Enhancing Breathline with Posture Tracking

Development and Design of a posture tracking feedback module

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Abstract

Diaphragmatic breathing is a respiration technique that has been proven to have benefits in both mental and physical health. This technique describes the individual purposefully engaging their diaphragm to take deep and slow breaths. The belly should expand whilst inhaling and contract during exhalation. Parviz Sassanian, a breathing therapist based in Enschede teaches this technique at his clinic and wanted to find a way to help his patients train this technique correctly at home.

Ben Bulsink, a product developer in Enschede created a device called Breathline that can measure the expansion and contraction of the abdomen by using Respiratory Inductance Plethysmography (RIP). Using this method, Breathline can be used to estimate diaphragmatic breathing. At the beginning of this project, it had an inbuilt accelerometer that was not being used. Mr. Bulsink wanted to know whether it was possible to integrate posture tracking in his device with the accelerometer which led to the research question: **How can body posture be tracked most effectively with a physical prototype combination of an accelerometer and other sensors to give the user constructive feedback with the Breathline device?**

Background research showed different sensors and classification algorithms that have been used in the past to track posture. By using this research, additional interviews with experts and potential users, the choice was made to use two accelerometers to track posture using the Breathline device.

A prototype was made consisting of two accelerometers, one placed on the belly and one on the upper back that could differentiate between 9 different posture states by converting the raw accelerometer data to angles in degrees. The prototype also had a calibration button for it to be adaptable for every user. Feedback was given to the users through a graphical user interface made in Processing and through haptic feedback on their belly by two vibration motors when they slouched.

The prototype was tested on 12 users for setup accuracy, usability and to explore whether a relationship between diaphragmatic breathing and posture could be determined. The conclusion of this research is that the setup has a 95.2% accuracy on posture tracking, the visual and haptic feedback implementations were received overall positively by the test participants. However, this research was unable to establish a generalisable link between diaphragmatic breathing and body position as the individual differences between the participants were too large. Moreover, expert interviews and literature concluded that a more rigorous testing procedure was needed that would classify the mental and physical state of the participants as these have been proven to have an effect on breathing patterns.

For future work, to establish a link between diaphragmatic breathing and posture, there should be a breathing expert present during the test and the test participants should have prior knowledge and practice at breathing diaphragmatically. Furthermore, this test should also be conducted with spirometry to directly measure the expansion and contraction of the lungs, as the RIP method can only be used as an estimation of tidal lung volume, as it primarily measures abdominal movements.

Acknowledgements

I would like to thank several people for their time, dedication and participation in this project. I would like to begin by expressing my great appreciation for my supervisor Erik Faber, for his constant support, guidance and round-the-clock availability in this project. I would like to thank my critical observer, Cora Salm for her input and interest in this project. Next, I would also like to thank my clients, Ben Bulsink and Parviz Sassanian, for their expertise and aid in the development of this project.

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Furthermore, I would like to thank the participants in this study who participated in the brainstorms, interviews, usability testing and evaluation. They took time out of their schedules to partake in this lengthy process and provided insightful data for this project.

Table of contents

1. Introduction

The Breathline device, its functionality and the current situation will be introduced in the first section of this report. This is followed by a short context analysis where terminology will be explained and subsequently, the structure of the rest of the report will be described.

1.1 Problem Statement

"Life begins with a breath and ends with the last" [1]. The process of breathing is fundamental to life - an automatic process, that for the most part is taken for granted. Respiration is assessed (by healthcare providers) for quality, rhythm and rate, where the quality is dependent on the usage of the accessory muscles in the neck and chest [2]. Babies naturally practice the art of deep abdominal breathing also known as diaphragmatic breathing. As humans get older factors like fear, bad posture and stressful lifestyles affect the way they breathe. Ma *et al.* [3] found that diaphragmatic breathing triggers the body's relaxation response, has benefits in both mental and physical health and could improve sustained attention, affect and cortisol levels.

Parviz Sassanian, an acupuncturist and breathing therapist in Enschede uses this technique to coach his clients to breathe better. In order to help his clients train diaphragmatic breathing correctly at home, he got together with Ben Bulsink, an independent product developer in Enschede and made the Breathline device. Breathline records breathing through Respiratory Inductance Plethysmography (RIP) method and movement through accelerometer data, as is described in section 1.2. Currently, this device is still under development and is not being used to its full potential as the data from the accelerometer is not processed and therefore only the breathing data can get analysed. Therefore, there is currently no implementation of correct posture in the device.

Studies have shown that relationships between respiratory activity and posture have been researched in the past, however, they are not focussed on diaphragmatic breathing which is what the focal point of this paper is. Guan *et al.* have shown that body position and postural changes influence human respiratory activity [5]. Different postures affect respiratory mechanics by changing the amount of pulmonary gas exchange, ventilation to perfusion ratio, side expansions contracting the floor and increases in abdominal pressure and can even have effects on the cardiovascular system [6] [7]. More information about the correlation between diaphragmatic breathing and posture can be found in section 1.2.1.

The main objective of this thesis is to develop a posture tracking feedback module for Breathline and to explore how body position and diaphragmatic breathing are related. This will be done by processing the data from the accelerometer and possibly using other sensors to track body position.

1.2 Context Analysis

This section will briefly introduce important terminology that will reoccur during this paper and should hereby give a clearer idea of each term.

1.2.1 Diaphragmatic breathing and Health

Diaphragmatic breathing is a respiration technique by which an individual purposefully engages their diaphragm in order to take in slow and deep breaths [8]. During this type of breathing, the belly expands and contracts rather than the chest. Inhaling tightens the diaphragm, moving it down whilst sucking air into the lungs. This process pushes the abdominal contents down, which forces the abdominal wall out. Exhaling flattens the abdominal wall and relaxes the diaphragm [9]. A visualisation of this process can be seen in Figure 1.

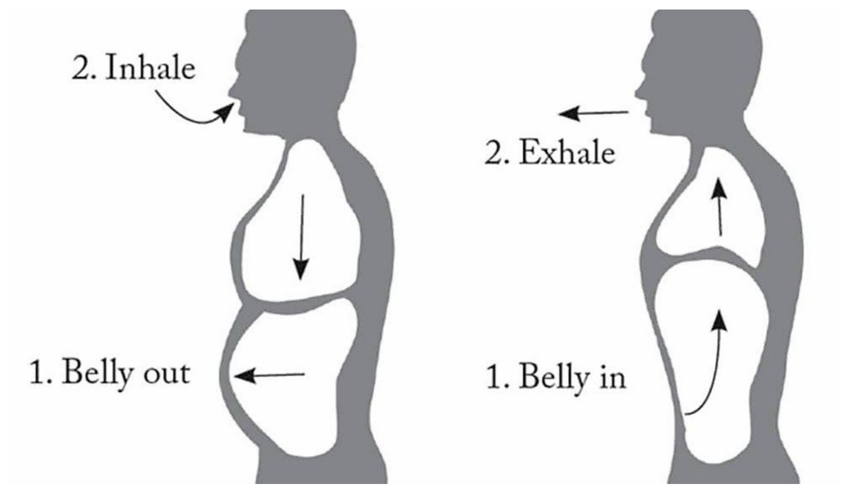

Figure 1: Diaphragmatic Breathing process [10]

Various studies have proclaimed that there are many physiological benefits to diaphragmatic breathing. Manikonda *et al.* stated that diaphragmatic breathing can reduce blood pressure by an average of 18mm Hg. This relates to halving the likelihood of cardiovascular mortality in middle-aged people [11]. Kulur *et al.* demonstrated prolonged diaphragmatic breathing to have shown increased heart rate variability and blood glucose homeostasis. A reduced heart rate variability is believed to be an indicator for potential cardiovascular issues, which is why an increased heart rate variability is a desirable characteristic. Moreover, a stable blood glucose homeostasis can help patients control their blood sugar levels with increased consistency [12]. Furthermore, Kim *et al.* have shown that deep breathing can also help reduce post-traumatic stress disorder-like symptoms [13]. The above-mentioned studies illustrate the health benefits of diaphragmatic breathing and its positive physiological and mental effects to increase the quality of life of the person employing the breathing technique.

There have been a number of studies that have also researched the correlation between breathing, measured as tidal volume of the lungs and body posture, with mixed results. Moreno and Lyons researched the minute ventilation and the tidal volume of the lungs on twenty people in the sitting, supine (lying flat on back) and prone (lying flat on stomach) positions [14]. They found that both the minute ventilation and the tidal volume of the lungs had the highest values in the sitting position, followed by the supine and prone position. It was stated that this decrease was constant, however, it was not significant [14]. Moreno and Lyons also found that the respiratory frequency in all three positions remained the same [14].

Michels *et al*. investigated the influence of the supine and sitting body positions on lung volume in 105 adults [15]. Similar to Moreno and Lyons, they also discovered that the sitting upright position had a higher measured vital capacity of the lungs as compared to the supine position. As this study differentiated between smokers and non-smokers, it was also found that male smokers, in general, have a lower lung capacity than nonsmokers [15].

Clague and Hall conducted a study on the effect of posture on lung volume on eight patients with hemidiaphragmatic paralysis and also found that the mean vital capacity of the lungs in the sitting posture was much higher than the results in the supine posture [16]. This study is significant as its results are similar to Moreno and Lyons [14] and Michels *et al.* [15] despite being conducted on patients with hemidiaphragmatic paralysis. The values for the vital capacity of the lungs, measured in both positions from the aforementioned studies [14] [15] [16], suggest that breathing is more effective in the sitting position than the supine position.

Landers *et al.* [17] also demonstrated that there are statistically significant increases in the tidal volume of the lungs and minute ventilation in the sitting upright posture as compared to a forward slumped posture in their study conducted on 30 adults. Similar to Moreno and Lyons [14], they found the respiratory frequency not to be statistically different from one posture to the next. Avbelj *et al.* also showed that in their study, within a test group of 12 healthy subjects the average breath interval and respiration rate did not change appreciably between the supine position and the right recumbent position (lying on right side) [18].

These studies [14] [15] [16] [17] [18] have shown that different postures do indeed have an influence on the tidal volume measurement on the lungs, but the difference is not always statistically significant. Furthermore, the sitting upright position has consistently had the highest measured values for the lung volume as opposed to any other posture. This suggests that breathing can be practiced most effectively in the sitting upright position, as this is where the participant takes the deepest breaths. Moreno and Lyons [14], Landers *et al.* [17] and Avbelj *et al.* [18] have also all shown that the respiration rate amongst all their measured positions has remained the same, suggesting that different postures only change the depth of breath of the individual but not their breathing frequency. However, the aforementioned studies had researched breathing in general and not diaphragmatic breathing. Diaphragmatic breathing will be treated in this thesis and will be measured as described in the following subsection.

1.2.2 Breathline Device

The Breathline device, as seen in Figure 2, measures diaphragmatic breathing by using the Respiratory Inductance Plethysmography (RIP) method.

Figure 2: Breathline Device

As can be seen in Figure 3, RIP habitually utilises 2 belts, one strapped around the thorax, at the level of the nipples and one around the umbilicus, at the navel [19]. Both these belts have a long copper coil in them that induces an alternating magnetic field by abdominal movements of respiration. The alternating magnetic fields change the current with which RIP can measure the movement of the chest and abdominal wall that can be used to estimate the tidal volume of the lungs. Respiratory patterns can also be calculated by processing this data [20]. The Breathline device only utilizes the umbilical cord (abdomen coil) of the RIP method.

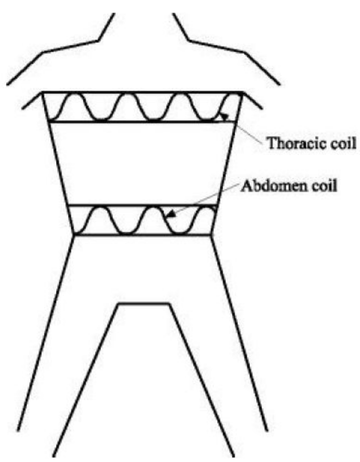

Figure 3: RIP bands for tidal volume measurement [1]

The Breathline device, as seen in Figure 2, includes an embedded tri-axial accelerometer. An accelerometer is an electromechanical device that can be used to measure acceleration (rate of change of velocity of an object) [21]. They work on the principle of inertia (Force = Mass x Acceleration) by measuring the force against a known mass in order to derive the unit's acceleration. However, they do not only measure acceleration they experience but also the Earth's gravitational acceleration. Additionally, they also measure the centripetal acceleration due to the Earth's spinning around its rotational axis [57]. Tri-axial accelerometers, like the one embedded in the Breathline device, can capture data simultaneously in the three orthogonal directions which can be used to estimate orientation and movement [21].

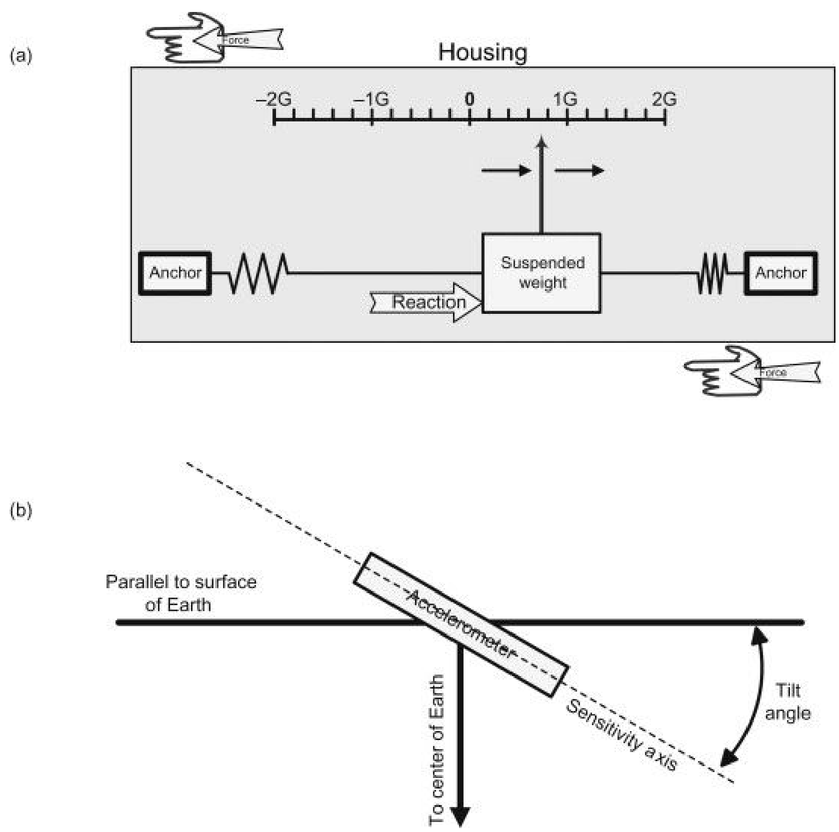

Figure 4: Working principle of an accelerometer [57]

The working principle of an accelerometer can be seen in Figure 4. Figure 4a illustrates that the basic underlying principle of an accelerometer is nothing more than a suspended mass on a spring. When this device experiences acceleration, the mass gets displaced with the same rate equal to the acceleration it sensed concluding the relationship to be proportional. This principle can also be applied in Figure 4b. If there is no movement, the accelerometer would only sense the Earth's gravitational pull. Once displaced, the angle sensed would be proportional to the acceleration applied. The 2D tilt angle in figure 4b can be calculated with the following equation:

(1) $Tilt\ angle = tan^{-1}\left(\frac{To\ center\ of\ Earth}{Parallel\ to\ surface\ of\ Earth}\right)$

1.3 Research Questions

To tackle the above-mentioned challenges, several research questions have been formulated. The main research question is:

How can body posture be tracked most effectively with a physical prototype combination of an accelerometer and other sensors to give the user constructive feedback with the Breathline device?

This thesis also answers sub-questions based on the technicalities and choice of sensors and their placement on the body.

1. *How has body position been tracked in the past and which sensor combination should be chosen to track body position in this project?*
2. *Where is the optimal placement of these sensors on the human body?*
3. *If the sensor picks up on interference of breathing measurements, how can they be cancelled out during body position tracking?*
4. *How accurate is the chosen setup in recognising body position?*
5. *What forms of feedback are considered constructive from a user perspective on posture tracking?*
6. *What effect do different body positions have on diaphragmatic breathing and can an optimum be defined?*

The first subquestion will delve into literature research to present what possibilities there are for body position tracking before making a choice on which sensor will be implemented in this project. The second to fifth sub-questions will be answered through programming, testing and user feedback. The last research question will be answered through user testing and literature.

1.4 Challenges

Firstly, a constraint even before starting this project is the embedded accelerometer. As it is already integrated into the device, a requirement of the project is that it must be used to track body position and will be looked at as the primary sensor in the setup. Additional sensors will have to somehow also be integrated into the device, if chosen to be utilized, using the same power source as the device.

Secondly, correct posture is imperative for optimal breathing. However, it is unknown in which position, diaphragmatic breathing is most effective. This will be tackled through literature reviews and expert interviews.

Thirdly, it is unknown to what extent posture and respiration are related. This poses an empirical challenge that will be combated and answered both in literature and in measurement analysis.

Fourthly, due to COVID-19 the University of Twente is on indefinite lockdown for the rest of this academic year. This is a challenge as it puts constraints on all practical aspects of this project since all the resources and testing spaces have become unavailable.

1.5 Report Structure

This paper contains 9 parts. Chapter 1 provides an introduction to diaphragmatic breathing, body posture and the challenges of this graduation project. Chapter 2 discusses background research, where a literature review will be conducted answering the above-mentioned questions. Chapter 3 lists up the methodologies and techniques that will be used in this project. The Creative Technology Design Process is elaborated on as well as other methods that were used. Chapter 4 describes the ideation phase of the project where information is acquired through the research conducted in chapter 2 but also through the methods and techniques listed in chapter 3. Chapter 5 is the specification phase that will build upon the ideation phase and iterates through multiple prototype designs and tests to conclude on a list of requirements and functions the prototype should have. Chapter 6 describes the realisation phase which entails the building and actual development of the final prototype that will be used for user testing. Chapter 7 is the evaluation phase, that will test the prototype against the requirements specified in chapter 5. The prototype will also undergo a usability test with test participants to evaluate how well it fulfils its purpose and what improvements it could have. Chapter 8 will entail the conclusion of the project followed by chapter 9 that has recommendations for future work.

2. Context

This chapter conducts a literature study firstly, on the definition of correct and incorrect posture, secondly on which sensor is best suited to track body position with and thirdly on which data post-processing method fits this application best by assessing the advantages and disadvantages of each sensor and method. The findings are complimented with expert interviews by Parviz Sassanian on posture, and Angelika Mader on sensor choice and post-processing method. Finally, a state of the art is presented on existing posture tracking / posture correction devices. This chapter concludes by answering the research question: *How has body position been tracked in the past and which sensor combination should be chosen to track body position in this project?*

2.1 Posture

As explored in the work of F. Visser [22], there are three steps to attain correct posture and these are visualised in figure 5.

1. The pelvis should be tilted to the neutral position, meaning it is drawn up straight. By tilting the pelvis to its correct state, the lumbar spine automatically moves along. The tilting of the pelvis can be externally supported by exercising a pressure that moves from the sacrum up to the lumbar vertebrae.
2. The inferior angle of the scapulae (collarbone) should be moved down and slightly inwards. The muscle that has to execute these movements is the trapezius.
3. All the cervical vertebrae should be placed on top of each other and the head should balance on the spine. The crown of the head points upwards.

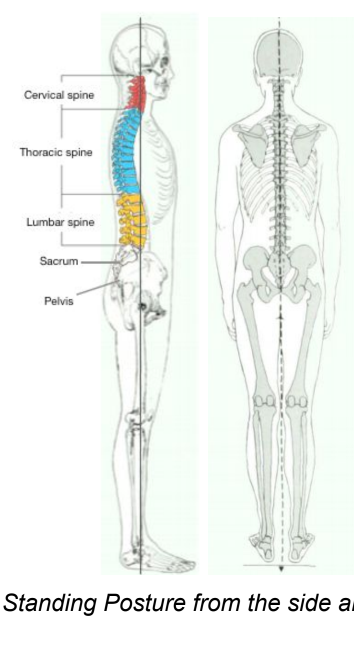

Figure 5: Ideal Standing Posture from the side and the back [23]

As seen in figure 5, the pelvis is in a neutral position. This is a fundamental requirement for "good" posture as all other elements of the spine are built upon this one [24]. The center of gravity of the body is close to the navel. Furthermore, the natural curves of the spine should be retained in the ideal standing posture. Therefore, as seen in figure 5, the lumbar spine curves slightly in an anterior direction and the thoracic spine curves in a slightly posterior one. The scapulae are flat against the upper back and the cervical spine curves slightly in anterior direction. The head is neutral.

There are several forms of incorrect posture in which the spine deviates from the ideals described above. figure 6 shows three instances where the pelvis is tilted which results in a faulty posture position.

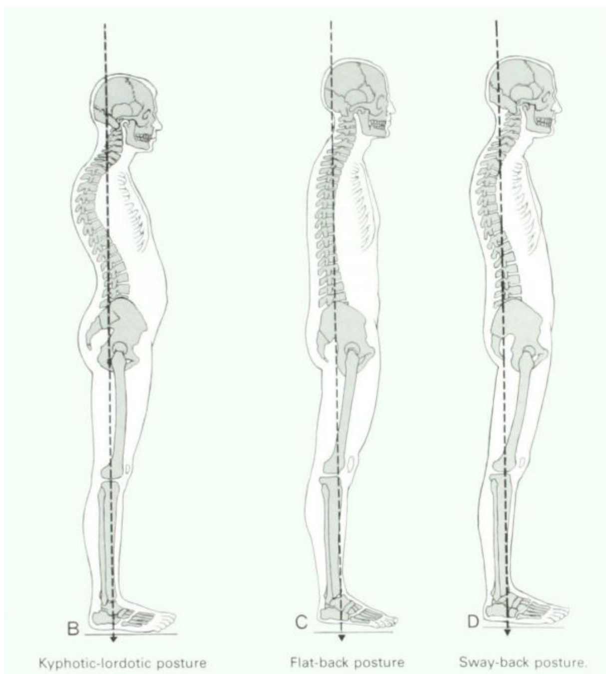

Figure 6: Faulty Standing postures [23]

Any tilting of the pelvis involves simultaneous movements of the lower back and hip joints. In the Kyphotic-lordotic posture (B), the pelvis is tilted forward, resulting in flexion of the hip joint and an increased forward curve in the lower back. In the Flat-back (C) and the Sway-back posture (D) the pelvis is tilted backward and the lower back is flattened. These postures put unnecessary pressure on the vertebrae and joints to keep the body balanced that can result in pain as the center of gravity of the body is shifted and the body no longer is aligned with the plumb line [22] [23].

There is an increasing body of literature starting primarily in the last twenty years that has investigated the increasing global trend of sedentariness and reports that prolonged sitting is associated with spinal musculoskeletal pain. Work-related sitting (computer use) and generally more seated leisure activities (television, viewing, gaming etc.) have led to more time spent sitting by people of all ages [25]. Especially the usage of computers influences instantaneous spinal postures in both adults and adolescents. Over prolonged periods of time, this can influence the degree of spinal loading but also exaggerate its effects leading to reduced opportunities for tissue regeneration [26]. Moreover, “bad posture” does not just describe one faulty movement but various different ones with various causations. Sitting at a desk can cause wrong pelvis movements, looking down at a smartphone can cause neck strains, and lounging on a couch can affect the lumbar spine [27]. Some examples of faulty postures can be seen in figure 7b and 7c.

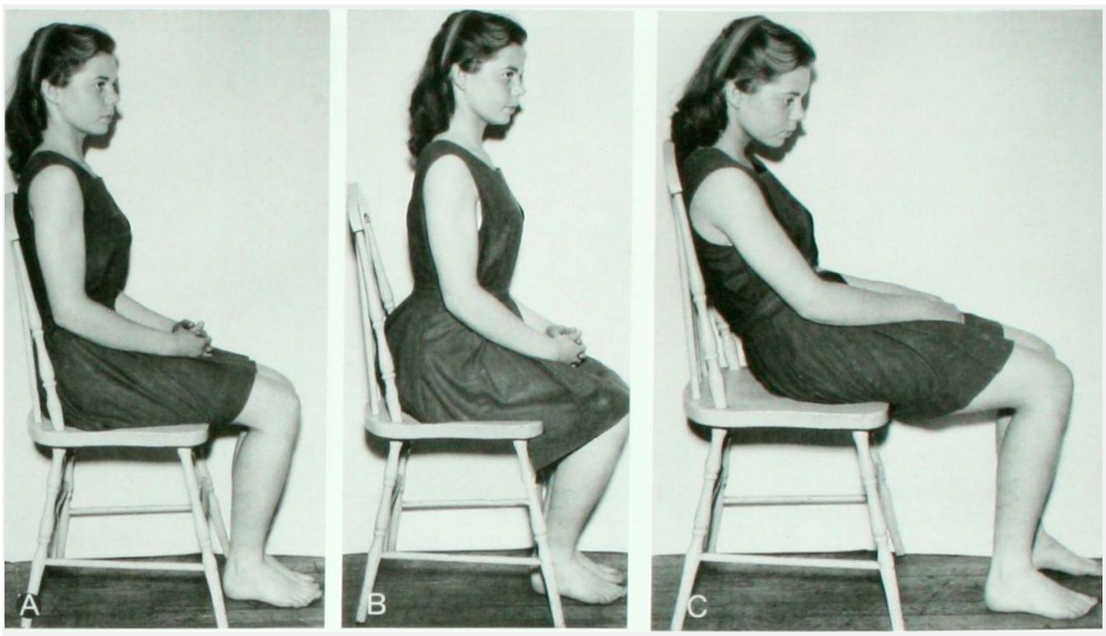

Figure 7a, 7b, 7c: Sitting postures [23]

Figure 7a shows good alignment of the body in a sitting posture and requires the least expenditure of muscle energy to keep this position. The subject's hips and knees are approximately at a 90° angle, their head is in a neutral position and their shoulders are in line with the rest of her body. Figure 7b shows lower back lordosis in a sitting position. This posture is commonly and mistakenly regarded as a correct position. However, this is not the case it takes a lot of muscular effort to maintain this position. The pelvis is tilted and the body is leaning forward leading the back muscles to fatigue. Figure 7c is the typical “slumped” position that is taken from a lack of support for the lower back and results in faulty positions for the neck, upper back and head [23].

To summarize, there are various different body positions that are classified as bad posture. Good posture is when the natural curves of the spine are retained and is a posture that causes no pain. The shoulders should be over the hips and the head balanced on top of the spine. This should be the case in both sitting and standing postures.

2.1.1 Expert Interview : Parviz Sassanian

Parviz Sassanian is an acupuncturist and breathing therapist with a specialisation in Chinese medicine. He also teaches Tai-Chi and Qigong in his Dao foundation called Heaven, Earth, Man in Lonneker where he utilises the technique of diaphragmatic breathing explained in section 1.2.1.

Mr. Sassanian explained that the technique of diaphragmatic breathing tries to use as many parts of the lungs as possible during respiration. For this, the lungs need to expand and contract as much as possible without any additional interference. To help visualise this process, figure 8 illustrates the expansion and contraction of the lungs whilst breathing. It is important to note that the lungs utilise the entire 3D space of the chest (anterior, posterior and lateral) during these movements.

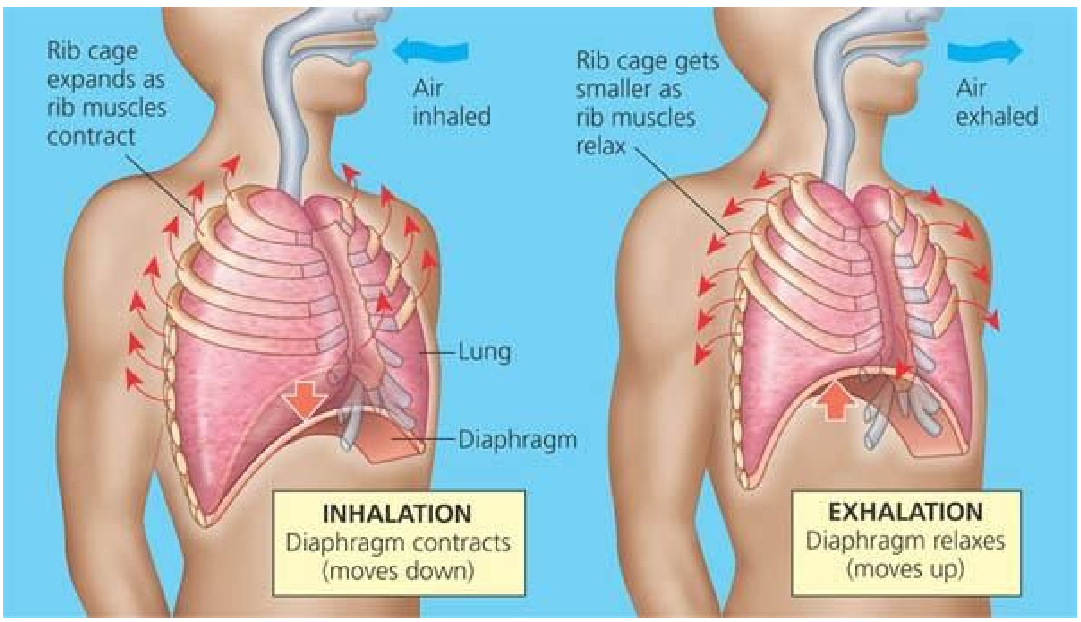

Figure 8: Expanding and Contracting of Lungs during breathing [58]

Mr. Sassanian further explained that whilst sitting, the back is habitually leant against the backrest of the chair. This backrest could block the lungs from expanding posteriorly, meaning that this form of breathing would not make most efficient use of the lungs. Another aspect to the sitting posture is that more often than not, it can lead to slouching forward. This posture blocks the diaphragm from fully expanding and adds difficulty to practicing the technique of diaphragmatic breathing properly. However, Mr. Sassanian mentioned that sitting upright without leaning against a backrest is a perfect posture for diaphragmatic breathing.

Nevertheless, sitting upright is not the only perfect posture but standing upright is also considered an ideal state for diaphragmatic breathing. This is because there is no obstruction to the lungs anywhere whilst standing in a free space. Diaphragmatic breathing can also be practised whilst lying down flat with the back on the ground, but has the same disadvantage of the sitting posture, as the lungs cannot expand fully posteriorly.

The target group that Mr. Sassanian aims the Breathline device to be directed at are people that want to enhance and improve their breathing. He imagines this group to be between the ages of 25 - 65, as this is the age range where people habitually are confronted with questions about the inner and intricate workings of their bodies and want to improve themselves.

The Breathline device should be able to detect changes in body position when the body fluctuates from being upright in either a sitting or standing position. The minimal requirements of the device is that it should recognise the spine at 90°, 60°, 45° angles. However, he clearly underlines that the main focus of the device should be breathing detection. If the breathing is still “good” in an “incorrect” posture, there should not be any correctional feedback given to the user as the focus of the device is breathing and not posture. Moreover, he distinctly emphasizes that he does not want the Breathline device to be similar to shock collars dogs wear that prevent them from straying too far from their owner. The Breathline should be a calm correctional device and should not be associated with shock therapy.

2.2 Sensor Review

There are several sensors and sensor combinations that can be used to track body posture with varying results. This section of this paper provides an overview of appropriate sensors that have been used successfully in other studies, compares their results and assesses their feasibility for this project.

2.2.1 Strain and Elongation Sensors

Elongation or bend sensors are variable resistors that have been used to monitor the flexion of objects. When bent, the conductive layer stretches and extends, increasing its resistance, as seen in figure 9.

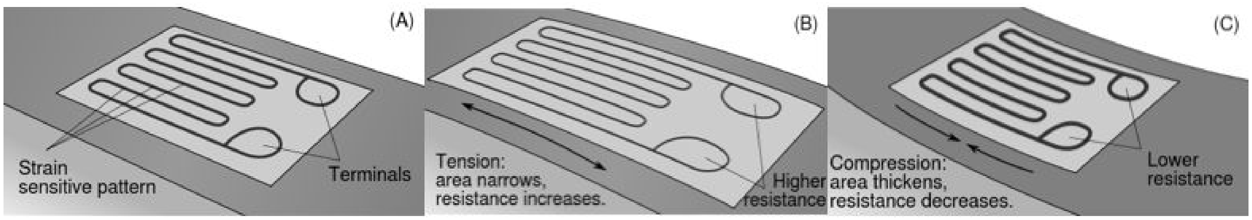

Figure 9: Visualisation of the working concept behind strain gauge [28]

Mattman *et al.* [29] used a thermoplastic elastomer strain sensor integrated into a tight-fitting garment, as seen in figure 10, for identifying 27 different upper body postures with a complete recognition rate of 97%. However, the sensor used was a novel strain sensor developed by EMPA (https://www.empa.ch) and is not available for commercial use.

De Rossi *et al.* [30] used similar elongation sensors based on carbon loaded rubbers to differentiate between various trunk postures, as seen in figure 11. However, there are no formal results stated in the paper as it was presented as a proof of concept.

Dunne *et al.* [31] evaluated four different bend sensors (polypyrrole-coated open foam sensor, Abrahams piezo-resistive sensor, Flexpoint resistive sensor, Plastic fibre optic sensor) against a control measurement made by a CODA motion capture system to monitor seated spinal posture with a test group of 9 healthy subjects. As seen in figure 12, the foam sensor exhibited a poor and highly variable response, whereas the optical sensor recorded the overall flexion most precisely and was therefore also used as the end sensor that was integrated into a garment. It’s precision measurement for a single point varied between 20.29% the range of motion [31].

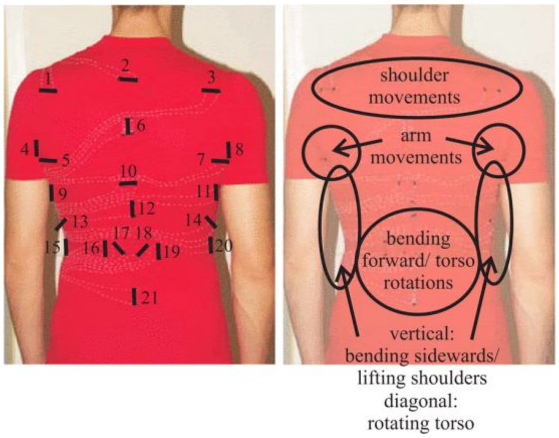

Figure 10: Garment using elastomer strain sensor

Figure 11: Carbon loaded rubbers strain sensor

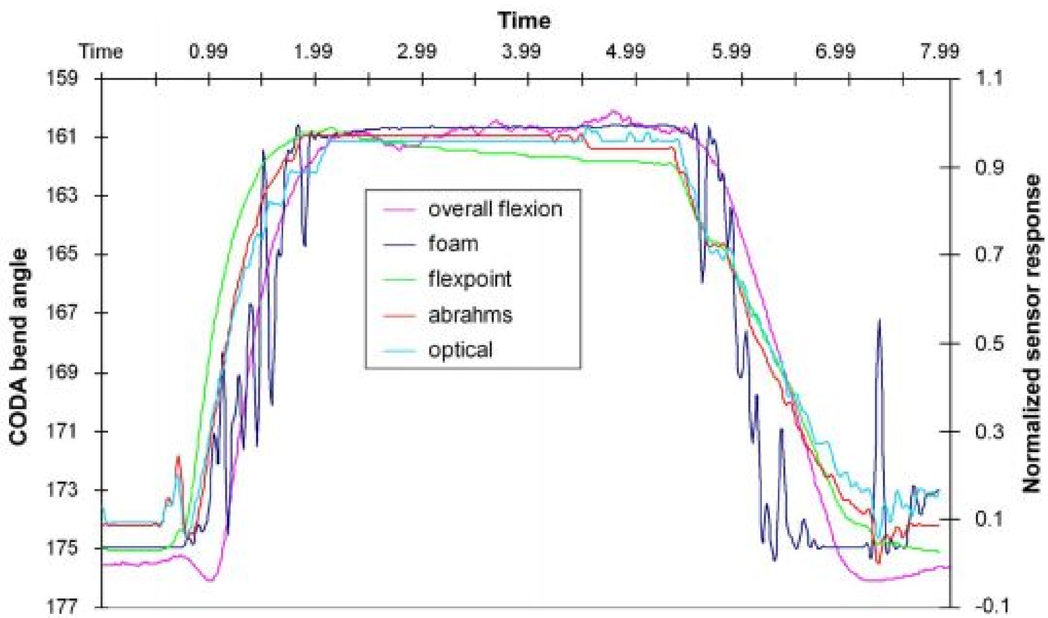

Figure 12: Comparison graph of 4 types of strain sensors

2.2.2 Fiber Optic Sensors

Fiber optic sensors are fiber-based devices that use optical fibres to detect strain, temperature, concentration of chemical material, acceleration, rotation, pressure, vibration and displacements [28]. The elements that they are made up of can be seen in figure 13a.

Zawawi, Keeffe and Lewis [32] used intensity-based optical fibre bending sensors to monitor human spine bending in a clinical environment. The results of their implementation was a resolution less than 2° with an output drift of 0.25% during a 2h measurement and a working sensor range between 0° and 20°. The experimental setup of the sensor configuration exceeded $500 because of the cost of the combination of optical fibre sensors [33] [34].

NASA's Langley Research Center [20tt] developed a method that uses FBG strain sensors in a multi-core optical fibre to determine how at any point that fibre is positioned in space. Using their FOSS (Fibre Optic Sensing System) technology, their algorithm notices light propagating down the fibre. When the light waves come in contact with Bragg gratings, they reflect at unique wavelengths that are calibrated and can measure displacement, stiffness, torques, pressure, cracks and temperature. This process can be seen in figure 13b. However, this technology is still patent-pending and is not yet on the market for commercial use [28].

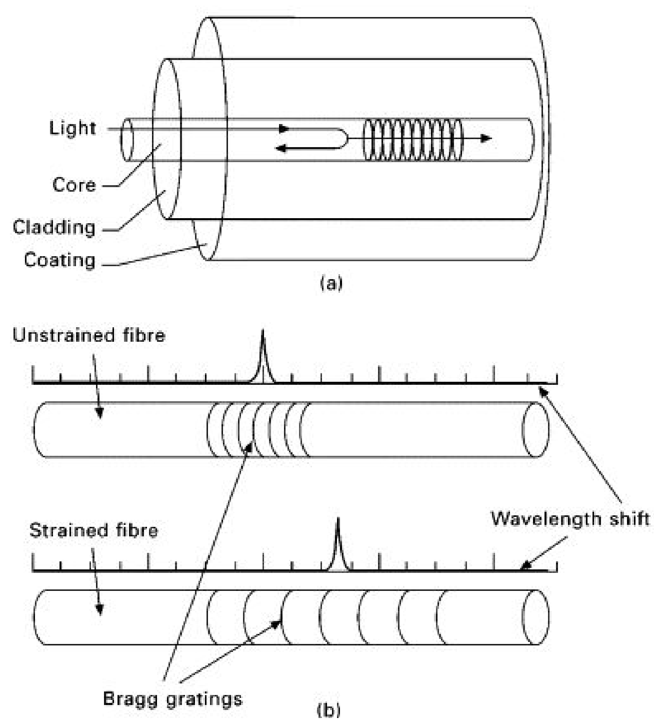

Figure 13: Bragg grating sensor: (a) schematic showing core and cladding; (b) operating principles. [36]

2.2.3 Electromagnetic Sensors

Electromagnetic tracking systems work by using a magnetic field generator (3D Emitter) and at least one 3D magnetic sensor. The emitter sends signals and the receiver picks up the sent out magnetic field signals, as seen in figure 14.

