IMPLEMENTING TEXTILE PRESSURE SENSOR INTO CAR SEATS

Master Thesis
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0. Summary

The smart textile technology shows its strength in seamlessly merges the electrodes within the soft fabric. The textile pressure sensor has been used in many researches for sensing the pressure distribution. However, the existing sensors are not made for daily use. Sensors like the XSENSOR has a high price and contains plastic films, making it not breathable and not friendly for the skin. A sensor made entirely out of fabric is desirable. According to research (Techtextil, 2015), the car has around 30 kilograms of textiles. What role can a fabric pressure sensor plays inside the car? This project aims to show a new design using smart textile technology - the fabric pressure sensor.

The design approach is co-evolution model. The design problems are analyzed and reframed during the process. The solution also goes through iterations to reach the final product.

Five design phases are included based on the basic design cycle.
Analysis - frame the right problem. For the user needs the meaning of comfort, privacy in the car, and the health problems are analysed. For the pressure sensor, the two working principles – capacitance sensing and resistance sensing are explored. The yarn and spacer material are also researched. A list of requirements is generated.

Preliminary Tests - get to know the technological solution in context. Three tests are conducted to make decision on four aspects of the sensor – the spacer material, the conductive stripes' dimensions, the code for sensing matrix, and the knitting and sewing techniques.

Synthesis - generate concepts from the analysis, finding the right "click" between the problem and the solution. Two concepts are generated considering the two key stakeholders – the driver and the passenger. The lumbar support concept is chosen for further development.

Embodiment - improve the pressure sensor and elaborate on the concept. For the sensor, knitted samples with different patterns are made for seating and lumbar support. Five iterations are conducted on the connection, calibration, and test the sensor with people. In the final test, the sensor can detect four postures, showing stable output. Other stakeholders, benchmark lumbar supports, patterns, fprm and exiperiece, and cost are also considered to elaborate on the concept.

Evaluation - check how far did this project reach. By checking the list of requirements, also using the TRL level, the sensor prototype is evaluated. The concept is evaluated using a storytelling method.

Some recommendations on the material choice and the concept are given to researchers who want to explore this project further. The accuracy of the sensor, the effect from the environment like humidity and temperature needs to be further researched. For the concept, a short – term and a long-term plan is suggested.

In general, this project sets a start of the implementation of the textile pressure sensor in the car. The project starts from technology in researches and reached the level of a working prototype validated in the laboratory.

Table of contents

1. Introduction

1.1 Project Description

This project aims to show the new potential of smart textile technology. The focus is on making use of the fabric pressure sensor in the automotive field.

Technological affordances like control panels and screens easily push the user to the background (Heijboer, S.,2019). Textiles come with a rich cultural heritage and diversity of fabrication and manufacturing traditions. (Donneaud, M.D. 2017). Smart textiles with its strength of seamlessly merging the everyday physical world and digital computing (Poupyrev, I. 2016), have a significant potential in the future to give the attention to the user again.

The car interior design focuses more on the comfort and non-driving-related user interactions during the trip. Several sensors in the car seats are under development. For instance, sensors used to measure bodily conditions (Ford ECG seat), to detect pressure distribution to assess sitting comfort (XSENSOR) and to detect touch to create a tangible interaction (BMW shy tech).

This project considers two aspects:

1. Technical aspect- Learn the sensing principle and sensor structure from literature. Make the textile sensor work. If possible, make the sensor work under the automotive context.

2. Societal aspect- Identify user needs. Determine where and how to use this new technology. Design around the sensor and make the data output fulfill the demands from the user.

Two main questions are asked
Will it work?
To check the performance of a fabric pressure sensor. Make a fabric pressure sensing mat.

Will it work in this context?
To find out what role can a textile pressure play in the car interior. Design a product around the sensing mat

There is no client in the project. The focus is more on exploring the possibilities of making and using the textile sensor.

1.2 Project Approach

In this project, the context- the car interior and the solution- the textile pressure sensor are already defined. The challenge is to find the right use of this technology under the context.

The approach of this project refers to the co-evolution model mentioned in (Kees Dorst, 2001). Christiaans reported from his study that " the more time a subject spent in defining and understanding the problem, and consequently using their frame of reference in forming conceptual structures, the better able he/she was to achieve a creative result."

Figure 1.1 shows the co-evolution model of Maher et al. The problem and the solution are both developing during the design.

Both the concept and the prototype are developed in iterations. Every time after research or testing, a new problem is identified, and another iteration is conducted.

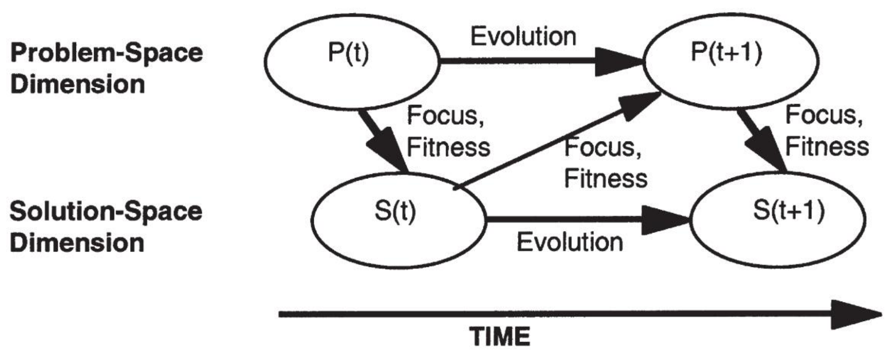


Figure 1.1 The co-evolution model of Maher et al

1.3 Definitions & Abbreviations

Textile material	Material made of textile fibers, for use together with another textile or non- textile products or stand-alone. (Wagner, 2013)
E- textile	Textile with electronic properties included in textile fibers
Smart textile/ fabric	Textiles with the ability to react to different Physical stimuli; mechanical, electrical, thermal and chemical, etc.
TRL	Technical readness level
Autonomous Driving Level 4	As level 3, but no driver attention is ever required for safety, Self-driving is supported only in limited spatial areas (geofenced) or under special circumstances. Outside of these areas or circumstances, the vehicle must be able to safely abort the trip.
LCA	Life cycle analysis
ECG	Electrocardiography The process of tracking heart activity through measuring voltage changes.
Jacquard	A knitting technique that is used to create intricate knitting patterns.
BMI	The Body Mass Index is an index for weight in relation to height. The BMI provides an estimate of the health risk of your body weight.
Jersey	Jersey is a knit fabric used predominantly for clothing manufacture.
Neoprene	Synthetic chloroprene stretched into textile fiber
Spacer knit	Spacer fabrics are much like a sandwich and feature with two complementary slabs of fabrics with a third layer tucked in between.
IP55	A product with an IP55 rating is protected against quantity of dust that could interfere with the normal operation of the product but is not fully dust tight. The product is completely protected against solid objects. It is also protected against water jets projected by a nozzle (6.3mm) from any angle.
IVIS	In-Vehicle Information System

2. Analysis

The car is described as a social-technical "hybrid" (Sheller, 2016). The biggest challenge to use textile sensor is that the car has its demand (Castano & Flatau, 2014). Considering both social demands and existing technical solutions, four general steps are taken to find a detailed direction.

1. What are the user needs? (What)
From the societal aspect, the design scope - autonomous driving & smart textiles and what people do in their cars are considered. The underlying user need is analyzed, and a design vision is defined.

2. What are the existing solutions? (How)
From the technical aspect, benchmark products of the textile pressure sensors on the market are researched. The working principle and existing textile pressure sensor structures in literature from the year 1996 to 2020 are explored and analyzed. In conclusion, a list of requirements and wishes is generated as the criteria for designing and evaluating the product.

3. The added value of the new design. (Leads to)
To define the role a new design plays, a future road map, including the development of technology and market trend, is summarized. The motivation of the new design, its strength, and weakness are analyzed.

2. Analysis

2.1 What are the user needs?

Finding out the user's need is a process of reframing the problem. The approach is shown in Figure 2.1.1

Firstly, a design scope needs to be defined. Which kind of car is considered? Who is the target group? Who are the main stakeholders if a new product comes to the market?

Secondly, the activities of the target group are analyzed. What do people do in their cars? What is the underlying user need from their activities?

Thirdly, a definition of the problem is concluded. A design vision is generated for the new product.

When analyzing the target group's activities, user research has its limitation in the number of participants. It is not representative to cover most of the users. The data in this chapter is drawn from the literature, as there are already existing data sources and researches with more participants.

