure K.7: Difference between the shivering windowed FFT and the moving windowed FFT with a Welch window for the 'sitting straight' posture

Appendix L

Arduino code - end prototype

```
/*

moet nog gedocumenteerd en opgeschoond worden. Sensitivity level toevoegen, nu altijd 0
*/

#include <math.h>
#include "arduinoFFT.h"
#include <toneAC.h>
#include <SHT1X.h>


//Band pass butterworth filter: sitting 8-10Hz alpha1=0.16 alpha2=0.2, laying 9-11Hz alpha1=0.18
alpha2=0.22, order=2
class  FilterBuBp2
{
  public:
    FilterBuBp2()
    {
      for (int i = 0; i <= 4; i++)
        v[i] = 0.0;
    }
  private:
    float v[5];
  public:
    float step(float x, int p) //class II
    {

      if (p == 0) { //sitting position, 8-10Hz
        v[0] = v[1];
        v[1] = v[2];
        v[2] = v[3];
        v[3] = v[4];
        v[4] = (1.335920515923225659e-2 * x)
               + (-0.70089678118840248455 * v[0])
               + (1.30862793567505475423 * v[1])
               + (-2.26416434984956360665 * v[2])
               + (1.56535622816321762230 * v[3]);
        return ((v[0] + v[4]) - 2 * v[2]);
      }
      else if (p == 1) { // laying position, 9-11Hz
        v[0] = v[1];
```

```
    v[1] = v[2];
    v[2] = v[3];
    v[3] = v[4];
    v[4] = (1.335920119429599012e-2 * x)
       + (-0.70089678118840237353 * v[0])
       + (0.94976030879978579069 * v[1])
       + (-1.97230236060631503037 * v[2])
       + (1.13608549390705593218 * v[3]);
    return ((v[0] + v[4]) - 2 * v[2]);
   }

   else {
    return 0;
   }
  }
};


//Low pass butterworth filter order=2 alpha1=0.014
class  FilterBuLp2
{
 public:
  FilterBuLp2()
  {
   v[0] = 0.0;
   v[1] = 0.0;
  }
 private:
  float v[3];
 public:
  float step(float x) //class II
  {
   v[0] = v[1];
   v[1] = v[2];
   v[2] = (1.820128711054497250e-3 * x)
      + (-0.88302608655343883814 * v[0])
      + (1.87574557170922084914 * v[1]);
   return ((v[0] + v[2]) + 2 * v[1]);
  }
};


/* Accelerometer:
  Receive input from a 3-axis device, and perform some useful calculations.

  Specify the three axis pins
*/
```

```
class Accelerometer
{
  int p[3]; // which analog pins
  int a[3]; // incomming data
  float b[3]; // acceleration, mapped
  float vector; //calculating vector from incoming data
  int scale; // scaling factor between ADC and gravity
  float vectorFiltBP; //vector after bandpass filter
  float vectorFiltLP; //vector after lowpass filter
  float absVector; //absolute values vector after lowpass filter
  FilterBuBp2 filterBP = FilterBuBp2(); //bandpass filter
  FilterBuLp2 filterLP = FilterBuLp2(); //lowpass filter
  int pos; // position of user, laying or sitting

 public:
  Accelerometer(int pinX, int pinY, int pinZ)
  {
   pinMode((p[0] = pinX), INPUT);
   pinMode((p[1] = pinY), INPUT);
   pinMode((p[2] = pinZ), INPUT);
   for (int i = 0; i < 3; i++) {
    a[i] = 0; // incomming data
    b[i] = 0; // scaled data map
   }
   vector = 0;
   vectorFiltBP = 0;
   vectorFiltLP = 0;
   absVector = 0;
   scale = 1500; // can be 1500 or 6000
   pos = 0;
  }

  void update()
  {
   for (int i = 0; i < 3; i++) {
    a[i] = analogRead(p[i]);
    b[i] = mapf(a[i], 0, 675.84, -scale, scale);
   }

   if (b[0] >= 300) { //sitting
    pos = 0;
   }
   else if (b[0] <= -200 ) { // laying
    pos = 1;
   }
   else {
    pos = 2;
   }
```

```
    vector = sqrt(sq(b[0]) + sq(b[1]) + sq(b[2]));
    vectorFiltBP = filterBP.step(vector, pos);
    absVector = abs(vectorFiltBP);
    vectorFiltLP = filterLP.step(absVector);
  }

  float getVector() {
    return vector;
  }
  float getVectorBP() {
    return vectorFiltBP;
  }
  float getVectorLP2() {
    return vectorFiltLP;
  }

  int getPosition() {
    return pos;
  }

  float mapf(float x, float in_min, float in_max, float out_min, float out_max)
  {
    return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
  }

  void dump()
  {
    Serial.println();
    Serial.print(b[0]); // mapped data x as
    Serial.print("\t"); Serial.print(b[1]); // y as
    Serial.print("\t"); Serial.print(b[2]); // z as
    Serial.print("\t"); Serial.print(vector); // vector
    Serial.print("\t"); Serial.print(vectorFiltBP);
    Serial.print("\t"); Serial.print(absVector);
    Serial.print("\t"); Serial.print(vectorFiltLP);

    Serial.print ("\t");
    // Serial.println();
  }

  void loop()
  {
    update();
  }
};


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

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


float tempC;
float humidity;
int count;
int countM;
int countS;
int threshold = 15;
bool collecting;
bool moving;
bool shivering;
bool cold;
float signalVBP;