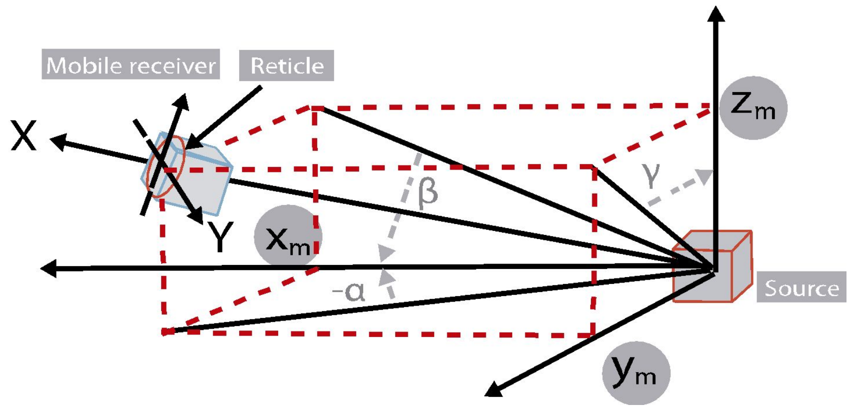

Figure 14: Example schematic of electromagnetic sensor tracking [37].

Rowe and White [38] measured lumbar spine motion in gait in a group of ten nurses, aged 24 - 39, by an electromagnetic sensor - Polhemus Isotrack. The sensor was mounted across the lumbar spine to measure the 3D dynamic motion as seen in figure 15. This research was done using an already commercialised sensor, which is why there is no precision and accuracy data mentioned in the paper. Moreover, this system incorporated two infrared beams consisting of an emitter and detector with a range of 10m, mounted on wooden stands and were used to start and stop data capture and measure subjects walking velocity which makes this method feasible for a clinical setting but not for home use due to the amount of equipment required to recreate the setup and is therefore not viable for the Breathline project.

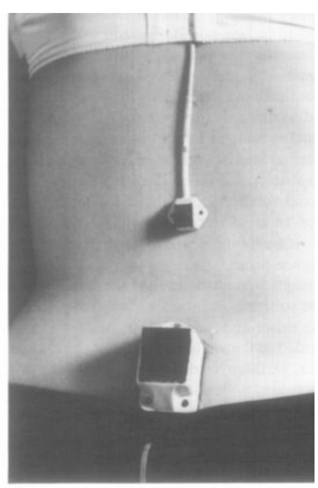

Figure 15: Isotrack device mounted across the lumbar spine

2.2.4 Ultrasonic Sensors

Ultrasonic sensors can measure the distance to an object using ultrasonic sound waves. The working principle for these sensors is to use a transducer to send and receive ultrasonic pulses that relay information back about the object's proximity as seen in figure 16.

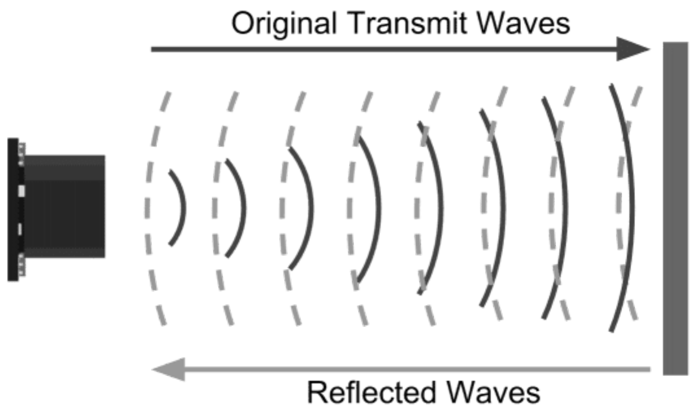

Figure 16: Ultrasonic Sensor working principle [39]

Ultrasonic sensors can also be used to monitor movement as Vogt and Banzer have shown in their research of analysing and comparing the pelvic and trunk oscillations during level and uphill walking [40]. They used the Zebris CMS 50 device to obtain 3D kinematic data from 22 subjects aged 27 - 32 whilst they were walking on a motorized treadmill at 4.5km/h. Three ultrasound microphones were used to determine a local coordinate system to track the ultrasonic markers with an accuracy better than 0.6mm.

Ohtani, Baba and Konishi [23a also used ultrasonic sensors to measure position and posture by changing characteristic quantities such as the peak values to the penetrating and reflecting waveforms, positions and deflection points to get a higher resolution. Their paper showed that the method has been proved to be very effective when applied to position measurements and shape recognition but cannot yet be implemented for home use as their prototype setup is simply too large, as seen in figure 17. This is also the case for the previously mentioned study done by Vogt and Banzer [40], as there is too much equipment required (Zebris CMS 50 device and three microphones) for this to be implemented in the Breathline product.

Figure 17: Ultrasonic sensor prototype setup

2.2.5 Inertial Sensors

Inertial sensors are based on inertia. They encompass uni-,bi-, and triaxial accelerometers, gyroscopes and magnetometers. Gyroscopes measure angular velocity and magnetometers measure the magnetic field in the vicinity of an instrument. A device that consists of (at least) a triaxial accelerometer and a triaxial gyroscope is called an Inertial Measurement Unit (IMU).

Triaxial accelerometers (described in section 1.2.2) can track movement alone without integration of the other 2 sensors as Gjoreski and Gams [42] have shown. They analysed several approaches of activity and posture recognition whilst varying the number, type of the sensors and using different body placements to evaluate how well an accelerometer performs without the aid of additional sensors by using MTx sensors from Xsens. Their results showed a 17 percentage point improvement accuracy rate when including the gyroscope and magnetometer module. This is significant because it illustrates the added value that the additional sensors bring to the results. Moreover, increasing the number of sensor modules from one to three also saw a 15 point rise in the accuracy rate which highlights the importance of measuring all aspects of movement to achieve the highest accuracy rating and demonstrates the superiority of the IMU over a single accelerometer.

Furthermore, an IMU provides more reliable and accurate measurements than accelerometers because the latter are prone to two very obvious measurement errors. Valldeperes *et al.* [43] justifies the use of an IMU for body position tracking over them because firstly, the variability of the device is determined by its hardware and second, the measurement of the gravity acceleration is included in the data. These issues can be rectified by using corrective algorithms for the accelerometer measurement but also by using a gyroscope / magnetometer system. The integration of the gyroscope adds another three degrees of freedom (DoF), giving the IMU a total of 6DoF of measurement data, as illustrated in figure 18. Moreover, all output data can be compared to each other and consequently corrected with the additional sensors, as there are more data points also.

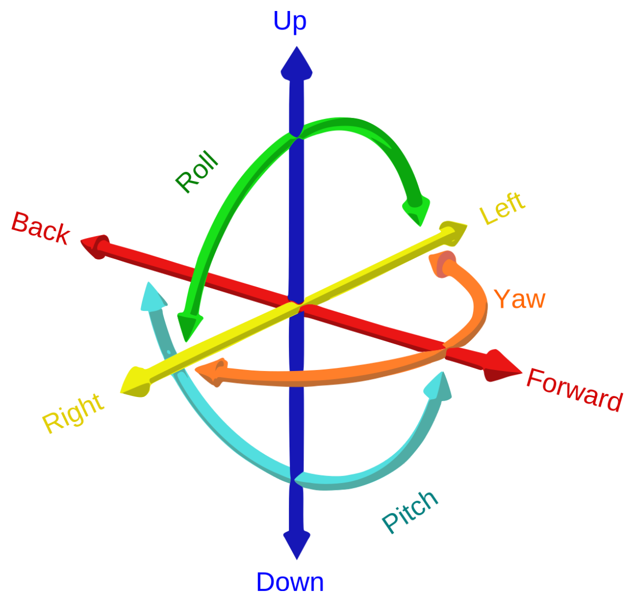

Figure 18: 6DoF of IMU. Accelerometer: up,down,forward,back,right,left. Gyroscope: roll, yaw, pitch [48]

These two studies have independently shown that using an IMU will output more accurate results than only using an accelerometer because of the data comparison and correction the IMU can do and of the additional degrees of freedom that it measures.

To summarize, most strain and elongation sensors that were mentioned in this paper are not available for commercial use. The optical sensor that had the highest accuracy rate in the study of Dunne *et al.* [31] still had a precision variation rate of 20.29% which is not a desirable characteristic for this study. Fiber Optic sensors have very good specifications, however, their price would heavily impact the whole price of the Breathline device making it less accessible for the current market. The setup required if electromagnetic sensors or ultrasonic sensors would be integrated with the Breathline device would be too large. These sensors were used in the chosen studies for measurements in a clinical environment and would therefore not be ideal for usage in a home environment. Inertial sensors would be the most fitting choice to track body posture and position as they combine three sensors and are therefore very accurate [43]. The IMU is superior over an accelerometer because it can compensate for its measurement errors and allows for measurements in six degrees of freedom. Moreover, there is already an accelerometer embedded in the device that is not being used, as explained in section 1.2.2. Combining an IMU with this accelerometer only brings benefits because both sensors measure in the same way and would be placed on different parts of the body, thereby covering more area and being able to pick up on more aspects that contribute towards bad posture and drive the user to correct them.

2.3 Classification Method Review

There are several different machine learning approaches that can be taken to process data measurements taken from accelerometers. This section provides an overview of different methods taken in independent studies and compares and critically assesses their results before finalising on a choice that is most applicable for the Breathline project.

2.3.1 Butterworth Filters vs. Random Forest

The choice of sensor is not the only important aspect of activity recognition but also how it gets connected to the system and how its data gets processed. Figure 19 shows a general system architecture of a posture recognition algorithm to help visualise the common data processing procedure discussed in this paper. Gjoreski and Gams [42] used a Random Forest Classifier whilst Valldeperes *et al.* [43] used Kalman and second-order Butterworth filters to assign their measured attributes to classes to allocate them to predefined postures. As mentioned in the paragraph above, solely using filters like Valldeperes *et al.* [43] did, has the risk of over-smoothing the data to get very good results with one test group, but is then only applicable to them with the chosen parameters. Even though filters are easier to implement than machine learning, this method is unable to eliminate noise if the signal is not stationary and does not perform well if the data contains outliers [44]. The predictive performance of the Random Forest Classifier method that Gjoreski and Gams [42] used, is far superior to the filters as it can process linear and nonlinear data, gets trained to recognise the outliers the filters would miss but consequently can have high computational costs. Additionally, in Random Forests one can avoid overfitting issues by adjusting the number of trees or the maximal size or depth of the single trees where no such precise tuning parameter exists in the filter method [45]. For the reasons listed above, the Random Forest Classifier would yield better results than a filter because of its ability to process more complex data sets and its robustness towards outliers.

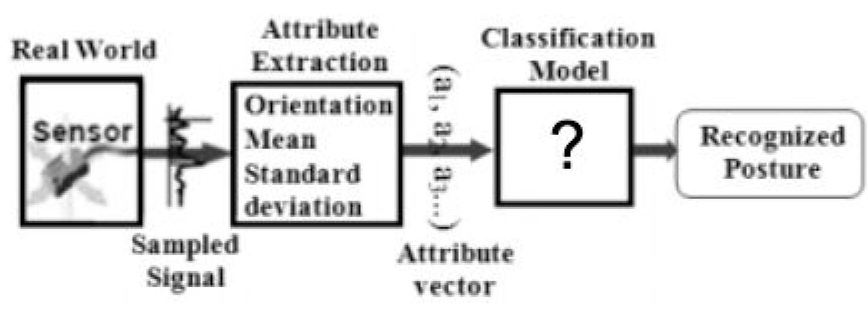

Figure 19: System architecture model of posture recognition algorithm

A comparative study was conducted on seven different machine learning techniques, shown in figure 20, where the Bayesian Decision Tree Method was proven to be most effective. Altun, Billur and Tunçel [46] developed an algorithm that had to differentiate 19 activities and was trained by Repeated Random Sub Sampling (RRSS), P-fold and 10-fold cross-validation where ⅔ of the data samples were used for training and ⅓ for testing. Similar to the study of Gjoreski and Gams [42], the data was obtained by using 5 MTx sensors (xsens.com), where two were placed on the legs, two on the wrists and one on the chest of the 8 participants [46].

The result of this study, as can seen by the statistics in figure 20, showed the Bayesian Decision Tree method (BDM) having the highest classification rate followed by the Support Vector Machine (SVM) and the *k*-nearest neighbour (kNN) algorithm. However, BDM was proven superior to the other classification methods because it also has a relatively small pre-processing time, minimal storage requirements and a 99% classification rate (not included in figure 20). A question that needs to be asked, however, is whether the success rate of this algorithm would be this high with every individual, as the sample size of the study was only restricted to 8 individuals with no stated method of selection. This success rate of the BDM algorithm could correspondingly just be specific to one demographic or none at all.

Method	Pre-processing/training time (ms)			Storage requirements	Processing time (ms)		
	RRSS	*P*-fold	L1O		RRSS	*P*-fold	L1O
BDM	28.98	28.62	24.70	Mean, covariance, CCPDF	4.56	5.70	5.33
RBA	2514.21	3874.78	3400.14	Rules	0.64	0.95	0.84
LSM	6.77	9.92	5.42	Average of training vectors for each class	0.25	0.24	0.21
k-NN	–	–	–	All training vectors	101.32	351.22	187.32
DTW_1	6.77	9.92	5.42	Average of training vectors for each class	86.26	86.22	85.57
DTW_2	–	–	–	All training vectors	116.57	155.81	153.25
SVM	7368.17	13,287.85	10,098.61	SVM models	19.49	7.24	8.02
ANN	290,815	228,278	214,267	Network structure and connection weights	0.06	0.06	0.06

The processing times are given for classifying a single feature vector.

Figure 20: Pre-processing and training times, storage requirements and training times of the classification methods with BDM (Bayesian Decision Tree Method) , RBA (Rule Based Algorithm), LSM (Least-Squares Method), k-NN (k-Nearest Neighbour, DTW (Dynamic Time Warping), SVM (Support Vector Machine), ANN (Artificial Neural Network) [46].

Posture and movement of infants can also be classified using different machine learning techniques. Contrary to Altun, Billur and Tunçel [46], the sample size and selection method that Airaksinen *et al.* [47] used for their research was quite comprehensive, as it consisted of 24 approximately 7-month old participants with no prior history of significant medical conditions. This was done by using 4 Suunto Movesense Sensors (movesense.com/showcase/suunto/), placed on the legs and arms of the body. These sensors have a smaller range than the MTx Xsens trackers as Table 1 shows below. Airaksinen *et al.* [47] also compared the SVM algorithm to a convolutional neural network (CNN) for their classification model, where the results show that the CNN classifier yielded a notably better performance as seen in figure 21 [47].

	Suunto Movesense Sensor	Xsens MTx Sensor
Accelerometer	$\pm 8g$	$\pm 18g$
Gyroscope	$\pm 500°/s$	$\pm 1200°/s$
Magnetometer	-	$\pm 75\mu T$

Table 1: Range comparison between Suunto Movesense Sensor and Xsens MTx Sensor

However, this result does not coincide with the results of Altun, Billur and Tunçel [46], only because their neural network required a considerable training time which lowered its score. In spite of this, once it was trained and the connection weights were stored, the classification was completed very rapidly. Another aspect that differentiates the two studies is their participant group. Airaksinen *et al.* [47] studied the movement of infants that had a range between 4-8 months of age whilst Altun, Billur and Tunçel [46] analysed adult movement within the age range 20-30. This comparison is relevant because infant movement patterns differ substantially from the prototypical adult categories [47] which makes their classification less studied and therefore has imprecise boundaries. This suggests that despite the results seen in figure 21, BDM could still be the most efficient algorithm to classify movement activity.

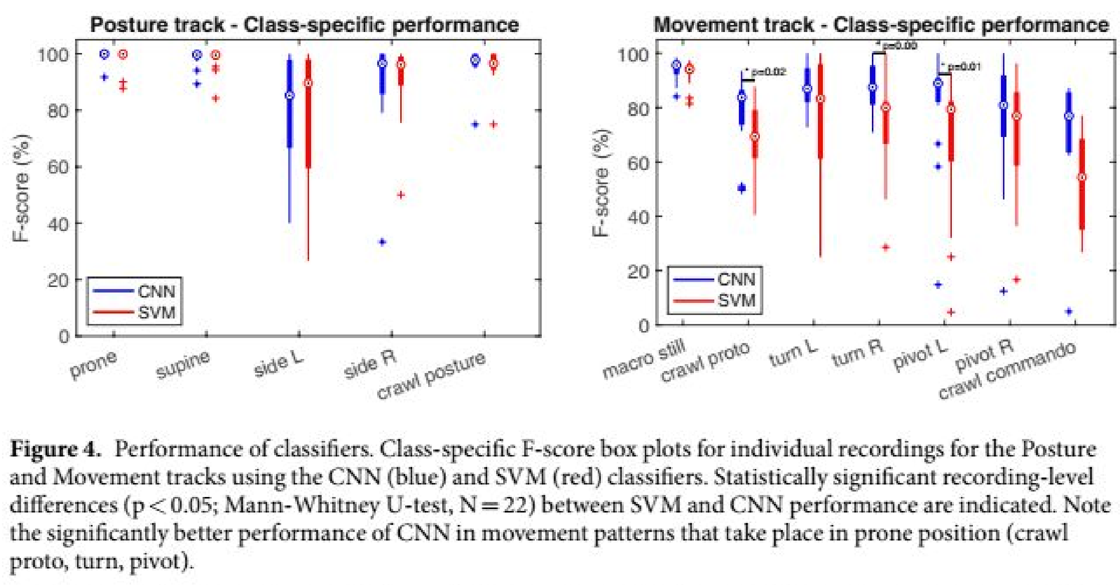

Figure 21: Class specific F-score box plots performance of classifiers where CNN (blue) and SVM (red) [47]

2.3.2 Decision Tree vs. Random Forest

The final stage in this comparison is to compare the Bayesian Decision Tree Method (BDM) against the Random Forest (RF) algorithm. The CNN will not be considered in this comparison because of its extremely high preprocessing time and storage requirements [43][47]. Decision trees are principally a set of rules and are the predecessors of Random Forests. The total population of the trees are split into two or more homogenous sets based on the input variables. The main advantage of BDM is its small processing time because the tree structure will always remain the same and therefore does not need variable transformations [49]. However, not unlike filters, Decision Trees show a lack of reliability in their application to new data as they tend to perfectly fit all samples in the training data and do not perform well with outliers [45]. RFs are made up of multiple single decision trees based on a random sample of the training data. They are more accurate and robust than the individual classifiers because they are made out of trees that did not have access to the complete data during the build process so that it can compensate for potential errors of single trees in the forest by averaging or majority voting, depending on the context [49]. Moreover, RFs can also effectively deal with large databases, can create an internal unbiased estimation of the generalized error and can estimate the importance of each variable for classification [45].
Furthermore, because RF's are made of Decision Trees they have similar preprocessing times and storage requirements meaning if compared to the other classifying methods shown in figure 20, it would come out superior. Thus, because the RF algorithm can compensate for errors of its individual classifiers and is much more powerful than the BDM without incurring much higher computational costs, it should be chosen as the data processing algorithm for the Breathline project.

The most effective classification algorithm to implement with the IMU would be the Random Forest because it can avoid overfitting, can handle outliers and large databases without incurring much higher computational costs than the BDM [45]. This makes them far more reliable than filters that have a tendency to over-smooth data and the CNN algorithm that has very high preprocessing times and storage requirements [49]. By implementing the found methods with the Breathline device, this research can continue to explore how diaphragmatic breathing and body position are related by practical tests before finally bringing the device to the market so that patients can train with this technique effectively at home.

2.3.3 Expert Interview : Angelika Mader

Angelika Mader is an assistant professor in the Human Media Interaction Group at the University of Twente. Her current main research interest is in the field of wearable technology with haptic stimulation and has worked on many projects within this area.

When having described the main objective of this paper, she suggested using flex sensors between the bottom of the sternum and the navel. She mentioned that an important consideration that one has to regard is that these sensors need to be firmly attached to the body for the measurements to be accurate. Furthermore, the body type of the user affects measurements too as if the user has a large stomach, the sensor attached to the sternum slides upwards and can falsify data.

Mrs. Mader also stated that in her previous work, she has worked with accelerometers to track body position and that calculations between the sensors were her main data processing method, and that it was quite successful. *“Accelerometers are quite good at measuring angles which can be linked to posture quite easily.”* She has personally never used machine learning for processing data for body position but suggests that using decision trees could substitute the calibration phase that is usually needed to initialise the sensors.

However, she called attention to the importance of recognising various different poor postures as bad posture is not only defined as slouching but also is dependent on the position of the hips, the shoulders and the neck also. Another fact worth noting is that commercial posture monitoring products on the market that are made to be stuck on one place of the body are quite easy to fool because they do not measure the entire body posture. *“You can satisfy the sensor whilst still having bad posture.”* It should still be considered that the main disadvantage of these sensors is that they need to be very close to the body which can make the experience uncomfortable for the user.

A suggestion for implementation would be to place a sensor on the lower back and the shoulders to primarily focus on whether the user is slouching and or have bad posture in their shoulders. Furthermore, there should be a delay built in the feedback system because posture is dynamic (e.g if the user is putting a book back in its place they will have bad posture for w negligible amount of time and getting feedback too fast can be perceived as being irritating).

2.4 State of the Art

This section provides an overview of the state of the art of commercially available posture tracking devices. They will be analysed on placement on the body, sensor, price and functionality. The results will be summarised and presented in a table.

The LumoLift, iPosture, Upright GO and Finis Posture are quite similar as they measure posture using IMUs and provide feedback using vibration motors.

Figure 22: Lumo Lift: $169.95 [50]

Figure 23: iPosture: $74.95 [51]

Figure 24: Upright GO: $95.00 [52]

Figure 25: Finis Posture Trainer: $19.99 [53]

The LumoLift [50] and iPosture [51] devices, as seen in figures 22 and 23 are meant to be worn on the user's clothing by being clasped on either magnetically (LumoLift) or with the clasp (iPosture). Contrarily, the Upright GO device [52], as seen in figure 24, is meant to be stuck to the skin near the spinal column of the user by using adhesive tape. This could mean that the LumoLift and iPosture are more susceptible to movement elsewhere in the body as they are not

attached directly to it. Furthermore, these two devices could try and compensate for this by having a longer delay before detection of movement, making them less sensitive than the Upright GO.
The LumoLift and Upright GO have a Bluetooth module integrated into them so that they can also be paired with mobile applications to see their performance statistics. The Finis Posture trainer [53], as seen in figure 25, is aimed to help swimmers keep proper posture by wearing the device on their head on top of their swimming caps. When they are swimming and the sensor detects an “incorrect position” of the cervical spine, it vibrates to indicate the mistake the user is making.

Figure 26: Prana: $149.99 [54]

Prana [54], as seen in figure 26, is also an IMU-using device that tracks diaphragmatic breathing and posture by being clipped onto your waistband. It has Bluetooth to notify you with notification on your phone when breathing or posture can be improved. Additionally, it has a training mode that is exercises that have been gamified to train breathing and posture for relief from stress and anxiety. It recognises when you sit, stand and walk and also has an inbuilt step counter to monitor daily activity.

Figure 27: Alignmed Posture Shirt for Men and Women: $95.00 [55]

The AlignMed Posture shirts [55], as seen in figure 27 consist of Neurobands technology. These are composed of variable elasticity that mirror the contractive properties of muscles that train soft tissues and joints. This shirt works without sensors and is said to strengthen and align the body naturally by targeting specific anatomic zones. These shirts have no electronics embedded in them but are included in the state of the art to illustrate an alternative method to improve posture.

Figure 28: Darma: $179.00 [56]

Darma [56], as seen in figure 28, is a smart cushion that works with an optical fibre sensor to monitor posture. Similar to the previous sensor-integrated devices, Darma also provides vibration feedback and has a Bluetooth module to connect to your phone. Additionally, it can track heart rate and breathing rate.

All the products mentioned in the state of the art have been summarised in Table 2.

	LumoLift	**iPosture**	**Upright GO**	**Finis Posture Trainer**	**Prana**	**Alignmed Posture Shirt**	**Darma**
Sensor	IMU	IMU	IMU	IMU	IMU	-	IMU
Bluetooth	Version 4.0	-	Version 4.0	-	low energy	-	low energy
Battery Life	5 days	3 weeks	10h	unknown	7 days	-	2 weeks
Calibration	Button	Button	Button	-	Button	-	App
Price	$169.95	$74.95	$95.00	$19.99	$149.99	$95.00	$179.00

Table 2: Summary of State of the Art

2.4.1 Discussion

This chapter presented an explanation for correct and incorrect postures and listed up a review of sensors and classification methods used in previous studies to measure body position and postures. Interviews with Parviz Sassanian and Angelika Mader were also conducted to gain additional information from experts in the field. A number of posture tracking devices were listed in the state of the art and analysed on functionality, price and placement on the body. All the findings from chapter 2 will be summarized and discussed in this section of this paper and will answer the research question: *How has body position been tracked in the past and which sensor combination should be chosen to track body position in this project*.

The ideal posture is described by having the pelvis and the head in a neutral position. The natural curves of the spine should be retained and the shoulders should be towards the back in the ideal standing or sitting posture. Parviz Sassanian validated the research conducted in section 2.1 as he stated that an upright posture is considered best to practice diaphragmatic breathing as there is no obstruction to the expansion and contractions of the lungs. To measure deviations from the aforementioned posture, a literature review on different sensors was conducted which resulted in showing that Inertial Measurement Units seemed to be the best choice of sensor to interface because they don't require a large setup, are cheap and since IMU's contain three sensors in one, they can compensate for measurement errors of their single components too. Angelika Mader confirmed this hypothesis as she has successfully used accelerometers in the past to track posture but did not use machine learning to classify the postures, but did it using calculations. This is significant because it leads to the possibility that programming machine learning for post-processing the data may not be necessary. However, the result from the comparison review of machine learning algorithms for tracking body posture is that the Random Forest algorithm would be most efficient because of its predictive performance, its ability to avoid overfitting, and that it can also compensate for errors its individual classifiers can make without incurring much higher computational costs [45].

Angelika Mader suggested using flex sensors to track posture, however, Floor Visser experimented with three different placements flex sensors in her study [22] and came to the conclusion that the sensor does not give a wide variation of values and is therefore not possible to distinguish between different postures and consequently that flex sensors are unsuitable for this application. Contrarily, as seen in figure 12, the flex sensors used in the study of Dunne *et al.* [31] output a highly variable response. These facts conclude that flex sensors are quite unstable and do not have the level of accuracy that is needed for this application.

The analysis of the state of the art illustrated that IMU's have been integrated in almost every posture tracking device. The optical fibre sensor has also been used in an application but is not as popular as the IMU. All forms of feedback are given through a vibration motor and most of these devices also have positive reviews.

To conclude, body position has been tracked through various methods and sensors in the past as elaborated in sections 2.2 - 2.4. The Inertial Measurement Unit has been chosen as the sensor to measure posture as they are small, cheap and have multiple sensors in one unit. The primary data processing method was chosen to be the Random Forest algorithm. However, in hindsight, this was not able to be implemented. Therefore, calculations for angle measurement, similar to what Angelika Mader described shall be used to process the accelerometer data.

3 Methods and Techniques

This chapter lists up the methodologies and techniques that will be used in the rest of this thesis. Interviews, brainstorms and different forms of analysis frameworks are covered, amongst others.

3.1 Creative Technology Design Process

This section serves to familiarize the user with the Creative Technology Design Process that was introduced through Mader and Eggink [59] in 2014. The four phases of this design process, as seen in figure 29 are:

- **Ideation**
- **Specification**
- **Realisation**
- **Evaluation**

Ideation
The ideation phase encompasses the process of going from a user need or creative inspiration to a product idea. This is usually done through defining the problem, as shown in Chapter 1, acquiring relevant information which was done through the literature research and state of the art in Chapter 2, and idea generation with similar approaches which can be done through the techniques listed in sections 3.2-3.5 which is implemented in Chapter 4.

Specification
The specification phase describes the making of multiple prototypes to explore the design space that includes a short evaluation and feedback loop. These prototypes are subsequently discarded, improved or (partially) merged into new prototypes with help of evaluations and comments from user testing [59]. Methods such as FICS (Functions, Interactions, Contexts, Services), PACT(People, Activities, Context, Technology) and MoSCoW (Must, Should ,Could, Will not have) analysis, listed in section 3.6 and 3.7, are used to refine, prioritize and even alter requirements [1]. This phase leads the idea, born in the ideation phase, to the engineering domain.

Realisation
The realisation phase is characterised by combining the knowledge acquired in the previous phases to construct and realise the final prototype. This can be done in several iterations where each iteration is tested and evaluated. This phase has a cyclic nature in the sense that it can go back to previous phases, gain new information and come back and adjust.

Evaluation
Functional testing and user testing are common approaches to evaluating a prototype. The functional test entails testing the prototype against the original functional requirements identified in the specification phase. The user test evaluates the user experience and whether the earlier defined non-functional requirements result in the intended interaction. The final product will be critically reflected upon by comparing it against all previous requirements but also by evaluating the comments from the user testing and the expert review [59].

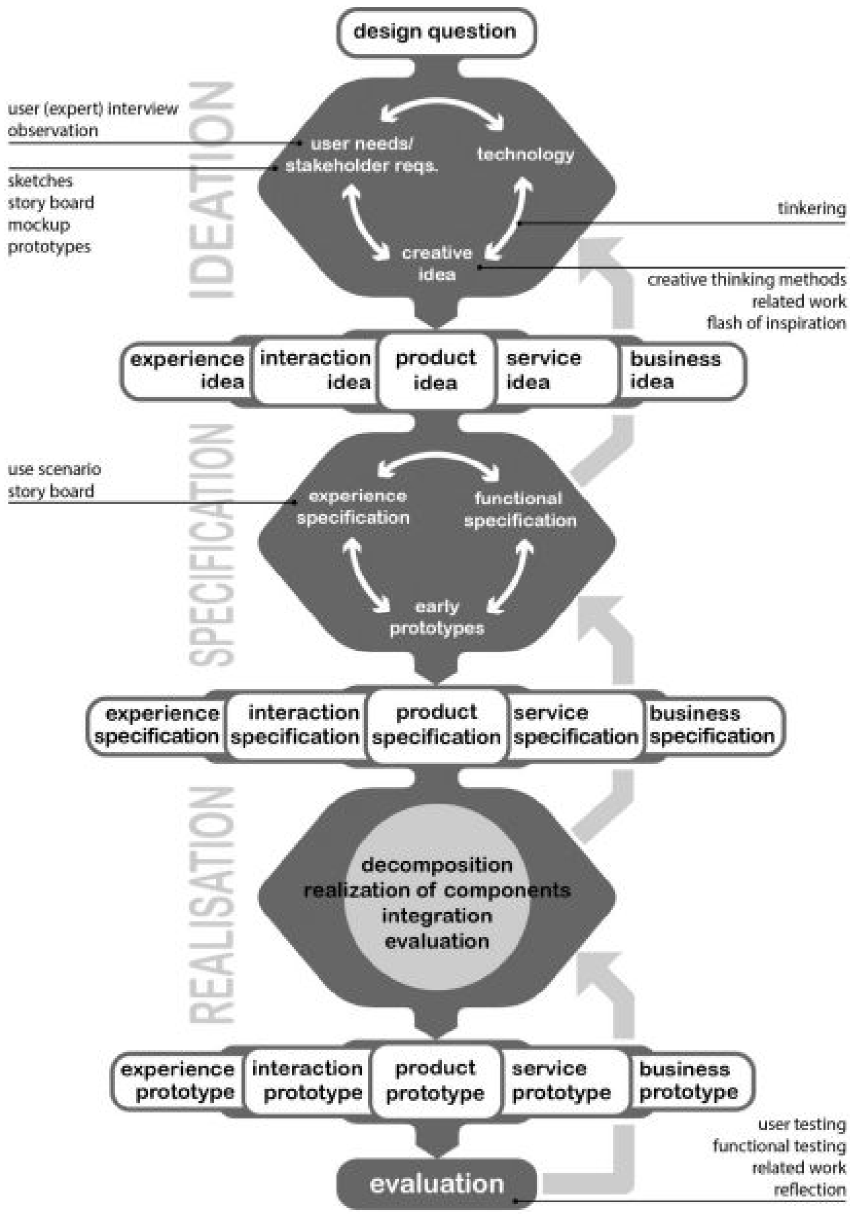

Figure 29: Creative Technology Design Process [59]

3.2 Brainstorm Techniques

Brainstorming is a process for generating creative ideas and solutions through intensive and freewheeling group discussion. Critique, analysis and discussion of the generated ideas are done at the end of the brainstorming session, as to not disturb the spirit and the flow of the process [60]. Brainstorms can be conducted individually or in a group setting [1], of which both are done in this project. The different techniques used in this project are stated in this section.

3.2.1 Analytic Brainstorming

The primary focus of analytic brainstorming is problem-solving by analysing the problem with tools that lead to creative solutions. Most people find this technique relatively easy as it brushes on idea generation skills that most people have already built-in school and in the workplace [61].

Gap Filling
The Gap Filling technique begins with a statement locating in which situation one starts at and a statement determining where one wishes to be. The gap that needs to be filled is how one gets to the goal [61]. This technique will be executed for the group brainstorm. The participants' responses will be collected and organized to develop a vision for action in the individual brainstorm.

Starbursting
The Starbursting technique starts with creating a six-pointed star. The challenge or opportunity should be written in the center of this star. The 6 question words (who, what, where, when, why and how) should be written at each point of the star. These words should be used to generate questions that should thereafter be used to generate a discussion [61]. For this project, this technique will be used for the individual brainstorm and can be seen in section 4.2.2.

3.2.2 Quiet Brainstorming

The technique of quiet brainstorming is employed when meeting a group of people cannot be scheduled due to various circumstances or when team members are unwilling to speak up in a meeting due to feelings of insecurity or fear of disapproval [61].

Collaborative Brainwriting
Collaborative Brainwriting begins with writing the question or concern on a large piece of paper and posting it in a public space or on the internet. Team members are asked to write or post their ideas at their convenience over the course of a week. The ideas are then collected and evaluated with or without the group's involvement [61]. This technique will be executed in the group brainstorm by using Google Slides. Instead of a large piece of paper, each participant will fill out an individual slide using the Gap Filling technique.

3.3 Interview Techniques

Interviews can be classified into three techniques, namely the fully-structured, semi-structured and unstructured interview [62].

Fully-structured Interview

Fully structured interviews use a rigid script to present questions in a well-defined order. There is no room for asking questions out of order or for adding questions not found in the predefined interview script. This rigid structure means that they are relatively easy to analyse but asking follow-up questions for clarification are considered inappropriate [62].

Semi-structured Interview

Semi-structured interviews generally start with a list of predefined questions but can deviate from this to ask for clarification and to follow comments from the interviewee. They open up the possibility of exploring topics in a depth and breadth that is harder to achieve with fully structured interviews, but as a consequence are also not that straight-forward to analyse [62].

Unstructured Interview

Unstructured interviews do not have a list of questions but may have a list of topics, called an interview guide. The objective of this technique is to let the interviewee focus on the topics they find important by enabling them to lead the conversation [62].

All interviews conducted in this thesis were semi-structured interviews. As mentioned above, semi-structured interviews allow the interviewer to follow up on comments of the interviewee to gain additional insights and increase knowledge of the subject. This technique was chosen as the goal of the interviews was to get as much relevant information as possible in a constricted time period.

3.4 Stakeholder Analysis

To understand a stakeholder analysis, the term stakeholder needs to first be defined.

"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" [58, p.1].

Sharp, Finkelstein and Gamal [63] have categorised stakeholders into four roles for better identification purposes namely:

Users: People who make the purchasing decision of the product and / or interact with the system directly (primary user) or indirectly (secondary user).

Developers: People who work and develop the system but their interest in the system is different from the users.

Legislators: Any group or body that provides guidelines for operation that will affect the development and / or operation of the system.

Decision Makers: Managers of the development and financial team i.e anybody within the organisation who has a decisive role in the development of the product and its future sale strategy.

The identified stakeholders of this project will be grouped into the above-mentioned categories. They will then be ranked on "Interest in Project and "Influence on project" in terms of low, medium and high. This ranking will be visualized in an Interest vs. Influence Matrix. These aspects will be presented in section 4.1.

3.5 iPACT and FICS

iPACT stands for intention, People, Activities, Context and Technology. The intention describes the aim of the product. The people section describes the users. To better understand the users, personas will be created that should depict the users with representative characteristics, namely age, gender, education, job responsibility, technical experience and experience with specific software or hardware devices [62]. The activities encompass how the user interacts with the product. The context describes the environment in which the activities take place and events that may influence those activities. Technology stands for essential technologies required by domain experts to support the activities. An iPACT analysis expresses the domain activities of the users but is independent of the intended system [64]. The use scenario is written from the user's point of view [4].

FICS is an abbreviation for Functions, Interactions, Content and Services [64]. Functions are the functionality of the intended system that can mediate user activities. Interactions describe how the user interacts with the system [64]. Content relates to how the system stores data and how it is accessed [1]. Services are what capabilities the system can deliver. Unlike the iPACT analysis, a FICS analysis is written from the system's point of view which is why both analysis', even though quite similar, complement and complete each other for a comprehensive view of the use scenario.

3.6 Requirements

Multiple methods exist to explore the requirements of a system. This project will primarily use two techniques. The MoSCoW analysis will be used to prioritize the requirements that will later be divided again into functional and non-functional requirements.

MoSCoW analysis
MoSCoW is an abbreviation for Must Have, Should Have, Could Have, and Will not Have. Must Haves are requirements that the system indisputably needs. In this thesis they will come from interviews with the clients and full usage of the existing hardware. Should Haves are requirements that are convenient for the system but are not necessary. Could Haves are the lowest requirements on the priority list and are looked at as a "nice to have", if they do not disrupt any other functionality the system has. Will not Haves are requirements that are unrealistic for the determined timeframe but are wished to be implemented in the future [1][4].

Functional and Non-Functional Requirements
Functional requirements are processes that describe what the system should do and what services they should provide. Non-functional requirements refer to the constraints, behavioural and usability properties of the system and describe how the system works [4].

3.7 System Architecture

A system architecture is the conceptual model that defines structure, behaviour and more views of a system [65] and how they connected. The iPACT and the FICS analysis will help form a foundation for the system architecture by listing up requirements. A general model of a system architecture can have multiple levels, in which deeper levels describe workings of individual components of the system. In this project there shall be three levels of the system architecture model. The first level will be composed of the inputs and outputs of the system. The second level will describe the functionalities of the system with block diagrams, where each block represents a different functionality [4]. The third level will decompose the second-level functionalities into sub-functionalities to show the inner workings. The arrows connecting the blocks will illustrate which components are connected and in which order they are called upon [1].