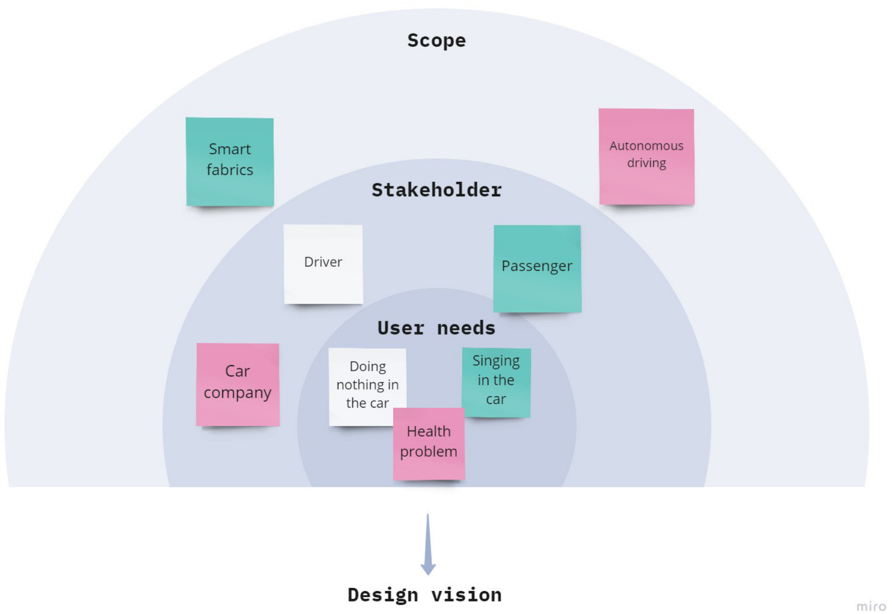


Figure 2.1.1 Overview of Chapter 2.1

2.1.1 Define the scope: Autonomous driving & Smart Fabrics

It is essential to consider whether to include autonomous driving in the scope as autonomous driving has a significant impact on both the driver and the passengers. A driver or a "jobless driver." The interaction between the driver and other passengers will also be different—there will be more freedom of no-driving related activities. Thus, the requirements of the interior will be different.

According to the German Textil research board of trustees, on average, a car has around 30 kilograms of textiles (Techtextil, 2015). Smart fabrics, as an emerging technology used in cars, show their potential to provide new functions more than a normal fabric. As shown in Figure 2.1.2, the Gartner Hype Cycle for Emerging Technologies 2018 and 2019 (Appendix D), Autonomous Driving Level 4 takes over ten years to reach its plateau. However, the smart fabric is estimated to reach its plateau within five to ten years, which is much sooner.

Therefore, **Autonomous Driving Level 4 in this project is not considered as user context but a trend of what people expect in the future.** Drivers will be considered to still perform driving tasks. Smart textile in the car interior, on the other hand, can value as a preparation for this trend and to gradually meet the expectations of the customers, guiding the market of how the car interior would look like in the future.

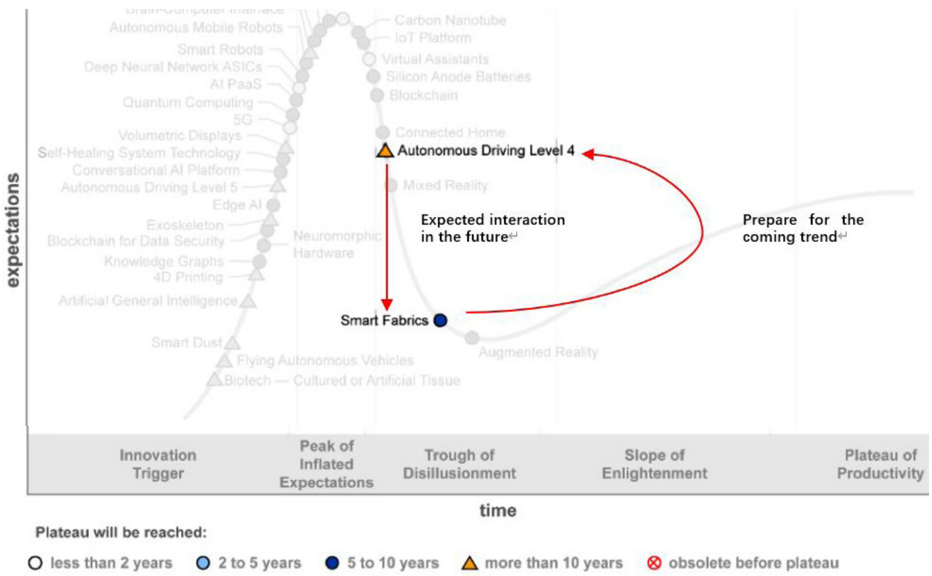


Figure 2.1.2 Gartner Hype Cycle for Emerging Technologies 2018 (Panetta, K. 2020)

2.1.2 Stakeholder Analysis

The stakeholder is also part of the scope. The stakeholders of "having a new fabric pressure sensing product inside the car" are mapped out in the stakeholder interest and influence matrix(Ashby, M. F. 2016), as shown in Figure 2.1.3. The x-axis means the impact, and the y-axis indicates the influence. Stakeholders with both significant impact and influence are "Key players." The effect between different stakeholders is shown in the figure using arrows. Stakeholder analysis helps to find out the most relevant stakeholder and their concerns.

Drivers, passengers, and car companies are considered key players because they are the primary user and producer of the new product. Other stakeholders can also affect key players. Context setters like yarn and fabric producers have a strong influence on the material source, which will affect the company's cost to produce their product. As concerned citizens, existing companies that have smart textile products like XSENSOR can be a competitor or alliance with the car company, providing ready- to use software and experiences.

A further look at the benchmark product is discussed in Chapter 2.2.2.

In this project, the design focus on the user - the driver and the passenger. The car company plays a role as a "client" of the designer. It will be considered in a later stage when thinking about the cost of the product.

The people included in the group of drivers and passengers also have different ages, gender jobs. The car interior design is considered to be neutral and fits most of the ergonomics aspects from different individuals.

The identity and needs of the three stakeholders are researched and defined on the next page.

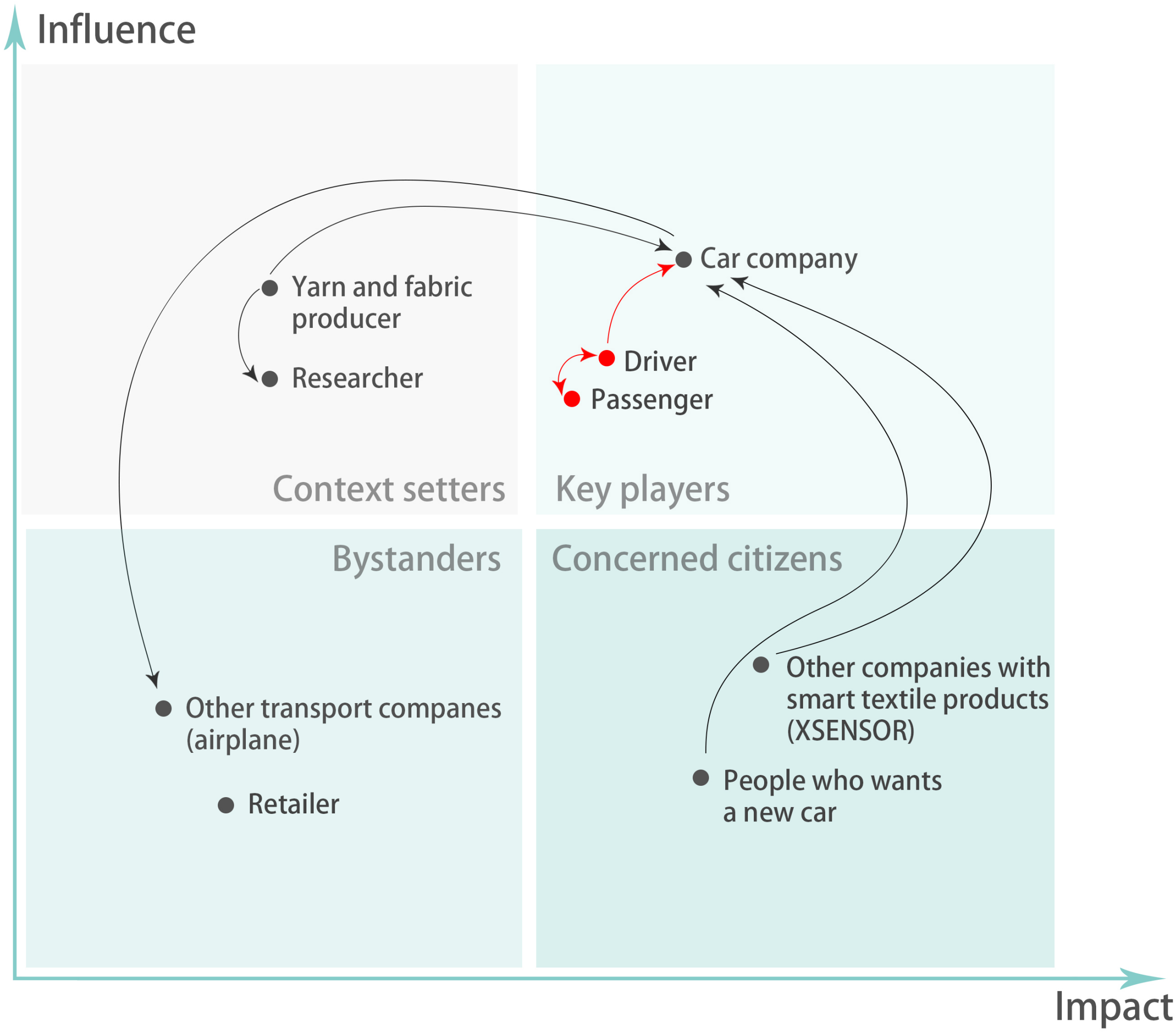


Figure 2.1.3 Stakeholder interest and influence matrix

2. Analysis

Drivers

Who are they: The driver is the one who drives the car. They have the most interaction and control of the car. Some of them occasionally drive with private cars, while others regularly drive as a job, like a taxi or truck driver. When driving, the drivers are exposed to whole-body vibration (Robb & Mansfield, 2007).