float signalVLP2;
int pNew;
int pOld;
int minV;
int minMaxY;
arduinoFFT FFT = arduinoFFT();
const uint16_t samples = 64; //This value MUST ALWAYS be a power of 2
const double samplingFrequency = 50;
/*
  These are the input and output vectors
  Input vectors receive computed results from FFT
*/
double vReal[samples];
double vImag[samples];

#define SCL_INDEX 0x00
#define SCL_TIME 0x01
#define SCL_FREQUENCY 0x02


void loop() {
  ;  // we do our own loop below
}

void setup()
{
  Serial.begin(115200);
  // pinMode(13, OUTPUT); digitalWrite(13, LOW);
  // pinMode (12,OUTPUT); digitalWrite(12, HIGH);
  Accelerometer accel1 = Accelerometer(A0, A1, A2);
  count = 0;
  countM = 0;
  countS = 0;
  signalVLP2 = 0;
```

```
 signalVBP = 0;
 pNew = 0;
 pOld = 0;
 collecting = true;
 moving = false;
 tempC = 0;
 humidity = 0;
 SHT1x sht15(A4, A5);//Data, SCK
 minV = 0;
 minMaxY = 0;
 cold = false;


 while (collecting == true)
 {

   moving = false;
   bool noValue = false;
   for (uint16_t i = 0; i < samples; i++) {
    accel1.loop();
    accel1.dump();
    signalVBP = accel1.getVectorBP();
    signalVLP2 = accel1.getVectorLP2();
    pNew = accel1.getPosition();

    if ((pOld != pNew && i > 1) || pNew == 2) { // detect if values do not correlate with only one
position for one session of 64 values
      Serial.println("NO POSTURE");
      noValue = true; // only if no change of position is measured in the 64 samples, the sample can be
determined as shivering
    }
    else if (pNew == 0) { //sitting
      Serial.print("sitting");
      minV = 12;
      minMaxY = 250;
    }
    else if (pNew = 1) {        // laying
      Serial.println("laying");
      minV = 5;
      minMaxY = 125;
    }
    pOld = pNew;

    if (signalVLP2 >= minV && moving == false && noValue == false) { // detects if a filtered value of
the 64 samples passes the threshold
      moving = true;
    }
    vReal[i] = double(signalVBP);
```

```
     vImag[i] = 0;
     delay(16); // +/- 50Hz with printing values
     // delay(19); // +/- 50Hz without printing values
   }


   //COMPUTE FFT
   FFT.Windowing(vReal, samples, FFT_WIN_TYP_RECTANGLE, FFT_FORWARD);  /* Weigh data */
   FFT.Compute(vReal, vImag, samples, FFT_FORWARD); /* Compute FFT */
   FFT.ComplexToMagnitude(vReal, vImag, samples); /* Compute magnitudes */
   PrintVector(vReal, (samples >> 1), SCL_FREQUENCY);
   double x = FFT.MajorPeak(vReal, samples, samplingFrequency);

   // DETECT WHAT THE HIGHEST VALUE IS OF THE FFT
   double maxY = 0;
   for (uint16_t i = 1; i < ((samples >> 1) - 1); i++) {
     if ((vReal[i - 1] < vReal[i]) && (vReal[i] > vReal[i + 1])) {
       if (vReal[i] > maxY) {
         maxY = vReal[i];
       }
     }
   }

   if (moving == true && maxY > minMaxY) { // if moving is detected and frequency amplitude has the
right value, then it is registered as moving
     countM = countM + 1;
   }

   count ++;

   if (count == 13) { // after 13 rounds, around 20 sec, the amount of movements are counted, if
higher then 4 and temperature is low enough, shivering is detected

//     // Determining if temperature is low enough
//     tempC = sht15.readTemperatureC();
//     humidity = sht15.readHumidity();
//     float tempThreshold = 0.375*humidity-5.5;
//     if (tempC<tempThreshold) {
//       cold = true;
//     }

     if (countM >= 4 ) {
       countS++; // duration of the shivering, with every increase the sound volume, duration and
frequency increase, the sensitivity of the system is 0, meaning that there is immediately a risk of
getting hypothermia when shivering is detected
    //   cold = false
       if (countS >= 10) {
         countS = 10;
```

```
      }
    }
    else {
      countS = 0; // if no shivering is detected for 13 times (20 sec), the danger level goes back to 0
    }
    count = 0;
    countM = 0;
  }
  toneAC(countS * 100, countS, 100 + countS * 200, true);
 }
}

void PrintVector(double *vData, uint16_t bufferSize, uint8_t scaleType)
{
 for (uint16_t i = 0; i < bufferSize; i++)
 {
  double abscissa;
  /* Print abscissa value */
  switch (scaleType)
  {
    case SCL_INDEX:
      abscissa = (i * 1.0);
      break;
    case SCL_TIME:
      abscissa = ((i * 1.0) / samplingFrequency);
      break;
    case SCL_FREQUENCY:
      abscissa = ((i * 1.0 * samplingFrequency) / samples);
      break;
  }
  if (abscissa > 1) {
    Serial.println();
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");
    Serial.print("\t");

    Serial.print(abscissa, 2);
    Serial.print("\t");
    Serial.print(vData[i], 2);
    Serial.println();
  }
 }
 Serial.println();
```

```
}
```