3.8 Evaluation

The product will be evaluated using two methods in order of a functional test and then a user test. This order is important as the functional test ensures that the prototype works correctly before the user test [4]. The functional test encompasses checking whether the developed prototype meets all the functional requirements set up in the specification phase, as listed in Chapter 5. The user test is executed in order to validate whether the product is intuitive to use by checking whether the non-functional requirements have been met whilst being interacted with by a user.

4 Ideation

The ideation phase describes the process of taking inspiration to a product idea. This shall be done by firstly conducting a stakeholder analysis that will be summarised in an influence vs. interest matrix. Thereafter, the findings of the group and individual brainstorms will be presented. Interviews will be held with representatives of the target group and various user requirements will be explored through performing an iPACT analysis. The chapter will be concluded by user scenarios and a list of preliminary requirements for the project which shall help to frame the idea of the final prototype.

4.1 Stakeholder Analysis

This section will take the methods stated in section 3.4 to identify the stakeholders in this project by category.

Users: The Breathline product has several potential users. The interview with Parviz Sassanian conducted in section 2.1.1 concluded that the preferred user group is individuals between the ages of 25 - 65 that have an active wish to enhance and improve their breathing. However, the potential users do not need to be restricted to this definition as it can also be used by anyone who has an interest in their biometric data. Other user categories could be physiotherapists as this device could help them train diaphragmatic breathing of their patients and parents that want to retain this breathing technique in their children.

Developers: The Breathline product has multiple developers. First and foremost Ben Bulsink is the main developer and creator of this device. The researcher of this project, Radhika Kapoor along with Martijn Poot are working on different implementations of posture tracking for this device. Tijmen Smit is developing a wireless connection using Bluetooth for the device for seamless data transfer. Zaccaria di Giorgio is developing the corporate identity of the device and Dimana Stambolieva is creating a digital therapeutic platform that can coach the users to practice diaphragmatic breathing online.

Legislators: As the breathline product measures biometrics, it is classified as a class IIa medical device, as can be seen by the highlighted route in figure 30. There are strict regulations that medical devices need to comply with, to be allowed on the market. Farmatec is a governmental organization that oversees the registration of medical devices to be sold on the market in the Netherlands. The Breathline product would need to be registered with them in order to be allowed and sold on the Dutch market [1]. Lawyers and medical policymakers can also be defined as legislators as both of them need to work together in order to establish laws that restrict or permit the use of this device. Moreover, because this project is taking place during COVID-19, the Dutch government and the University board indirectly control the pace of the project through their decisions concerning social interaction. This is especially important in regard to the group brainstorms, interviews and user testing components.

Decision Makers: There are three primary decision-makers of this project who are also the clients. Ben Bulsink is the developer and creator of the device. Parviz Sassanian is a breathing specialist who will presumably be the primary user of the device and Erik Faber who is the supervisor of this project. Other decision-makers include Cora Salm who is the critical observer of this project and all the students in the developer section. These students count as decision-makers, as they all work on different aspects of the project and their implementation will affect the outcome of the device as a whole.

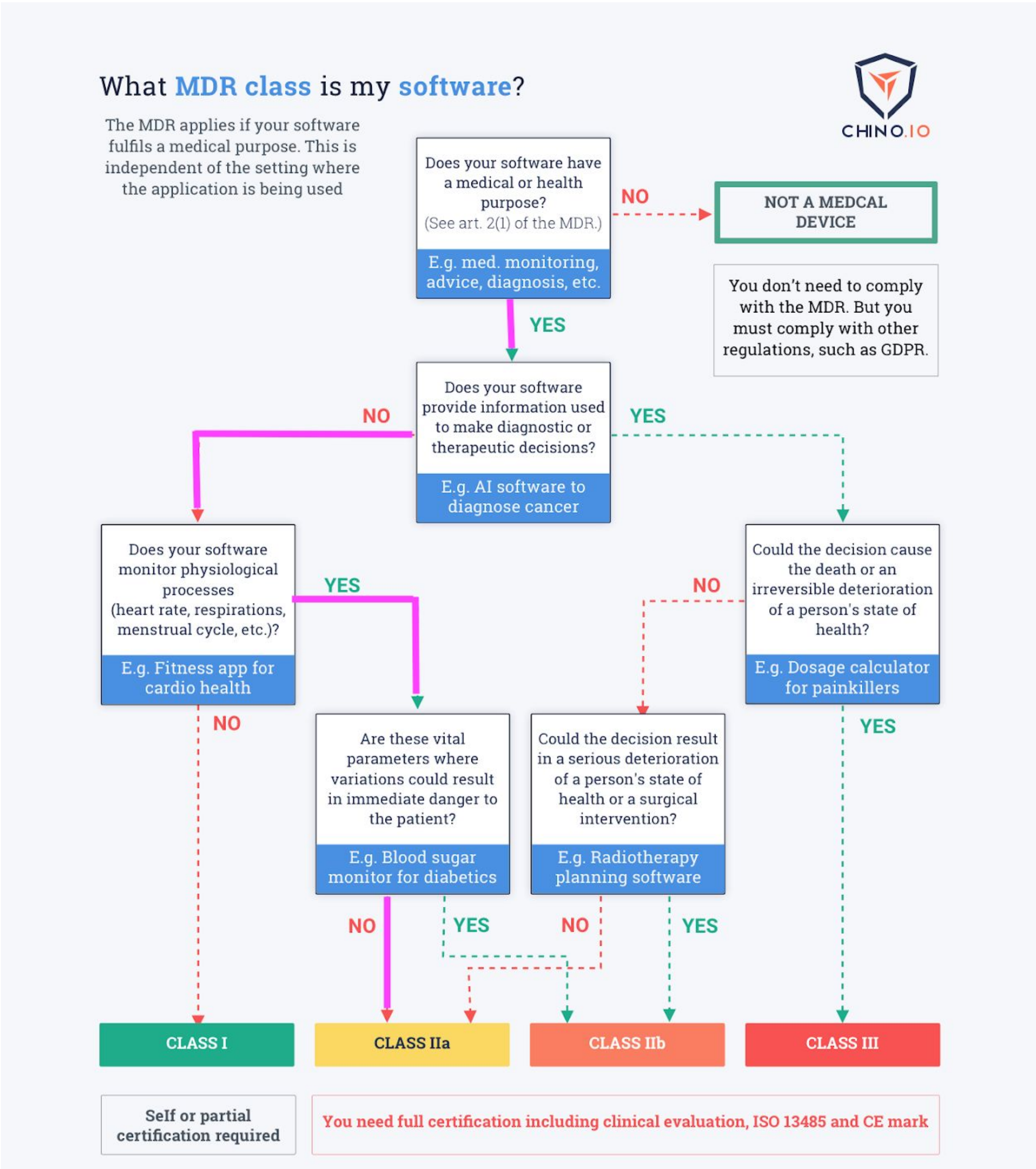

Figure 30: Medical Device grading [66]

Table 3 represents the stakeholders sorted by category, interest in an influence on the project. A graphical depiction of the influence on the project vs. the interest in this project is illustrated in figure 31.

Stakeholder	**Category**	**Interest in project**	**Influence on project**
Children	User	Low	Low
Young adults	User	Medium	Low
Working adults	User	Medium	Low
Elderly	User	Medium	Low
Patients	User	Medium	Low
Physiotherapists	User	Medium	Low
Farmatec	Legislator	Low	High
Dutch Government	Legislator	Low	High
University Board	Legislator	Low	High
Medical Policymakers	Legislator	Medium	High
Lawyers	Legislator	Medium	High
Ben Bulsink	Developer / Decision Maker	High	High
Parviz Sassanian	Decision Maker	High	High
Erik Faber	Decision Maker	High	High
Cora Salm	Decision Maker	Medium	High
Dimana Stambolieva	Developer / Decision Maker	High	Low
Zaccaria di Giorgio	Developer / Decision Maker	High	Low
Tijmen Smit	Developer / Decision Maker	High	Low
Martijn Poot	Developer / Decision Maker	High	Medium
Radhika Kapoor	Developer / Decision Maker	High	High

Table 3: List of all stakeholders with their ranking of influence and interest

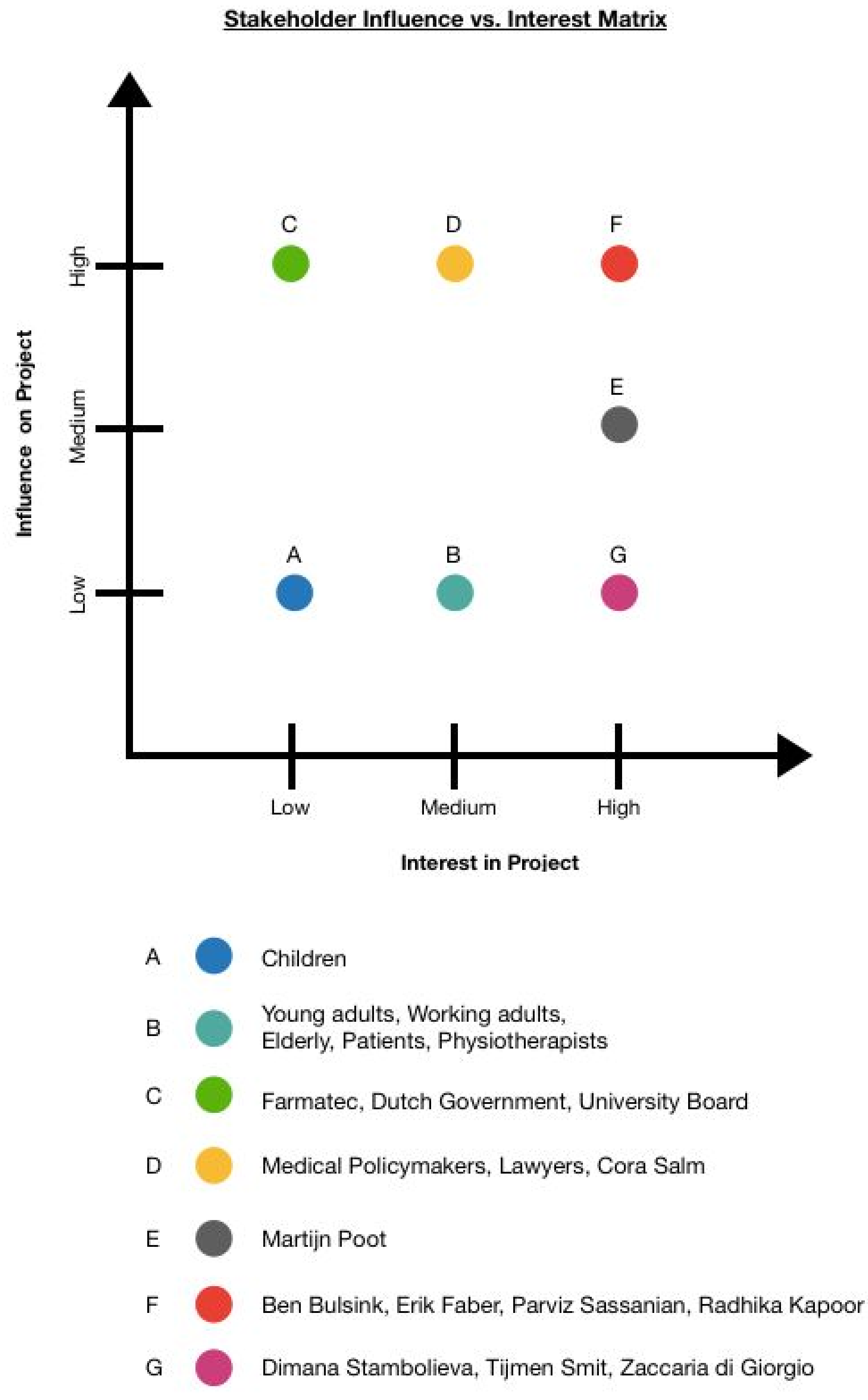

Figure 31: Breathline Project Stakeholders: Influence vs. Interest Matrix

To summarize the findings of the stakeholder analysis, Ben Bulsink and Parviz Sassanian, the clients of this project, Erik Faber, the supervisor of this project and Radhika Kapoor, the author of this thesis are the most important stakeholders. In spite of the fact that medical policymakers, lawyers and the Farmatec firm are also important players in the project, due to the scope and the timeframe of this thesis they shall not be approached. Moreover, as mentioned above, the Dutch Government and the University Board have a great influence over the pace of this project, as their restrictions due to the COVID-19 pandemic determines the availability of resources and testing facilities.

4.2 Idea Generation

This section presents the results of the group and individual brainstorms. The group brainstorm was conducted by using the Gap Filling and Collaborative Brainwriting technique described in section 3.2. These brainstorms were evaluated and together with the Starbursting technique also described in section 3.2, a mind map was created for the individual brainstorm of which the results can be seen in section 4.2.2. The group brainstorm slides can be seen in Appendix B.

4.2.1 Group Brainstorm

The group consisted of 17 participants (11 male, 6 female), between the age range of 18 - 46, of which the majority showed interest in biometric data. The statistics of the participant group can be seen in Appendix B. The brainstorm touched upon the themes of placement of the sensors for position tracking, data processing, feedback forms and noise cancellation. Due to this thesis taking place during the COVID 19 pandemic, conducting brainstorms in person was not permitted. This restriction was tackled by inviting the participants to each fill out one slide with how they would get from the start to the finish. The results have been summarised per topic below.

Placement of sensors
All participants intuitively thought that placing the IMU at the back of the neck or between the shoulder blades would make most sense to track posture, as it is the body part that experiences movement the most. However, one person mentioned that placing a sensor directly on skin could cause itching and / or sweating which would be undesirable.

Data processing
Different postures should be measured, classified and saved in an array. The live sensor data can be compared to the predetermined values and be classified. If absolute position is needed, it can be calculated through using kinematic equations as the sensors output acceleration and angular velocity data. Another method that was suggested was including the orientation of the sensor and the angles between the two sensors.

Feedback
The most common form of feedback mentioned in the group brainstorm was haptic feedback in the form of vibrations. All participants seemed enthusiastic about a small vibration motor that would inform them if they stray away from good posture. However, visual and auditory feedback were also mentioned, mostly in the form of a smartphone application. Whichever form of feedback is chosen, it should not be too invasive as it would be preferred if the feedback happens without disturbing the user's external environment.

Noise cancellation
Inertial Measurement Units experience drift over time. This can be combated by using Kalman Filters, Low pass and High pass filters. Moreover, the moving average filter was frequently mentioned as a method to process the data of the IMU. Using Welch's method of identifying power spectral densities with a periodogram for certain frequencies was suggested. Attention was brought to the fact that the electrical interference frequency component at 50Hz should not be forgotten and be filtered. Additionally, the gravity component at 0Hz could also be removed, if the goal is to only process the data from the 3 axes.

Miscellaneous Comments
If an app were to be created and paired with the Breathline device, it could give weekly updates of how well the user performed with their breathing and posture. The app could also have a button that would begin the calibration for posture tracking. If the Breathline device is developed to a stage where it can be brought to the market, it could also establish partnerships with companies that sell chairs or gymnastic balls to reach a larger group of people and gain added publicity. The device could also be paired with a smartwatch that could display breathing / posture progress and give haptic feedback for correction.

4.2.2 Individual Brainstorm

The starbursting method was used in the individual brainstorm to come up with questions related to the project that helped frame the mindmap to answer them. The diagram of the starbursting technique with the questions can be seen in figure 32. The mindmap with possible answers can be seen in figure 33. The results have been summarised in this section. Aspects from the group brainstorm were included in the individual brainstorm to expand upon.

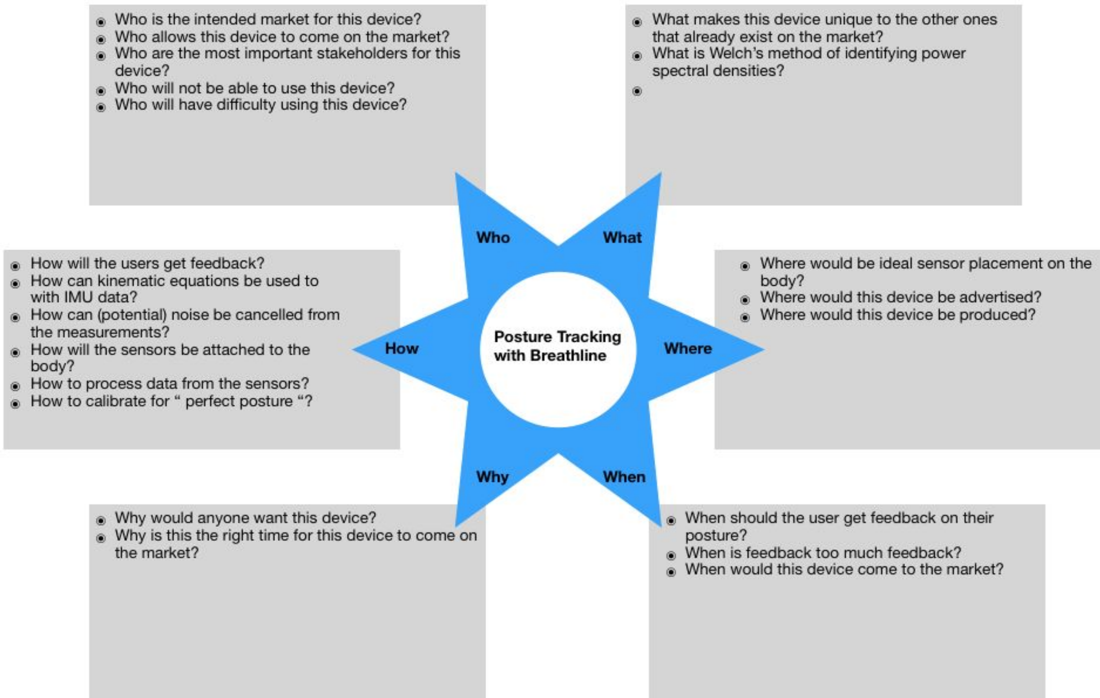

Figure 32: Starburst Diagram

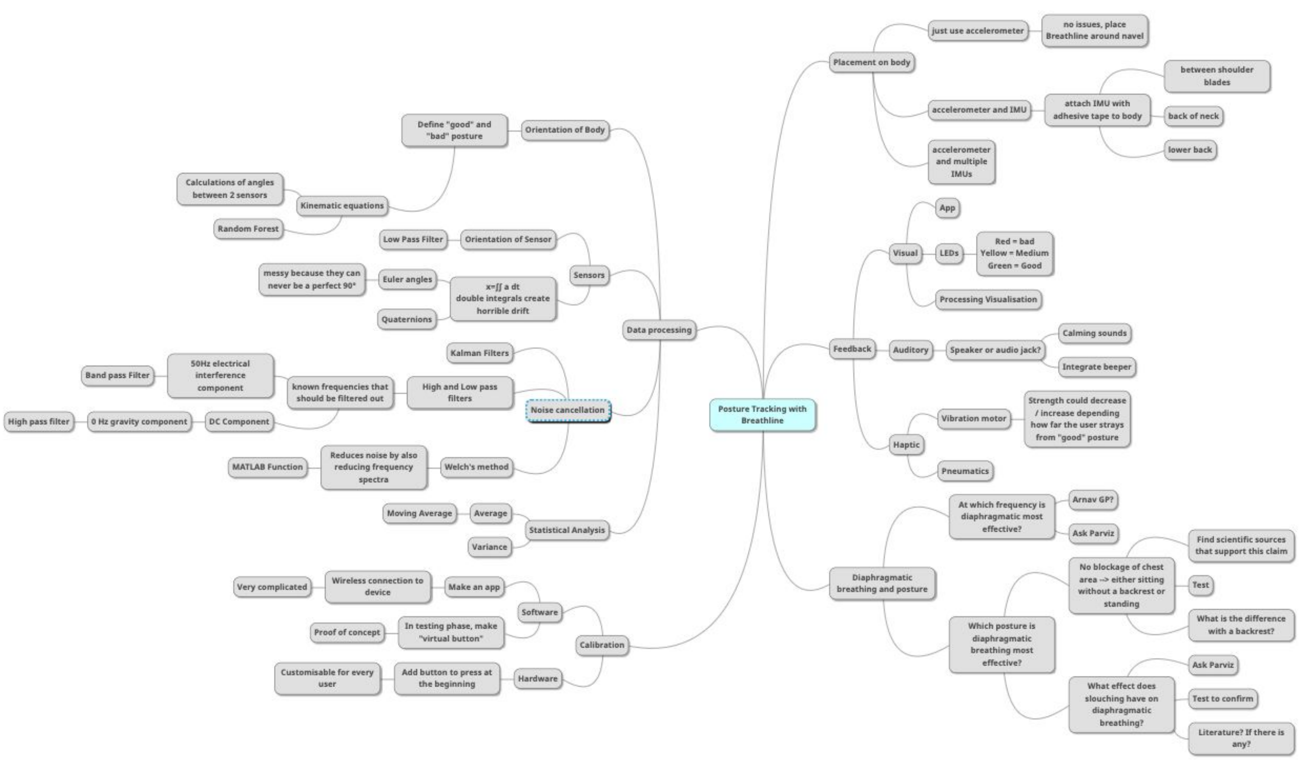

Figure 33: Individual Brainstorm Mindmap

Placement of sensors on body
The ideal scenario of this project would be to track body position and identify posture changes by just using the embedded accelerometer in the Breathline device. Ideally the placement of the sensor would be the abdominal band around the navel. If these measurements prove to be too inaccurate, an IMU will be added to the setup. The placement will be experimented with to find the ideal position between the neck and between the shoulder blades, as described in section 5.2.

Data Processing
The final accelerometer values should output degrees. This can be done by double integration of the acceleration values to get position. The radian value can then be converted into degrees. Alternatively, quaternions can also be used to express rotation. This method needs to be further researched for full understanding.

Calibration
Like many of the products mentioned in the state of the art, it is easiest to embed a button in the Breathline device that would calibrate the sensor upon touch. The user manual for the LumoLift states that the device should be calibrated multiple times per day for the best user experience. This shows that commercially available products still do not have absolute calibration.
The idea for the Breathline device is to also have a button that would calibrate the accelerometer when the user is sitting / standing upright. Any deviations from this posture should provide feedback in either an auditory, haptic or visual form.

Feedback
From the group brainstorm, haptic feedback was the most popular option for feedback as it is hidden and discrete. However, many people also mentioned having an app, which can be interpreted as a demand for visual feedback. A way to implement this could be to pair Arduino and Processing to get both haptic and visual feedback. Florian Naumilkat, a Creative Technology Alumnus from 2018 [4] made a breathing visualization, shown in figure 34.

The flower represented vitality in his project which was received quite well by his user tests. This idea was adopted to this project for the visualisation as flowers are often present in nature and are quite delicate. A concept sketch is shown in figure 35. Flowers can represent mindfulness and calm which is what diaphragmatic breathing has been proven to do [3] [67]. Moreover, it was thought that keeping a flower straight would be an intuitive activity that could subconsciously also help the users keep their backs straight if the flower would move with the accelerometer values.

However, for future iterations of the project, development of an app should be considered that provides real-time posture feedback. An idea from the group brainstorm would also be to have the ability to link the Breathline device with a smartwatch that could provide feedback and reminders / notifications.

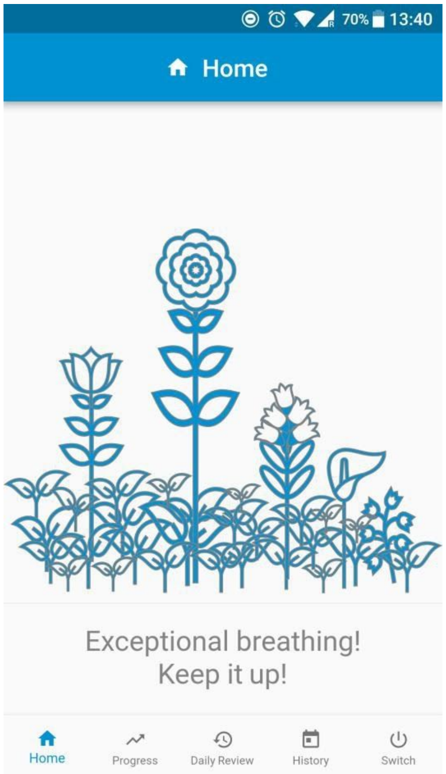

Figure 34: Breathing Visualization of F. Naumilkat [4]

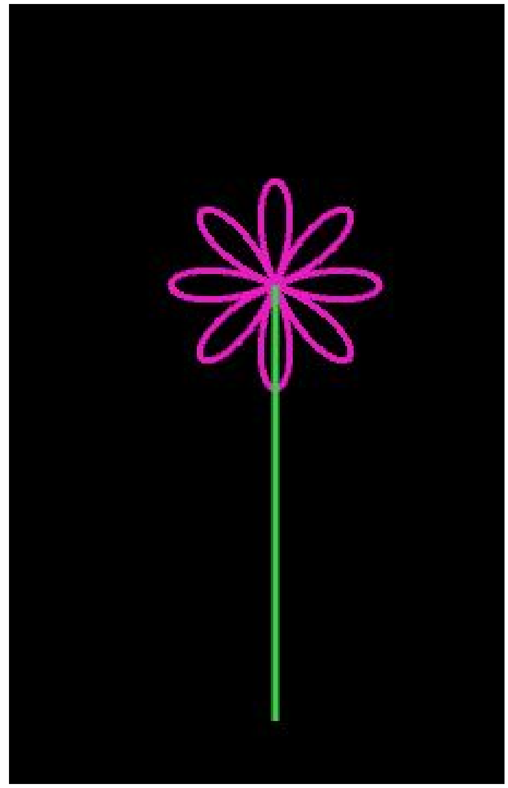

Figure 35: Concept Sketch of Visualization

Diaphragmatic breathing and posture
This relationship will be identified during testing once it becomes more clear how diaphragmatic breathing works and which values are important for "ideal" qualities. However, research can be conducted by looking at literature and consulting previous iterations done on this project.
Mr. Sassanian mentioned in his interview in section 2.1.1 that there should be no obstruction to the lungs while practicing this breathing technique. This can be tested in the testing phase to explore the effects that the obstruction of the lungs actually causes to diaphragmatic breathing. This test can be done on a user in multiple positions to evaluate how these two aspects are related.

Market Analysis
The starbursting technique addressed some questions that are out of the scope of this project but could be helpful for further iterations.
→ Where would this device be advertised?
→ Where would this device be produced?
→ Why is this the right time for this device to come on the market?
→ When would this device come to the market?

If there is sufficient time at the end of this project, these questions will be addressed, however, they are not the main focus or goal.

4.3 Target Group Interviews

To better understand the user requirements, interviews were conducted with representatives of the envisioned target group. The focus of the interviews was to explore whether there is a demand for a posture tracking device and which features potential users might want it to have. A semi-structured interview, described in section 3.3 will be conducted with one person per category. Due to the COVID-19 pandemic, all interviews were conducted through online applications. The question list can be found below:

1) *Do you suffer from back pain?*
2) *How conscious are you about your posture?*
3) *What parts of your posture are you concerned about?*
4) *What sort of feedback / statistics would you like to see if there were an application that would tell you about your posture?*
5) *How often would you wear such a device?*

4.3.1 Young Adults

The category young adults describes people who are still pursuing their education and are between the ages of 18 - 27. Only one interview was conducted for this category as all of the user testing will be done with university students because of the restrictions placed on this project by COVID-19 and the University of Twente.

Interview 1:
Allie Schurman is a 21 year old psychology student who is currently studying at the Australian Catholic University in Melbourne, Australia. She sometimes suffers from backaches that come from bad posture and her currently inactive lifestyle. She notices the ache most when she is not sitting up straight. She tries to fix her posture when she notices the pain but she feels that slouching is her natural position.

She would not describe herself as very conscious of her posture as she only thinks about it occasionally at most, or whilst complaining about it. The aspects of posture that Allie is most concerned about are her upper back and her shoulders. She does not like the look of slouching when she notices other people doing it, or when she sees pictures of herself sitting. She emphasises that people look nicer with good posture and that slouching looks ugly.
When asked what kind of feedback she would like to see in a posture correction application she mentioned four distinct aspects.

1) How many times the user slouches per hour or per day.
2) Length of time the user goes without slouching.
3) What the spine does whilst sleeping.
4) Integrated GPS to see what posture you had at which location

Allie adds that she would love to wear the Breathline device all day after she purchases it, as she would be very enthusiastic about the product. However, she sees her usage of the device declining once she feels like she has learnt enough to control her own posture and breathing.

4.3.2 Working Adults

The category working adults describes people who have a fixed source of income and spend the majority of their day at their job. The envisioned age range for this category is 27 - 55. Two interviews were conducted for this category, as this group will not be permitted to user test the final prototype because of the COVID-19 restrictions placed on this project by the University of Twente.

Interview 2:
Rense Kuipers, 29 is a journalist at U-Today in Enschede, The Netherlands. He does not suffer from back pain regularly but notices slight nagging between his shoulders depending on the desk he sits at. He says that he is quite conscious about his posture, defining good posture at having a straight back and an ideal workstation enabling a 90° angle at the knees and the elbows. Due to COVID-19, he works at home and his desk is not as ergonomic in his home as his work but he tries to correct himself as much as he can. Additionally, whilst running he consciously tries to keep his shoulders back, enforcing a straight back.

He is most concerned about his lower back and shoulders. His shoulder posture is of concern, as his profession as a journalist entails conducting many interviews where he would slouch over oddly to make notes, and this position would come back to bother him at the end of the day. His lower back concerns him because it is an essential part of his body that is used whilst cycling, which he does a lot.

Rense emphasizes that he does not like devices or people telling him that he is doing something wrong. He gives an example of his smartwatch giving him inactivity stamps when he is watching a movie or dentists giving him a sense of guilt every time he has an appointment. He wants a subtle device that will reward good behaviour but not punish bad behaviour as he wants to keep the reins in his own hands. Rense would like the device to provide an analysis of what the user needs to improve the first time the user puts it on e.g. Head should be straighter, Balance out your shoulders more.

He says that he would presumably wear the device for a month before it would inevitably land up in a cabinet. The reason for this is that he feels that he can control his own posture well enough without a correction device but if he were older he would use it more.

Interview 3:
Dr. Taruna Chakravorty, 49, is an academician and a life coach based in New York. She sometimes suffers from back pain, mostly occurring after she has either stood, walked or slept too much. She describes herself as being fairly conscious about her posture and maintains good posture as a habit. She explains that she has a good understanding of what correct posture is because of what she was taught in school and in her yoga lessons. She describes good posture as having an erect spine from top to bottom and mentions that she notices after a maximum of 10min when she deviates from this definition.

The aspect of posture that she is most concerned about is the position of the neck. In her daily life, she notices that reading the newspaper on the table strains her neck sometimes which is undesirable.

Feedback that she would like to see in a posture correction application are mentioned in the following points.

1) Length and number of times the user slouches per day
2) Nudge to stop slouching once the device detects slouching in form of vibration Feedback.

Dr. Chakravorty mentions that upon purchasing the Breathline, she would wear it twice or thrice a week. She would not want to wear the device too often as she fears it would become cumbersome. She compares it to the FitBit in saying that the Breathline would be an additional piece of technology that she would have to carry on her, whereas the FitBit replaces the watch, which is why she would use the latter more.

4.3.3 Elderly

The category eldery describe people that are older than 55 and are nearing retirement. People in this category are envisioned to have a relatively calm lifestyle and are not “action-hungry”. For the same reason as the working adults category, two interviews were conducted in this category also.

Interview 4:
Anja Huisman, 57 is a garden designer based in Zutphen in the Netherlands. Anja’s spine is slightly curved, a condition she has had for quite a few years. However, it has healed and she has no current complaints. She says that she is not conscious of her posture at all in her daily life. However, if a posture correction device were to come on to the market she would want it to target the part of the spine below the neck and between the shoulder blades.

Anja would like the device or the application to give additional exercises on how to strengthen the abdominal and low back muscles that contribute towards good posture. She would also like to have vibration feedback when the device notices that the user has incorrect posture.

She mentions that she would wear the Breathline for 1 - 2h a day. Wearing it for short periods would be more effective because the user would concentrate more. She underlines that she could never wear the device all day because she would get frustrated with the constant posture correction reminders she would get. Her ideal scenario would be a posture correction and breathing device with postural muscle strengthening exercises that one could also use with a physiotherapist.

Interview 5:
Richard Bults, 58, is the coordinator of graduation projects in Creative Technology at the University of Twente in the Netherlands. If he does not overdo working in the garden, he does not suffer from back pain. He says that he is quite conscious about his posture, but also knows that he has a tendency to slouch. When he notices himself slouching, he immediately corrects himself to a straight-back posture but mentions that he would like a device to provide him with some feedback when it notices that he slouches for a certain period of time.

Richard is most concerned about his lower back and his belly area. He would like the device to recognise good posture at a position that does not block or hinder his intestines from digestion but also one that supports his lower back. He underlines the fact that his profession as a lecturer, especially during this period of COVID-19 forces him to stay behind his desk for long intervals and that his height of 1.86m needs good postural support.

He mentions that he strongly prefers direct obscured-from-the-outside-world haptic feedback. He explains that if the device would provide him with direct feedback once he slouches he would have no need for statistics about his daily activity. He sees the Breathline device as a tool that would help him change his behaviour and says that it would become arbitrary once he would have adapted the behavioural change.

Richard says that he is very interested in improving his posture and that his wearing of the device is dependent on how much time it would take him to adopt new posture behaviour. He hypothesises that he would wear the device for 2-3 months between normal working hours, as this is the period where he has the highest chance of slouching. He underlines that he would not wear the device 24/7, as the belt form of the device puts pressure on the body and he sees this as cumbersome.

4.4 iPACT Analysis

An iPACT analysis will be conducted to better picture the potential users of the system and their interactions with it. An explanation on the methodology can be found in section 3.5. Because it is still unknown whether the additional inertial measurement sensor will be needed, two user scenarios will be presented. One with only the accelerometer of the Breathline and one with an additional IMU. These scenarios are made under the assumption that the additional sensor setup has a higher accuracy in posture tracking.

Intention

The primary intention of the system is to track and classify body posture with a combination of inertial sensors to provide users with constructive feedback in order to help them attain correct posture, as defined in section 2.1. The system should also allow tests to be performed that simultaneously measure diaphragmatic breathing and posture, to explore whether a relationship between the two can be established.

People

Meaghan is a 17 year old high school student in Amsterdam. She has been practicing ballet since she was 5 years old. Correct form is an integral part of ballet which is also the main critique she gets from her teachers. She is quite insecure because of this, but lets out her frustration through gardening. She is vegetarian, only uses natural products and cares about the wellbeing of her body. She would be interested in a device that would train her breathing and posture but has no experience with using something similar.

Olivia is a 24 year old student pursuing her masters in Business Information Technology at the University of Twente. She is a triathlete and exercises 4-5 times a week. She strictly keeps to an 8h / day working schedule to fit in time for her workouts. She occasionally gets stressed with this hectic schedule and has tried practicing Pranayama yoga to relax, but to no avail. She found the breathing techniques odd and did not pursue it further. Olivia is interested in devices that track biometric data as she does not leave her house without her FitBit and gets excited to see her statistics of the week. She suffers from back pain sometimes and is therefore very interested in a posture training device.

Elias is a 35 year old lawyer at Brouwer Legal in Enschede. He works long hours behind his desk, moreso for the past half year as he is striving for a promotion. He is concerned that his posture is deteriorating at work and owns multiple posture correcting shirts, but does not wear them often as he finds them uncomfortable. He does not get a lot of daily activity but enjoys taking long walks on the weekend. He uses the Headspace app daily before going to bed to reach a certain level of calmness. Elias does not own any biometric tracking devices but shows visible interest in them.

Activities
The Breathline device can be worn all day or only during specific activities where the user wishes to monitor their breathing and posture. The users can choose to wear the device under or over their clothes. At the end of the day, the users will get an overview of their activity through an interface, app or website. The users will take off the bands and charge the device for the next day.

Context
There are multiple scenarios that the Breathline device has been designed for. It can be worn in any social context, for any period of time. It can also be used in a medical environment to help patients train diaphragmatic breathing correctly under supervision of a physiotherapist or a breathing therapist. Examples of contexts are students studying at university, mothers doing grocery shopping, grandfathers cooking or a young adult jogging. The usage scenario that this thesis will focus on is a full-time 9am - 5pm work or study day, where the system will primarily focus on identifying, classifying and correcting slouching.

Technology
Respiratory Inductance Plethysmography, described in section 1.2.2 is used for breathing data acquisition from the Breathline device. The Arduino Nano, a small microcontroller is used to store the acquired breathing data and movement data from the embedded accelerometer. Breath.exe, a program developed by Ben Bulsink records and saves this data to a .csv file. However, the code that runs on the Breathline is classified. To process the posture data in real-time, a clone setup needs to be made. Therefore, the programs that will be used in this project are Arduino, Breath.exe, Processing, Microsoft Excel and MATLAB. These programs are elaborated on in section 6.2.

Usage scenario I (only with belly accelerometer in Breathline)
Olivia wakes up at 6am to go on her morning run. She quickly gets dressed, places the Breathline device around her navel, calibrates it and heads out to get in a quick 5 km. The device occasionally vibrates reminding her to keep her back straight, as she has a tendency to lean forward whilst running. In the two months she has owned Breathline, she feels that her posture as a whole has improved. After her run, she showers, eats breakfast complimented by a fresh cup of coffee and cycles to the university. She has to get through three lectures, a project group meeting and complete an assignment she has been putting off.

After the lectures are completed, she glances down at her FitBit to see that she currently has 6’000 steps. Her daily goal is 15’000 and by 3pm she expects to be at least halfway there. However, she still has a lot to do at university before she can concentrate on her step count and this frustrates her. Her FitBit notifies her that her heart rate is going up and she reacts by taking out the Breathline device from her bag to practice diaphragmatic breathing during her 15min break. Since she has been sitting for most of the day, she decides to train whilst standing up and straps the band around her navel. She sways a bit but feels no vibration on her stomach telling her she is not standing straight. Confused but happy she does not need correction, she completes her 15min of breathing training. Feeling more relaxed and full with new ambition, she is ready to face the rest of her day.

Olivia leaves the university around 6pm to do some grocery shopping for dinner. She opts for lentils as she read on a fitness blog that they are a good natural source of protein. She had envisioned this grocery trip to be a short in-and-out but there is a large queue in front of the cash register. Olivia is aggravated because of this and exhales sharply leading her back to slouch. The Breathline vibrates sharply which makes Olivia roll her eyes and smile slightly before correcting her posture to continue waiting in line.

After dinner, she plugs in the Breathline device in her computer to see her stats of the day. She confirms that her posture has improved since she first wore the device. She remembers the incident earlier in the day where she was slouching and the Breathline did not notice. Olivia is unsure whether she feels happy with the false statistics and good results or whether she would rather have bad results and accurate statistics.

To ponder over this dilemma and to complete her step count goal, she decides to go for a walk before bed. She does like the good feeling she gets by seeing good statistics and decides she will carry on using the device. She comes home, puts the device to charge and heads to bed around 11pm.