What do they want: Occupational driving has often been associated with a high prevalence of back pain (Robb & Mansfield, 2007). A literature review, however, concluded that occupational sitting does not appear to be independently causative of lower back pain (LBP) in workers (Roffey, Wai, Bishop, Kwon, & Dagenais, 2010). Another research shows that poor postures in some types of trucks have been linked with neck and trunk pain (Robb & Mansfield, 2007). Taxi drivers are more likely to report musculoskeletal pain, less sleep, more fatigue, and less physical activity as compared to non-drivers (Chen, Tigh Dennerlein, Chang, Chang, & Christiani, 2005). **In general, a long- term solution is needed for the health problem of the drivers.**

How do they get it: A strategy employed in the Physical Agents (Vibration) Directive (European Commission 2002) was generated. It has a primary focus on vibration, but it also mentioned that all risks must be minimized: 'ergonomic design' and 'layout of workplaces' are mentioned explicitly in the document. De Looze discloses a relationship between an optimal pressure distribution in the seat and the comfort experience indicated by several studies (Kilincsoy, Wagner, Vink, & Bubb, 2016). Create lumbar support, mesh support, move more during sitting are recommendations from health websites ("Prevent Back Pain While Driving,"2019, Hedge, n.d.).

Passengers

Who are they: The people do not have driving tasks in the car. They bear little or no responsibility for the tasks required for the vehicle to arrive at its destination (Wikipedia contributors, n.d.).

What do they want: For the passengers, sitting in the same position, with a limited amount of space, and with no control over the situation can prompt a person to look for something to draw his interest.(Inbar & Tractinsky, 2011) . **One issue associated with being a passenger, especially for a long period and especially for children, is boredom.** (Inbar & Tractinsky, 2011)

How do they get it: Looking out the window, playing games, singing, and watching DVDs are some ways in which this is done.(Inbar & Tractinsky, 2011). Research (Inbar & Tractinsky, 2011) suggests sharing some of the in-vehicle information already there with the passengers, making them more involved in the trip. Other activities require more variety of feedbacks. From the research, the most preferred input and output device during highly automated driving activities are smartphones, followed by in-vehicle information systems (Heijboer, Schumann, Tempelman, & Groen, 2019). Non- driving-related interactions are important, and much broader ways of feedback can be considered. What people do in their cars apart from driving is discussed in 2.1.3. For example, singing, or listening to music.

Car company

Who are they: Companies that design, and provide smart textile technology in the car interior.

What do they want: **Using the new product as a selling point to attract more consumers.**

How do they get it: Investigate in designing a product or service that meets the user needs and fits their company vision.

The relationship between the three key players is also shown in Figure 2.1.3. The driver and passenger affect each other's activities. The drivers can also do some no-driving-related tasks. The passenger can be the friend or relative, colleague or boss, or customer of the driver. This relationship affects the interaction between the driver and the passenger. The users' requirements will affect the decision made by car companies, like whether to investigate further on a particular product.

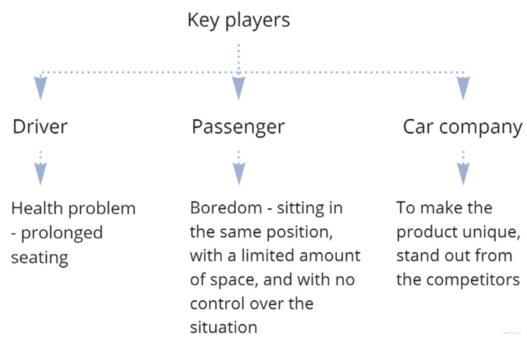


Figure 2.1.4 Overview of the problem each stakeholder has

In conclusion, the concerns of the keyplayers are shown in Figure 2.1.4. The design should focus on solving these problems. How can fabric pressure sensor help? Further analysis needs to be done to see the underlying user needs.

2.1.3 User needs: What do people do in their cars?

" The car is a social space where people spend large amounts of time every day and perform a range of activities" (Laurier et al. 2008).

In general, it is quite usual for people to use a phone (Esbjörnsson et al. 2007), to do office work (Laurier 2004), to read newspapers, to eat, as well as to engage in various conversational activities, such as chatting, spreading the news, speaking about politics, interrogating children about their homework, exchanging confidences. Other activities concern the management of the journey, such as searching for a parking space (Laurier 2005), giving directions, and deciding the itinerary (Mondada 2005,2007a; De Stefani and Mondada 2007; Brown and Laurier 2005; Haddington 2010; Haddington and Keisanen 2009)

For drivers, the main task in the car is driving. At the same time, it is quite usual for them to do other activities. Research (Mondada, L. 2012) conducted some video recordings of various naturally occurring car journeys. It shows the mutual relations between driving and talking: one can be momentarily foregrounded, as the other is backgrounded, and vice versa. The expected activities of the driver in a high- automated ride are also researched. **Relaxing or doing nothing is the primary need during automated driving** (Pfleging et al., 2016)

For passengers, researches (Pfleging, Rang, & Broy, 2016) have been conducted around the world about activities people do in cars, public transportations, and expected activities during a high- automated ride. Another interesting aspect is found from the websites ("10 Things people will do in their driverless car,"n.d.;Duffy, 2019) where it describes some activities like "singing in the car." Those entirely emotional-based activities showed the unique meaning of a car than other means of transport.

As shown in Figure 2.1.5, people do activities like singing, dancing, calling, personal hygiene. In regular private cars. Privacy, personal control, and autonomy ("The importance of the private car," 2016). Detailed data refer to Appendix E. **The car is tightly connected with the emotion and daily routine of the user. The interior should provide a comfortable private environment for the user to be themselves in their cars.**

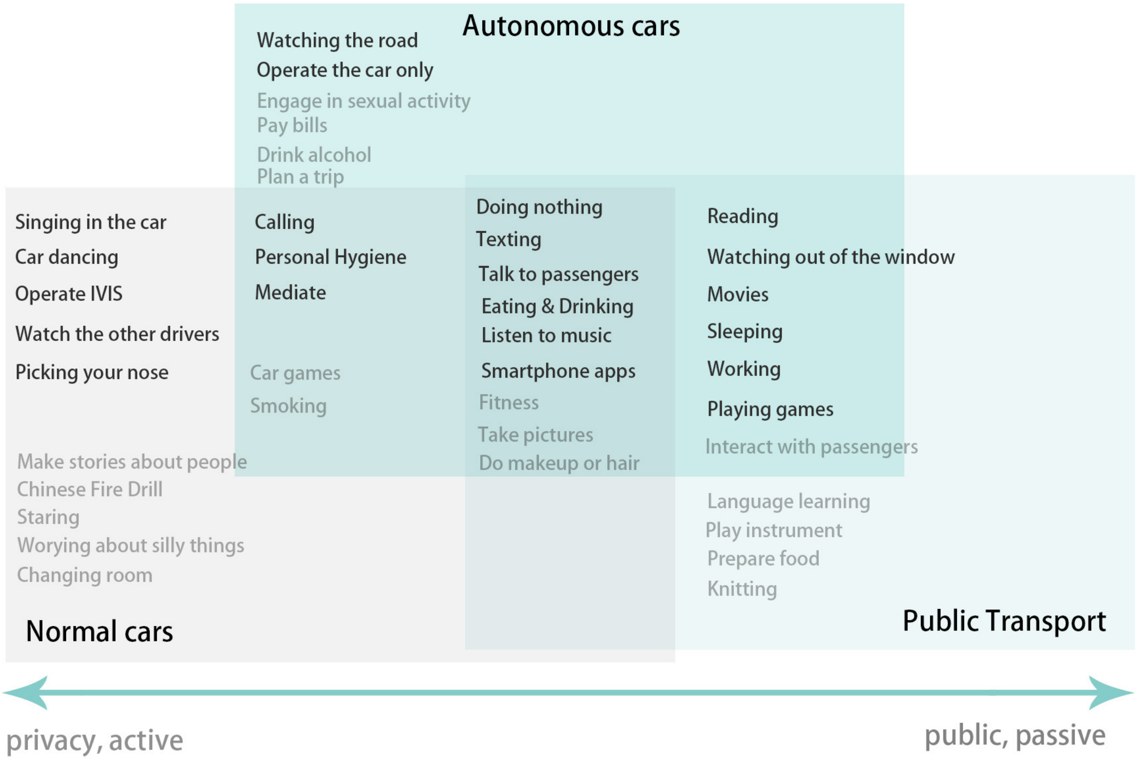


Figure 2.1.5 Overview of what do people do in normal cars, public transoprt, and automomous cars from researches.

2.1.4 User needs: The meaning under "doing nothing in the car"

As described in 2.1.3, Relaxing or doing nothing is the major need during automated driving. What does "doing nothing" mean? What is the underlying user need?