Usage scenario II (with additional IMU)

Elias wakes up at 7:30 am. After taking a quick shower and shave, he dresses himself, wraps the Breathline strap around his belly and sticks the additional posture sensor between his shoulder blades on his back. He glances at his watch and sees that he is running late, so he grabs a cup of coffee and drives his 15 min to work. He pays for a sandwich at their café, switches on his laptop, and starts drafting documents for the newest divorce case he has been assigned to. It is arduous work and after 2h, he notices that his posture has gone from sitting upright to almost completely hunched over. He looks down, perplexed that his posture could be this bad but sees that he forgot to switch the device on. He corrects this by switching on the device and calibrating it by sitting up straight. However, he also detects an advancing ache in his upper back due to his bad posture and decides to get another cup of coffee to loosen himself up.

He gets up out of his chair, stretches whilst hearing multiple cracks in his back and feels the vibrations of the Breathline on his stomach and back. (Stretching does not count as correct posture) He walks 20 steps to the coffee machine to get himself a beverage. He returns to his desk and carries on working until the office starts buzzing with movement, signaling him that it is time for lunch. He’s proud of himself, the Breathline did not vibrate since he switched it on and he had made good progress on his divorce drafts.

Elias heads down to the café and orders a pizza hawaii. He checks his phone and sees that he has been allocated three new cases that need to be prepared before tomorrow. He sighs deeply, feels the vibration on his belly, stands up a bit taller and tells the cashier to make the order a “to-go”. It’s going to be another lunch at his laptop followed by a very screen-heavy day.

He trudges up the stairs to his desk and carries on working, whilst occasionally munching his pizza. It is 8pm before he rubs his eyes tiredly and decides to call it a day. He drives home with a long face but gets happier as he reaches his apartment. He takes off the Breathline, makes a mental note to get more adhesive tape for the back sensor and plugs it in to see his stats. He got a late start today, as he forgot to switch the device on but sees the constant bouts of slouching that he corrected during the day. He is quite happy with this device as he can see how this device helps him with his posture and is glad that the ache in his upper back did not grow stronger and went away when he switched Breathline on.

Elias makes himself a cup of instant noodles whilst watching the news. Shortly thereafter, he does his Headspace mindfulness exercises and combines them with the diaphragmatic breathing exercises of the Breathline device.

He feels a lot calmer than he was at work and is content. He gets ready for bed, brushes his teeth, plugs his phone and the Breathline in to charge, writes about his day in his diary at his bedside table and promptly falls asleep.

4.5 Preliminary requirements

Concluding the results from the stakeholder analysis, the group and individual brainstorm, the interviews and the iPACT analysis, a list of preliminary requirements has been created and is listed below. These requirements have been listed according to the MoSCoW technique described in section 3.6 and may be subject to change during the following phases.

Must:

1. The device must be able to recognise a 45°, 60° and 90° back posture.
2. The device must have an option for calibration.
3. The device must (at least) give haptic feedback to the user.
4. The device must output degrees.

Should:

5. The device should give the user feedback about their posture in real time.
6. The device should be able to recognise sitting and lying down body positions.
7. There should be visual feedback about posture.
8. The device should buzz with more force when the posture is “incorrect” and slowly decrease as the posture gets better.
9. There should be a counter showing the total recording time of the session.
10. A quality factor should be calculated based on the user’s posture throughout the recorded session.

Could:

11. The device could allow the user to set daily goals.
12. The device could give the user the possibility to see their statistics of their posture and position throughout the day.
13. The device could have a time slider for the user to see which posture they had at exactly what time.
14. Counter showing how many times the user slouches per day.

Will not:

15. The feedback will not be given via an app.
16. The user will not have the possibility to switch the wearable off.
17. There will be no instructional feedback integrated into the device.
18. The device will have integrated GPS.
19. The device will not coach the user through postural strengthening exercises.

The quality factor described in requirement 10 will be calculated by dividing the total duration of the time spent with correct posture by the time spent recording. This user requirement was mentioned multiple times during the target group interviews. Moreover, it is still unknown whether the additional IMU sensor is needed. This will only be known once the data from the accelerometer is processed and evaluated on its accuracy.

5 Specification

The goal of this chapter is to go through multiple design iterations to be able to take the prototype to the realisation stage. This will be done by firstly by testing the different sensors in the IMU, finding an optimal placement for the back sensor and testing out multiple designs for the different parts of the prototype. To analyse the usage from a system's perspective a FICS analysis will be conducted, followed by the system architecture that will be broken down to understand the inner workings of the program. Thereafter, an activity diagram will be presented to show a usage scenario and the interactions between the system and the user. The chapter will conclude with a second iteration of the requirements that will be taken further to the realization stage.

5.1 Sensor Implementation Choice

As mentioned in section 4.4, the code that runs on the Breathline is classified. For data processing in real-time, a clone setup needs to be made. Therefore, the sensor chosen to implement the posture tracking was an Invensense MPU-6050. It is considered to be one of the more precise and reliable MEMS sensors on the consumer market, therefore also widely available and affordable [24]. The MPU-6050 contains a MEMS accelerometer (see section 1.2.2) and a MEMS gyroscope on a single chip. It can capture x,y and z channels from both sensors at the same time and uses the I^2C bus to connect with the Arduino [68].

Accelerometers, as mentioned in section 1.2.2, measure linear acceleration, but do not respond to angular velocity. Gyroscopes measure angular rotation and subsequently do not respond to linear velocity. The original plan was to fuse both the gyroscope and the accelerometer data to estimate device orientation. Combining both readings could serve to offset each other's noise and drift errors to provide more complete and accurate movement tracking. The data from the gyroscope is integrated over time to get position from velocity. The sensor fusion calculation would have been done by a complementary filter with the equation 2 [69]:

(2) $angle = 0.98 * (gyroscopeAngles * dt) + 0.02\ (accelerometerAngles)$

However, gyroscopes are prone to drift over time [70]. Leaving the MPU-6050 stationary showed that the integrated gyroscope had a prominent linear drift as can be seen in figure 36.

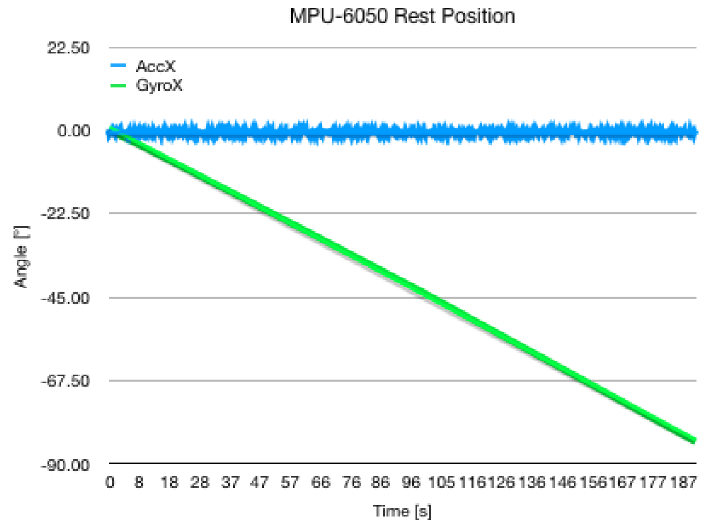

Figure 36: MPU-6050 Rest Position

This drift was compensated by calculating the slope and adding it to the output. This solved the drift when the gyro was stationary, but reappeared when it started moving. The gyro's precision was reduced with this method which introduced an additional error. Moreover, it was very difficult to determine and keep the 0 point for the gyroscope, because of its drift not being perfectly linear.

Figure 37a shows the drift compensation and raw output of the gyroscope with the accelerometer signal. The drift was eliminated when the sensor was stationary, visible in the graph until ca 18s. After this point, the gyroscope was unable to record rest of the movement accurately. The accelerometer is used as a reference line here and both gyroscope recordings seem to have missed the full scale of the third negative peak. After the sensor is placed at a stationary position for the second time at ca. 26s, the drift is compensated for, as seen by the straight blue line but it has a new offset.

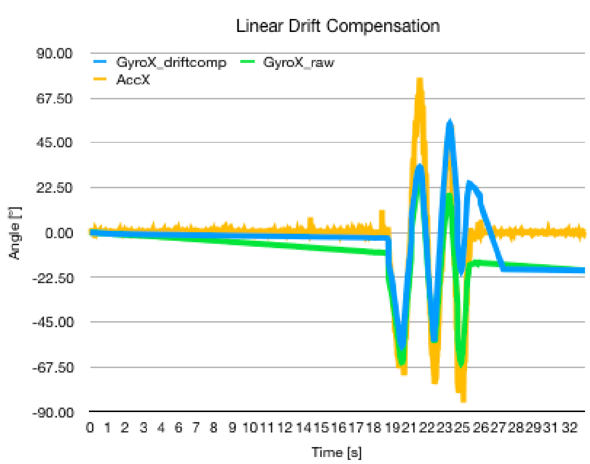

Figure 37a: Linear Drift compensation gyroscope

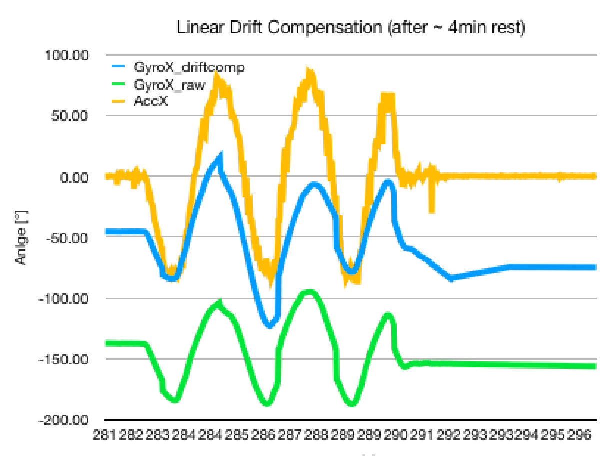

Figure 37b: Linear Drift compensation gyroscope after ~4min

This can be explained through the drift of the gyroscope not being perfectly linear as a whole, but also particularly so during movement, as it records slower movement more accurately than faster movements. Moreover, the offset of the drift compensated signal keeps increasing with time, although on a much slower scale than the raw values output. This can be seen clearly on figure 37b as the entire compensated signal shifted -50° after 4min, whereas the raw output drifted to around -140°.

More experiments were conducted with trying to compensate for the drift of the gyro but they proved unsuccessful because of the changing drift in different states. Combining the signals of the accelerometer and the gyroscope was also attempted by using varying values for the above-stated equations. The results can be seen in Figure 38-41.

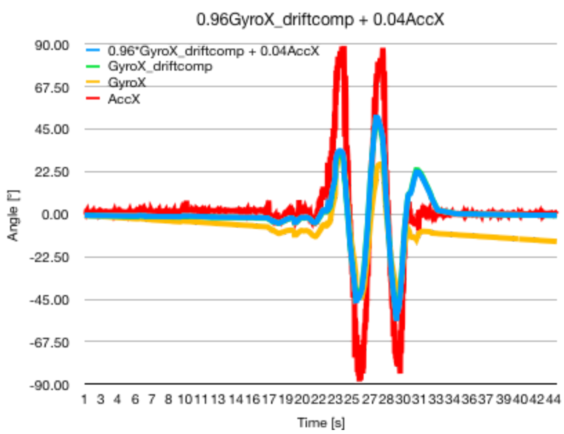

Figure 38: 9.6:0.4 ratio of Gyro to Accelerometer signal

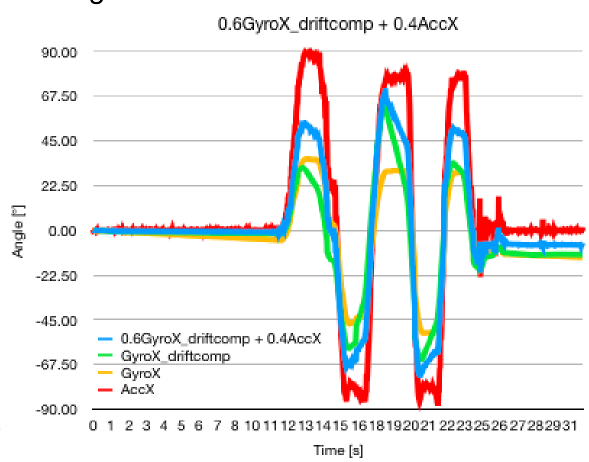

Figure 39: 6:4 ratio of Gyro to Accelerometer signal

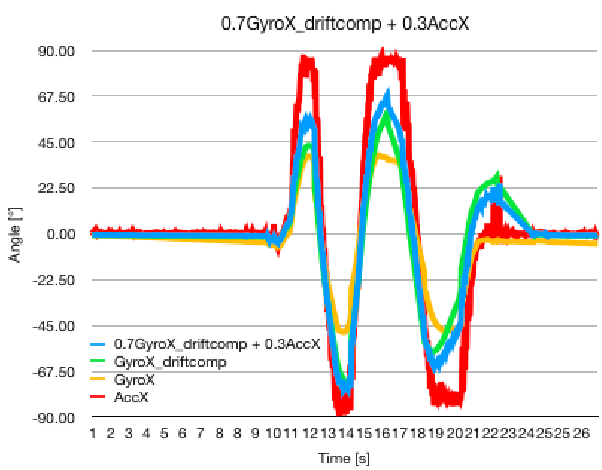

Figure 40: 7:3 ratio of Gyro to Accelerometer signal

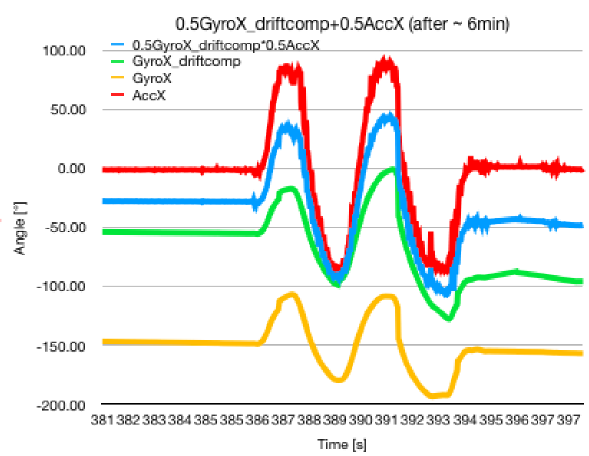

Figure 41: 5:5 ratio of Gyro to Accelerometer signal

Figures 38-41 show different ratios of the drift compensated gyroscope measurement and the accelerometer data. In general, the gyroscope signal is quite clean in comparison to the accelerometer signal which has a lot of noise. Increasing the weight of the accelerometer shows an increase in noise and a decrease of drift. However, as seen in figure 41 the drift is still present in the combined signal. This will be the case for every ratio of the combined signal if the gyroscope signal component is included, because of its eventual drift over time. To summarize, the gyroscope's drift was unable to be compensated to a reliable degree as it had a different offset whilst moving that differs to a stationary one. Furthermore, moving the gyroscope at different speeds output different drifts.

Another way to combat the drift problem of the gyroscope is to implement a Kalman Filter [66]. This is also mentioned in section 2.2 and 4.2.1 of this thesis. However, the library and functions of the Kalman Filter for Arduino were incomplete and therefore, would not upload correctly. Furthermore, to eliminate the possibility of unwanted frequencies distorting the signal, a fast Fourier transform was applied to the raw signal using a pre-existing library for Arduino. However, due to the memory restraints of the Arduino Nano, 128 samples were the maximum number that could be analysed, as it was unable to capture all the component frequencies which created unexpected and inaccurate artefacts. Neither the gyroscope nor the accelerometer signals could be analysed or further processed by using any of these methods. This also eliminated the possibility of correctly using a high or low pass filter because the cut-off frequency could not be correctly defined due to the inability to perform a Fast Fourier Transform.

For this reason, the decision was made to not include the gyroscope in the realisation stage, as it would introduce discrepancies instead of making the orientation estimate more accurate. The accelerometer signal, although noisy, is very accurate and tracks the changes in movement quite well. To lessen the noise, a moving average filter will be applied in the realisation stage.

5.2 Integration of the back sensor

This section explores and justifies the choice of the integration of an additional MPU-6050 on the back of the user for more accurate posture measurement. This section will also answer the sub research question: *Where is the optimal placement of these sensors on the human body?*

Currently, the accelerometer embedded in the Breathline device is strapped around the navel. The interview with Mrs. Mader, conducted in section 2.3.3, suggested that only having one sensor is not sufficient to accurately track posture as it is quite easy to find loopholes in what the sensor can measure. This statement was tested, confirmed and is illustrated in figure 42 below.

Figure 42 illustrates the shortcomings of only using a belly placed accelerometer. In both scenarios, the sensor outputs the same results although the second scenario very clearly displays incorrect posture. The placement of the sensor on the navel also plays a significant role in the accuracy of the results.

Figure 42: Belly placed accelerometer to measure posture [67]

The belly area is slightly rounded, irrespective of the body shape of the user. Placing the sensor below, on and above the navel output different results for the same posture. The ideal position for the sensor is a surface that is as close to 90° as possible. When sitting the area below the navel can extrude, depending on the body type of the user. For this reason the belly placed accelerometer will be placed slightly above the navel, as there are the fewest changes there between sitting and standing.

To combat the shortcomings of the belly placed accelerometer, another sensor will be placed on the back, to monitor spinal posture with more input. Three different placements on the back were considered and are illustrated in figure 43 below.

Figure 43: Back sensor placement options

The different placements of the sensor on the spine measure different parts of the spine. Option 1 mostly measures displacement of the lumbar spine. Option 2 and 3 mostly measure displacement of the thoracic spine, where option 3 would potentially also sense displacement of the cervical spine. The structure of the segments of the spine can be seen in figure 5.

Tests were done on all three spinal positions to evaluate which one was the most accurate. The sensor was placed in each position and its output was noted down for 0°,15°,30°,45°,60°,75° and 90°. This test was repeated three times and the results are shown in figure 44a and 44b. The absolute spinal position was determined by the angle from the top of the neck to the bottom of the trunk. This is the position that all measurements were compared to.

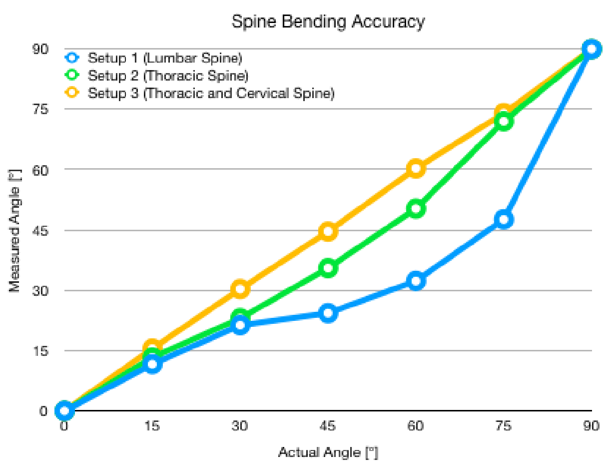

Figure 44a: Spine Bending Accuracy Results

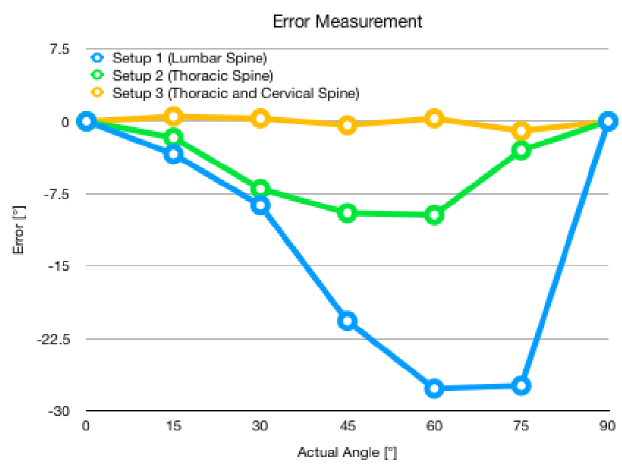

Figure 44b: Error Measurement Results

As can be seen from the results, setup 3 where the back sensor was placed between the shoulder blades on the upper back was the most accurate. All measurement setups noticed changes when the angle of sitting was changed but it can be clearly seen that setup 3 had the best results.

In this experiment the spine was kept as straight as possible whilst bending it, to not cause any additional anomalies but exclusion of these cannot be guaranteed. A reason that setup 3 was the most accurate could also be that its position is the furthest away from the trunk, allowing it a larger range of movement, but also detection of a larger range of movement. Moreover, setup 3 would also be able to detect movement in the shoulders but also slight movements of the neck, all in all making it very favourable for this project.

For all the reasons and results stated above, setup 3 will be chosen for the realisation stage as it incorporates the most optimal sensor placement on the human body to measure body posture with two sensors.

5.3 Design Iterations

This section will cycle through the different lo-fi prototypes that were made and illustrate why certain design choices were discarded and others were kept. It will describe the haptic and visual feedback system and conclude with a list of which aspects should be taken further to the realisation stage.

5.3.1 Haptic Feedback

This section will describe the design iterations made for the haptic feedback system of Breathline. As mentioned in section 4.2.1, the group brainstorm had already shown peaked interest for haptic feedback integration with a posture tracking system. The target group interviews, transcribed in section 4.3 confirmed this demand as 3 out of 5 participants explicitly mentioned that they would like haptic feedback to improve their posture as it is obscured-from-outside-world and not too invasive. Moreover, elaborated on in section 5.1, the code of the Breathline is classified. The Breathline already has an embedded vibration motor in it, but because of the restriction of the code being classified, it cannot be interfaced. Therefore, the following setups are meant to be seen as recreations of the Breathline, which is also why the vibration motors have been placed on the belly PCB and not on the back.

As posture can be incorrect in various different ways, a preliminary idea was to give feedback for 4 different directions, as seen in figure 45. If the accelerometer would measure the user leaning to the right, the left vibration motor would vibrate and vice versa. If the user slouches forward, the top vibration motor would vibrate and if the user slouches backwards, the bottom vibration motor would vibrate.

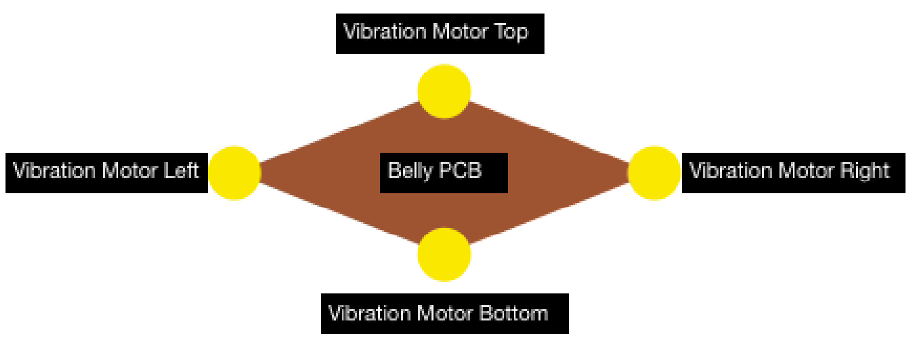

Figure 45: Preliminary Haptic Feedback Setup with 4 motors

This motor setup recognised slouching in all 4 different directions and vibrated accordingly. However, it was very difficult to separate left and right slouching from forward and backward slouching as they are not mutually exclusive. Moreover, the vibrations on this setup were plentiful and centred around a very small belly area. It was challenging to discern which vibration motor was vibrating and what it was indicating. For this reason, the setup was simplified to two vibration motors as seen in figure 46.

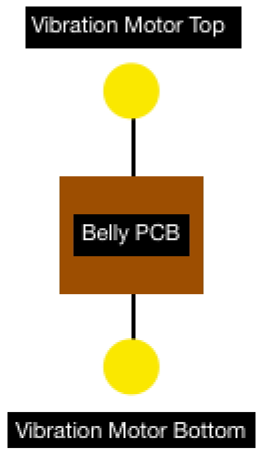

Figure 46: Simplified Haptic Feedback Setup with 2 motors

The two vibration motors, seen in figure 46, differentiated between forward and backward slouching. Moreover, requirement 8 in section 4.5 stated that the device should buzz with more force when the posture is “incorrect” and slowly decrease as the posture gets better. The vibration motors used in this setup are MPN316040001 with an operating range from 2.5V - 3.5V, with an ideal operating voltage of 3V.

The change in the vibration strength was tested by the author of this thesis with the analogWrite() function Arduino has. However, there was no significant vibration difference to be felt between the operating range of the motors. Therefore, the operating voltage, taken from the datasheet, 3V was chosen and the difference in state was chosen to be implemented by changing the frequency of the vibration.

5.3.2 Visual Feedback

This section will describe the design process in finalising the posture representation through a flower. In this project, the flower is meant to characterize mindfulness and calmness whilst representing the user’s posture. Accelerometers can capture three-dimensional data, which is why the flower will also have a three-dimensional range of movement which illustrates a 1:1 portrayal of the incoming data.

Moreover, flowers should spark the association in people’s heads of being straight and therefore want to make them keep the flower being straight. The statistics of the user will be displayed in a bar chart, as these are very intuitive to understand and are widely used in applications to show user statistics.

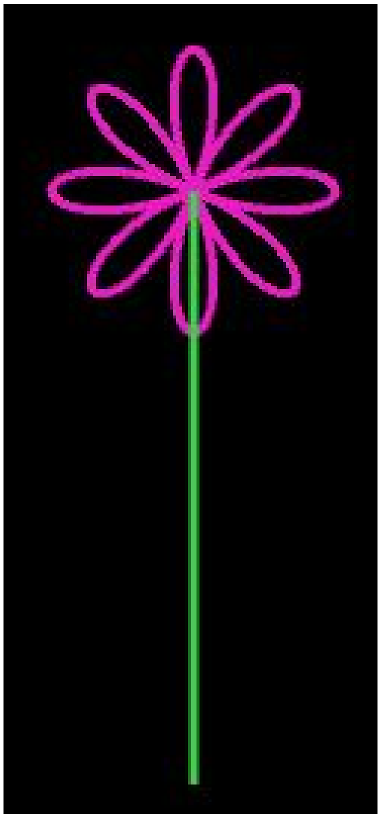

Figure 47a: First flower design

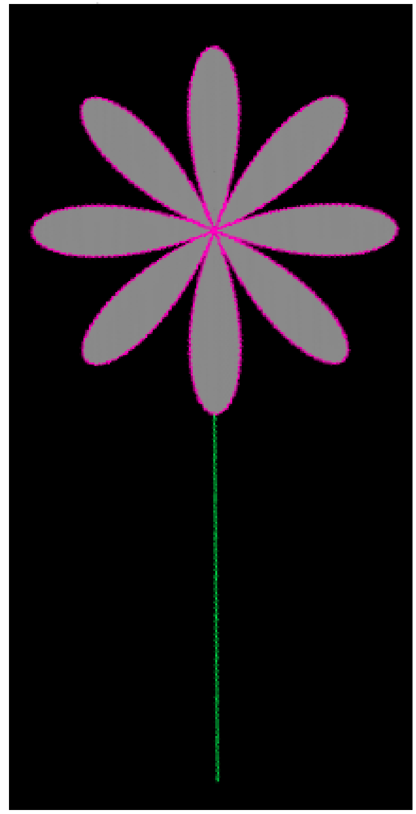

Figure 47b: Second flower design

Figure 47a and 47b show the process of developing the flower. The neon colours seen in figure xa were replaced with milder tones, as seen in figure 47b to not be that harsh on the eyes. The stroke of the stem was reduced and the petals were filled with colour, to make the flower seem more realistic. The dark background was chosen to be easy on the eyes.

A preliminary version of the graphical user interface can be seen in figure 48a. The flower moved with the values of the back accelerometer instead of the belly one because of the assumed better accuracy and the larger range of movement. The bar charts on the left moved depending on the posture state that the user was in. The user would only know their state by the moving of the bar, but it was not clearly indicated otherwise. The time counter on the top left showed how long the program had been open in seconds and had an accompanying moving bar.

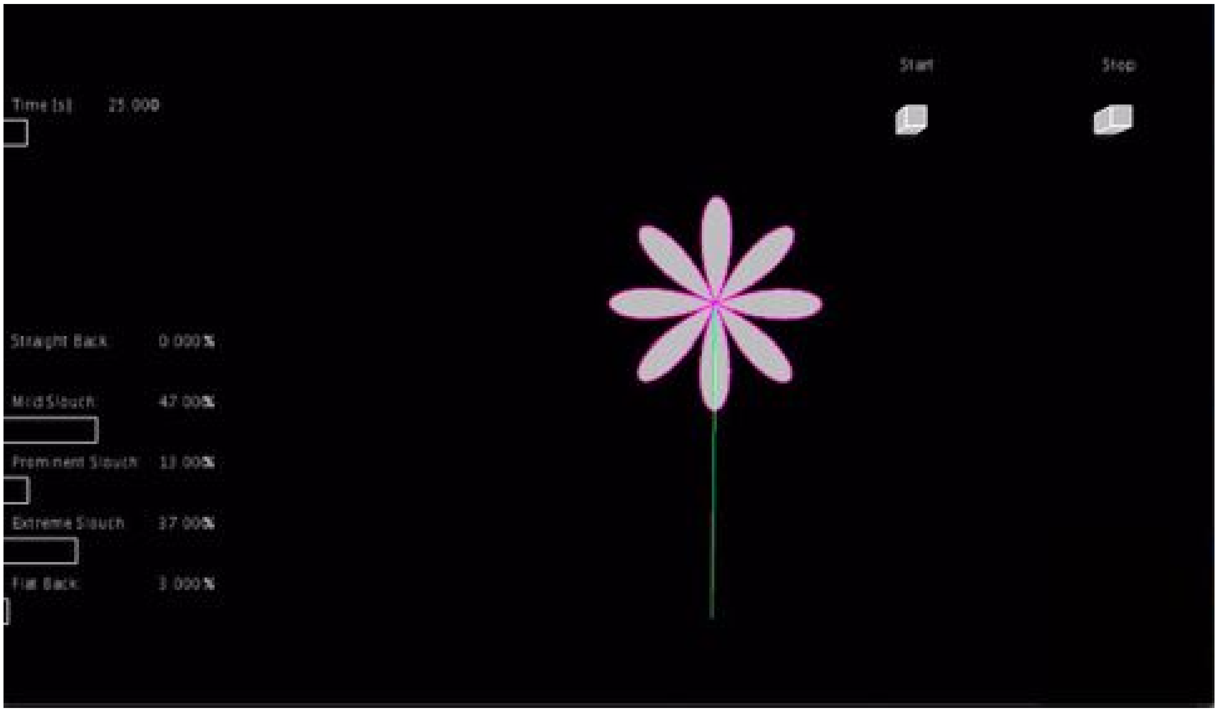

Figure 48a: First GUI design

The design shown in figure 48a was expanded upon and more visual cues were added as seen in figure 48b.

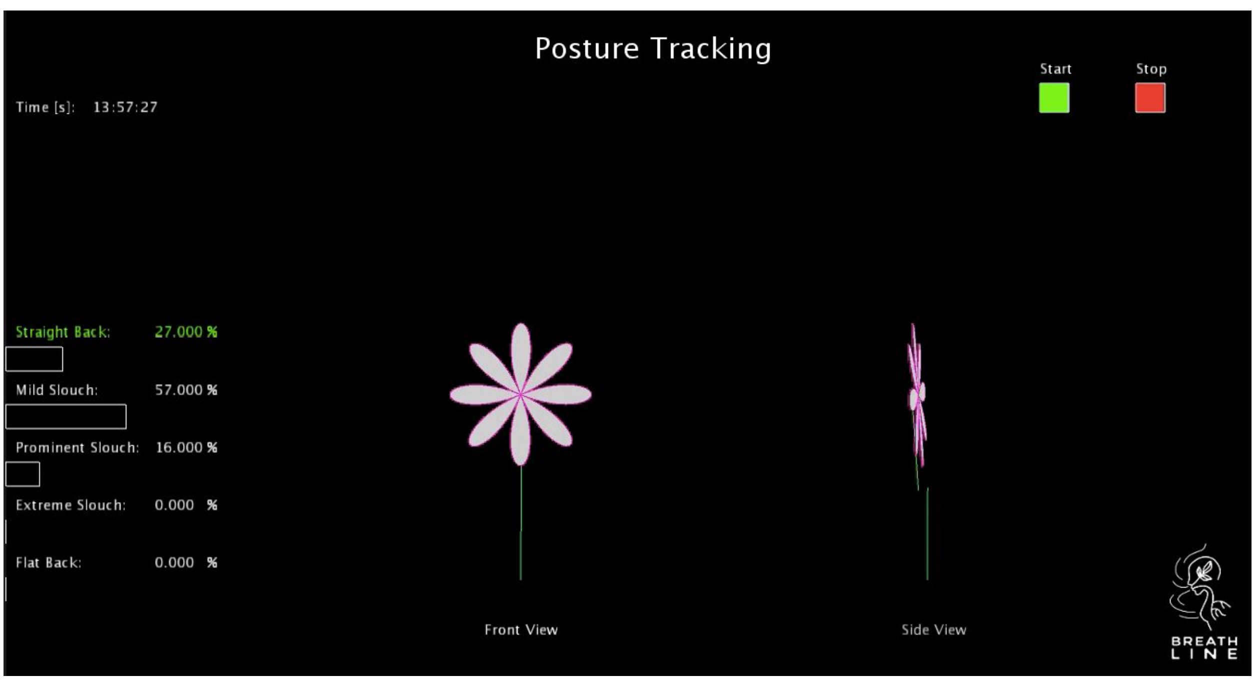

Figure 48b: Second GUI design

The bar chart of the time counter was too distracting as it would continuously grow and took attention away from the more important parts of the interface. Therefore, it was replaced through the time which is used for the timestamp for the.csv file. The buttons in the top right corner were made more minimalistic and were made functional for writing and saving the .csv file. Breathline's logo, made by Zaccaria di Giorgio was added in the bottom right corner to showcase the brand identity. Furthermore, the stem of the flower was split into two parts, with the head moving with values from the back accelerometer and the bottom part moving with values from the belly accelerometer. A side view was also added for a different perspective on the user's posture state. The user's posture state is lit up in green on the left-hand side of the screen to clearly indicate in which pre-determined slouch position, explained in section 5.5.2, the user is currently in. The percentages next to the states represent how much of the total time the user has spent in which state.

The second version of the design of both the haptic and visual feedback systems will be taken forward to the realisation stage.

5.4 FICS

The FICS analysis, outlined in section 3.5 is seen from the system's point of view and thus provides an overview of the system usage. The individual components in the FICS analysis are Functions and Events, Interaction and Usability, Content, and Structure and Services.

Function and Events

There are two activities that will be analysed in this research, namely posture tracking and diaphragmatic breathing. Therefore, the measurement setup will conduct two tests simultaneously. The measurement setup will recreate the Breathline's embedded accelerometer by using the MPU-6050 IMU, which shall be placed on the navel along with the respiratory band of the Breathline. Furthermore, as stated in section 5.2, an additional MPU-6050 shall be placed on the upper back of the user to get a more accurate picture of the user's posture

<u>Posture Tracking System:</u>

Arduino:

There are 7 main functions that are responsible for the hardware programming that will be implemented in Arduino.

1. Communication must firstly be set up between both MPU-6050s and the Arduino.
2. The raw sensor data from both IMUs must be read and converted into degrees.
3. The must be a moving average filter that outputs the average of ~20 readings of both sensors to smoothen the data and eliminate some of the high frequency noise.
4. By pressing a button on the measurement setup a "zero position" or a "straight back position" should be set.
5. The program must recognise different posture states based on the calculated angles from the two accelerometers and their difference from the calibrated "straight back position" by a number of "if-statements".
6. The accelerometer angles and the user's state should be sent to Processing at 8Hz to match the Breathline's sample frequency.
7. The vibration motors should be controlled through PWM with the aim to nudge the user to correct their posture and go back to their calibrated "straight back position".

Processing:

There are 4 main functions that are responsible for the graphical user interface that will be implemented in Processing.

1. Serial communication must be set up with Arduino. The data must be parsed and saved in independent variables in Processing.
2. A table must be initialized for writing the incoming data from Arduino to a .csv file.
3. The flower and the bar graphs must move with the accelerometer values.

4. There must be a button for starting and stopping the writing of the incoming data to the .csv file when the mouse clicks the “start” or “stop” button respectively.

Diaphragmatic breathing analysis system:

There are 4 main functions to the diaphragmatic breathing analysis system:

1. The data from the RIP band of Breathline will be read from the Breath.exe program. Once the button is pressed it is written to a .csv file with the timestamp of the computer.
2. This file will be read and plotted in MATLAB.
3. A peak-to-peak analysis will be conducted for the local maxima and minima where the average values per test participant and per posture will be saved.
4. The average respiration frequency shall also be calculated and saved per test participant and per posture.

It is important to note that the respiratory data processing will not be done in real-time, whereas the posture tracking will be. For the analysis of both activities, the timestamp will be used to match the respiratory and movement data together.

Interaction and Usability

The system provides the user with two types of interaction, active and passive. There is passive interaction when the user wears the Breathline device during the day. Moreover, the feedback that the vibration motors provide can also be considered as passive interaction with the device, if the user does not purposely slouch. The active interaction with the device is when the user calibrates it by pressing a button but also when they view the feedback on the interface.

Content and Structure

Posture tracking:

The graphical interface will show a bar chart of the user’s performance during the recorded session and real-time visualisation of their posture.

Diaphragmatic Breathing:

The data will be recorded with the Breath.exe program where features such as the local maxima and minima of the RIP data, and the respiration frequency will be extracted. This data will not be visualised and will only be used to support posture analysis.

Services

The only service needed for both systems is a USB connection to the computer for data transfer. The posture tracking system converts the raw accelerometer data to degrees and outputs visual and haptic feedback. The diaphragmatic breathing system records and saves data from the RIP band.

5.5 System Architecture

The system architecture provides an overview of the inner workings and relations between various system components. It has been broken down into two levels where each level goes deeper into the system to show its inner workings. The arrows connecting the blocks will illustrate which components are connected and in which order they are called upon.

5.5.1 Level 0

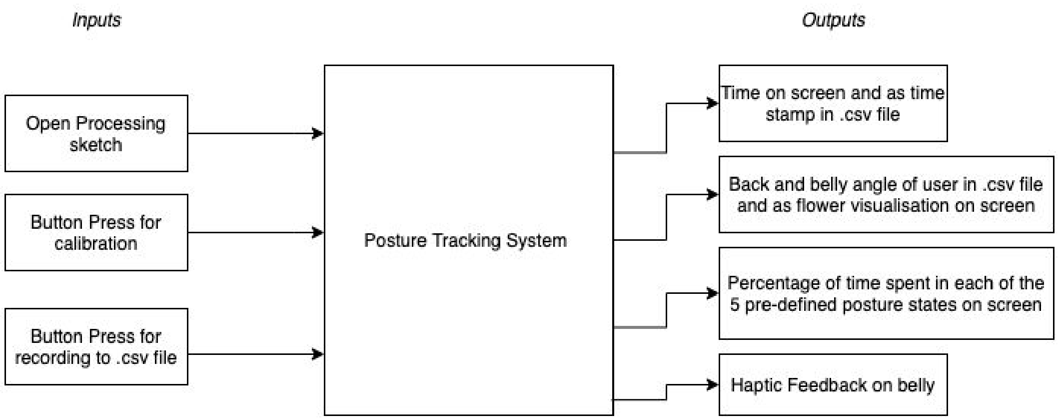

Figure 49: System Architecture - Level 0

This level comprises of the inputs and outputs of the system, shown in figure 49. The inputs to the system consist of firstly opening the processing sketch, secondly, pressing the button on the measurement setup for calibration and thirdly, pressing a button on the GUI to start the recording. The outputs of the system are the .csv file with the recorded postures and time, the real-time visualisation of posture on the GUI as a flower and bar charts and haptic feedback on the belly.

5.5.2 Level 1

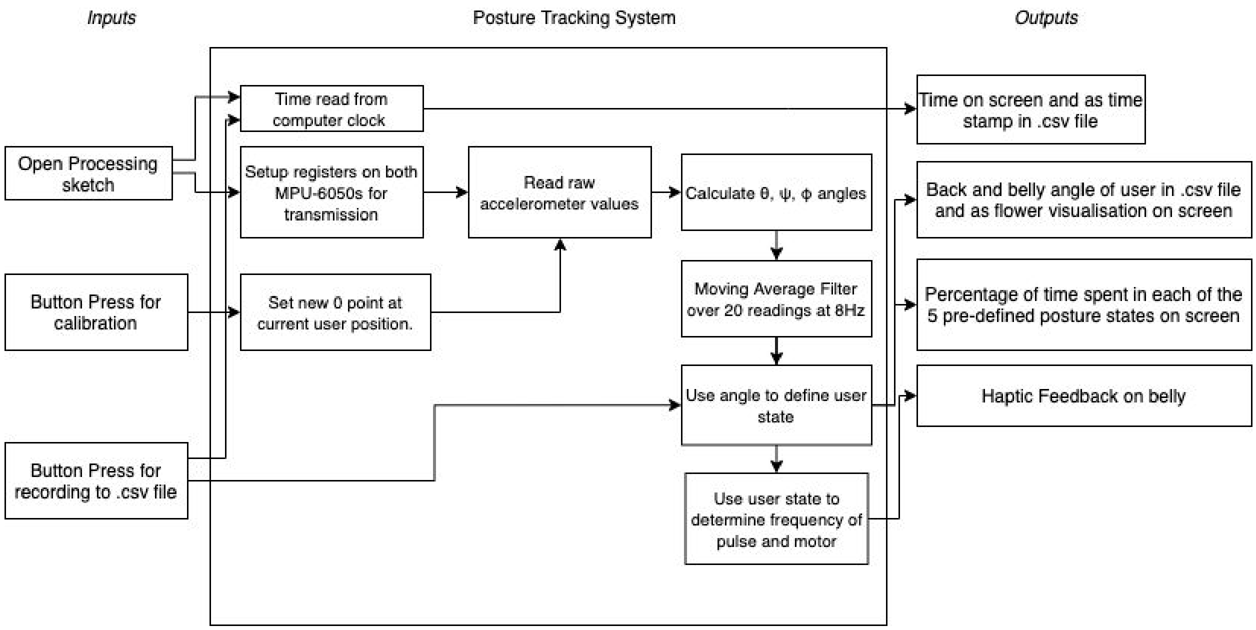

Figure 50: System Architecture - Level 1

The first level, shown in figure 50 consists of the processes undertaken in the system to get the outputs. The angles are calculated with the method explained in section 6.1. A moving average filter is applied to smoothen the accelerometer angles, as justified in section 5.1.

Using the tilt angle equations elaborated in section 6.1, 9 user states were defined with 0° as the sitting straight reference point. They are listed below.

1. Sitting straight : from -11.25° to 11.25°
2. Mild slouch forwards : from 11.25° - 34°
3. Mild slouch backwards : from -34° to -11.25°
4. Prominent slouch forwards : from 34° to 56.25°
5. Prominent slouch backwards : from -56.25° to -34°
6. Extreme slouch forwards : from 56.25° to 78.25°
7. Extreme slouch backwards : from -78.25° to -56.25°
8. Flat back forwards : from 78.25° to 90°
9. Flat back backwards : from -90° to -78.25°

As a difference can be recognised between forward and backward slouching, appropriate feedback will be given to the user by integrating 2 vibration motors into the setup, to be placed on the abdomen of the user. One of the vibration motors will vibrate if the user is bending forwards and the other one will only vibrate if the user is bending backwards. There will be no haptic feedback given if the user is sitting straight or lying flat on their backs.
The GUI will not differentiate between forwards and backwards, as it will make the interface too text-heavy and will therefore only display 5 user states.

5.6 Activity Diagram

This activity diagram in figure 51, will show usage of the system in its current iteration. The diagram shows the major actions completed by the user and the system's response to understand the dynamic of the interaction. The arrows are colour coded depending on the system, diaphragmatic breathing analysis or posture tracking analysis. The pink squares illustrate steps that the researcher will do in addition to the system and user interaction to evaluate the data from both.

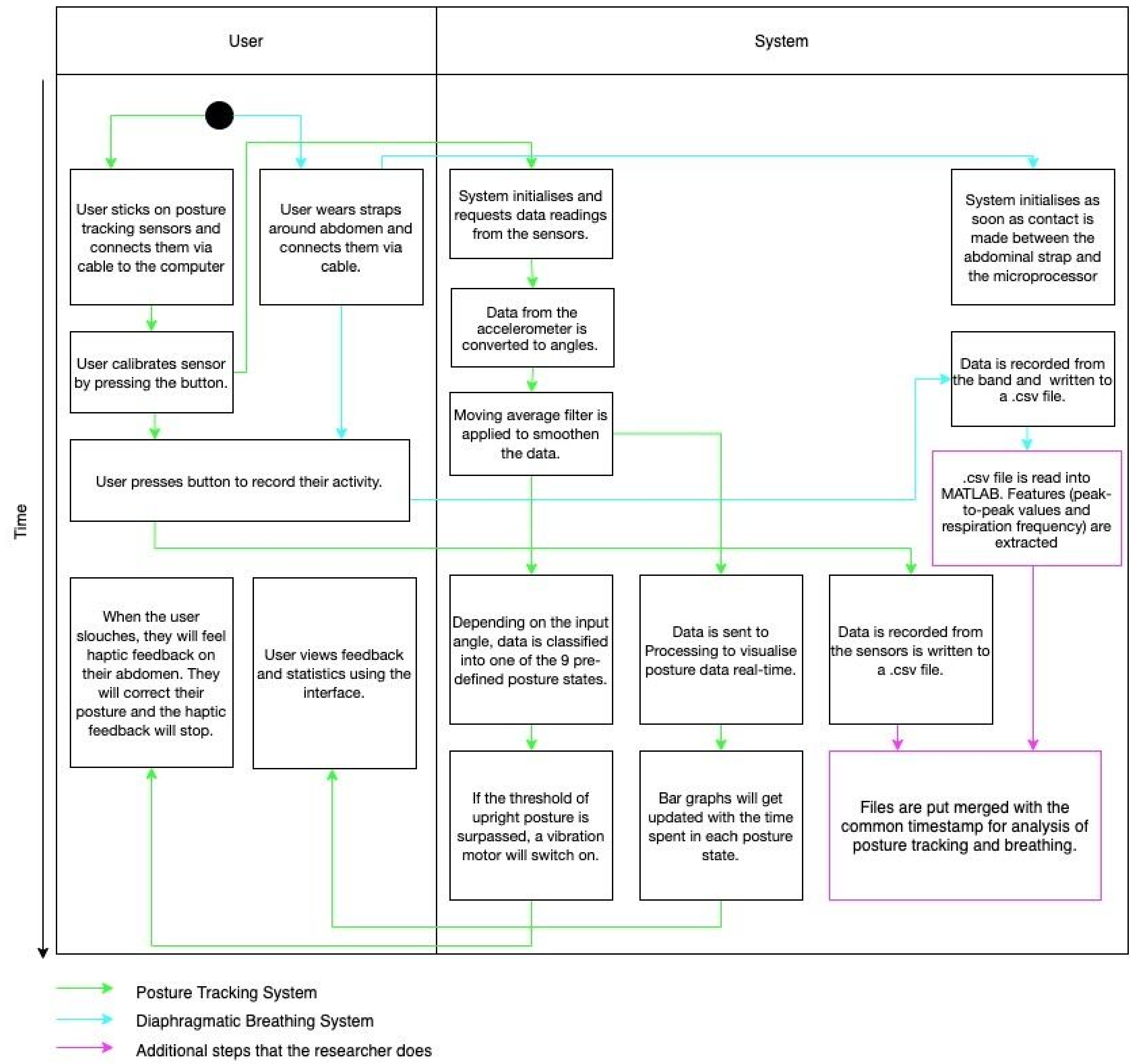

Figure 51: Activity Diagram of project

5.7 Requirements 2nd Iteration

Taking everything mentioned in the specification chapter into consideration, an updated list of the requirements firstly stated in section 4.5 was created. Additionally, the requirements have been classified into functional and non-functional requirements as described in section 3.6.

Must

1. The posture tracking system must recognise at least 5 posture states (90°,60°,45°, 30°,0°) with the back and the belly accelerometer. (functional)
2. The posture tracking system must be able to set a zero-point position through calibration. (functional)
3. The posture tracking system must provide haptic feedback through at least one vibration motor. (functional)
4. The posture tracking system must output degrees. (functional)
5. There must be visual feedback about the user's posture through a GUI. (functional)
6. The breathing and posture measurements must be combined with a mutual timestamp (functional).

Should

7. The user should be able to see their statistics being updated in real-time. (functional)
8. The visual feedback should make sense and be insightful for the user. (non-functional)
9. The vibration motors should be controlled through PWM, to vibrate with a higher frequency when the posture is “incorrect” and slowly decrease as the posture gets better. (functional)
10. The haptic feedback should urge the user to improve their posture. (non-functional)
11. The placement of the vibration motors should be satisfactory to the user. (non-functional)
12. The strength of the motor vibration should be satisfactory to the user. (non-functional)
13. There should be a counter showing the total recording time of the session. (functional)
14. A quality factor should be calculated based on the user’s posture throughout the recorded session. (functional)

Could

15. The device could allow the user to set daily goals. (functional)
16. The device could give the user the possibility to see their statistics of their posture and position throughout the day. (functional)
17. The device could have a time slider for the user to see which posture they had at exactly what time. (functional)
18. Counter showing how many times the user slouches per day. (functional)

Will not

19. The feedback will not be given via an app. (functional)
20. The user will not have the possibility to switch the wearable off. (functional)
21. There will be no instructional feedback integrated into the device. (non-functional)
22. The device will not have integrated GPS.(functional)
23. The device will not coach the user through postural strengthening exercises. (non-functional)
24. There will not be real-time analysis of breathing data. (functional)

The quality factor described in requirement 14 will be calculated by dividing the total duration of the time spent with correct posture by the time spent recording.

The number of functional requirements exceeds the amount of non-functional ones. This is because the primary goal of the posture tracking system is to track posture. There was no requirement stated in the thesis description that a user interface and a feedback system needs to be created. However, the results from the interviews showed that there was an interest from potential users in visual and haptic feedback which is why this idea will be expanded upon in the realisation stage.

6 Realisation

The goal of this chapter is to develop the prototype to a standard that can be taken forward to the user testing stage. The prototype development in this stage is based on the system architecture, activity diagram and preliminary requirements mentioned in chapter 5. Furthermore, a small test on the RIP band of the Breathline will also be conducted to ensure that the prototype is in working order.

6.1 Tilt Angle Calculation

As mentioned in section 1.1.2, accelerometers can measure the earth's gravitational acceleration as well as pure acceleration. As there is no movement of the accelerometer in figure 52a, it only senses the earth's gravitational pull, experienced by the z-axis as 1g. This shall be noted as the reference position, as the x- and y-axes are in the plane of the horizon (0g-field) and the z-axis is orthogonal to the horizon (1g-field).

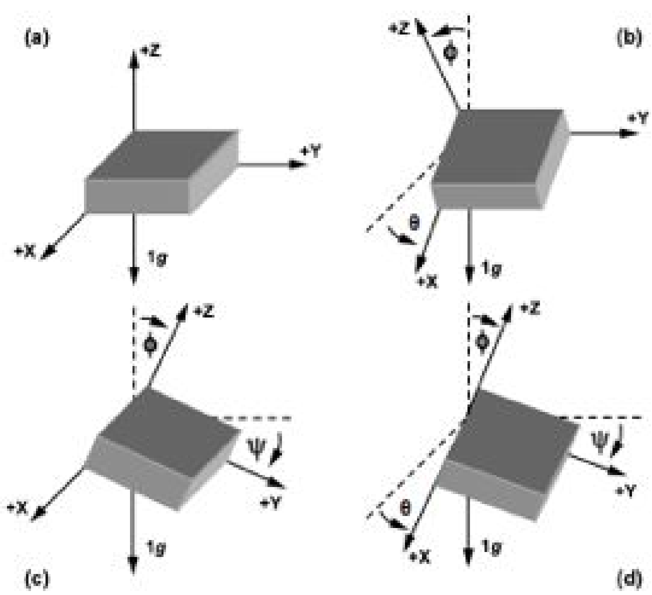

Figure 52: Angles for independent tilt sensing [76]

Figure 52 shows φ as the angle between the z-axis of the accelerometer and the gravity vector, θ as the angle between the x-axis of the accelerometer and the horizon and ψ as the angle between the y-axis of the accelerometer and the horizon [76].

(3) $\theta = tan^{-1}\left(\frac{A_{X,OUT}}{\sqrt{A_{Y,OUT}^2 + A_{Z,OUT}^2}}\right)$

(4) $\Psi = tan^{-1}(\frac{A_{Y,OUT}}{\sqrt{A^2_{X,OUT}+A^2_{Z,OUT}}})$

(5) $\Phi = tan^{-1}(\frac{A_{Z,OUT}}{\sqrt{A^2_{X,OUT}+A^2_{Y,OUT}}})$

Equations 3 - 5 illustrate how each of the angles of inclination can be calculated. Conversion to degrees is done by multiplying the results by (180/π). If the output shows a positive angle, it means that the positive axis of the accelerometer is pointed above the horizon. If the output shows a negative angle, it means that the axis is pointed below the horizon. It is important to note that the acceleration that the accelerometer is measuring whilst tilting is the acceleration due to gravity and not the acceleration of the movement of the device, as this is negligible. During a tilt, the 1g gravitational pull is distributed over the axis which is what results in the angle calculations. Adding up all axis measurements would result to 1g.

6.2 Programming Software

This section will give a brief description of the programs used for the entire system of posture tracking and diaphragmatic breathing analysis. Figure 51 illustrates which program is responsible for which task, but here the individual programs shall be described. The code used in the programs can be found in Appendix D.

Arduino:
Arduino is an open-source electronics platform based on easy-to-use hardware and software [68]. The language is based on C and can be expanded through C++ libraries. As the prototype will be controlled with an Arduino, the Arduino software is used for development of the posture tracking prototype.

Processing:
Processing is a programming environment based on Java, that has an emphasis on animation and providing users with instant feedback through interaction [69]. This program is used to visualise the measurements from Arduino and to make the graphical user interface.

Breath.exe:
This program was developed by Ben Bulsink for the Breathline device. Its inputs are the readings from the RIP band which it visualises in real time. This data can also be saved in a .csv file where the format is the readings of the RIP band, the X,Y,Z axis data from the embedded accelerometer and a timestamp every 10 seconds. As the setup of the accelerometer needed to be recreated, only the readings of the RIP band and the timestamp will be used.

Microsoft Excel:
Microsoft Excel is the industry-leading spreadsheet program, a powerful data visualization and analysis tool [70]. In this project it shall primarily be used to select, sort and graph the breathing and movement data acquired from Arduino, Processing and Breath.exe.

MATLAB:
MATLAB is a programming language used for iterative analysis and design processes. It has many libraries and an extensive set of functions that are fully documented [71]. In this project MATLAB is used to analyse the breathing data for the peak-to-peak values and breathing frequency.

6.3 Prototype Setup

This section will show the different components of the final prototype which shall be used for the user testing in section 7.2. It will firstly present the hardware before showing the final iterations of the haptic and visual feedback systems.

6.3.1 Hardware

This subsection will showcase the setup of the Enhancing Breathline with Posture Tracking project.

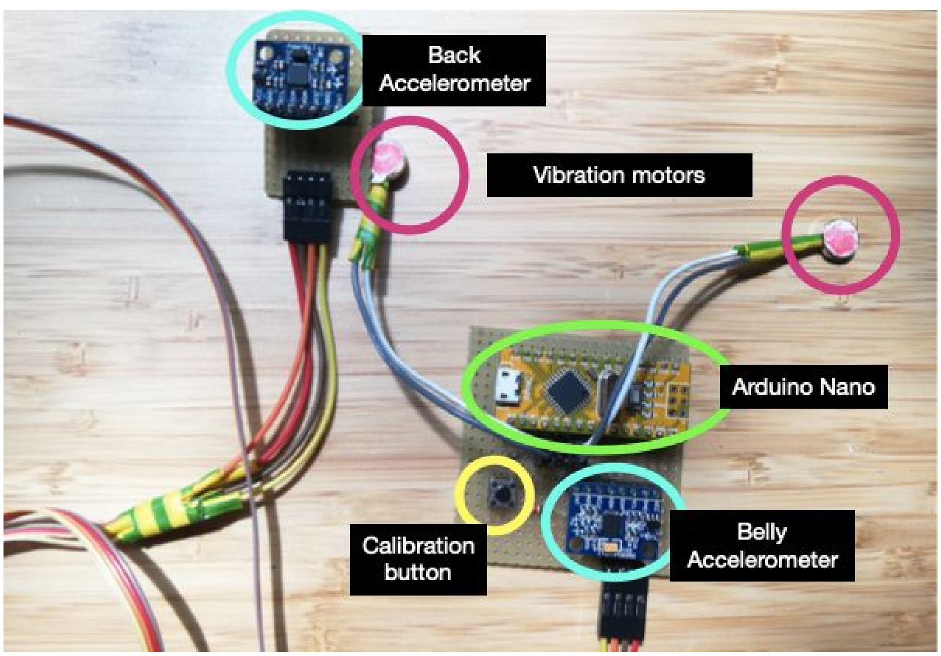

Figure 53: Posture Tracking Setup

Figure 53 shows the hardware components with their parts. The component list shown, partly visible in figure 53 is enumerated below:

- 2 x Tri-axial accelerometer → Model: MPU-6050
- 2 x Coin Vibration motors → Model: MPN: 316040001
- 1 x Push Button → Model: 1825910-6
- 1 x Arduino Nano → Model: ATmega328P
- 2 x Matrix Circuit Boards
- Wires
- Breathline (Not shown in figure 54)
- 2 x Micro USB to USB cable (not shown in figure 54)

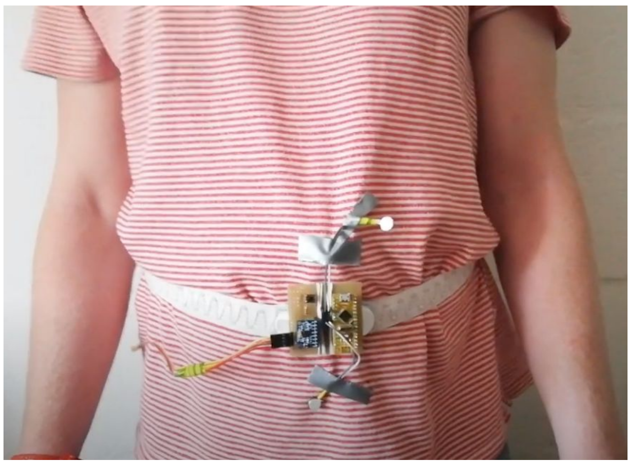

Figure 54a: Setup on belly

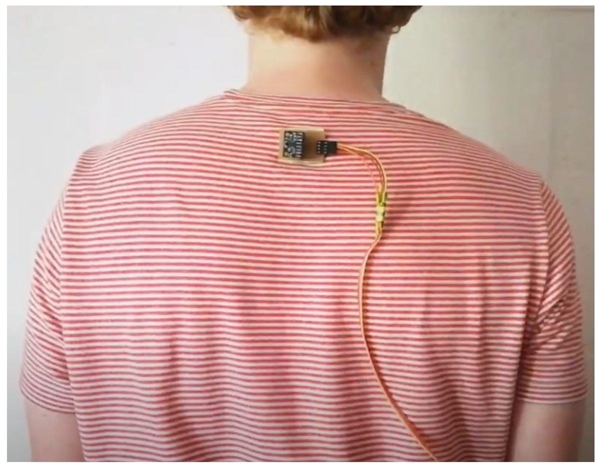

Figure 54b: Setup on back

Figure 54a shows the posture tracking prototype strapped to the Breathline on the user's belly. The vibration motors are duct-taped to the user's abdomen. Figure 54b shows the wired connection from the Arduino Nano to the back sensor, also duct-taped on to the user's back.

The Breathline and the posture tracking setup will be attached through micro USB to USB cables to the laptop for power and the writing and saving of the .csv files.

6.3.2 Haptic Feedback

This subsection will explain the functionality of haptic feedback on the final posture tracking prototype. As mentioned in section 5.3.1, the operating range of the coin vibration motors are from 2.5V - 3.5V, where no significant change in vibration strength can be felt. This is why requirement 8 in section 5.6 was changed to altering the frequency of the vibration pulses. The vibration pulse was chosen at 0.5s. Table 4 provides an overview of how the haptic feedback works.

Posture State Name	Posture State: From	Posture State: To	Motor	Vibration pulse: ON	Vibration pulse: OFF
Straight	-11.25°	11.25°	-	-	-
Mild Slouch Forwards	11.25°	34°	Top	0.5s	2.5s
Mild Slouch Backwards	-34°	-11.25°	Bottom	0.5s	2.5s
Prominent Slouch Forwards	34°	56.25°	Top	0.5s	1.5s
Prominent Slouch Backwards	- 56.25°	-34°	Bottom	0.5s	1.5s
Extreme Slouch Forwards	56.25°	78.25°	Top	0.5s	1s
Extreme Slouch Backwards	- 78.25°	-56.25°	Bottom	0.5s	1s
Flat Back Forwards	78.25°	90°	-	-	-
Flat Back Backwards	-90°	- 78.25°	-	-	-

Table 4: Overview of haptic feedback per state

As seen in Table 4, the frequency of the pulse remains constant but it is the time between the pulses that change with the extremity of the slouch. The worse the slouch is, the furthest away from the straight back position, the faster the frequency of the vibrations. There is no vibration feedback for sitting straight or lying backwards or forwards as the spine would still be straight in these positions.

6.3.3 Visual Feedback

This subsection will explain how the final visualisation of the posture tracking feedback module prototype of Breathline looked like. The second GUI design shown in figure 48b, was used as the final prototype. The values in degrees for the posture states can be in table 4. Moreover, the bar charts of the visualisation only show 5 states.

1. Straight Back
2. Mild Slouch
3. Prominent Slouch
4. Extreme Slouch
5. Flat Back

These states do not differentiate between forwards and backwards because this additional information would take up too much space on the screen and too text-heavy. Moreover, the flower shows whether the user is bending forwards or backwards and the vibration feedback differentiates between forwards and backwards with the motor that vibrates. Therefore only 5 states are displayed, as seen in figure 48b.

6.4 Breathline RIP Test

This section describes a small test done on the RIP sensor to ensure that its values have a proportional relationship to the expansion and contraction of the abdomen. The circumference of the RIP band was measured to be 77cm. The maxima of the points shown in the graph in figure 55 by the green circles, portray a 3cm expansion of the band that was done by stretching it to 80cm, with help of measurement tape.

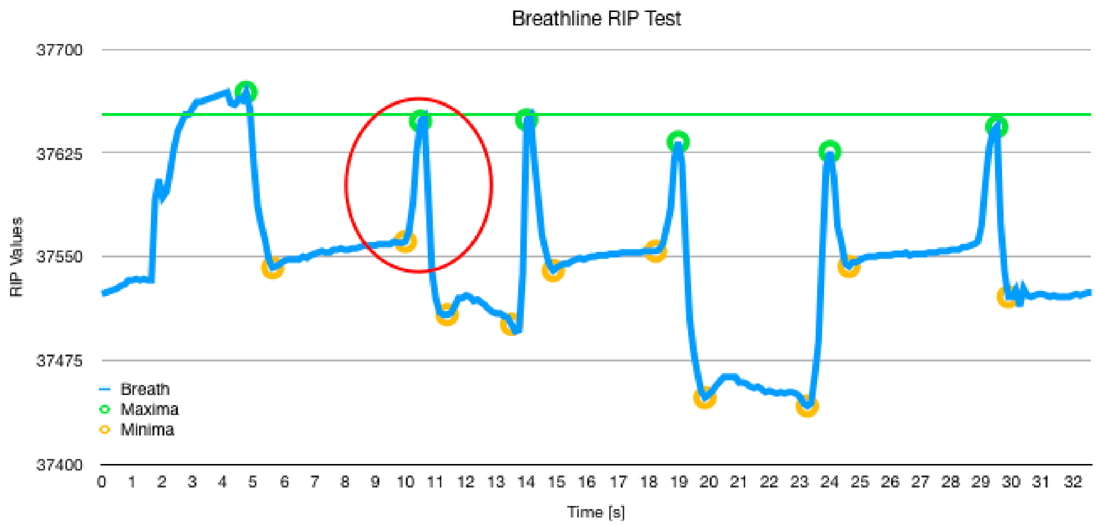

Figure 55: Results of Breathline RIP Test

It can be seen that the maxima points are consistent over the 6 times the band was stretched and output a value close to 37670 every time, as seen by the green horizontal line. After stretching the band 3cm it was let loose to return to the original 77cm, however, this was not rigorously checked. This can be seen by the fluctuations of the minima, displayed by the orange circles, as it did not consistently return to the same offset every time. However, it can very clearly be seen that the sensor responds linearly with expansion and contraction of the abdominal muscles by looking at the slopes of the peaks. This will be examined further by looking at the slope encircled by the red circle. The section of the graph in the red circle can be seen in figure 56.

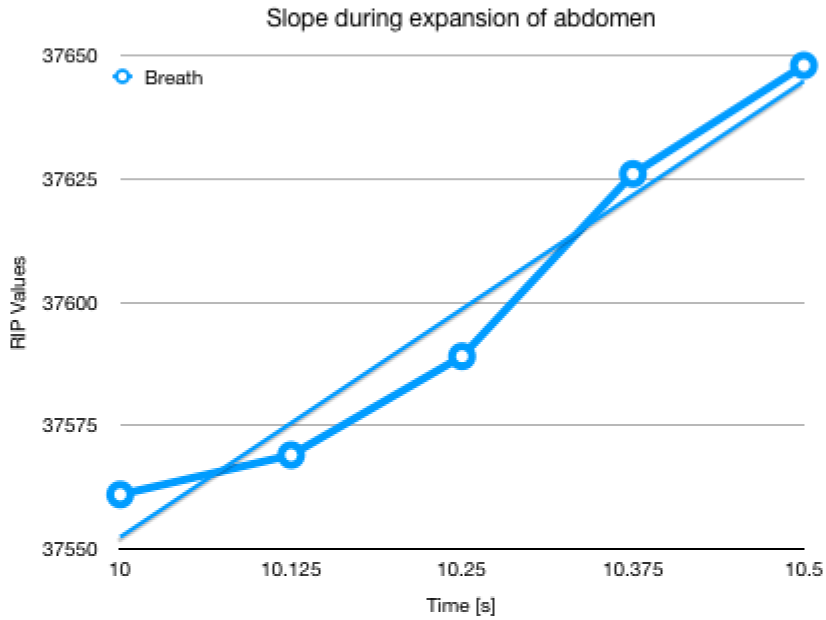

Figure 56: Slope of expansion of abdomen of Breathline RIP test

The slope seen in figure 56 can be estimated to be linear. The blue line with the circle data points are the measured values from the RIP band plotted against a linear trend line created with the values. It starts at 77cm and ends at 80cm. As can be seen from figure 56, both graphs do not match perfectly, however, it should be noted that these measurements took place in 0.5s, which is a very small time frame to show perfect linearity.

The results of this test showed that the RIP works as expected and can be taken further to the evaluation phase without alterations.

In summary, this chapter covered the calculations of how the raw accelerometer data can be used to estimate its tilt angle. The programming software used in this project was described, followed by the prototype setup where the hardware, haptic feedback and visual feedback choices were justified. This chapter concluded with a test conducted on the RIP band to ensure all components of the project are in working order before commencing the functional and user tests.

7 Evaluation

This chapter will evaluate the prototype by a functional and usability test. However, because this project also uses the user test to collect breathing and posture data, an evaluation between the relationship of the two will also be conducted. Furthermore, the third to sixth sub-research questions, listed in section 1.3 will all be answered in this chapter.

7.1 Functional Test

The purpose of the functional test is to evaluate whether enough functional requirements have been met. The test will be binary, as the requirement will have either been successfully met or not. All the “Must” requirements must have been met. The “Should” and “Could” requirements are preferred but are not essential. Table 5 will list all functional requirements and provide an overview of the functional test.

Number	Requirement	Met?
	Must	
1	The posture tracking system must recognise at least 5 posture states (90°,60°,45°, 30°,0°) with the back and the belly accelerometer.	**x**
2	The posture tracking system must be able to set a zero-point position through calibration.	**x**
3	The posture tracking system must provide haptic feedback through at least one vibration motor.	**x**
4	The posture tracking system must output degrees.	**x**
5	There must be visual feedback about the user's posture through a GUI	**x**
6	The breathing and posture measurements must be combined with a mutual timestamp	**x**
	Should	
7	The user should be able to see their statistics being updated in real time.	**x**
9	The vibration motors should be controlled through PWM, to vibrate with a higher frequency when the posture is “incorrect” and slowly decrease as the posture gets better. (functional)	**x**

13	There should be a counter showing the total recording time of the session.	
14	A quality factor should be calculated based on the user's posture throughout the recorded session.	**x**
	Could	
15	The device could allow the user to set daily goals.	
16	The device could give the user the possibility to see their statistics of their posture and position throughout the day.	
17	The device could have a time slider for the user to see which posture they had at exactly what time.	
18	Counter showing how many times the user slouches per day.	

Table 5: Functional Test

As seen in table 5, all "Must" requirements have been met. Both accelerometers are able to recognise 5 posture states in the forward and backward direction. There is a button that allows calibration on the prototype. Haptic feedback is provided through two vibration motors. The posture states are defined through angles which the accelerometer can measure. Visual feedback was provided by a GUI implemented in Processing. The Breathline as well as the posture tracking module both output a timestamp that can be used to merge both .csv files.

3 out of 4 of the "Should" requirements have also been met. The user can see the bar graphs and the flower being updated in real-time. The haptic feedback has 3 different frequencies which differentiates between forward and backward slouching. The quality factor is present as the percentage next to the state on the bar graphs that also gets updated in real-time. The counter was present in the lo-fi prototype but it proved too distracting which is why it was removed and therefore, cannot be checked off.

The "Could" requirements were not met.

7.2 User Test Procedure

This section describes the procedure of the user test. As the user test took place during the COVID-19 pandemic, the participants were restricted to students between the ages of 18-24 within the immediate circle of the author. The user test consists of two parts, the biometric data collection and usability test. A diagram displaying the procedure with both tests can be seen in figure 57.

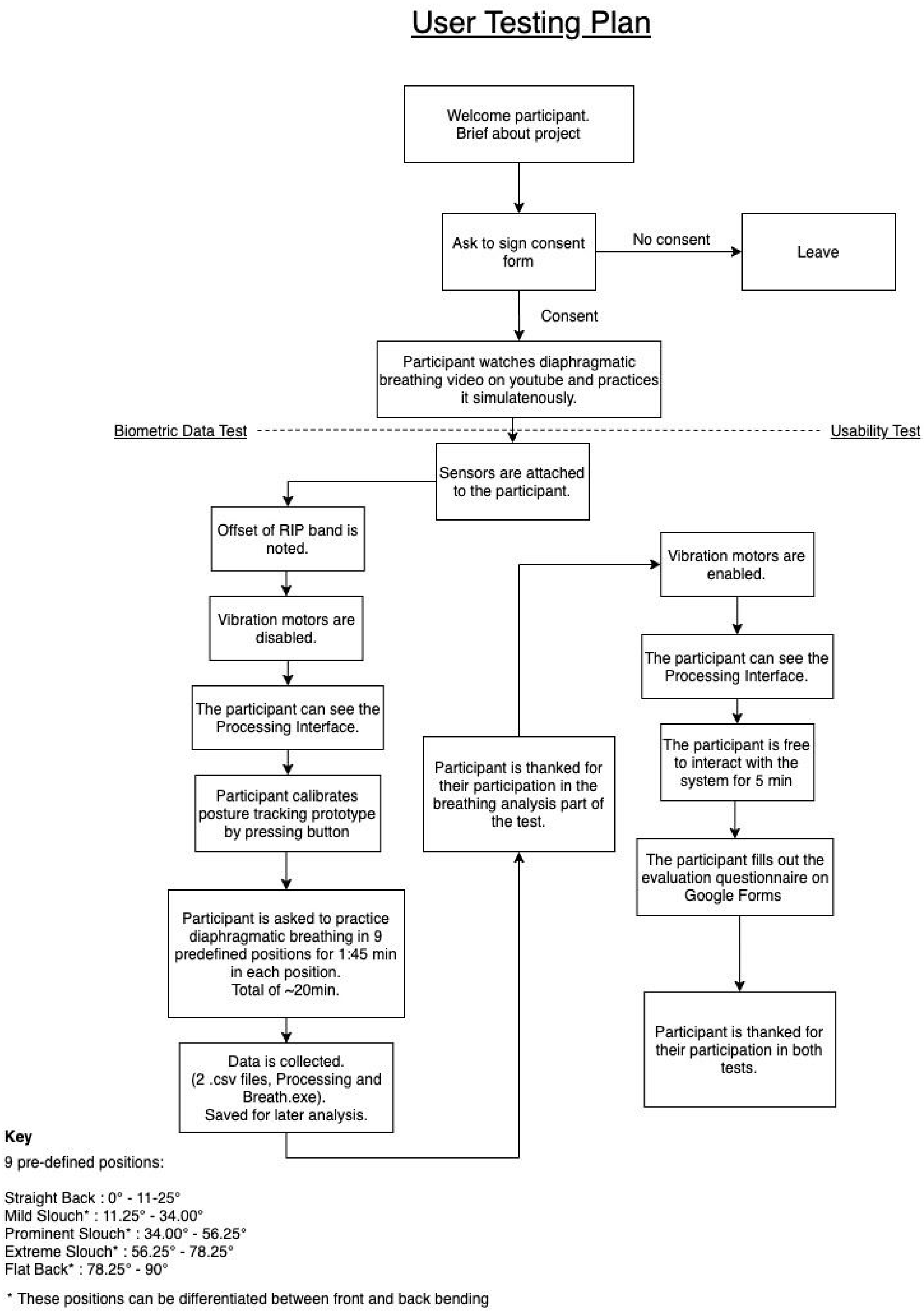

Figure 57: User Test Procedure

The user test was conducted on 12 participants individually, in the author's bedroom. The participants were asked to breathe diaphragmatically for 1:45 min in the 9 pre-defined positions whilst wearing the Breathline device and the posture tracking setup. Once the breathing and posture data had been collected, the vibration motors were activated and the participant was left to interact with the product and the GUI freely for 5min.

The participants were first briefed about the project and asked to sign a consent form that can be seen in Appendix C. They were then asked to watch a video from the Massachusetts General Hospital that explained how to breathe diaphragmatically [72]. The duration of the video is 1min.

Thereafter, the sensor setup was attached to the participant. The back sensor was attached to the participant by using double-sided duck tape and the belly sensor was taped on to the Breathline device and secured on to the participant by using thin strands of rope. The participants were asked to calibrate their 0-point by pressing the button on the prototype. Thereafter, they were asked to breathe diaphragmatically for 1:45 min in the 9 pre-defined positions, listed again for convenience.

1. Sitting straight : from -11.25° to 11.25°
2. Mild slouch forwards : from 11.25° - 34°
3. Mild slouch backwards : from -34° to -11.25°
4. Prominent slouch forwards : from 34° to 56.25°
5. Prominent slouch backwards : from -56.25° to -34°
6. Extreme slouch forwards : from 56.25° to 78.25°
7. Extreme slouch backwards : from -78.25° to -56.25°
8. Flat back forwards : from 78.25° to 90°
9. Flat back backwards : from -90° to -78.25°

The participants were asked to sit down in a chair with a backrest for the first eight positions. For the ninth position, which is lying down flat on their backs, they were asked to move to the bed.

The GUI for the posture tracking was used to determine the state and posture that the participant had to keep for 1:45min, as the state gets highlighted in green. The vibration motors were not activated for this part of the experiment as the biometric data test part of the experiment as shown in figure 51, was purely meant for data collection. After the data collection that participant was thanked and the usability test began. The vibration motors were activated and the users were allowed to interact freely with the prototype for 5 minutes. Thereafter, they were asked to fill out a questionnaire about their experience with the prototype, attached in Appendix C.

7.3 Evaluation Body Posture Tracking System

This section will firstly evaluate the setup of the posture tracking system on the integration of the back accelerometer. It will thereafter evaluate the breathing interference before evaluating the setup on its accuracy and error.

7.3.1. Integration of the back sensor

This subsection will evaluate the posture tracking setup on the integration of the back accelerometer by analysing a graph showing the total recording period of the user test. Figure 58 shows a graph of a recording session of one participant across the 9 different positions. The values of the belly and back accelerometer are inverted because of the way they were soldered on to the perf boards and attached to the body. As can be seen very clearly in figure 58, the back accelerometer did not notice the change from the ExtS_F to the FlatB_B state, shown by the red circle around the green line, whereas the belly accelerometer did, shown by the orange circle around the blue line. On the other hand, the back accelerometer noticed the change from ExtS_B to FlatB_B, shown by the orange circle around the green line, whereas the belly accelerometer did not, shown by the red circle around the blue line. These state changes can be seen by the change in the y-axis.

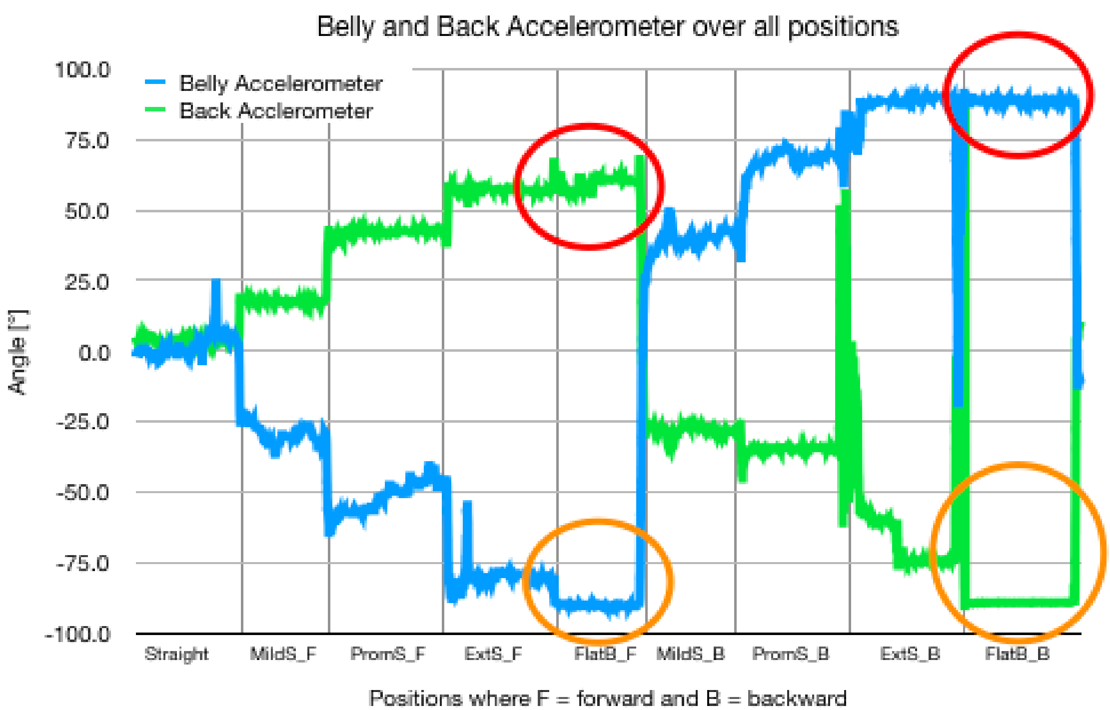

Figure 58: Belly and back accelerometer measurements over all 9 states

The conclusion that can be made from the information in figure 58 is that the belly accelerometer is more sensitive to changes in forward bending, and the back accelerometer is more sensitive to changes in backward bending. One accelerometer alone could not have recognised all 9 nine states, but together were able to do so.