Comfort is associated with feelings of relaxation and well- being. It is a neutral condition. Garment comfort researchers regard garments as comfortable when the wearer is physically unaware of them (W.F. Fung, 2001). **The meaning of "doing nothing" can also mean that people are physically unaware of the interior support and can relax without worrying about adjusting the interior.**

The seat, as the main interface of man and machine in the car, is also the first thing the customer sees when the car door is opened. It needs to provide the body with support under all road conditions, including concerning, accelerating, and braking. (W.F. Fung, 2001) Therefore, seat comfort is of paramount importance.

Hiemstra-van Mastrigt described the relationship between human, seat, and context characteristics (Hiemstra-van Mastrigt, Groenesteijn, Vink, & Kuijt-Evers, 2017). The perception of comfort and discomfort can be explained by three mediating variables: **posture, pressure, and movement.** It is also affected by the time: The first contact of the seat and human in the very first instance, short- term comfort of about 30 minutes, and long- term comfort of more than 30 minutes. (Ü. Kilincsoy, 2018). National preference for comfort factors are known to exist; for example, the hardness of cushion foams vary by more than 50% when measured by compression stress/ strain (W.F. Fung, 2001).

The three variables that can affect the perception of comfort is analyzed below.

Posture:

(Ümit Kilincsoy, 2014) Observed the posture of 580 people in the train and concluded 12 postures. These postures are comparable to the postures used by the passengers in the car as both of them do not have driving tasks. The three most used posture are shown in Figure 2.1.6 - **upright position for short term traveling (left), a slightly relaxed seating (middle),** and a particular position for bigger cars and long-term traveling (right).

Figure 2.1.7 shows some examples of the posture of the drivers from the Southeast University (SEU) database. The research (Zhao et al., 2012) used vision- based method with a camera consists of detecting systems to detect the postures , automatically understand and characterize driver behaviors. The detected posture can also be used to predict some risky activities a driver performs, such as falling asleep and generating feedback to remind the driver.

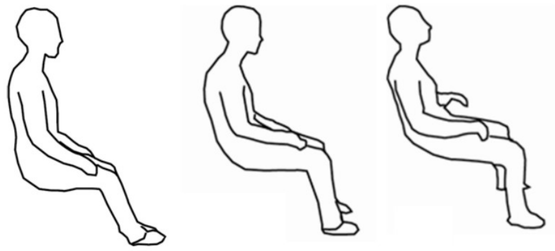


Figure 2.1.6 The three most observed postures during train journeys. (Ü. Kilincsoy, 2018)

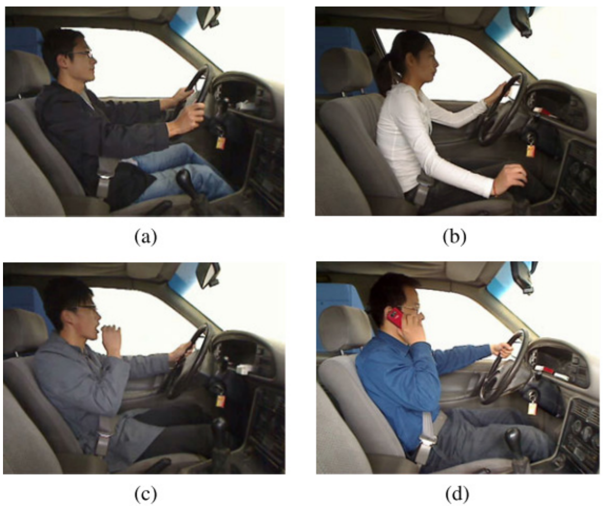


Figure 2.1.7 Example images of SEU driving posture dataset. a Grasping the steering wheel. b Operating the shift lever. c Eating a cake d Talking on a cellular phone.(Zhao, Zhang, & He, 2012)

2. Analysis

Pressure:

The uniformity of pressure distribution on the backrest and seat pan contributes to reducing discomfort. It is found that leather wrinkles or unevenness can result in pressure peaks (U. Kilincsoy, Wagner, Vink, & Bubb, 2016). Lots of research and designs of pressure sensing mats (Cork & Du, 2007) are made for designers and companies to check their products' pressure distribution. However, no pressure sensing product are designed for daily use.

Figure 2.1.9 shows the Marginal percentages of the ideal load distribution. It is used for evaluating the seat structure to make changes on the discomfort parts.

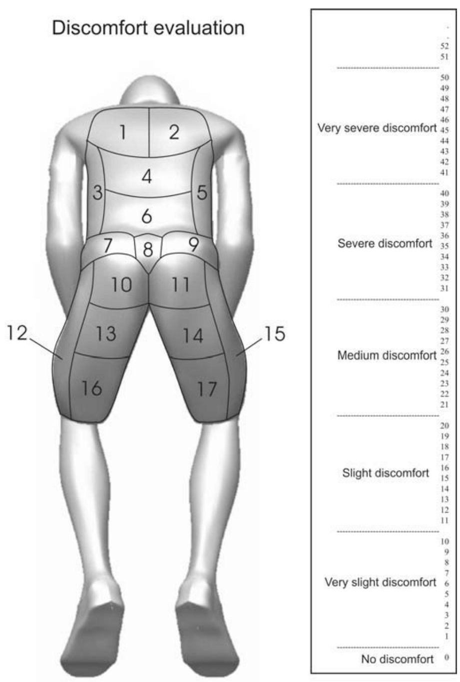


Figure 2.1.8 Body map (Hartung, 2005 ; U. Kilincsoy et al., 2016)

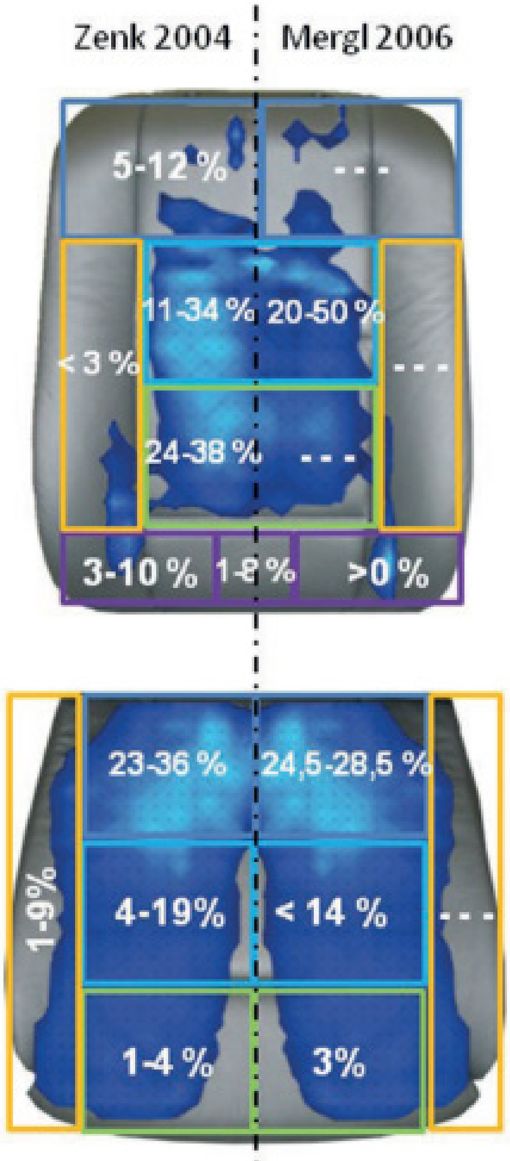


Figure 2.1.9 Marginal percentages of the ideal load distribution according to the body map (Mergl, 2006; Zenk, 2004).

Movement:

Take pressure ulcers as an example; they form when soft tissues and the skin are in prolonged contact. It requires the weight of the person to be repositioned frequently. (Hughes-Riley, Oliveira, Morris, & Dias, 2019). As feedback after sensing the pressure distribution, stimuli are required for people to make certain movements. In other words, the posture is input from the user. The pressure is a method to convert the input into measurable data. The data can be used to access the comfort or discomfort of the user. The movement is an output when the user feels uncomfortable; they can move and do some small activities. At the same time, the movement is again changing the posture, and act as another input of pressure change.

The effect of human, seat and context is concluded in Figure 2.1.10. The relationship between posture, pressure and movement is drawn as shown in Figure 2.1.11.

In this project, the textile pressure sensor is used for measuring the pressure distribution. The output can be used to either detect the posture or evaluate the comfort level. At the same time, the fabric is directly contacted to the user. Therefore, comfort can also be affected by the material of the sensor itself. To ensure the comfort experience of the user, so that they will be able to relax without worrying about adjusting the interior, three aspects are required.

1. There should be enough sensing range for the user with different anthropometry to be in their comfort range.
2. The shape, dimension, and material of the seat should be friendly to the skin.
3. Certain feedback should happen as a reaction to the pressure input, and this feedback should stimuli the movement of people.