7.3.2 Breathing Interference

This subsection will analyse whether the setup experienced any breathing measurement interference by analysing a graph showing readings of both accelerometers over 45s in the straight posture. It will also answer the sub research question: *If the sensor picks up on interference of breathing measurements, how can they be cancelled out during body position tracking?*

Looking at both signals from the belly and back accelerometer over the recording session as illustrated in figure 58, does not give an impression that one has more interference than the other. This suggests that the participants breathing does not have a large effect on the belly accelerometer readings. This hypothesis was analysed further in figure 59, which shows an enlarged graph of the straight posture of figure 58.

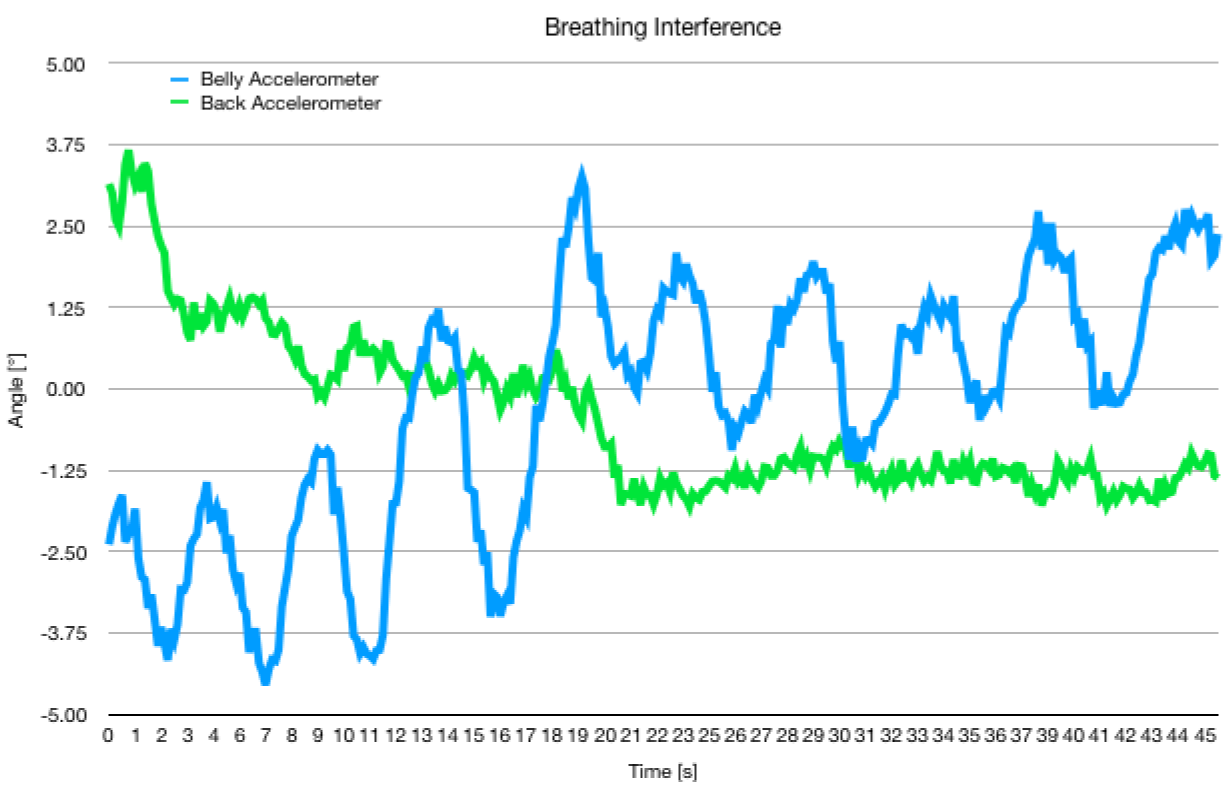

Figure 59: Breathing Interference in Straight Back posture

Figure 59 shows a recording of the user sitting in a straight posture for 45s. The breathing interference can clearly be seen in the belly accelerometer signal. However, the maximal peak to peak amplitude detected was 6°, which can be seen at 16s-19s of the recording. There was no special procedure undertaken to combat the breathing interference as it was too small to inhibit the posture measurement and there was no requirement stating that the prototype had to be this precise. To summarise, the setup did indeed notice breathing interference from the belly accelerometer, however the interference was negligible (highest peak-to-peak value was 6°), which is why no procedures were undertaken to minimise it.

7.3.3 Accuracy and Error

This subsection will evaluate the body position tracking setup on its accuracy and error and will answer the sub research question: *How accurate is the chosen setup in recognising body position?*

To measure the error and accuracy of the accelerometer used in the posture tracking setup, it was held next to a protractor for 19 measurements from -90° to +90° in 10° steps. This test was repeated twice. The average accuracy from this test evaluated the average accuracy of the accelerometer at 95.2%, the average error at 1.22° and the standard deviation at 1.61°.

This test evaluated not only the accelerometer embedded in the MPU-6050 module, but also the code on its accuracy and error, which is what the results represent. Nevertheless, it is important to note that the spine is not perfectly straight and these values assume that the tilt angles are taken from a perfectly straight position. The statistical values can differ per person as everyone has different curves and bends in their backs making them unique. To summarise the statistical values shall be listed once again.

Average accuracy: 95.2%
Average error: 1.22°
Standard deviation:1.61°

7.4 Evaluation Body Posture and Diaphragmatic Breathing

This section will present the results from the biometric data test described in figure 51. Furthermore, it will describe the findings from the expert interview conducted with the clients of this project and present the findings of an additional survey the participants filled out after this test. Moreover, this section will also answer the sub research question: *What effect do different body positions have on diaphragmatic breathing and can an optimum be defined?*

To reiterate, 12 participants were asked to breathe diaphragmatically for 1:45min in the 9 pre-defined postures by watching a video from the Massachusetts General Hospital that explained the technique [72].

The collected data was separated into the nine positions using both the timestamps on the both.csv files and the changing of the accelerometer data. The cleanest data for 1 minute was selected and the peak-to-peak values (vertical arrow) and the breaths per minute (horizontal arrow) were calculated for each position, as can be seen in figure 60.

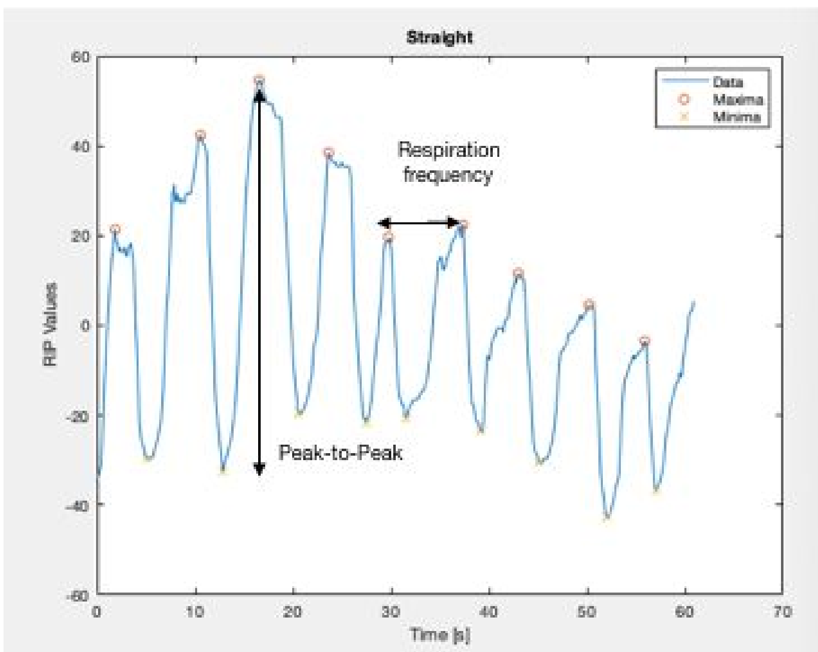

Figure 60: Extracted features from breathing data

The mean was subtracted from each measurement to minimise the difference in the offsets between the participants so that their data could more easily be compared. The average value of both the peak - to peak amplitude and the breaths per minute was saved for each position. These operations were all done in MATLAB and the code can be found in Appendix D. Moreover, this section only covers some of the graphs. More data on the measurement analysis can be found in Appendix C.

7.4.1 Depth of Breath Analysis (Peak-to-Peak Values)

This subsection handles the analysis of the peak-to-peak amplitudes of the RIP data that were interpreted as the depth of breath of the participants.

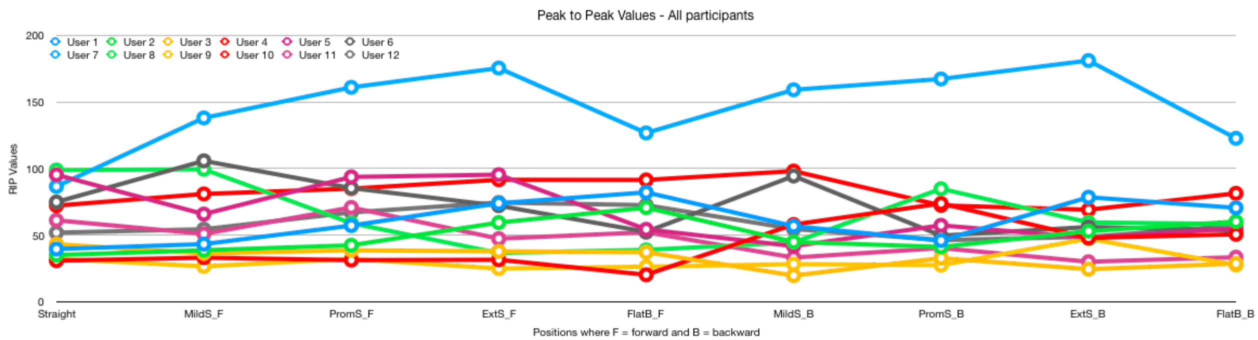

Figure 61: Peak-to-Peak Values - All participants

Figure 61 depicts the average of the peak-to-peak data for each individual position. As can be seen, there is no visible trendline that all the participants follow and no uniform highest or lowest value. Instead, there are unnatural peaks and inconsistencies between every graph.

Figure 61 also shows that the participants still have different offsets, despite having subtracted the mean. To normalise this, the values for every position for each participant were ranked on a scale from 1-9 where 1 signified the highest peak-to-peak amplitude and 9 the lowest peak-to-peak amplitude. The mean of this ranking system was taken across all participants and is plotted against an expected trend line following the same data point ranking, as seen in figure 62.

The expected trend line, illustrated by the blue line in figure 62, assumes that the sitting straight position would be where the participants breathe the deepest, which would be illustrated by the highest peak-to-peak values.. This hypothesis was taken from the results of the literature review conducted in section 1.2.1 and the interview with Parviz Sassanian transcribed in section 2.1.1, that stated that in the straight posture, the lungs can expand and contract as much as possible without any additional interference. He also mentioned that slouching can lead to an obstruction of the lungs that can result in difficulty in practicing the technique of diaphragmatic breathing. This is why the expected trendline experiences a negative slope with the increase of slouch degree. The worst expected position is the flat back forward posture (> 90°), as this is where the slouch would be at its most extreme state. Moreover, Moreno and Lyons [14] also found when comparing the tidal volume of the lungs in the sitting, supine (flat back backwards) and prone posture (flat back forwards) to each other, that the prone position experienced the lowest values across their test participants. The flat back backwards posture was expected to have relatively good breathing again, as the back would be straight and, similar to sleeping, the participant would be relaxed. However, It is important to mention that the Breathline does not measure lung movements, but measures abdominal movements. As mentioned in section 1.2.2, respiratory inductance plethysmography can be used to estimate lung volume from respiratory movements, which is the logic that the expected trend line is based on.

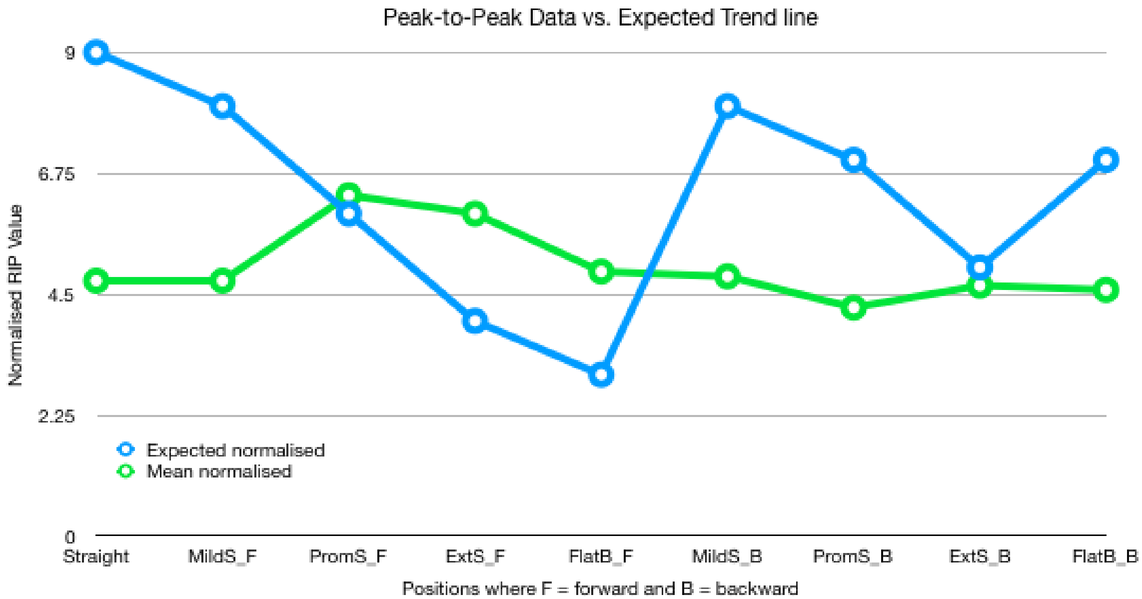

Figure 62: Peak-to-Peak Data vs. Expected Trend line

By comparing both graphs to each other, it can be identified that there is no correlation. According to figure 62, over 12 participants, the prominent slouch forward position (34° - 56.25°) has the relative highest peak-to-peak amplitude, suggesting that in this position, the participants breathe the deepest. This was not according to the hypothesis at all. Furthermore, the data collected in this experiment, shown in the green line in figure 62, suggests that posture only has a minimal influence on diaphragmatic breathing, as the normalised mean is almost constant. However, it is important to mention that the setup of this experiment only used the abdominal band of the RIP method and therefore could not measure whether a chest breathing component was present. Hence, this data cannot say with certainty that the participants were practicing the diaphragmatic breathing technique correctly.

In summary, the peak-to-peak RIP data values did not follow the expected trendline. The acquired data suggested that posture has a minimal effect on diaphragmatic breathing. The position with the highest peak-to-peak values was the prominent slouch forward position (34° - 56.25°). However, this cannot be seen as a conclusive optimum as it cannot be ensured that the participants were indeed practicing the diaphragmatic breathing technique correctly.

7.4.2 Respiration Frequency Analysis

This subsection analyses the respiration frequency of the participants of the user test. Similar to the peak-to-peak analysis, the data for the respiration frequency, seen in figure 63 is extremely random. Moreover, there was no logical way to normalise the respiration rate for every participant, as this is completely individual.

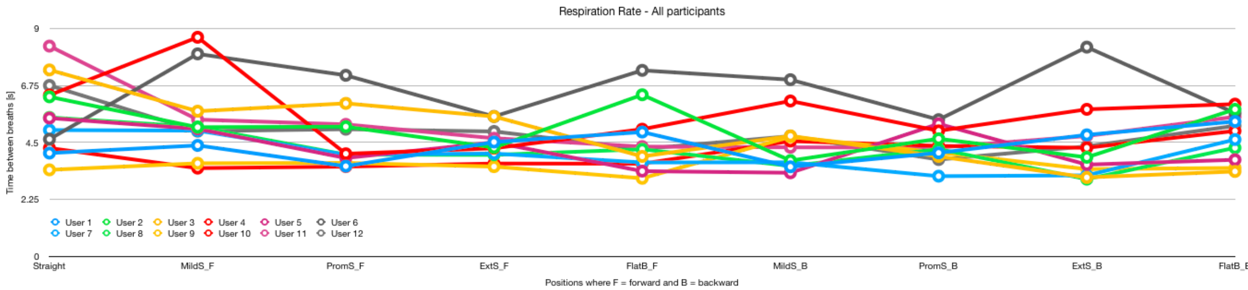

Figure 63: Respiration Rate - All participants

It was expected that the respiration rate would only experience slight changes during the different positions, as the breathing rate was assumed to be the same whilst sitting and slouching, which is reflected in the expected trendline in figure 64. Moreover, it was shown in the studies conducted by Moreno and Lyons [14], Landers *et al.* [17] and Avbelj *et al.* [18] that the respiration rate amongst their participants in different postures also remained the same. However, figure 63 clearly showed that this statement is not true for this study. The respiration rate however, can give insights into whether the participants were breathing diaphragmatically as diaphragmatic breathing ranges from 6-12 breaths per minute (0.1 Hz - 0.2 Hz). Over all test participants, the range of breathing was 6 - 19 breaths per minute (0.1 - 0.316 Hz). Numerically, the highest limit is 158% larger than what diaphragmatic breathing is defined as, suggesting that not every participant was breathing diaphragmatically and therefore, there are significant errors present in this data.

As mentioned above, the trendline was expected to be relatively constant with the small deviations reflecting the same reasoning as the peak-to-peak amplitudes. However, this was also not always the case in this experiment if one were to compare figure 61 to figure 63. One user, however, slightly followed the expected trendline, as shown in figure 64.

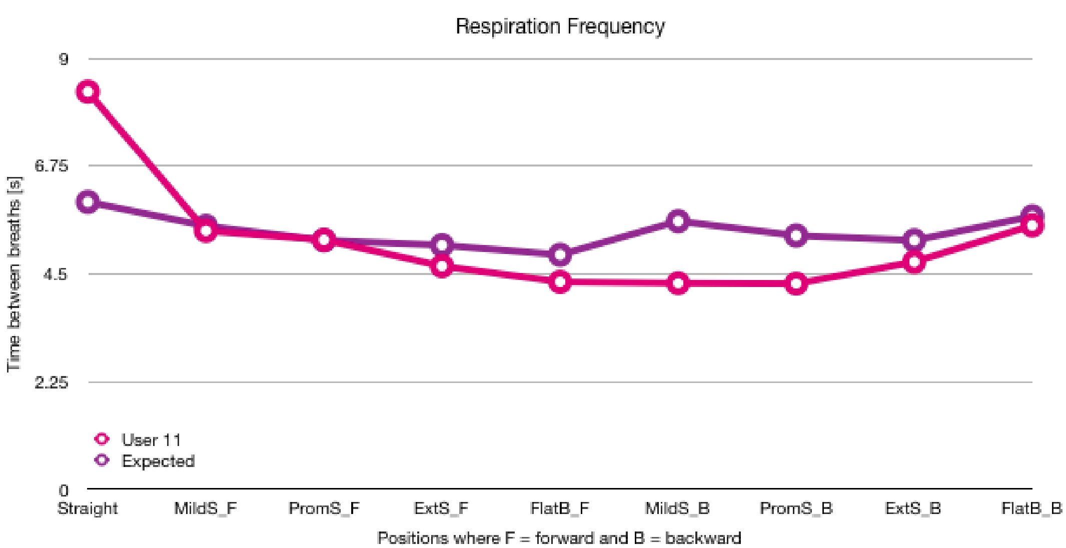

Figure 64: Respiration Frequency: Expected vs. User 11

The hypothesis that respiration rate would only experience slight changes during the changes in positions is correct in the case of user 11, as seen in figure 64.

However, due to the randomness of the results, inconsistencies over all test participants and to gain more insight, an expert review was conducted with the clients of this project which shall be described in the following subsection.

7.4.3 Expert Review: Clients and further literature

Parviz Sassanian, a breathing therapist and acupuncturist in Enschede and Ben Bulsink, the electrical engineer behind the Breathline device were presented with the results of this experiment.

Mr. Sassanian, in particular, underlined the fact that diaphragmatic breathing has many different parameters that cannot always be quantified. He listed up some factors where he has noticed people changing their breathing pattern but emphasizes that this list is not absolute.

- Age
- Gender
- Which part of the lung is used
- Mental state
- Emotional state
- Physiological state
- Comfort

As Mr. Sassanian practices in his own breathing clinic, he notices these differences between his patients by these parameters. He accentuates that breathing is completely individual and can be seen as being as unique as a fingerprint. To try and find trends that apply to a large group of people is a challenging task and should be approached very carefully and systematically.
A method to do this would be to do a thorough screening of each participant beforehand. Mr. Sassanian mentioned that to coach someone to breathe correctly it is essential that he gets to see them beforehand, to get a feel for the person. Moreover, he declared that it is quite an impossible task to learn how to breathe diaphragmatically, correctly in one minute. He himself has been practicing for 30 years and still says he can improve.

Ben Bulsink took a different approach to explaining the results. He underlined that his sensor measures the relative expansion and contraction of the abdominal muscles. The features that were extracted from the data (the peak-to-peak amplitude and the breathing frequency) do not have a direct correlation to the lung expansion. The peak-to-peak amplitude of the readings can be interpreted as the depth of breath of the individual but should be backed up by actual data of breathing to see if there is a direct correlation. The respiration rate is an extracted feature that he considers more relevant than the peak-to-peak amplitude, but even this says nothing about the amount of air flow in the lungs.

Mr. Bulsink draws a parallel to analysing breathing patterns from an eastern and western point of view. He explains that in the west people look at treatment as a “one medicine should treat all”, whereas in the east there is much more individuality ingrained in the mindset of people that might be more applicable to this sort of study as people and breathing patterns are extremely unique to each other.

This observation was also made by *Zaccaro et al.* [73] where they stated that heuristically, it is commonly acknowledged that breathing techniques are profoundly intermingled with cognitive aspects of meditation, and in eastern culture, their role for achieving altered states of consciousness is undisputed [73] . A common belief of western culture is that breathing control has beneficial effects on health status, such as wellness, relaxation and stress reduction. Nevertheless, western science has paid little attention to the investigation of the effects of pure breathing control on neural correlates of consciousness, and on specific mental functions [73]. Moreover, Ospina *et al.* [74] also stated that there are many uncertainties that surround the practice of meditation (Mantra meditation, Mindfulness meditation, Yoga, Tai Chi, and Qi Gong). Scientific research on meditation practices does not appear to have a common theoretical perspective and is characterized by poor methodological quality. Future research on meditation practices must be more rigorous in the design and execution of studies and in the analysis and reporting of results.

These remarks can also be seen in this study as there was no link drawn between the physiological and psychological state of the participants and their breathing, where both the literature and the clients have stated that might be one. For this reason and as a suggestion from the clients, a survey was sent out to the participants of this study to better understand how they experienced the testing and how they were feeling during the test.

7.4.4 Evaluation Breathing Test Survey

To gain more insights on how the participants experienced the test, they filled out an online questionnaire of which the questions together with the results are presented in this section. Participation was completely voluntary and 67% of the original test participants filled it out. The whole survey can be seen in Appendix C.

How did you experience the testing? (Was it difficult, easy, what did you feel?)
When asked how the participants experienced the testing, there were mixed remarks. The tone of the answers indicated that there were some issues between the definition of slouch and tilt, keeping the breathing monotonous and not overdoing it, uncertainty about their own performance, uncertainty whether they were breathing correctly or not and difficulty keeping to

some of the predefined positions. However, 3 participants did mention that the entire procedure was quite straightforward, easy and comprehensible.

Did you feel like after watching the video, you knew how to breathe diaphragmatically? (Belly breathe?)
All participants felt like the video provided a good explanation on how to practice diaphragmatic breathing. Some participants claimed to have previous knowledge on this practice whereas others were unsure whether they were executing it correctly during the entire session.

In what sort of state would you have described yourself whilst you were being tested? (e.g calm, nervous, anxious, relaxed, frustrated, hungry etc.)
There was a mix of participants that felt calm and relaxed and participants that felt anxious because it was a test and that they had to focus on their breathing. One participant mentioned that they were anxious at the beginning and became calmer during the session.

Which position did you feel most comfortable in, whilst breathing?
As shown in Figure 65, there was no uniform position that all participants agreed on being the most comfortable. This was quite unexpected as the hypothesis was that the straight position would be the best breathing position and therefore also the most comfortable for all participants.

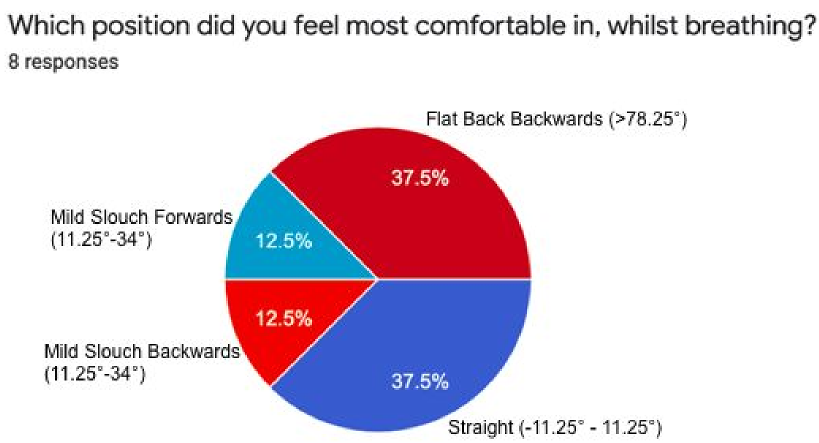

Figure 65: Survey Results - Most comfortable position

Why did you feel this position was the most comfortable?
People related their most comfortable positions with habit. All participants stated that their position was either their most normal or typical one or that the other ones were simply new and unnatural, indicating that habit and comfort could have a correlation to the position that they would breathe the best in.

Were you more conscious of your breathing during the test because you were being observed?
As shown in figure 66, all participants were more conscious of their breathing during the test because they were being observed. This occurrence is called the Hawthorne effect (also referred to as the observer effect) and describes behavioural changes of the participants in a study in response to their awareness of being observed [75].

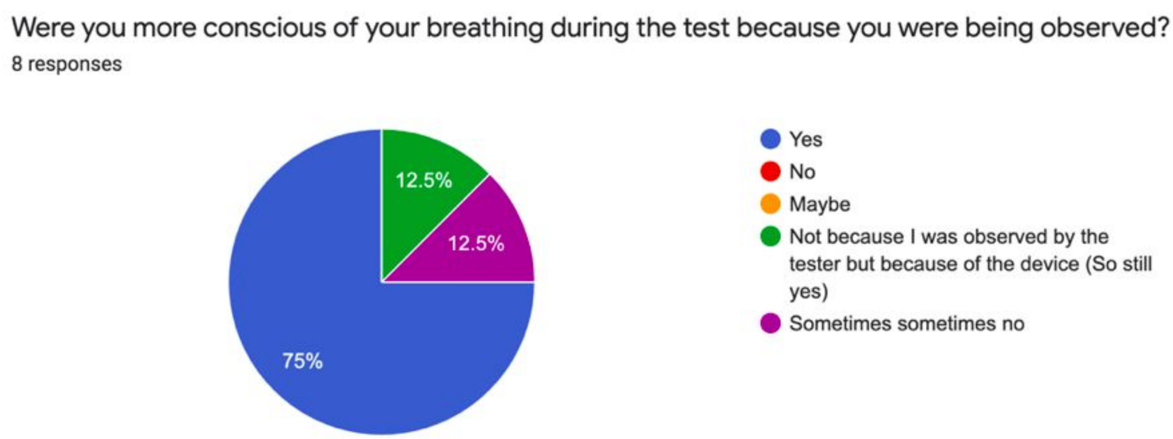

Figure 66: Survey Results - Awareness of breathing during test

The fact that all participants were more conscious of their breathing and may have changed it can be a significant source of error and may have undermined the relationship between their breathing and posture. Moreover, the fact that there were also changes between their calmness during the session could have also had some influence on how they breathed.

7.4.5 Summary

This section presented the test results of diaphragmatic breathing in 9 different positions with 12 test participants. Because of the inconclusive results and the collected data suggesting that posture has a very minimal influence on breathing, an expert interview was conducted. Here it was found that diaphragmatic breathing has many different parameters and cannot be quantified without a detailed screening process of the participant beforehand. Additionally, Parviz Sassanian, a breathing therapist in Enschede clearly stated that it is almost impossible to learn diaphragmatic breathing from a video. It is a technique that takes years to perfect which suggests that there was a very high probability that the participants were not breathing diaphragmatically which could have also introduced a source of error and led to non-generalizable results.

Studies have shown that there is a link between physiological and psychological state of humans [73] [74], and this should be correctly identified with a proper methodological process to be able to generalise the connection between breathing and posture.

Moreover, Ben Bulsink, the engineer of Breathline underlined that his sensor cannot measure the direct expansion of the lung volume and only measures the relative expansion and contraction of the abdominal muscles. This suggests that in this stage of development, only using the abdominal band of the Breathline to gain insights on breathing behaviour might have been too optimistic and could have introduced a source of error. If done again, the chest band should be included in the setup to measure the chest movements also.

Furthermore, the additional survey that was sent out to the participants after their data had been analysed showed that many participants were uncertain about their performance and did not know whether they were breathing correctly or not. They also described their state to have changed during the recording from nervous to calm. Moreover,all participants mentioned that they were more conscious of their breathing during the test, which are all factors that could have led them to change their breathing habits. Additionally, there was no uniform position that all participants agreed on being the most comfortable which clearly shows that without a proper screening process, there is no general conclusion that can be made with a sample size of 12.

In summary, this research was unable to find generalisable effects of different body postures on diaphragmatic breathing which also meant no conclusive optimum was able to be defined. The hypothesis that sitting straight would result in the best forms of breathing was unable to be proven.

7.5 Evaluation Usability Test

The usability test serves the purpose of determining whether the prototype can fulfil the non-functional requirements. Furthermore, the user can give feedback on the prototype and recommendations for future work to make it better. This was approached by asking the test participants to fill out a questionnaire, seen in Appendix C. Participation was voluntary and 10 people completed the questionnaire. This section will firstly evaluate the haptic feedback and secondly, the visual feedback. It will conclude with a summary of the findings and then answer the sub research question: *What forms of feedback are considered constructive from a user perspective on posture tracking?*

7.5.1 Haptic Feedback

This subsection evaluates the prototype's haptic feedback based on the questionnaire the test participants filled out. The questions asked were based on the non-functional requirements stated in section 5.7.

Did the haptic feedback (vibration motors) improve your posture?
This question was related to the task that the participants got asking them to sit straight with the vibration motors enabled. They would pulse when the user entered a state that was not straight or lying flat on their backs. 80% of the users thought that the vibration motors improved their posture whereas 20% of the participants were unsure whether the haptic feedback contributed to improvement of their posture. None of the participants thought that they were counterproductive or did not help at all.

Did the different pulses for different positions make sense?
This question is related to the different vibration frequencies of the different states. The vibration motors vibrate with a higher frequency from the mild slouch state to the extreme slouch state, indicating that the user's posture is getting worse and needs immediate attention. 90% of the participants thought that this feature made sense but it did not appeal to 10% of the participants.

Did you think the strength of the haptic feedback was satisfactory?
This question related to the vibration motors being powered by 3V, which is their operating voltage, stated in their datasheet. They could have been powered by 2.3V which would have resulted in a less powerful vibration. 70% of the participants thought that the strength of the feedback was satisfactory whereas the 20% were unsure and 10% thought it was unsatisfactory.

Was the placement of the vibration motors good?
This question relates to the up and down placement of the vibration motors to indicate that the user is either bending back or bending forward. 60% of the participants thought the placement was good, whereas 30% thought it was not. 10% were unsure.

Comments or improvements to the haptic feedback?
There were quite a few comments given as suggestions for improvement on the haptic feedback. The participants that were unsatisfied with the strength of the haptic feedback thought it was too strong. The participants that were unsatisfied with the placement of the vibration motors thought they could either be more spread out on the abdomen or placed on the back instead. The pulses of the vibration motors could have been more diverse for the different states as at least one participant mentioned that she would have not noticed it if it had not been explained. A participant mentioned that the visual feedback on the GUI gave more immediate feedback than the motors which they thought excessive. Another participant mentioned that pressure feedback would maybe be a better feedback mechanism than vibration feedback. Another participant mentioned that the feedback between forward and backward should have been reversed as he intuitively moved away from the vibration.

7.5.2 Visual Feedback

This subsection evaluates the prototype's GUI based on the questionnaire the test participants filled out. The questions asked were based on the non-functional requirements stated in section 5.7.

What did you think of the interface? (Visuals)
The participants liked the minimalistic look of the interface. They were split over the intuitiveness of the flower, where some thought that it represented mindfulness where others could not understand why their posture was represented by a plant. One participant was not sure what the percentages next to the states represented whereas another thought the bars gave good feedback on the users position. The tone of the comments of this question was quite positive.

Did the bending flower make sense to you?
70% of the participants agreed to the question. The remaining 30% agreed that the bending of the flower made sense but did not understand why there was a flower on the screen. One participant mentioned that the front view was more intuitive than the side view.

Did the different states provide insightful information?
The majority of the participants felt that the different states did provide insightful information about how they were slouching with 20% saying definitely yes and 70% saying yes. 10% if the participants were neutral about this statement.

In general, what did you think about the entire project?
The general tone of the comments were quite positive with 60% of the participants mentioning words like insightful, meaningful and interesting. A participant commented that the haptic feedback was very intuitive and action-inducing, more than audio feedback would have been and noted that the interface was a more interesting way to learn about posture than reading values off a sensor. Another participant stated that if the posture tracking module were to be

incorporated in an unobtrusive manner into clothing, that it could be a good means of rehabilitation during a recovery process. Another participant stated that the module should be able to differentiate between bending forward and slouching forward as that distinction was still unclear to them. The other participants were keen to see how the project develops and voiced readable interest.

7.5.3 Summary

This section presented the results of the user's thoughts and comments on the haptic and visual feedback given by the posture tracking prototype.

The haptic feedback was appreciated by the participants and 80% of the test participants thought that the vibration motor setup helped to improve their posture. There were quite a few comments that the strength of the vibration motors was too strong. The placement of the vibration motors on the abdomen made sense for the participants but many felt that it would have been more useful if it were more spread out or placed on the back. If this project is taken further, vibration motors with a lower voltage than 3V should be picked. More user tests should also be conducted to find the ideal placements of the motors.

The minimalistic look of the interfaced was liked by the participants. The bar charts and the states made sense and were described as being intuitive and insightful. The representation of posture through the flower made sense to 70% of the participants but could be improved by a more thorough explanation of the project beforehand.

The general tone of the comments was quite positive about the project and the feedback provided was seen as constructive. One participant, in particular, mentioned that the interface was a more interesting way to learn about posture than reading values off a sensor.

Therefore, having 2 vibration motors with 3 frequency states and a GUI as shown in figure 48b is considered to be constructive feedback on posture tracking.

However, more information about constructive feedback forms for posture tracking can be found in the target group interviews in section 4.3, as not all of the suggestions were implemented.

8 Conclusion

This chapter marks the end of the report and will address the main research question of this thesis:

How can body posture be tracked most effectively with a physical prototype combination of an accelerometer and other sensors to give the user constructive feedback with the Breathline device?

A system was developed using two accelerometers from the MPU-6050 module. These were placed on the upper back and the belly, with the latter mimicking the Breathline's embedded accelerometer. Through the calculation of angles, described in section 6.1, tilt angles at two points of the spine could be measured. The measured posture from the accelerometer could be assigned to nine posture states, as listed below

1. Sitting straight : from -11.25° to 11.25°
2. Mild slouch forwards : from 11.25° - 34°
3. Mild slouch backwards : from -34° to -11.25°
4. Prominent slouch forwards : from 34° to 56.25°
5. Prominent slouch backwards : from -56.25° to -34°
6. Extreme slouch forwards : from 56.25° to 78.25°
7. Extreme slouch backwards : from -78.25° to -56.25°
8. Flat back forwards : from 78.25° to 90°
9. Flat back backwards : from -90° to -78.25°

The system had a 95.2% accuracy rate. A calibration button was integrated into the prototype so that it was adaptable to any user. The prototype provided visual and haptic feedback that were both considered as constructive, as the usability test described in section 7.5 illustrates. The visual feedback showed the user's posture represented by a flower of two parts that moved according to the accelerometer angles in real-time. The current state of the user was shown on the screen as well as the percentage of the recording time that they had in each state. The haptic feedback recognised three states of forward and backward bending and had different vibration frequencies for each. All "Must Have" requirements listed in section 5.7 were met. 80% of the participants felt that the haptic feedback helped improve their posture and 90% thought that the visual feedback of the states provided insightful information.

This research was unable to establish a generalisable link between diaphragmatic breathing and posture as the individual differences between the participants was too large. Expert interviews and literature concluded that a more rigorous testing procedure was needed to classify the mental and physical state of the participants as these have been proven to have an effect on breathing patterns and should be considered during the test.

9 Recommendations for future work

This chapter presents a list of suggested recommendations if this research is continued.

- Interviews should be conducted in person or by a video call.
  Telephone interviews lack input of non-verbal communication. It is easier to share information and understand feedback in person, especially when the topic is about a physical prototype.

- If a gyroscope is to be implemented in a future posture tracking prototype, MATLAB should be the software choice because of its extensive and complete set of functions that could help to eliminate its drift. A suggested method to do this would be the Kalman Filter [66].

- More user tests should be conducted to find the optimal constructive feedback by using the information listed and found in section 7.5.3.

- Breathing measurements of the RIP band should be backed up by spirometry.
  Spirometry measures the lung expansion rather than the abdominal expansion. By measuring both, a correlation between the two can be researched and the researcher can be certain that they are getting real breathing data, rather than an estimation of it. Moreover, both RIP bands should be used whilst measuring to collect data on both, the chest expansion as well as the abdominal expansion.

- A breathing expert should be present to monitor the subject's correctness of diaphragmatic breathing. Moreover, the participants should have prior training on breathing diaphragmatically to minimise the error when recording.

- Participants should be screened rigorously beforehand for an assessment of their mental and physical state before they are tested for their breathing, as expert reviews and literature have established a link between the two [73] [74].

- To minimise the participant's consciousness of being recorded during the test, the breathing test should be conducted over a longer period of time so that the participants have time to adjust to being recorded and can calmly conduct the test without being nervous.

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Appendix A

Interview Questions

Parviz Sassanian:

What position should your body be in to practice diaphragmatic breathing in full effect? (sitting / lying / standing / walking)

How should your upper body be positioned to practice diaphragmatic breathing? (Shoulder position / head position / back arch / pelvis)

What are common problems with posture that you see are associated with "bad" diaphragmatic breathing?

What positions / changes in posture would you like the Breathline device to detect?

Which characteristics would the target group of the Breathline device have?

Angelika Mader:

What type of sensors would you recommend for tracking changes in body position?

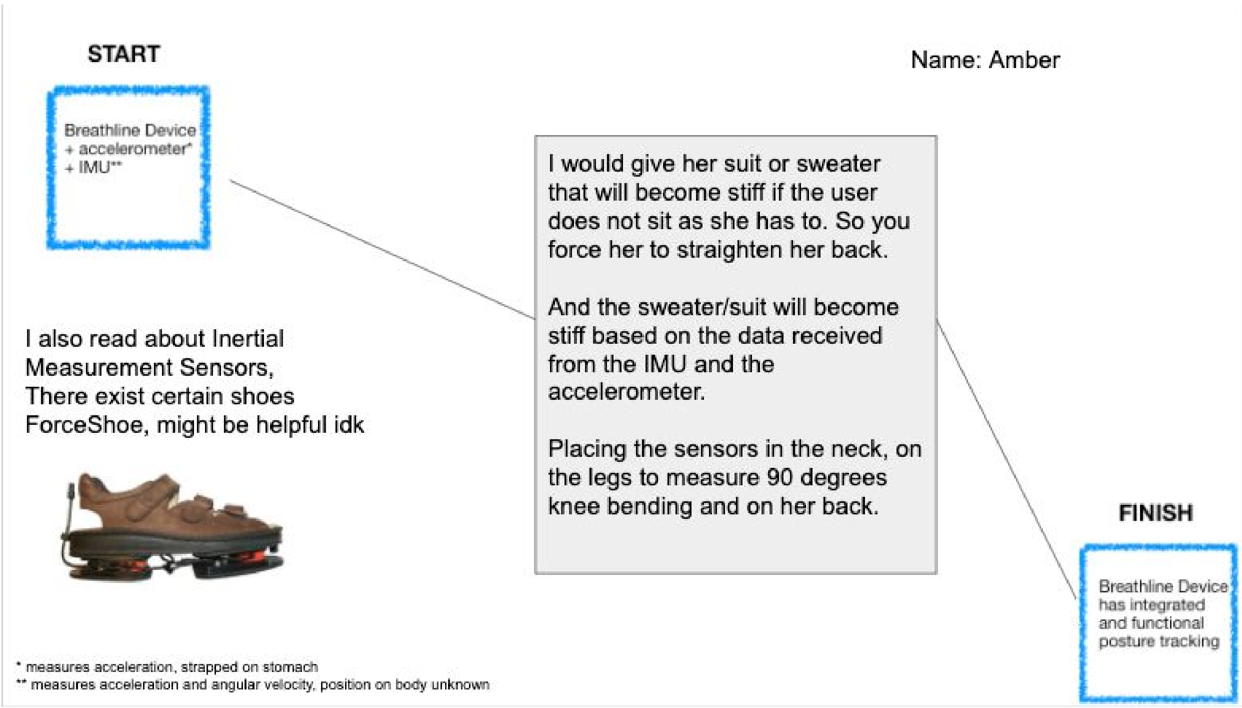
Which classification approach would you use to distinguish between different body positions and why?

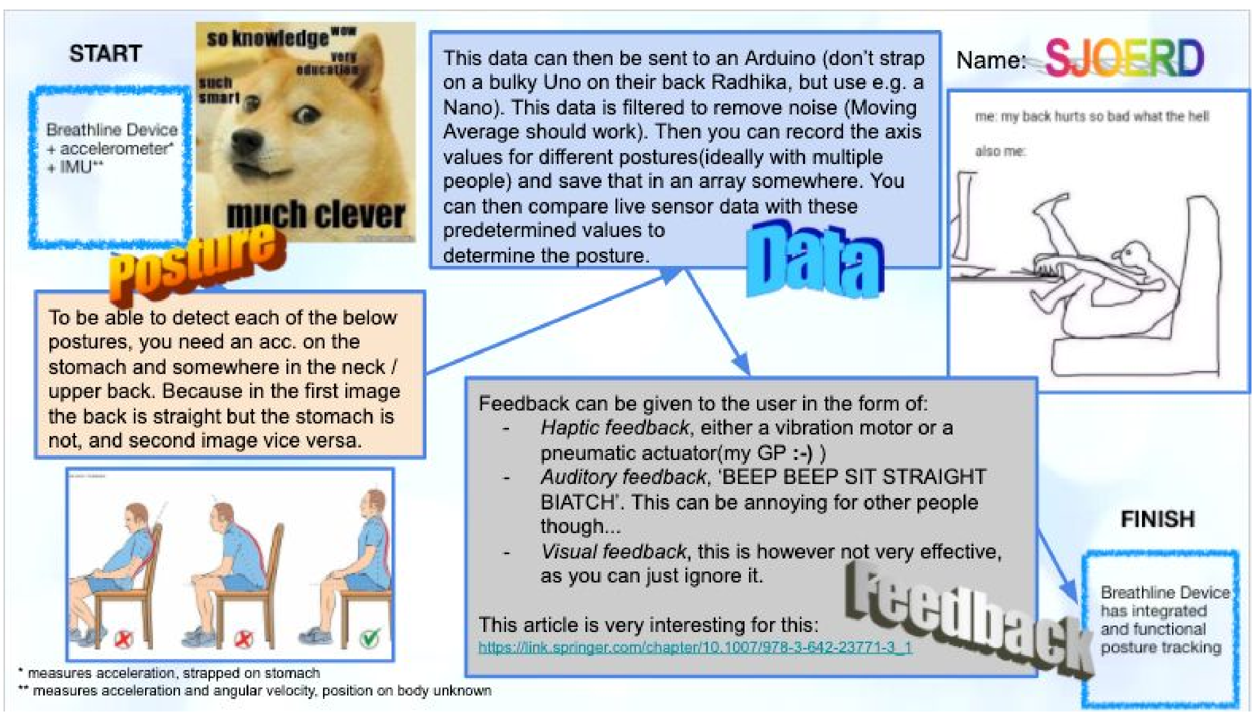
What type of characteristics should a good sensor to track body position have?

You have done work on body position tracking before. How would you approach this problem?

Appendix B

Group Brainstorm Slides





START

Breathline Device
+ accelerometer*
+ IMU**

Name: Elsi

-Vibrations to show if you are not sitting correctly (or electric shocks :))
-Little LEDs on the device itself: green for sitting correctly, yellow for not quite and red for no.
-Use certain parameters that it doesn't count if its not big enough of a difference or something.
-Maybe also make the thing textured so its more difficult to move on the body and less noise.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Breathline Device
+ accelerometer*
+ IMU**

Name: DreadNin

The accelerometer is integrated into a device that can fit into the belly button.
By using the same type of foamy material found in earplugs, it can be squeezed to make a snug fit in that area.

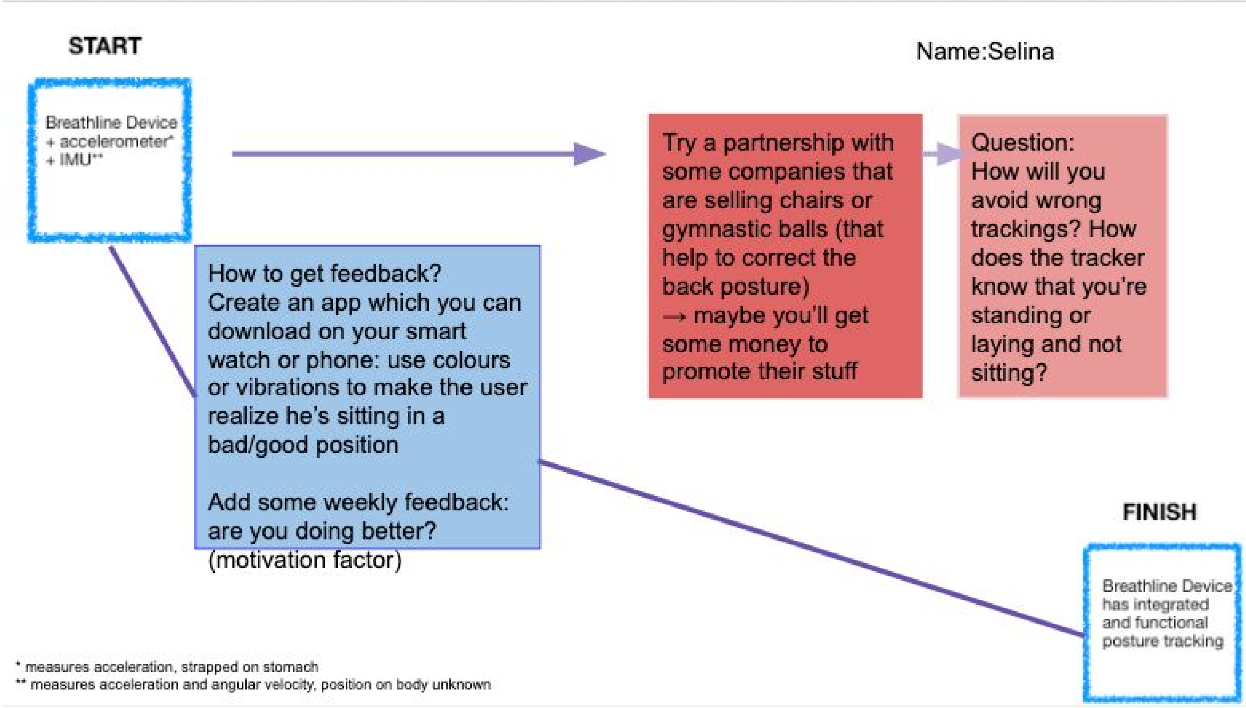
The person wears a belt with the receiver on it. This way the receiver is close enough to not require too much power to find the signal.

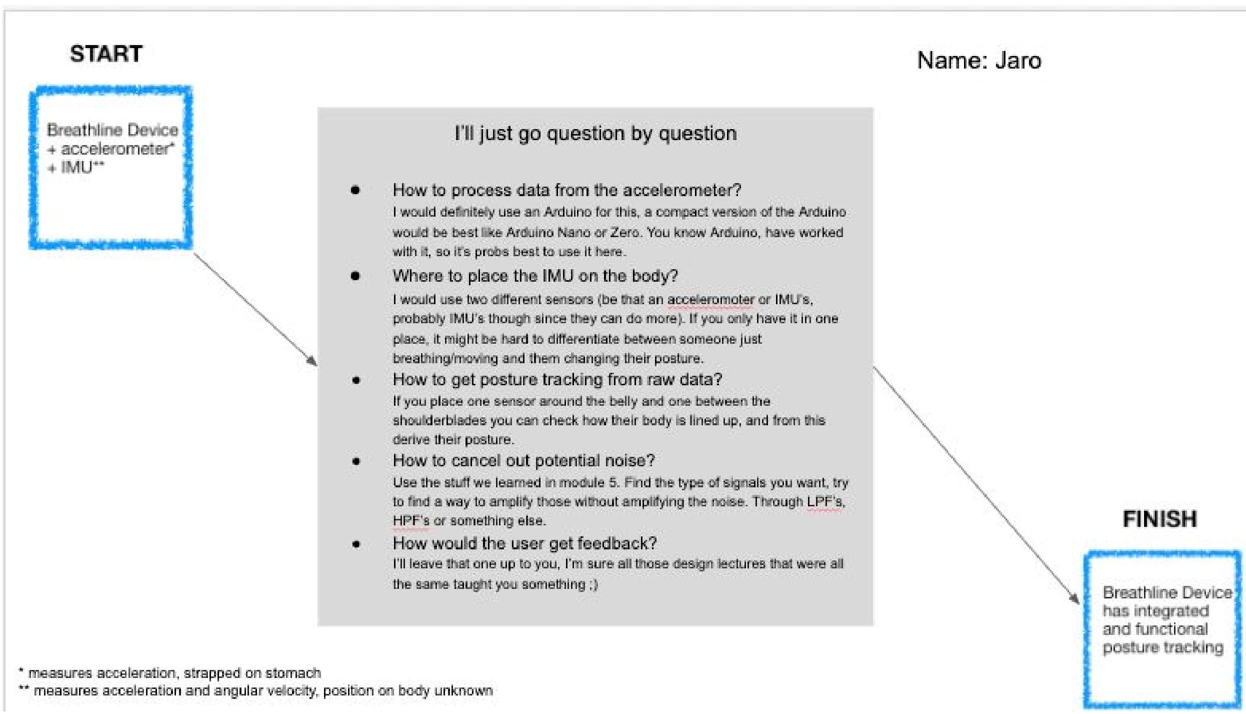
Noise is cancelled by the foamy tip (or exterior), as it is done with earplugs. Now it should be capable of detecting change in position and speed, with data processing with the least amount of "visual" disruption.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown


START
Name:Selina
Breathline Device
+ accelerometer*
+ IMU**
Try a partnership with some companies that are selling chairs or gymnastic balls (that help to correct the back posture)
→ maybe you'll get some money to promote their stuff
Question:
How will you avoid wrong trackings? How does the tracker know that you're standing or laying and not sitting?
How to get feedback?
Create an app which you can download on your smart watch or phone: use colours or vibrations to make the user realize he's sitting in a bad/good position
Add some weekly feedback: are you doing better? (motivation factor)
FINISH
Breathline Device has integrated and functional posture tracking
* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown


START
Name: Jaro
Breathline Device
+ accelerometer*
+ IMU**
I'll just go question by question
How to process data from the accelerometer?
I would definitely use an Arduino for this, a compact version of the Arduino would be best like Arduino Nano or Zero. You know Arduino, have worked with it, so it's probs best to use it here.
Where to place the IMU on the body?
I would use two different sensors (be that an acceleromoter or IMU's, probably IMU's though since they can do more). If you only have it in one place, it might be hard to differentiate between someone just breathing/moving and them changing their posture.
How to get posture tracking from raw data?
If you place one sensor around the belly and one between the shoulderblades you can check how their body is lined up, and from this derive their posture.
How to cancel out potential noise?
Use the stuff we learned in module 5. Find the type of signals you want, try to find a way to amplify those without amplifying the noise. Through LPF's, HPF's or something else.
How would the user get feedback?
I'll leave that one up to you, I'm sure all those design lectures that were all the same taught you something ;)
FINISH
Breathline Device has integrated and functional posture tracking
* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Name: Saskia

Breathline Device
+ accelerometer*
+ IMU**

Stuff to define more explicitly:

- What kind of posture you want to track. Just a straight back or also assymetrical shoulders/ leaning to the side, etc.
- Calibration: how are you going to do that?
- Wat kind of input you get from the breathline thing: is it the elongation? Just the stretch over time? You might also be able to get some additional info from that: breathing rate, but also how deep they breathe, if that changes over time, etc.

How to process data from the accelerometer?
Orientation + angle. Accelerations/velocities to see the change over time

Where to place the IMU on the body?
Depends on what you want to get out of it. Focus on shoulder/spine/lower back

How to get posture tracking from raw data?
Filter data. Don't forget about calibration + drift over time. How to do/standardize this. (You want to get different calibrations for multiple subjects)

How to cancel out potential noise?
Look at the possible sources. For example, electrical interference is at 50 Hz, but other sources might be less static. Magnetic fields (I'm not sure if this is the case, but I don't know other examples by heart) can cause quite some drift. Look at all the possible sources and then decide how to cancel this out.
How would the user get feedback?
You could think about feedback on a wearable device (smartwatch), speakers/vibration. Dependent on the environment in which it is used you'd want a more/less visible cue for the user.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

---

START

Name: Bas

Breathline Device
+ accelerometer*
+ IMU**

Assuming that good sitting posture == straight back, (at least) 2 IMUs can be used, placed close to the spine (to reduce jiggliness).

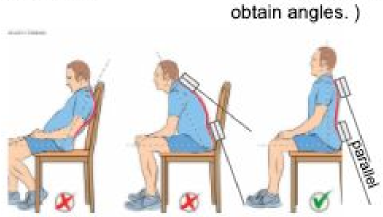
Place IMUs such that one of their axes are parallel when the user sits straight.

(From IMU: integrate angular velocity to obtain angles.)

From breathline: detect if user sits still. Threshold sum of accelerations, probably need to filter in time (moving average/median)

Over some time, calculate average absolute difference between IMU angles. If result > threshold : notify user that he/she should sit straight.

Stop calculating when user moves (to adjust posture), until the user stops moving.



Note 1:
Perhaps breathing rate changes when standing/sitting. Maybe the coils in the breathline device are more stretched when sitting, leading to a different signal height when standing vs sitting. Can be used to identify sitting.

Note 2
If posture tracking needs to do more than "sit-straight" detection, more IMUs can be implemented. E.g. calculate knee angle by comparing upper/lower leg angles to identify sitting vs standing.

Note 3:
This method needs calibration of "straight back" every once in a while, depending on drift of sensors. Also, thresholds (and maybe tolerances) need to be determined

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Name: Thijs

Breathline Device
+ accelerometer*
+ IMU**

- Placement is probably best where the movement is the greatest, so prolly on the chest or on the back at the height of the chest
- Use LEDs for feedback to not disturb too much. Maybe a certain sound?
- Device needs to be not very visible under normal clothing or people will not like it
- Process fully by analog electronics okay jk probably best to use an arduino or a PCB or somehing
- just use multiple sensors combined with complementary filtering is I think the best way to reduce noise/drift but who knows not me

Skabadabado

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

---

START

Name: Arnav M

Breathline Device
+ accelerometer*
+ IMU**

1 To process the data, you would need to be checking for any movement or position change. I believe IMU will be more effective, as with xyz,positions you can also see angular movements. (Key to determine if person is bending or not.

2 As for the placements of these IMU's I believe the best place would be the lower back and shoulder blades region.

3 For Posture tracking. I would focus on the IMU's x direction, and possible orientation. If both IMU's record within the same plane or using the angular velocity, calculate the angle of the 2 devices. If those match you have a straight line → straight back.

4 To cancel out noise, you would need to, average within a certain time frame(I.E. 2 seconds), as well as give a bit of breathing room. Say within a 10cm of each other in any direction.

5 The best way would be through minor shock or vibrations. I think in this you would also need to consider people bending and moving.(So the system on calculates when acceleration is below a certain threshold. This would help when someone is bending or exercising or just readjusting positions.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Name: Tim

Breathline Device
+ accelerometer*
+ IMU**

Positioning of the sensors: Maybe instead of positioning the sensors directly on the user's skin it would be nice to place them instead on the outside of the shirt? This way there is no direct skin contact which reduces potential itching/sweating etc. Don't know if that's possible in the case of this project (or if it's already the plan but considering slide 4 I think rather not?) but since nowadays there are really small acceleration sensors it should be possible to place them without the user even noticing during everyday use which I think would be key in a project of this type.
By placing them on the shirt additional sensors would not be a great disadvantage so i would recommend at least 3 sensors (each shoulder & lower back, considering main pressure points between ones back and the chair back). If one is wearing a "gadget" like this he is interested in a "precise" measurement, not a "part of your back seems to be straight" measurement.

Filtering the data: To eliminate acceleration errors due to movement a large integration/averaging time should be important. Also since the person is sitting, probably for a longer time, you have the time to do so, a fast response is secondary. A low pass filter might be added supposing that the change in "human movement acceleration" should be rather slow compared to typical noise.
Since we don't move while sitting you could try to determine the total amplitude of acceleration. If it's not equal to the gravitational acceleration the measurement is invalid due to the movement of the person and could be rejected.
It seems to me that the angular acceleration is not important since it's value will be 0 while sitting (not moving)
The simplest way to perform calibration might be by adding a button to the smartphone application where the user can start it himself ? Guided by instructions like "Stand in an upright position for the next 5 seconds", since the shape of your back should be similar while standing and sitting correctly.

FINISH

Breathline Device has integrated and functional posture tracking

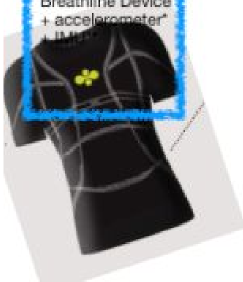
* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

Lol hope it makes sense! Good luck xx

START

Name: ***Stijn***

Breathline Device
+ accelerometer*
+ IMU**



So i havent read any of the others

But it be very cool and makes some sense

If you somehow integrate the sensing with fabric or basics in clothes

Or maybe you dont need emu and gyro, but if you make stretchy shirts, just stretch sensors of such are needed?

If both gyro and imu only sense derivatives, it make little sense to use them? -> you need absolute position would be myguess -> though i believe imu can also generate that.

An approach, that you could take is using a kinect (or other IR-sensor) and a suit with a lot of stipjes to get a clear view of what the most important causes are of pains or breathing stuff due to bad movement

Then you can just place the emu close to there where the big problem is.

And some little live opp on your desktop or even some lcd screen to tell youre doing great!

It just be cool if it is something sporty fit-like to wear. More c motivation

Or even a small screen somewhere in the fabric! Wow dat is wel vet denk ik

FINISH

Breathline Device has integrated and functional posture tracking

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START

Breathline Device
+ accelerometer*
+ IMU**

Name: Gonçalo

- I think there should be at least 2 IMU's (one in the lower back and another one in the neck region).
- Getting the data from the IMU can be done easily with an arduino (small one preferably).
- IMU's have quite a significant drift when stationary. There should be a calibration or some other sensor that can complement. Then use complementary filters (Kalman filters, etc).
- How to get accurate orientation measurements in order to extrapolate the posture? That's the problem I see
- Get posture information every 10 seconds (for example). Add a small wi-fi module of some sort and send the data to a smart watch or something.
- If the posture is not within a certain "range", notify the user through the watch.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Breathline Device
+ accelerometer*
+ IMU**

Name:Chaitali

Physics:
For the posture you need position/location. Your devices are giving you acceleration/velocity. So you need to use kinematic equations to calculate position. The equations can be implemented on an arduino or similar micro-controller.
Calibration: You need to know the initial position to calculate final position after the acceleration. You also need to know the positions of the 'correct posture' to compare with.

Placement of device: Define a set of 'good' and 'bad postures. See what are the main points of difference between them. That is where your devices should be. Eg. Difference between straight back and slump is best visible in the shoulder/back area.

Noise cancellation: A moving average filter should take care of not giving you random signals. You should also calibrate a minimum threshold of change after which the alert will be sent. It will also be a good idea to calculate the time in the bad posture and give an alert only after the bad posture continues for 15-20 seconds.

Feedback: Haptic feedback using a vibrating device like a fitness band should be ideal to alert people without distraction.

FINISH

Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

START

Breathline Device
+ accelerometer*
+ IMU**

How to make use of plethysmography data?

One obvious way of using the data is obtaining the displacement due to breathing-induced volume changes.

Question: is there a (significant) difference in the displacements for good and bad postures? Perhaps the z-component of the accelerometer is higher in case of a bad posture (see figures for reference →).
Think about which directions of the accelerometer data are relevant for the postures you are trying to detect.

1. Signal processing tips for Matlab

```
%remove gravitational acceleration (0 Hz component)
% Create order 2 HPF with cutoff at 0.5 Hz
[B,A] = butter(2, 0.5/(fs/2), 'high') ;
%filtfilt is a causal filter → more effective attenuation and no time delays
acc_filt = filtfilt(B, A, acc);
%integrate to get velocity
vel = cumtrapz(t, acc_filt);
% apply HPF again, since integration yields a constant (+C) an repeat %procedure
until you have the displacement.
```

2. Signal processing tips for Matlab

To see whether noise is present, consider the power spectral densities using a periodogram in matlab. Identify the frequency bands of interest, and filter accordingly.

Do not forget to use window functions (Hann or Hamming) to prevent spectral leakage.

Name: Michael

3. Signal processing tips for Matlab

Once you know which frequency bands to focus on, use Welch's method to create a better approximation of the power spectral densities by choosing your window size accordingly.

Feedback

Haptic would be best I think. Otherwise, users need to focus on external devices such as screens or LEDs.

FINISH

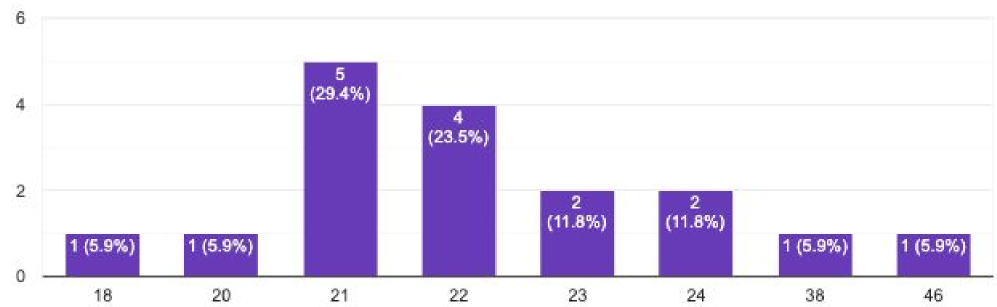
Breathline Device has integrated and functional posture tracking

* measures acceleration, strapped on stomach
** measures acceleration and angular velocity, position on body unknown

Participant Information

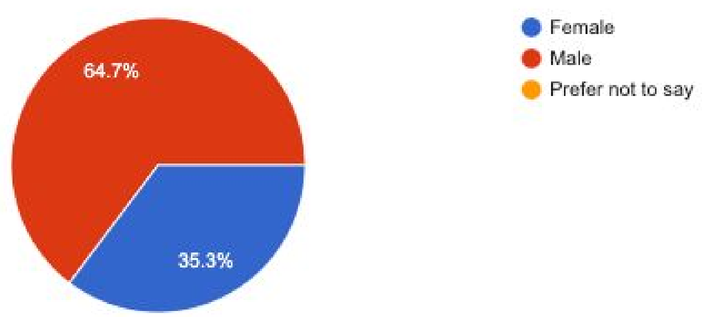
How old are you?

17 responses



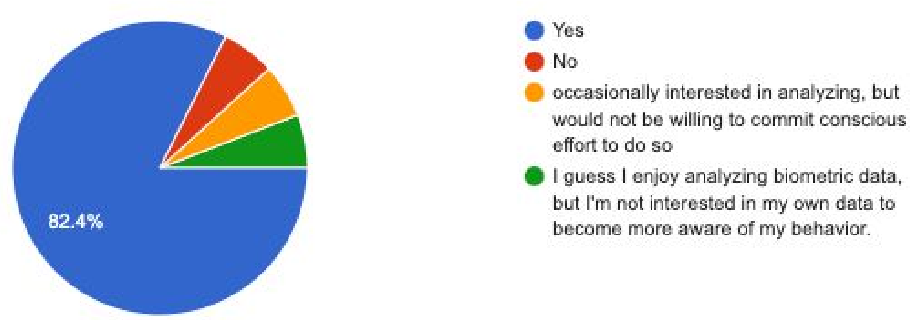
What is your gender?

17 responses



Are you interested in biometric data? (Data that tells you about your body e.g heart rate, breaths per minute etc)

17 responses



Appendix C

Informed Consent Form

May 20, 2020

Informed Consent for GP Enhancing Breathline with Posture Tracking

'I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure 'Enhancing Breathline with Posture Tracking Info Brochure'. My questions have been answered to my satisfaction. I agree with my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Radhika Kapoor.'

If any complaints about this research arise, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

Signed in duplicate:

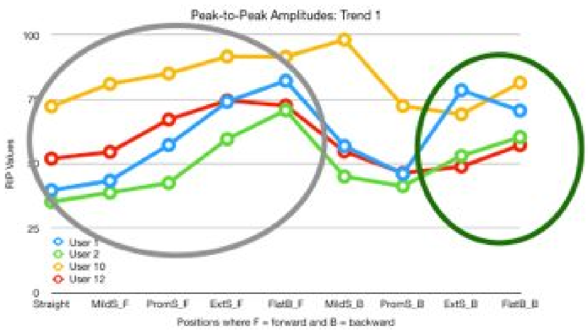
....	....
Name subject	*Signature*

I, Radhika Kapoor, have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.

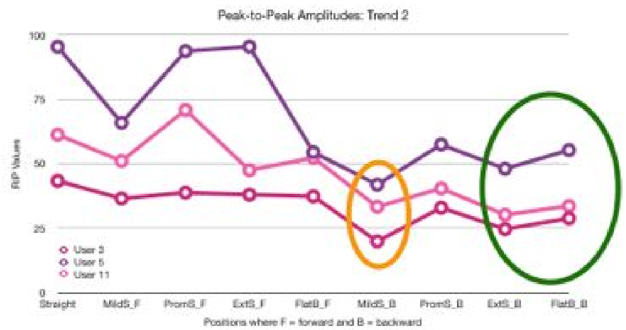
Radhika Kapoor	
....	....
Name researcher	*Signature*

Breathing Data Analysis

Breathing Analysis



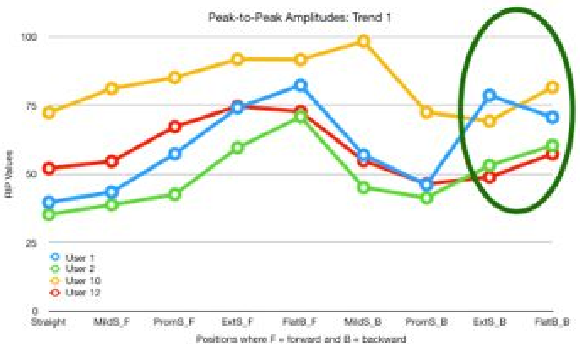
- All participants in Trend 1 show that lying flat on their backs results in higher peak-to-peak amplitudes than sitting in a straight position.
- There is no uniform position where every participant identified in this trend has the highest peak-to-peak amplitude.
- There is no uniform position where every participant identified in this trend has the lowest peak-to-peak amplitude.
- The peak-to-peak amplitudes have a positive slope when bending backwards from an extreme slouch backwards (56.25° - 78.25°) to a flat back backwards (< 78.25°), suggesting deeper breaths in the latter position.
- The peak-to-peak amplitudes have a positive slope when bending from a straight position (-11.25° - 11.25°) to an extreme slouch forwards (56.25° - 78.25°), suggesting deeper breaths.
- These trend lines have unnatural peaks and inconsistencies between each other.

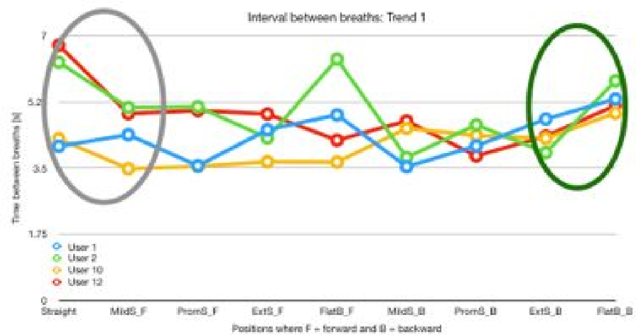


- All participants in Trend 2 show that lying flat on their backs results in lower peak-to-peak amplitudes than sitting in a straight position.
- There is no uniform position where every participant identified in this trend has the highest peak-to-peak amplitude.
- Mild slouch backwards is a uniform worst position when looking at the lowest peak-to-peak amplitudes of the participants of Trend 2. (Is not consistent with the results of the participants of Trend 1)
- The peak-to-peak amplitudes have a positive slope when bending backwards from an extreme slouch backwards (56.25° - 78.25°) to a flat back backwards (< 78.25°), suggesting deeper breaths in the latter position.
- These trend lines have unnatural peaks and inconsistencies between each other.

Despite both trends being very different from each other, they still had some similarities.

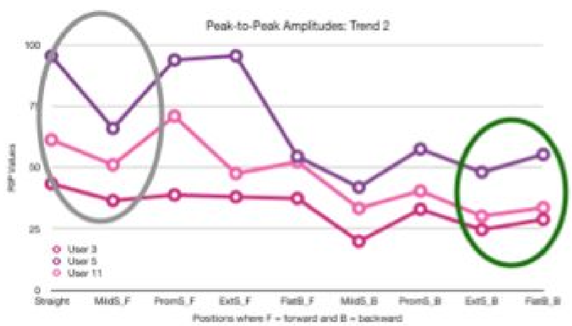
- The participants in both trends have no uniform position with the highest peak-to-peak amplitude.
- The peak-to-peak amplitudes have a positive slope when bending backwards from an extreme slouch backwards (56.25° - 78.25°) to a flat back backwards (< 78.25°), suggesting deeper breaths in the latter position.
- The participants in both trend lines have unnatural peaks and inconsistencies between each other.

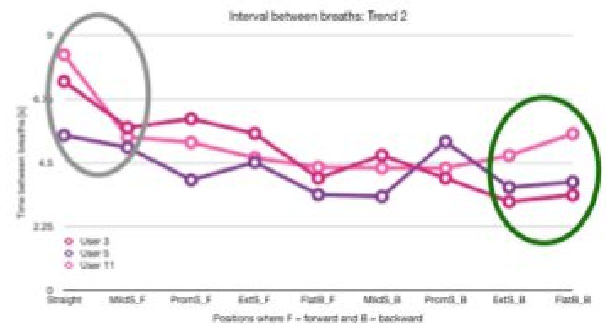




The participants in the Peak-to-Peak Amplitudes in Trend 1 do not have a homogenous trend in their intervals between breaths. It can be seen that for 3/4 participants the interval between their breaths decreases from the straight position (-11.25°-11.25°) to the mild slouch forward position (11.25°-34°), suggesting shallower breathing even though the corresponding peak-to-peak amplitude graph suggests the opposite. However, it should be noted that the scale is quite different between the two graphs as they have different values on the y-axis.

The only feature that connects the interval between breaths to the peak to peak amplitude is the positive slope between the extreme slouch backward position (56.25° - 78.25°) and lying flat backwards (< 78.25°), which indicates longer intervals between breaths suggesting deeper breathing. The peak-to-peak amplitude graph for the Trend 1 participants also suggests this between the same postures. Moreover, the participants in this group have a range of 8.5





For the participants of Trend 2 the features noticed in the Intervals between breaths graph of the participants of Trend 1 can also be seen in the participants of Trend 2. The interval between breaths decreases from the straight position (-11.25°-11.25°) to the mild slouch forward position (11.25°-34°), suggesting shallower breathing at a faster frequency, which correlates to their peak-to-peak amplitude data that also suggests shallower breathing. This correlation was not found with the participants in Trend 1. Moreover, the interval between breaths of the users in Trend 2 has a downward slope, signifying an increase of breaths in each of the positions, making breathing in every position shallower. This occurrence can also be seen in the peak-to-peak amplitudes graph.
The above depicted users have a range from 7.5 - 12 breaths per minute (0.125 - 0.2 Hz) which means that they are in the range of diaphragmatic breathing, suggesting that numerically, these participants are breathing correctly.

Over all test participants, the range of breathing was 6 - 19 breaths per minute (0.1 - 0.316 Hz). Numerically, the highest limit is 158% larger than what diaphragmatic breathing is defined as, suggesting that not every participant was breathing diaphragmatically and therefore, there are significant errors present in this data. Therefore, the suggestion made whilst analysing the peak-to-peak amplitudes that posture has little or no influence on diaphragmatic breathing cannot be true because the dataset has a significant amount of inaccuracy.

To gain more insights on the results of this experiment, a survey was sent out to the participants of this study and an expert review was conducted with the clients of this project .

Breathing Test Questionnaire Results

How did you experience the testing? (Was it difficult, easy, what did you feel?)

8 responses

- It was hard to keep the breathing monotone and not overdo the breathing.
- Getting into the extreme positions was a bit exhausting. The rest was okay
- It was weird, but it made sense
- I feel the definition for slouching was unclear. It could be slouching or tilting
- nothing to say, it was fine, sometimes I was not too sure if I was doing it right
- It was mildly difficult to keep the different slouching positions, especially the backward ones, and still keep breathing diaphragmatically
- Easy, just had to breathe in certain positions
- The testing itself was very straight forward and easy just the setup seemed a bit complicated

Did you feel like after watching the video, you knew how to breathe diaphragmatically? (Belly breathe?)

8 responses

- Yes
- Good explanation
- Yes it helped to remember, but I knew already
- Yes, though since breathing is so natural that during the tests I can't guarantee I kept breathing like that the whole time.
- yes, although I was not sure I was doing it correctly.
- I wasn't very confident that I was doing it correctly but thought I was doing it correct enough
- I already knew how to breath like that from playing the clarinet

In what sort of state would you have described yourself whilst you were being tested? (e.g calm, nervous, anxious, relaxed, frustrated, hungry etc.)

8 responses

Relaxed.

I felt calm

Awkward

At first slightly anxious as it is a 'test'. During the test I became more and more relaxed as I used belly breathing and the breathing position became more relaxed (lying on my back)

calm, happy and a little bit hungry.

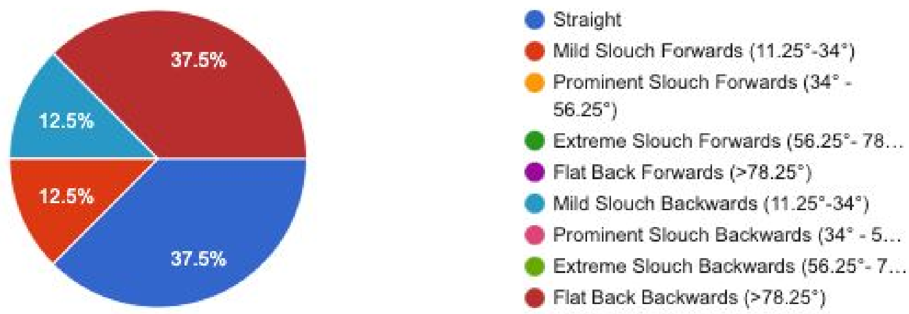
anxious

Calm

Mostly calm and relaxed but at times to focused on my breathing (as if I was gonna die if I don't actively breath)

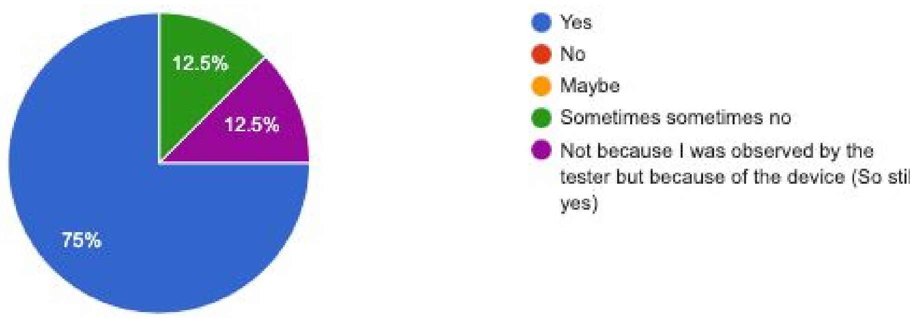
Which position did you feel most comfortable in, whilst breathing?