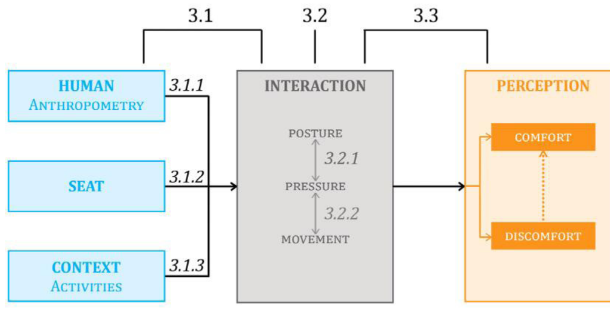


Figure 2.1.10 New conceptual model used as framework for literature review (numbers referring to subsections in this paper). The effect of human, seat and context characteristics (left) on the perception of comfort and discomfort (right) is influenced by mediating variables: sitting posture, interface pressure and movement (middle). (Hiemstra-van Mastrigt, Groenesteijn, Vink, & Kuijt-Evers, 2017)

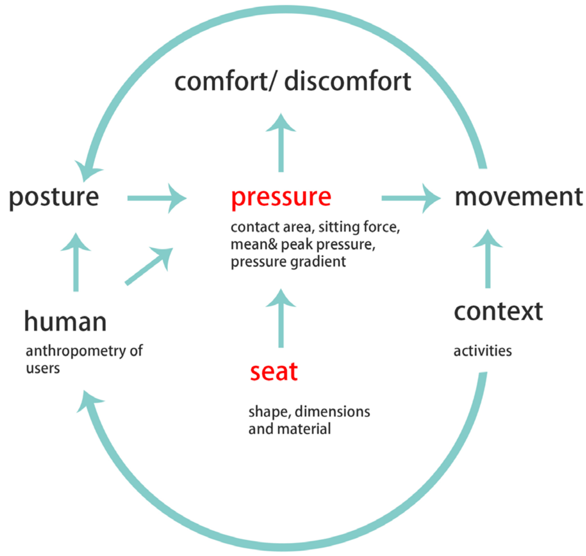


Figure 2.1.11 The relationship between posture, pressure and movement concluded from literature

2.1.5 User needs: The meaning under privacy and "singing in the car"

"In a car, you are physically cocooned." Singing is an activity both drivers and passengers do in their cars. A research in America shows that one third of people once sung in their cars. (Taylor, n.d.)

The meaning of people singing in the car is also the meaning of the car itself. When people drive, they have their control over a private place, and it can protect the driver from the world outside. The driver can sing whatever they like without worrying about if others would mind. The car is not only limited to standard family cars. If a truck driver uses the truck during his work every day, it is also considered that he has control over his car as his working place, meaning the car is also a "private car " to him.

The meaning of the car is also changing over time. The circuit of culture (du Gay et al., 1998) is used to understand the different meanings in connection ascribed in the design and use of private cars. The circuit of culture (CoC) is a metaphor for the interrelated processes that steer a cultural phenomenon.

As shown in Figure 2.1.12, the meaning of singing in a car is analyzed through 5 aspects: production, consumption, regulation, representation, and identity.

Production includes all activities that contribute to the creation of a product (or service). The car is designed for efficiency traveling. The car itself also represents a business model(car culture) for the company to develop and profit. It inherits the technology from history, and new technology keeps being implemented in the car. The technology again becomes a selling point of the car. **In this project, the unique selling point is also the technology itself - the textile pressure sensor.**

Consumption is about consumers that profoundly influence the meaning of products through their practices. "The metaphor of the car as a home has a long history in cultural theory" (Bull, 2001). The car is considered as a private space of the user, providing mobility. On the other hand, the meaning of " free dwelling on the road"   provides the user independence and freedom. When people start playing music and sing in their cars, they feel already at home. **Under this context, privacy also means being "cocooned" and doing the things we want without disturbing others.**

Regulation is about change in social regulation due to new ways of categorization and use of products. The car plays a role that bridges the private and public context of use. The driver also needs to consider the social friendly. Drivers have some "rules" to follow, just like other social activities. **Safety is the basic rule, as risks come along when people start driving.**

Representation is about the development of cultural meaning by language and other means of communication, visually and orally, such as in advertisements. Different cars have their own brand identity. Being robust and reliable, showing the style, or using new technology. The common focus of all companies is safety. The car needs to protect the driver from the road. At the same time, as the increasing number of cars, energy efficiency, and sustainability are advertised as a sign of responsibility to society.

Identity is about how social identities develop, such as the young, dynamic, global consumer expressing personal preferences associated with the product. The car has an identity that reflects the western cultural values of individualism and private property. (Bull, 2001) **The meaning of "free dwelling on the road" is also changed into "free dwelling in the car" when adding an audio player and start singing.** (Taylor, n.d.)

The new product is designed under this context, which should fit the meaning of " free dwelling in the car."

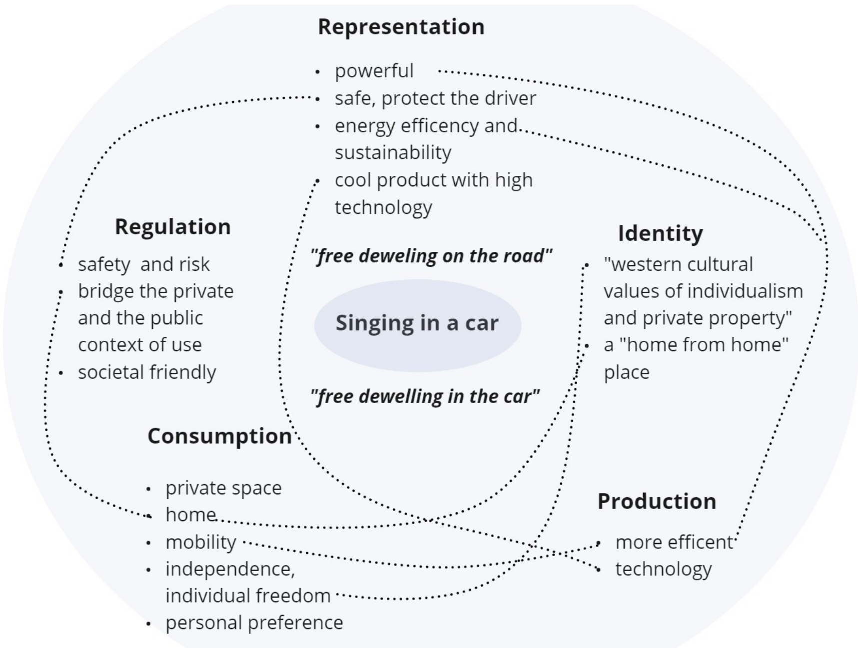


Figure 2.1.12 The circuit of culture based on "singing in the car"

2.1.6 User needs: Health problem in a car.

Prolonged seating and driving can cause health problems. Many types of research are conducted about different health problems in a car. The health problems described below are the internal problems caused by using the car. Health harm like death and injury from crashes, cardiorespiratory disease from air pollution, noise, community severance, and climate change are external effects caused by using a car, and these problems will not be considered in this analysis.

As shown in Figure 2.1.13, health problems are concluded in different body areas.

Fatigue
"Although people usually know when they are tired (McDonald, 1984), their tendency to continue the current activity and complete the task may induce them to continue driving rather than take a break or even stop to sleep for a while. "(SUMMALA, 1994) The fatigue itself is not a big problem, but what the fatigue in the car can lead to car accident, which will cause more server injury.

Musculoskeletal pain
Truck drivers are exposed to many risks associated with low back pain. Prolonged sitting, generally in a posture that is constrained by the driving task leads to the expulsion of fluids from the intervertebral discs and reduces their ability to cushion the spine (Pope et al. 1998). At the same time, drivers are exposed to whole-body vibration for extended periods, and this is also associated with low-back pain (e.g., Seidel and Heide 1986, Mansfield 2005).

The musculoskeletal pain includes not only lower back pain but also pain happens in the neck, shoulder, right leg due to step on the pads, and also in the knees. These pain can affect each other, also in general, affect the comfort of the user. ("Tips to Avoid Neck and Shoulder Pain While Driving," 2017)

Depression
Driving alone for long periods can have negative effects (some research has found it increases the risk of depression) (Bull, 2001). Depression is more of a psychological problem, which can be affected by many external and internal aspects. It is not considered in this project.

The health problems are mainly caused by long time seating, poor posture, tiredness, and vibration. The sitting time is hard to change due to the requirement for work and daily life. Tiredness can also affect the driver's posture. There are also many ways to monitor these aspects, some parameters, like heart rate or eye movement, have a more direct relationship to detect the driver's condition. The posture aspect can refer to Chapter 2.1.4. The pressure distribution affects the user's comfort level; on the other hand, a poor posture affects the health of the user, which in the end affects the level of discomfort. **The pressure sensor can either detect posture change or pressure distribution of the user to provide feedback to change the posture and pressure level of specific areas.**