8 responses



Were you more conscious of your breathing during the test because you were being observed?

8 responses



Why did you feel this position was the most comfortable?

8 responses

Most normal position

Because it's more natural for me to be in this position. In the other positions I had to change my posture. Also, I felt that the change in angles were quite big. I had to slouch quite a lot to get into other positions, maybe decrease the angles a bit.

Its what i do when i want to be comfortable

Bent over forward my legs get in the way. Laying back I tended to use my ribs for breathing quicker

I could properly relax and feel my belly

least amount of stress on my body was when I was lying down

It felt the most relaxed

That is the typical position I sit in

Comments or Remarks

3 responses

Extreme slouch forwards was the worst

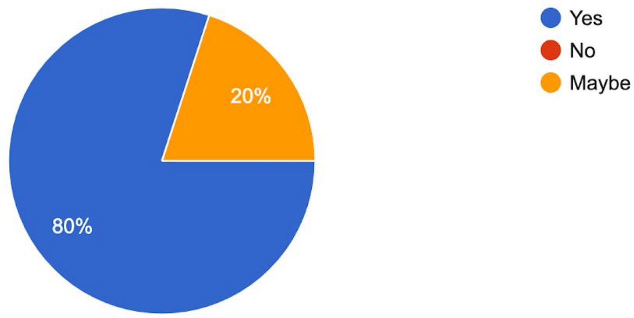
nothing, good luck! your spirit made testing a whole lot more fun :D

Sitting straight and slightly leaning back while in a chair was also comfortable though

Usability Test Questionnaire Results

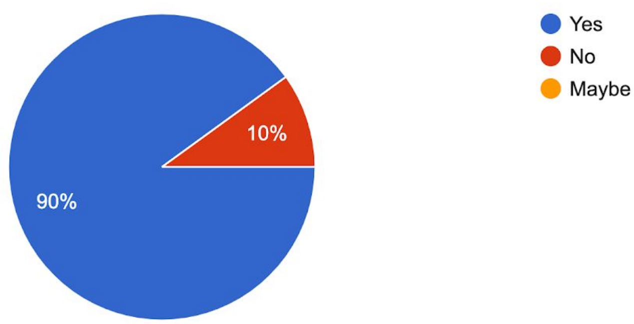
Did the haptic feedback (vibration motors) improve your posture?

10 responses



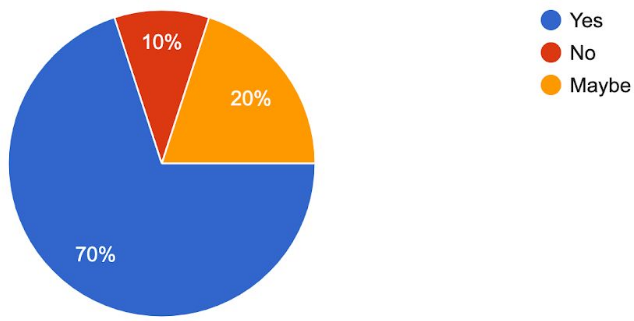
Did the different pulses for different positions make sense?

10 responses



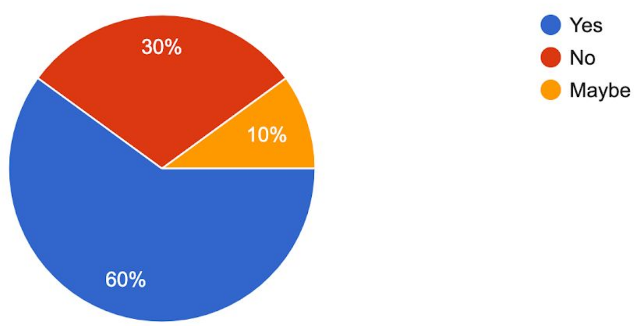
Did you think the strength of the haptic feedback was satisfactory?

10 responses



Was the placement of the vibration motors good?

10 responses



Comments or improvements to the haptic feedback?

10 responses

I would prefer the vibrations on my back

The motors werent attached. I would intuitively move away from the buzzing, so if the upper buzzes i would move backwards.

The difference in pulses for different postures could be a bit more diverse

The haptic feedback works okay, when attached better it would give good feedback. Pressure feedback would perhaps also be interesting for this instead of vibration

I liked the difference between upper and lower vibration, however if it wasnt explained to me that the 'faster' the pulse the more slouched I was I am not sure I would have guessed it myself.

Vibration was very pronounced was changing spontaneously with respect to different positions. More calibration fore completely flat position.

Maybe a slight bit too strong

Maybe a slight bit too strong

haptic feedback too strong - placement was weird

It could possibly be more spread out, instead of concentrated on one point.

the haptic feedback was mildly excessive. Visual indicators on the breath line GUI also did a good job on ensuring proper posture with more immediate feedback

Interface Evaluation

What did you think of the interface? (Visuals)

10 responses

I think the stem of the flower could be in 1 line

Why a plant? but it looked more restful, though a human might make more sense.

I don't get why it shows flowers
Otherwise good

The flower looks really nice, gives a nice zen feel. The bars give good feedback on your position.

the flowers were quite intuitive. Although the side view took me a while to understand what it exactly was representing. The highlighting of the state was also very clear. One thing I didn't understand was the percentages next to the states but I am not sure if that was part of the interface

Looking at the flower bending with respect to the adopted position was nice

Pretty

Nice, intuitive

Very satisfying, simple minimalistic design, and easy to understand.

it looked nice. was simple, easy to understand, but provided sufficient data to make me evaluate my posture

Did the bending flower make sense to you?

10 responses

Yes

especially the way the stem of the flower kinked made good sense. though sideways this kink is less visible due to the leaves

The visualisation of the bending is helpful but why its a flower i don't get

Yes, the flower is very zenny and helps to relax.

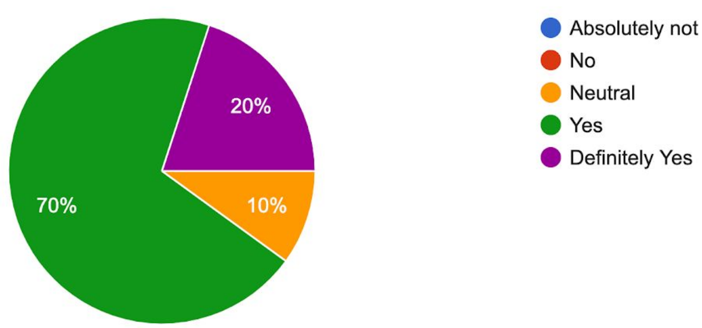
yes, although it took me a while to place myself in the side view. The front view was more intuitive as it felt like a mirror

yes

while the bending made sense, it being a flower did not

Did the different states provide insightful information?

10 responses



In general, what did you think about the entire project?

10 responses

It will help the world be a better place

I think there should be a better distinction between bending forward and slouching. Having a straight back isnt as bad as slouching i think.

I think the project researches a meaningful topic and could find some good data, however the prototype would need to be improved a bit to collect the data more accurately

The project is quite interesting, not sure if I would use it myself, but for some people it could be interesting. It doesn't work perfect yet, but with some improvements, like better/more comfy fitting of the sensors, it would be nice.

It is very interesting to be more aware of breathing and posture in a way that is less dry than just reading numbers off of a sensor. The haptic feedback was very intuitive and action-inducing, more than an audio feedback would have been.

I like it and I think can be helpful to learn how to sit upright because I could notice how difficult it was for me

Interesting, I think it has great potential for improving peoples posture

Interesting, would try the next

Very interesting and insightful

if incorporated in a unobtrusive manner into clothing, could be a good means of reducing injury likelihood during the recovery process

Appendix D

Arduino Code

```
/*Graduation Project: Enhancing Breathline with Posture Tracking
  Radhika Kapoor, s1977040, July 2020, Creative Technology, University of Twente

  This program interfaces 2 MPU6050 and uses the accelerometers in both.
  It gets the raw data, converts them to angles, puts it in a moving average filter,
  defines 9 different posture states, send vibration feedback and then finally sends the data to Processing to visualise.

  Sources of inspiration:

  MPU interfacing:
  - https://howtomechatronics.com/tutorials/arduino/arduino-and-mpu6050-accelerometer-and-gyroscope-tutorial/
  - http://www.geekmomprojects.com/gyroscopes-and-accelerometers-on-a-chip/
*/

#include <Wire.h>
const int MPU1 = 0x68, MPU2 = 0x69; // I2C Addresses for both MPU's. MPU1 = navel, MPU2 = back
long accelX, accelY, accelZ; // raw values accelerometers
float a1_AngX, a1_AngY, a1_AngZ, a1_AngX1; // angles of belly acceleromter
float a2_AngX, a2_AngY, a2_AngZ; // angles of back accelerometer
float a1_AngX_reset, a1_AngY_reset, a1_AngZ_reset; // saves angle when button is pressed for calibration of belly accelerometer
float a2_AngX_reset, a2_AngY_reset, a2_AngZ_reset; // saves angle when button is pressed for calibration of back accelerometer
const int total = 20; // number of readings in buffer array
float avg_a1Z[total], avg_a1Y[total], avg_a1X[total]; // arrays to save number of readings of belly accelerometer
float avg_a2Z[total], avg_a2Y[total], avg_a2X[total]; // arrays to save number of readings of back accelerometer
int index;
float average_Z1, average_Y1, average_X1; // smoothed value of belly accelerometer
float average_Z2, average_Y2, average_X2; // smoothed value of back accelerometer
long sampleTimer;
float perc_count_straight, perc_mildSlouch, perc_count45deg, perc_count60deg, perc_count_lyingdown; // quality factor of states
bool straight, mildS, promS, extS, lyD, mildS_F, mildS_B, mildS_R, mildS_L, promS_F, promS_B, promS_R, promS_L, extS_F, extS_B, extS_R, extS_L; // states

void setup() {
  Wire.begin();
  Serial.begin(115200);
  setupRegisters(); // put certain registers to HIGH to talk to
}

void loop() {
  GetMPUValue(MPU1); // Get values
  GetMPUValue(MPU2); // Get values
  vibFeedback(); // activate haptic feedback
  buttonCalib_2sensors(); // calibrate sensors by pressing button
  movingAverage(); // moving average filter
  userState_2sensors(); // define the state

  // sends values at 8Hz ( same as Breathline )
  if (millis() - sampleTimer > 125) { // 1000 / 8 = 125 ms --> 8Hz
    sampleTimer = millis();
    String msg = "";
    delay(3);
    msg = msg + String(average_Z1) + ',' + String(average_Y1) + ',' + String(average_Z2) + ',' + String(average_Y2) + ',' + String(perc_count_straight) + ','
          + String(perc_mildSlouch) + ',' + String(perc_count45deg) + ',' + String(perc_count60deg) + ',' + String(perc_count_lyingdown) + ',' + String(straight) + ','
          + String(mildS) + ',' + String(promS)  + ',' + String(extS) + ',' + String(lyD);
    Serial.println(msg);
  }
}

```

```
void setupRegisters() {
  //for belly accelerometer
  Wire.beginTransmission(MPU1);
  Wire.write(0x6B);
  Wire.write(0b00000000);
  Wire.endTransmission();
  Wire.beginTransmission(MPU1);
  Wire.write(0x1B);
  Wire.write(0x00000000);
  Wire.endTransmission();
  Wire.beginTransmission(MPU1);
  Wire.write(0x1C);
  Wire.write(0b00000000);
  Wire.endTransmission();

  //for back accelerometer
  Wire.begin();
  Wire.beginTransmission(MPU2);
  Wire.write(0x6B);
  Wire.write(0b00000000);
  Wire.endTransmission();
  Wire.beginTransmission(MPU2);
  Wire.write(0x1B);
  Wire.write(0x00000000);
  Wire.endTransmission();
  Wire.beginTransmission(MPU2);
  Wire.write(0x1C);
  Wire.write(0b00000000);
  Wire.endTransmission();
}

```

```

// Read MPU Values
void GetMPUValue(const int MPU) {
  Wire.beginTransmission(MPU);
  // Get accelerometer values
  Wire.write(0x3B);
  Wire.endTransmission();
  Wire.requestFrom(MPU, 6);
  while (Wire.available() < 6); // read raw accelerometer values
  accelX = Wire.read() << 8 | Wire.read();
  accelY = Wire.read() << 8 | Wire.read();
  accelZ = Wire.read() << 8 | Wire.read();

  // Get angles from belly accelerometer
  if (MPU == 0x68) {
    a1_AngX = (atan(accelX / sqrt(pow(accelY, 2) + pow(accelZ, 2))) * 180 / PI);
    a1_AngY = (atan(accelY / sqrt(pow(accelX, 2) + pow(accelZ, 2))) * 180 / PI);
    a1_AngZ = (atan(accelZ / sqrt(pow(accelY, 2) + pow(accelX, 2))) * 180 / PI);
  }
// Get angles from back accelerometer
  if (MPU == 0x69) {
    a2_AngX = (atan(accelX / sqrt(pow(accelY, 2) + pow(accelZ, 2))) * 180 / PI);
    a2_AngY = (atan(-1 * accelY / sqrt(pow(accelX, 2) + pow(accelZ, 2))) * 180 / PI);
    a2_AngZ = (atan(accelZ / sqrt(pow(accelY, 2) + pow(accelX, 2))) * 180 / PI);
  }
}
```

```

void userState_2sensors() {
  // all states start at 0
  static float count_straight = 0;
  static float count_mildSlouch = 0;
  static float count_45deg = 0;
  static float count_60deg = 0;
  static float count_lyingdown = 0;
  static float totalactivity = 0;

  // STRAIGHT
  if ((average_Z1 > -11.25 && average_Z1 < 11.25) || (average_Z2 < 11.25 && average_Z2 > - 11.25)) {
    count_straight = count_straight + 1;
    straight = true;
    mildS = false;
    promS = false;
    extS = false;
    lyD = false;
    mildS_F = false;
    mildS_B = false;
    promS_F = false;
    promS_B = false;
    extS_F = false;
    extS_B = false;
  }

  // MILD SLOUCH FORWARD
  else if ((average_Z1 < - 11.25 && average_Z1 > -34.00)  || (average_Z2 > 11.25 && average_Z2 < 34.00)) {
    count_mildSlouch = count_mildSlouch + 1;
    straight = false;
    mildS = true;
    promS = false;
    extS = false;
    lyD = false;
    mildS_F = true;
    mildS_B = false;
    promS_F = false;
    promS_B = false;
    extS_F = false;
    extS_B = false;
  }

  // MILD SLOUCH BACKWARD
  else if ((average_Z2 < - 11.25 && average_Z2 > -34.00)  || (average_Z1 > 11.25 && average_Z1 < 34.00)) {
    count_mildSlouch = count_mildSlouch + 1;
    straight = false;
    mildS = true;
    promS = false;
    extS = false;
    lyD = false;
    mildS_F = false;
    mildS_B = true;
    promS_F = false;
    promS_B = false;
    extS_F = false;
    extS_B = false;
  }
```

```
  -

  //PROM SLOUCH FORWARD
  else if ((average_Z1 < -34.00 && average_Z1 > -56.25) || (average_Z2 > 34.00 && average_Z2 < 56.25 )) {
    count_45deg = count_45deg + 1;
    straight = false;
    mildS = false;
    promS = true;
    extS = false;
    lyD = false;
    mildS_F = false;
    mildS_B = false;
    promS_F = true;
    promS_B = false;
    extS_F = false;
    extS_B = false;
  }

```

```
 // PROM SLOUCH BACKWARD
 else if ((average_Z2 < - 34.00 && average_Z2 > -56.25)  || (average_Z1 > 34.00 && average_Z1 < 56.25)) {
   count_45deg = count_45deg + 1;
   straight = false;
   mildS = false;
   promS = true;
   extS = false;
   lyD = false;
   mildS_F = false;
   mildS_B = false;
   promS_F = false;
   promS_B = true;
   extS_F = false;
   extS_B = false;
 }

 // EXT SLOUCH FORWARD
 else if ((average_Z1 < -56.25 && average_Z1 > -78.25) || (average_Z2 > 56.25 && average_Z2 < 78.25 )) {
   count_60deg = count_60deg + 1;
   straight = false;
   mildS = false;
   promS = false;
   extS = true;
   lyD = false;
   mildS_F = false;
   mildS_B = false;
   promS_F = false;
   promS_B = false;
   extS_F = true;
   extS_B = false;
 }

 // EXT SLOUCH BACKWARDS
 else if ((average_Z2 < -56.25 && average_Z2 > -78.25) || (average_Z1 > 56.25 && average_Z1 < 78.25 )) {
   count_60deg = count_60deg + 1;
   straight = false;
   mildS = false;
   promS = false;
   extS = true;
   lyD = false;
   mildS_F = false;
   mildS_B = false;
   promS_F = false;
   promS_B = false;
   extS_F = false;
   extS_B = true;
 }

// LYING DOWN FORWARD
 else if ((average_Z1 < - 78.25) && (average_Z2 > 78.25)) {
   count_lyingdown = count_lyingdown + 1;
   straight = false;
   mildS = false;
   promS = false;
   extS = false;
   lyD = true;
   mildS_F = false;
   mildS_B = false;
   promS_F = false;
   promS_B = false;
   extS_F = false;
   extS_B = false;
 }

// LYING DOWN BACKWARD
 else if ((average_Z1 > 78.25) && (average_Z2 < -78.25)) {
   count_lyingdown = count_lyingdown + 1;
   straight = false;
   mildS = false;
   promS = false;
   extS = false;
   lyD = true;
   mildS_F = false;
   mildS_B = false;
   promS_F = false;
   promS_B = false;
   extS_F = false;
   extS_B = false;
 }

// Calculation of the quality factor
// Divides each state by the total
 totalactivity = count_straight + count_mildSlouch + count_45deg + count_60deg + count_lyingdown;
 perc_count_straight = count_straight / totalactivity;
 perc_mildSlouch = count_mildSlouch / totalactivity;
 perc_count45deg = count_45deg / totalactivity;
 perc_count60deg = count_60deg / totalactivity;
 perc_count_lyingdown = count_lyingdown / totalactivity;
}
```

```
// Calibration for both sensors
void buttonCalib_2sensors() {
  static const int buttonPin = 13;
  if (digitalRead(buttonPin)) {
    / / if you press the button

    a1_AngX_reset = a1_AngX;
  a1_AngY_reset = a1_AngY;
  a1_AngZ_reset = a1_AngZ;

  a2_AngX_reset = a2_AngX;
  a2_AngY_reset = a2_AngY;
  a2_AngZ_reset = a2_AngZ;
}
}

void vibFeedback() {
  static bool feedT, feedB; // initalisation motor names
  static bool mildS_track = false; //tracks whether acc. values are in mildS state
  static bool mildS_pulse; // send power
  static float mildS_pulse_start, mildS_pulse_stop; // variables for timer tracking
  static float mildS_time_high = 0.5; // time to set motor high
  static float mildS_time_low = 2.5; // time to switch motor off
  static int feed_int;

  // same logic as above
  static bool promS_track = false;
  static bool promS_pulse;
  static float promS_pulse_start, promS_pulse_stop;
  static float promS_time_high = 0.5;
  static float promS_time_low = 1.5;

  static bool extS_track = false;
  static bool extS_pulse;
  static float extS_pulse_start, extS_pulse_stop;
  static float extS_time_high = 1;
  static float extS_time_low = 0.5;


  if (straight || lyD) { // if straight or lying down
    feedT = 0; // do not vibrate
    feedB = 0; // do not vibrate
  }

  // MILD BENDING FORWARD
  if (mildS_F) { // if in this state
    if (mildS_track == false) { // initial condition
      mildS_track = true; // set to true
      mildS_pulse = true; // set to true
      feedB = true; // power bottom motor
      mildS_pulse_start = millis() / 1000; // start counting
    }
    else {
      if (mildS_pulse == true) {
        if (millis() / 1000 - mildS_pulse_start > mildS_time_high) { // if motor vibrates more more than 0.5s
          feedB = false; // stop
          mildS_pulse = false; // stop
          mildS_pulse_stop = millis() / 1000; // start counting how much stopped for
        }
      }
      if (mildS_pulse == false) { // if not vibrating
        if (millis() / 1000 - mildS_pulse_stop > mildS_time_low) { // and the time for stopping is breached
          feedB = true; // vibrate again
          mildS_pulse = true; // vibrate
          mildS_pulse_start = millis() / 1000; // start counting for how long
        }
      }
    }
  }
  // ensure that this happens only in this state
  if (!(mildS_F || mildS_B)) { // if one of the two or both is not true
    if (mildS_track == true) { // set mildS to true
      mildS_track = false; // and definitely set to false to get out of state
    }
  }
```

```
// MILD BENDING BACKWARD
// same logic as mildS_F
if (mildS_B) {
  if (mildS_track == false) {
    mildS_track = true;
    mildS_pulse = true;
    feedT = true;
    mildS_pulse_start = millis() / 1000;
  }
  else {
    if (mildS_pulse == true) {
      if (millis() / 1000 - mildS_pulse_start > mildS_time_high) {
        feedT = false;
        mildS_pulse = false;
        mildS_pulse_stop = millis() / 1000;
      }
    }
    if (mildS_pulse == false) {
      if (millis() / 1000 - mildS_pulse_stop > mildS_time_low) {
        feedT = true;
        mildS_pulse = true;
        mildS_pulse_start = millis() / 1000;
      }
    }
  }
}
if (!(mildS_F || mildS_B)) {
  if (mildS_track == true) {
    mildS_track = false;
  }
}
// PROMINENT BENDING FORWARD
// same logic as mildS_F
if (promS_F) {
  if (promS_track == false) {
    promS_track = true;
```

```
    promS_pulse = true;
    feedB = true;
    promS_pulse_start = millis() / 1000;

  }
  if (promS_track == true) {
    if (promS_pulse == true) {
      if (millis() / 1000 - promS_pulse_start > promS_time_high) {
        feedB = false;
        promS_pulse = false;
        promS_pulse_stop = millis() / 1000;
      }
    }

    if (promS_pulse == false) {
      if (millis() / 1000 - promS_pulse_stop > promS_time_low) {
        feedB = true;
        promS_pulse = true;
        promS_pulse_start = millis() / 1000;
      }
    }
  }
}
if (!(promS_F || promS_B)) {
  if (promS_track == true) {
    promS_track = false;
    promS_pulse = false;
  }
}

// PROMINENT BENDING BACKWARD
// same logic as mildS_F
if (promS_B) {
  if (promS_track == false) {
    promS_track = true;
    promS_pulse = true;
    feedT = true;
    promS_pulse_start = millis() / 1000;
  }
```

```
      promS_pulse_start = millis() / 1000;
    }
    if (promS_track == true) {
      if (promS_pulse == true) {
        if (millis() / 1000 - promS_pulse_start > promS_time_high) {
          feedT = false;
          promS_pulse = false;
          promS_pulse_stop = millis() / 1000;
        }
      }
      if (promS_pulse == false) {
        if (millis() / 1000 - promS_pulse_stop > promS_time_low) {
          feedT = true;
          promS_pulse = true;
          promS_pulse_start = millis() / 1000;
        }
      }
    }
  }
  if (!(promS_F || promS_B)) {
    if (promS_track == true) {
      promS_track = false;
      promS_pulse = false;
    }
  }

  // EXTREME BEND FORWARD
  // same logic as mildS_F
  if (extS_F) {
    if (extS_track == false) {
      extS_track = true;
      extS_pulse = true;
      feedB = true;
      extS_pulse_start = millis() / 1000;
    }
    else {
      if (extS_pulse == true) {
        if (millis() / 1000 - extS_pulse_start > extS_time_high) {
          feedB = false;
          extS_pulse = false;
          extS_pulse_stop = millis() / 1000;
        }
      }
      if (extS_pulse == false) {
        if (millis() / 1000 - extS_pulse_stop > extS_time_low) {
          feedB = true;
          extS_pulse = true;
          extS_pulse_start = millis() / 1000;
        }
      }
    }
  }
  if (!(extS_F || extS_B)) {
    if (extS_track == true) {
      extS_track = false;
    }
  }
```

```
  }

  // EXTREME BEND BACKWARDS
  // same logic as mildS_F
  if (extS_B) {
    if (extS_track == false) {
      extS_track = true;
      extS_pulse = true;
      feedT = true;
      extS_pulse_start = millis() / 1000;
    }
    else {
      if (extS_pulse == true) {
        if (millis() / 1000 - extS_pulse_start > extS_time_high) {
          feedT = false;
          extS_pulse = false;
          extS_pulse_stop = millis() / 1000;
        }
      }
      if (extS_pulse == false) {
        if (millis() / 1000 - extS_pulse_stop > extS_time_low) {
          feedT = true;
          extS_pulse = true;
          extS_pulse_start = millis() / 1000;
        }
      }
    }
  }
  if (!(extS_F || extS_B)) {
    if (extS_track == true) {
      extS_track = false;
    }
  }

  if (feedB == true) {
    analogWrite(6, 153); // switch bottom motor on at 3V
  }
  if (feedB == false) {
    analogWrite(6, 0); // switch motor off
  }

  if (feedT == true) {
    analogWrite(9, 153); // switch top motor on at 3V
  }
  if (feedT == false) {
    analogWrite(9, 0); // switch motor off
  }
}

// smoothes signal out
void movingAverage() {
  avg_a1Z[index++] = a1_AngZ - a1_AngZ_reset; // save calibrated values of belly accelerometer in array
  if (index >= total) { // once 20 readings are reached
    index = 0; // start again
  }
  average_Z1 = 0;
  for (int i = 0; i < total; i++) { // iterate through 20 readings
    average_Z1 +=  avg_a1Z[i]; // add them up
  }
  average_Z1 /= total * 1.00; // divide by 20 and *1.00 to ensure output is a float

  avg_a2Z[index] = a2_AngZ - a2_AngZ_reset; // save calibrated values of back accelerometer in array
  average_Z2 = 0;
  for (int i = 0; i < total; i++) { // iterate through 20 readings
    average_Z2 +=  avg_a2Z[i]; // add them up
  }
  average_Z2 /= total * 1.00; // divide by 20 and *1.00 to ensure output is a float
  //---------------------------------------------------
  avg_a1Y[index] = a1_AngY - a1_AngY_reset; // same logic as for Z axis readings
  average_Y1 = 0;
  for (int i = 0; i < total; i++) {
    average_Y1 +=  avg_a1Y[i];
  }
  average_Y1 /= total * 1.00;

  avg_a2Y[index] = a2_AngY - a2_AngY_reset;
```

```
  avg_a2Y[index] = a2_AngY - a2_AngY_reset;

  average_Y2 = 0;
  for (int i = 0; i < total; i++) {
    average_Y2 +=  avg_a2Y[i];
  }
  average_Y2 /= total * 1.00;
  //----------------------------------------------------
  avg_a1X[index] = a1_AngX - a1_AngX_reset; // same logic as for Z axis readings
  average_X1 = 0;
  for (int i = 0; i < total; i++) {
    average_X1 +=  avg_a1X[i];
  }
  average_X1 /= total * 1.00;

  avg_a2X[index] = a2_AngX - a2_AngX_reset;

  average_X2 = 0;
  for (int i = 0; i < total; i++) {
    average_X2 +=  avg_a2X[i];
  }
  average_X2 /= total * 1.00;
  //----------------------------------------------------
}
```

Processing Code

```
/*
Graduation Project: Enhancing Breathline with Posture Tracking
 Radhika Kapoor, s1977040, July 2020, Creative Technology, University of Twente

 This program takes input data from the Arduino program and visualises it in a flower moving in 3D.
 Furthermore, it writes all data to an .csv file for later analysis.

 Sources of inspiration:
 Flower: https://discourse.processing.org/t/drawing-a-flower/3919
 Button: https://processing.org/examples/button.html

 */
import processing.serial.*; // use library
Serial port; // initialise serial port for communication
float angleX1, angleY1;  //Accelerometer data 1
float angleX2, angleY2; //Accelerometer data 2
float straightBack, mildSlouch, prominentSlouch, extremeSlouch, flatBack; // quality factor percentages
float str, mS, pS, eS, fB; // states
String  inString; // string from Arduino
String myString = null;
float LENS = 2;
float RATE = 8;
float k = RATE / LENS;
float w = 100; // positions of everything on screen
float h = 50; // positions of everything on screen
float add = 60; // positions of everything on screen
boolean firstLine = true;
String read = "";
Table table; // initialise table
float time = millis();  // timer
PImage img; // Breathline logo
int rectX1, rectY1, rectX2, rectY2, rectSize; // Position of buttons
color rectColor1, rectColor2, rectHighlight; // colours of buttons
boolean rectOver1 = false;
boolean rectOver2 = false;
boolean pressed = false;
long sampleTimer; // for 8Hz

void setup() {
  port = new Serial(this, "/dev/cu.wchusbserial1420", 115200); // define port
  fullScreen(P3D); // size
  // button variables
  rectColor1 = color(0, 255, 0);
  rectColor2 = color(255, 0, 0);
  rectHighlight = color(255);
  rectSize = 30;
  rectX1 = width/4*3+100;
  rectY1 = height/6-40;
  rectX2 = rectX1+100;
  rectY2 = rectY1;

  // Table initialisation
  table = new Table();
  table.addColumn("Time");
  table.addColumn("AngleX1");
  table.addColumn("AngleX2");
  table.addColumn("AngleY1");
  table.addColumn("AngleY2");
  table.addColumn("str");
  table.addColumn("mS");
  table.addColumn("pS");
  table.addColumn("eS");
  table.addColumn("fB");
  img = loadImage("logo.png");
}

```

```
void draw() {
  serialEvent();
  background(0);
  update(mouseX, mouseY);
  drawButton();
  int s = second(); // for clock
  int m = minute();
  int hr = hour();
  image(img, width-130, height-160); // logo
  img.resize(150, 0); //make logo fit
  // ----------------------------------------------------  title, start and stop text positions
  fill(255);
  textSize(30);
  text("Posture Tracking", width/2-100, height/2-300);
  textSize(15);
  pushMatrix();
  translate((width/4)*3, height/6);
  text("Start ", 100, -h);
  translate((width/4)*3+(2*w), height/6);
  text("Stop", 0, -h);
  popMatrix();
  // ---------------------------------------- Real Time Clock
  pushMatrix();
  translate(0, height/6, -0.25);
  text("Time [s]: ", w/10, -w/10);
  text(s, w+40, -w/10);
  text(":", w+34, -w/10);
```

```
  vertex(0, h/2+(2*add), 0);
  vertex(prominentSlouch*220, h/2+(2*add), 0);
  vertex( prominentSlouch*220, 2*add, 0);
  vertex(0, 2*add, 0);
  endShape(CLOSE);
  // ----------------------------------------------------------------- 67.5° Extreme Slouch
  beginShape();
  if (eS == 1) { // same logic as straight state
    fill(0, 255, 0);
  } else {
    fill(255);
  }
  text("Extreme Slouch:", w/10, -w/10 + 3*add);
  text(extremeSlouch*100, w+50, -w/10 + 3*add);
  text("%", w+110, -w/10 + 3*add);
  vertex(0, h/2+(3*add), 0);
  vertex( extremeSlouch*220, h/2+(3*add), 0);
  vertex( extremeSlouch*220, 3*add, 0);
  vertex(0, 3*add, 0);
  endShape(CLOSE);
  // ----------------------------------------------------------------- 90° Flat Back
  beginShape();
  if (fB == 1) { // same logic as straight state
    fill(0, 255, 0);
  } else {
    fill(255);
  }
  text("Flat Back:", w/10, -w/10 + 4*add);
  text(flatBack*100, w+50, -w/10 + 4*add);
  text("%", w+110, -w/10 + 4*add);
  vertex(0, h/2+(4*add), 0);
  vertex(flatBack*220, h/2+(4*add), 0);
  vertex(flatBack*220, 4*add, 0);
  vertex(0, 4*add, 0);
  endShape(CLOSE);
  popMatrix();
```

```
  popMatrix();
  // ----------------------------------------------------------------- Flower Front Side
  pushMatrix();
  fill(255);
  translate(width/3+100, height/2+250); // position of flower
  text("Front View", -35, 50);
  rotateX(radians(angleX1)); //BOTTOM STEM moves with belly accelerometer values
  rotateZ(radians((-angleY1))); //BOTTOM STEM moves with belly accelerometer values
  stroke(#00CE49);
  line (0, 0, -16, 0, -100, -16);
  translate(0, -100);
```

```
  rotateX(radians(-angleX2)); //TOP STEM moves with back accelerometer values
  rotateZ(radians((angleY2))); // TOP STEM moves with back accelerometer values
  line(0, 0, -16, 0, -100, -16);
  translate(0, -100, 10);
  drawRose(); //draw head
  popMatrix();

  // ----------------------------------------------------------------- Flower Side Side
  pushMatrix();
  translate(width/3*2+100, height/2+250); // position of flower
  text("Side View", -35, 50);
  rotateX(radians(angleX1)); //BOTTOM STEM moves with belly accelerometer values
  rotateZ(radians((angleY1))); //BOTTOM STEM moves with belly accelerometer values
  stroke(#00CE49);
  line (0, 0, -16, 0, -100, -16);
  translate(0, -100);
  rotateY(45);
  rotateX(radians(-angleX2)); //TOP STEM moves with back accelerometer values
  rotateZ(radians((-angleY2))); //TOP STEM moves with back accelerometer values
  line(0, 0, -16, 0, -100, -16);
  translate(0, -100, 10);
  drawRose();
  popMatrix();

  if (pressed) { // if start is pressed start table
    if (millis() - sampleTimer > 125) { // 1000 / 8 = 125 ms --> 8Hz
      sampleTimer = millis();
      TableRow newRow = table.addRow();
      newRow.setString("Time", nf(hour(), 2, 0)+":"+nf(minute(), 2, 0)+":"+nf(second(), 2, 0));
      newRow.setFloat("AngleX1", angleX1);
      newRow.setFloat("AngleX2", angleX2);
      newRow.setFloat("AngleY1", angleY1);
      newRow.setFloat("AngleY2", angleY2);
      newRow.setFloat("str", str);
      newRow.setFloat("mS", mS);
      newRow.setFloat("pS", pS);
      newRow.setFloat("eS", eS);
      newRow.setFloat("fB", fB);
      print("recording");
    }
  }
}
```

```

// draws flower
void drawRose() {
  beginShape();
  stroke(#F011B8);
  fill(200);
  for (float t = 0; t < TWO_PI * LENS; t += 0.02) {
    float r = 75 * cos(k * t);
    float x = r * cos(t);
    float y = r * sin(t);
    vertex(x, y, -20);
  }
  endShape(CLOSE);
}
```

```
// draws start and stop button
void drawButton() {
  if (rectOver1) {
    fill(rectHighlight);
  } else {
    fill(rectColor1);
  }
  stroke(255);
  rect(rectX1, rectY1, rectSize, rectSize);
 if (rectOver2) {
    fill(rectHighlight);
  } else {
    fill(rectColor2);
  }
  stroke(255);
  rect(rectX2, rectY2, rectSize, rectSize);
}

// recognises which button the mouse is over
void update(int x, int y) {
  if (overRect(rectX1, rectY1, rectSize, rectSize) ) {
    rectOver1 = true;
    rectOver2 = false;
  } else if (overRect(rectX2, rectY2, rectSize, rectSize) ) {
    rectOver2 = true;
    rectOver1 = false;
  } else {
    rectOver1 = rectOver2 = false;
  }
}
```

```
// recognises whether mouse is over button
boolean overRect(int x, int y, int width, int height) {
  if (mouseX >= x && mouseX <= x+width &&
    mouseY >= y && mouseY <= y+height) {
    return true;
  } else {
    return false;
  }
}

void serialEvent() {
  int incomingData = 0;
  while (port.available() > 0) { // when Arduino is sending values
    incomingData = port.read();  // save them in incomingData
    if (char(incomingData) != '\n') {
      if (!firstLine) {
        read += char(incomingData);
      }
    } else if (!firstLine) {
   String [] split = split(read, ','); // split the incoming string by comma
      float [] data = new float[split.length]; // save in array called data
      for (int i = 0; i <data.length; i++) { // go through array
       data[i] = Float.parseFloat(split[i]); // converts string to float
      }
```

```
      // save incoming values to these variables
      angleX1 = data[0];
      angleY1= data [1];
      angleX2 = data[2];
      angleY2= data [3];
      straightBack = data[4];
      mildSlouch = data[5];
      prominentSlouch = data[6];
      extremeSlouch = data[7];
      flatBack = data[8];
      str = data[9];
      mS = data[10];
      pS = data[11];
      eS = data[12];
      fB = data[13];
      read = "";
    } else {
      firstLine = false;
    }
  }
}
```

```
void mousePressed() {
  if (rectOver1) { // if start is pressed
    pressed = true; // save start is pressed
  }

  if (rectOver2) { // if stop is pressed
    saveTable(table, "data/accuracy1.csv"); // save .csv file with this name
    pressed = false;
    print("Save");
  }
}
```

MATLAB Code

```
clear all
close all
clc
%% Read in the data file
excelsheet = 1; % define which sheet
M = xlsread('cleanUserData_xlsx.xlsx', excelsheet);
t = M(:,1);
for i = 1:9
%% Local extrema extraction & plotting
peakprom = 15; %minimal peak prominence
mindist = 10; %minimal peak distance
[peaks_max, samp_max] = findpeaks(M(:,i+1), 'MinPeakProminence', peakprom, 'MinPeakDistance', mindist);
[peaks_min, samp_min] = findpeaks(-M(:,i+1), 'MinPeakProminence', peakprom, 'MinPeakDistance', mindist);

%Plot Graphs
figure(i);
plot(t,M(:,i+1)-mean(M(:,i+1)));
hold on;
plot(t(samp_max),peaks_max-mean(M(:,i+1)),'o'); % maxima x,y
plot(t(samp_min),-peaks_min-mean(M(:,i+1)),'x');% minima
ylabel('RIP Values')
xlabel('Time [s]')
title('Peak to Peak User 1')
legend('Data','Maxima', 'Minima')


%Fine tuning of sheet
if i == 1 | i == 2 | i == 3
  figure(10);
    plot(t,M(:,i+1)-mean(M(:,i+1)));
    hold on
    plot(t(samp_max),peaks_max-mean(M(:,i+1)),'o');
    plot(t(samp_min),-peaks_min-mean(M(:,i+1)),'x');
    ylabel('RIP Values')
    xlabel('time [s]')
    title('User 1 COMBINED PLOT')
```

```
    title('User 1 COMBINED PLOT')
    legend('Data1','Maxima1', 'Minima1','Data2','Maxima2', 'Minima2','Data3','Maxima3', 'Minima3')
end

%% Peak to Peak Values
% if the number of minima = number of maxima. subtract peakmax--peakmin
min_length  = min([length(peaks_max),length(peaks_min)]); %makes sure that two arrays with the same length will get subtracted.
pp(i) = mean(peaks_max(1:min_length)+peaks_min(1:min_length));
stdpp(i) = std(peaks_max(1:min_length)+peaks_min(1:min_length));

%% Respiration Rate
% same as Peak to Peak
rpr(i) = mean(diff(t(samp_max)));
stdrpr(i) = std(diff(t(samp_max)));
end
```