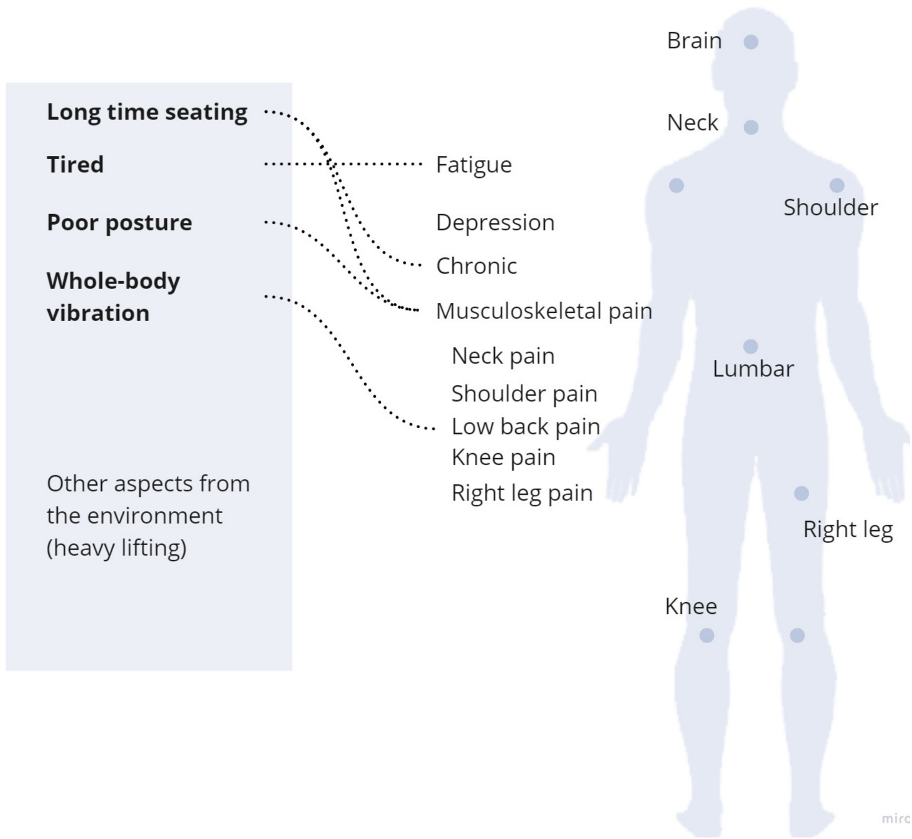


Figure 2.1.13 The health problem and reasons that can lead to the problem

2.1.7 Conclusion- Design Vision

Based on the interface Hierarchy (Heijboer et al., 2019), the user needs are linked to the function interior could provide.

Function: Detect the posture change of the driver.
Example: Reminding people to change posture.
Enabler: Pressure sensing fabric.

Taking the Audi A7 interior as an example, there are many places where the textile sensor can be implemented, like the green areas in Figure 2.1.14. As defined, the user needs in the previous chapters, to detect posture and pressure distribution, the seat is still the most direct and large area to use the pressure sensor. Taking the conclusion from the user needs of comfort, privacy, and maintaining healthy driving, a vision is generated:

" ***Provide a comfortable private product or service for the user to be themselves in their cars through fabric pressure sensors and feedbacks. Enable them to "free dwelling in the car."***

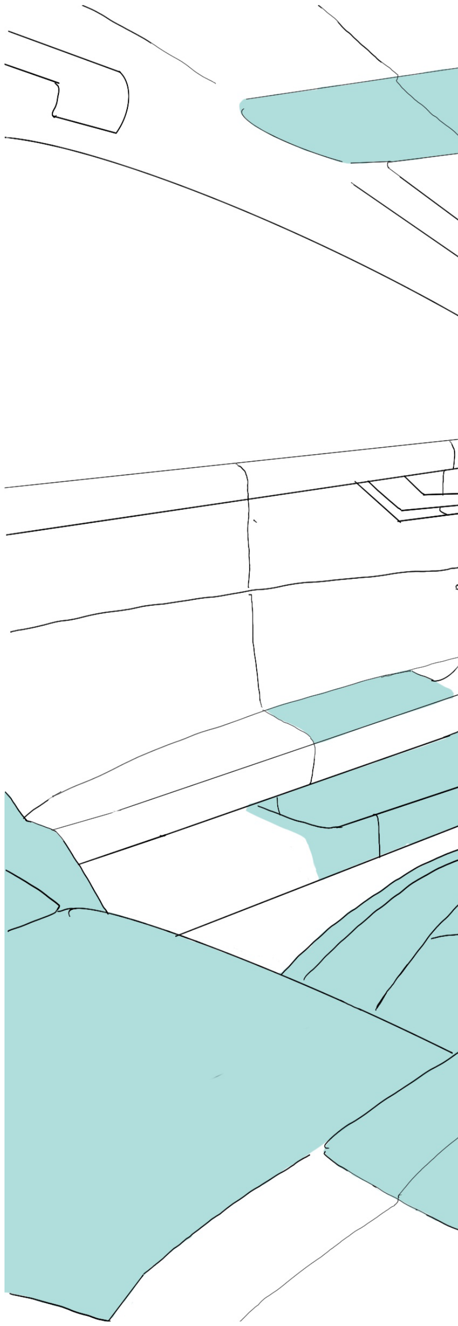
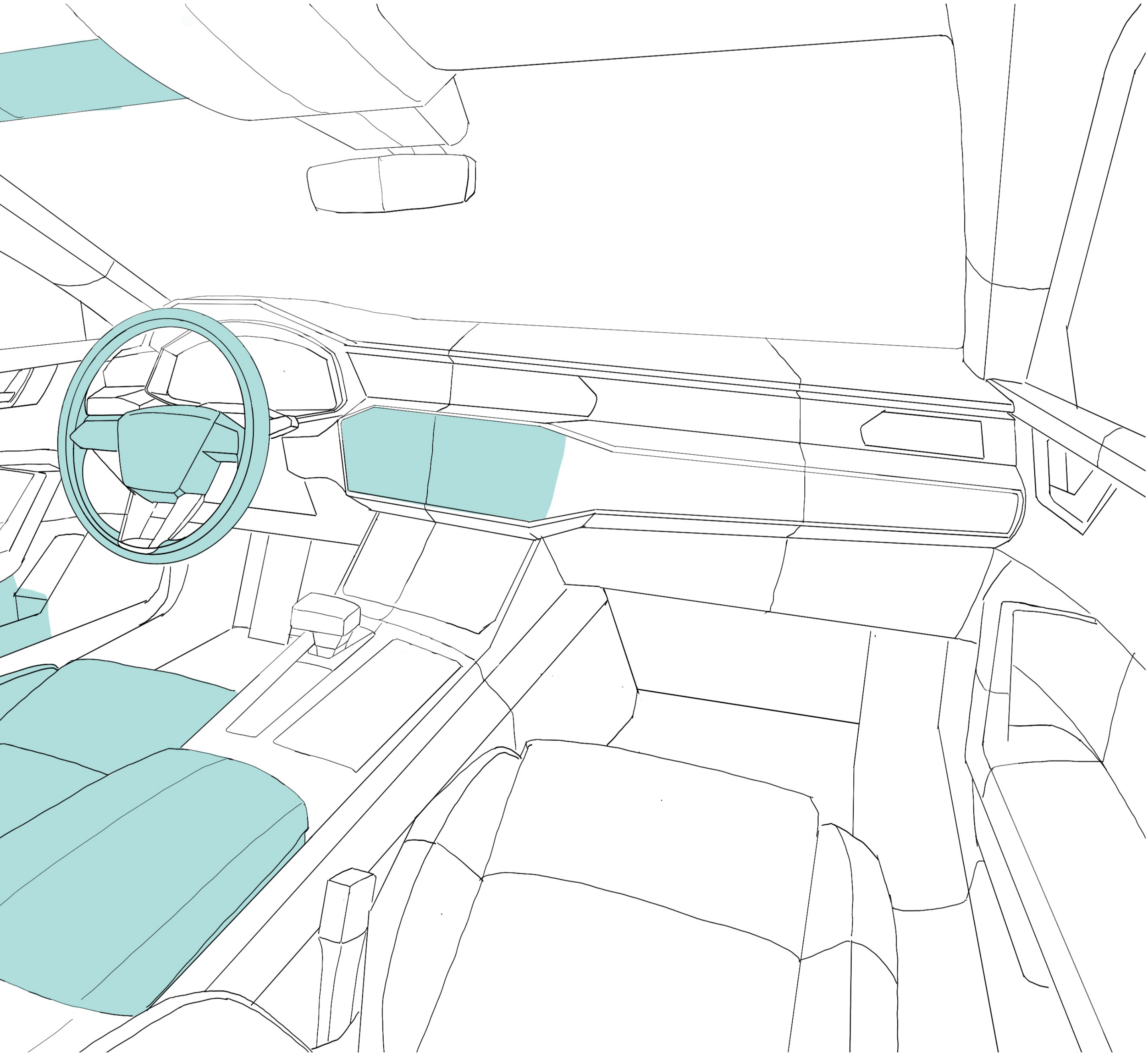


Figure 2.1.14 Indication of where smart textile can



be implemented

2.2 Existing solutions

Some examples of the smart textile in the interior are researched to check the existing implementations.

Regarding the fabric sensor, benchmark products are researched and compared. The advantage and disadvantages are concluded. Benchmark study is helpful to find the position of a new pressure sensor on the market.

The two working principles are researched- capacitance and resistance sensing. The structures used in different researches are concluded and compared. This analysis adds value to narrow the choice of the working principle and structure of the sensor used in this project.

For the material choice, the yarns and spacer material used in the literature are researched. Some general choices are made based on both the literature and the material available in the lab.

Lastly, how the knitting machine works refers to the Master Thesis of Daan about how to use the machine (Daan 2020).

Fabrics used in the automotive context are also briefly researched to check if the fabric sensor will be able to be sufficient to implement into the car. As the sensor is still under development in the lab, it is hard to already consider all the requirements of the material in the car, like durability and waterproof. Some recommendations are concluded from the research for companies who want to put the sensor on the market.

A list of requirement is generated at the end.

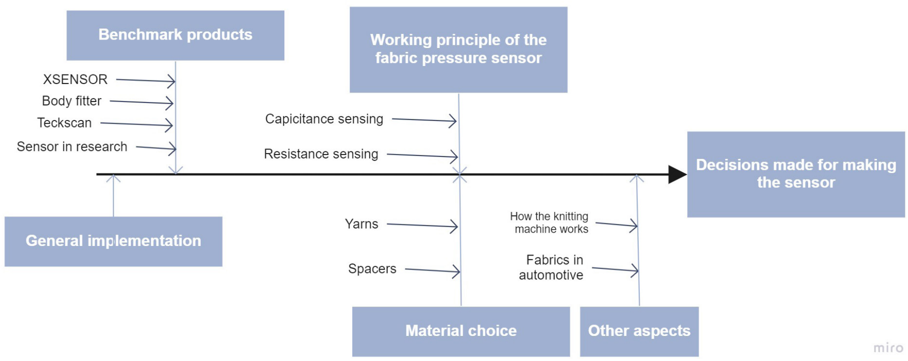


Figure 2.2.1 Overview of Chapter 2.2

2.2.1 Smart textiles in car interior

Some interior applications are already shown in the concept cars of some big companies like Mercedes Benz, BMW, Rolls-Royce, and new companies. The growing electromobility market offers opportunities for smart textiles to be implemented in typical textile components like seats, seatbelts, fabric covers for roofs, floors, sidewalls, and sometimes parts of the dashboard. (Wagner, 2013). A collage is shown below to show the implementation from seats, steering wheels to detailed buttons in the car.

Figure 2.2.2 Collage of the textile used in car interior.()

2.2.2 Textile pressure sensors on the market

Benchmark A XSENSOR

The XSENSOR pressure sensor is a fabric pressure sensing mat. Its working principle is capacitance sensing. When the pressure is applied to the sensing element's surface, a change in capacitance is correlated to a change in pressure (Cork & Du, 2007). The sensing element structure is conductive stripes with spacer material in the middle. As shown in Figure 2.2.3, two layers of conductive stripes are put perpendicularly to form a sensing matrix. Each cross point is a small sensing element. The XSENSOR mat contains sensing elements with a resolution of 100 per square centimeter. The size of the sensor mats is approximately 1mm thick, with standard sensing area sizes ranging from 7.6x 12.7 cm2 to 81.3x 203.2cm2. (Cork & Du, 2007)

Four advantages of the XSENSOR is mentioned in (Cork & Du, 2007).

1. The materials used and the way of assembling creates a pliable and conformable sensor pad. Distortion from the outside is minimized.

2. The sensor mat is extremely robust. For example, it can be repeatedly crumpled and still function (Figure 2.2.5). The sensor pads are made for long term usage in many sensing cycles.

Also, the advantages of the software are mentioned in researches:
3. XSENSOR system has a ready-to-use calibrated pressure mat system (Hughes-Riley, Dias, & Cork, 2018).
4. The add-on in Auto Seat Mode is already accessible in the market (U. Kilincsoy et al., 2016).

This product has been implemented in medical studies like managing pressure ulcers, seating sensors (for the automotive industry), and sleep solutions using pressure-sensitive mats to aid in mattresses selection (Cork & Du, 2007). The sensor is also available in the Lab of TU Delft, which will be used to compare further tests.

The price of an XSENSOR mat with 48*48 sensing elements is around 20000 Euros.

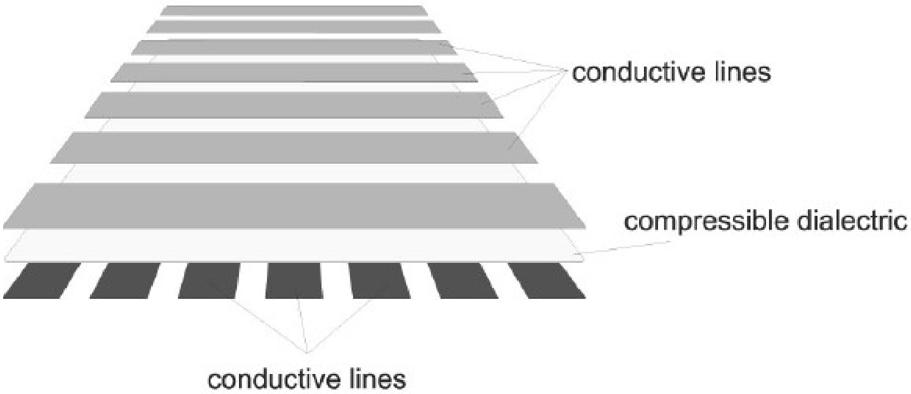


Figure 2.2.3 A schematic of basic sensor construction (Cork & Du, 2007)

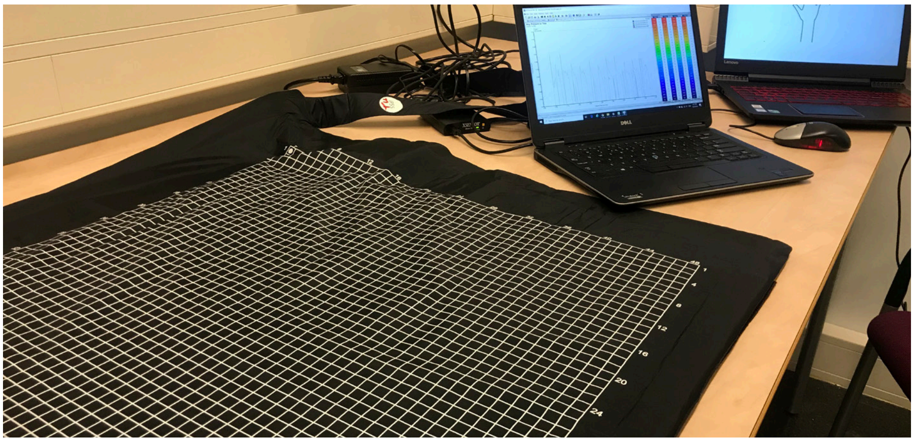


Figure 2.2.4 XSENSOR in the lab of TU Delft

Figure 2.2.5 An example of XSENSOR flexibility and durability (Cork & Du, 2007)

Benchmark B Tekscan

Tekscan is a similar product as XSENSOR. The most significant difference between the two sensing mats is that the Tekscan sensing mat's sensing principle is resistance sensing by sensing the resistance change between two conductive stripes, to correlate to the pressure change. An image of Tekscan is shown in Figure 2.2.6.

The sensing mat contains as many as 2016 individual sensing elements, with the sensing range of 0- 34kPa. The company also provides different sizes of sensor mat for the seats as well as the mattress. The data output includes real-time 2D and 3D pressure data, total force, peak pressures, and center of force. The software of Tekscan is similar to XSENSOR. The sensor is used for comfort test and analysis, support surface design, material testing, and ergonomics research.

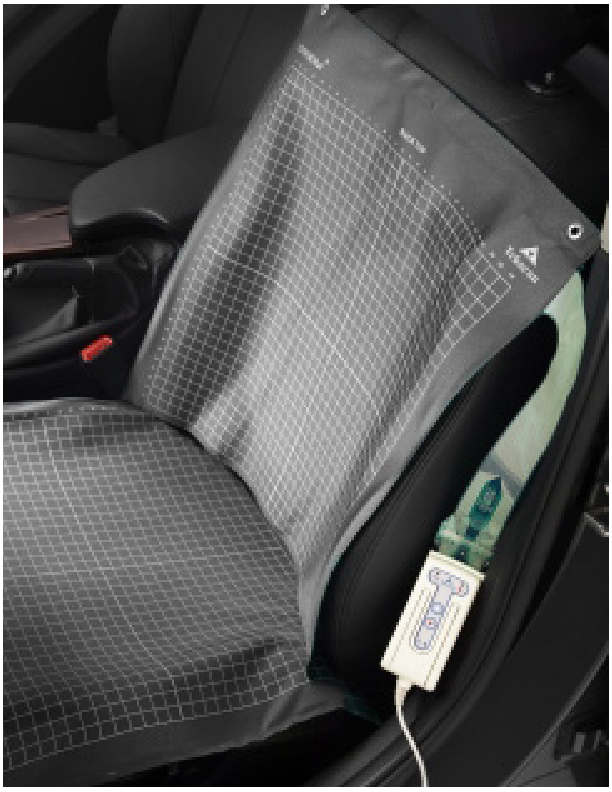


Figure 2. 2.6 The use of Tekscan (Automotive Seat Testing & Design, 2017)

Benchmark C Body fitter

Body fitter is also a sensing mat for the mattress, providing the best-fit mattress choice to the consumer.

The sensing principle of Body fitter is piezoresistive—the resistance of the piezoresistive material changes when pressure is added to a certain place. The stretchable sensor contains almost 2,000 discrete sensing points.
The sensing mat is used along with a kiosk, which provides recommendations on mattress choice. The kiosk meets the needs of people in choosing the most suitable mattress in a short time. The data makes the service more professional and bring trustworthy to the users. By combining a sensor mat with a kiosk, the service increases sales revenue, lower

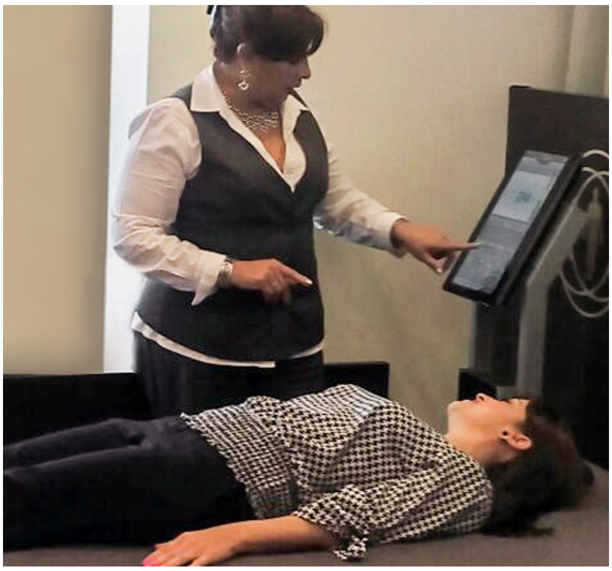


Figure 2. 2.7 The using contect of the Body fitter (BodyFitter Request a Demo. n.d)

post-purchase dissonance, translates into fewer product returns, lends "scientific" validity to an otherwise subjective process.

The software of Body fitter has not only a primary pressure sensing function but also a mattress portfolio database, which fits its implementation context. The database enables mattress companies to enter in details and graphical images of the mattress offerings. It benefits the user and makes it easy for the companies to operate the kiosk. The software design is similar to the Auto Seat mode of XSENSOR, providing the researcher with a professional analysis system.

Benchmark D Textile pressure sensor example from research

There are also researches studying the textile pressure sensor. The detailed structure of the sensors from the research will be discussed in Chapter 2.2.3. Research (Meyer, Arnrich, Schumm, & Troster, 2010) is an example of designing a pressure sensor and use it to monitor the posture change of people when seating. The research as a similar user context as this project as the sensing range required, and the data output is similar.

Figure 2.2.8 Textile sensor with 240 elements used for sitting posture measurement. 1: common electrode, 2: spacer, 3: sensing electrodes, and 4: electrodes switched to ground. (Meyer et al., 2010)

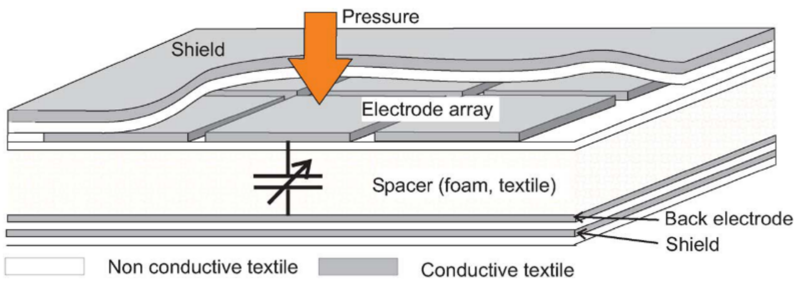


Figure 2.2.9 Array of electrodes of conductive yarn on one side and a common electrode on the other side of the spacer form the capacitors for pressure sensing. (Meyer et al., 2010)

The sensing principle is capacitance sensing, as shown in Figure 2.2.8. The conductive fabric is cut into squares and used as sensing elements. These provide a resolution of 1 cm with 42 x 48 sensing elements each. (Meyer et al., 2010). The application defines the needed pressure sensitivity: **pressure by sitting has been measured as up to 3 N/cm2.** The spacer material used in the research is 3Mesh spacer fabric from Müller Textil, Germany, with a thickness of 6mm. The research also checked the effect of humidity, temperature, and hysteresis.

The sensor is used to monitor different postures. Sixteen postures have been measured for each subject: seated upright (1), leaning right (2), left (3), forward (4), back (5), left leg crossed over the right (6), right over left (7), once seated upright and once leaning back (8) (9), once while the knees are touching and once with the ankle rested on the leg (10)–(13), slouching (14), sitting on the leading edge (15), and slouched down (16). Tekscan sensing mat is used as a reference, as shown in Figure 2.2.10. The classification accuracy reached with the data of the Tekscan mat recorded simultaneously is 56% without a back sensor with features optimized for the Tekscan data.

The sensor mat shows its advantage in using textile as the primary material, providing a data output comparable to the Tekscan sensing mat, in a lower resolution. It proves that it is possible to detect the posture in a lower resolution using textile as a sensor.

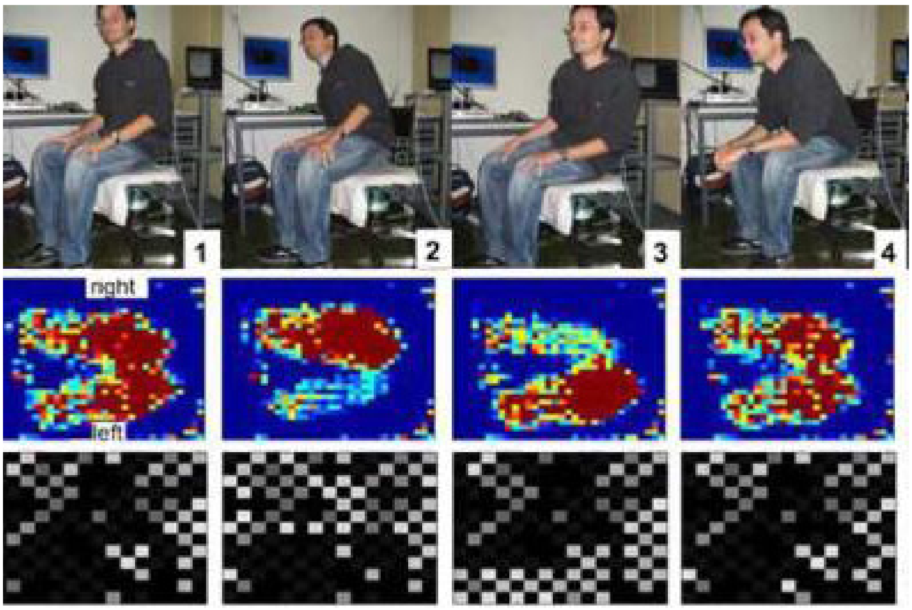


Figure 2.2.10 most used posture (Meyer et al., 2010) (Top) Different sitting postures have been performed and the pressure patterns measured with the reference sensor (middle) and the textile pressure sensor (bottom)

Comparing the benchmark products

As shown in Table 2.2.1, the property of the four benchmark sensing mats is compared. The data are drawn from the files from the company websites ("Body Pressure Measurement System (BPMS) - Research," n.d., "Mattress Surface Pressure Mapping," 2016). XSENSOR shows its advantage in accuracy, robustness as well as a marketing strategy to make the system specialized into Automotive seating analysis. It includes the technical knowledge of the textile pressure sensor and contributes to ergonomics knowledge in analyzing the data output. The disadvantage of the XSENSOR is the price. Although the price of other sensors can not be found, it can be concluded that in general, all the sensors are not made for daily private use.

Tekscan shows its advantage in sensing range. Body fitter has the strength of making use of the detected data. Similar to XSENSOR, the Bodyfitter combine the data with the property of the mattress to provide suggestions. **More value is added when combing the pressure output with other knowledge like ergonomics and marketing.** The sensing mat from research has its advantage in using textiles as the primary material instead of plastic films. The textile sensor in the research can also lead to lower robustness. The sensor mat performs okay but is not as professional as the other sensors on the market.

The new sensor mat can position itself in a place where it has a lower price, made out of textiles, and can have a comparable output with the sensors on the market—combing other knowledge with the pressure output, to put the sensing mat used for research into a context.

	XSENSOR	Tekscan	Body fitter	Sensing mat from research
Working principle	capicitance	resistance	resistance	capicitance
Sensing range	0- 27kPa	0- 34kPa	0- 14kPa	0- 30kPa
Resolution	12.7mm, 48*48 +	48*48 +	2000 sensing elements	10mm, 42*48 +
Accuracy	± 5%	± 10%	± 10%	
Price	20000 Euros/ piece			
Robustness	IP55			
Other	Auto Seat Mode is already accessible in the market		Used along with a kiosk which provides recommendation on mattress choice.	using textile as the main material

Table 2.2.1 Comparing different procucts.

2.2.3 Working principle

Smart fabrics are composites made from threads. As shown in Figure 2.2.11, threads are twisted into yarns. Yarns are woven or knitted into fabrics. Different layers of fabrics form the structure of fabric transducers. The smart fabric transducers include three major categories: Sensors, Actuators, and Batteries. Textile pressure sensor belongs to the sensor category, meaning fabrics given sensing property of diverse physical nature, such as capacitive, resistive, optical, and solar. (Castano & Flatau, 2014)

The smart fabrics contain electrodes to function as sensors. (Hughes-Riley et al., 2018) mentioned four methods of producing the conductive tracks.
1. Weaving in a mix of conductive and insulating fibers.
2. Embroidering the circuit using conductive thread.
3. Textile electrodes are separated by conducting strips.
4. The use of conductive paint

In the pressure sensor category, two pressure sensing principles are used by conventional electronic sensors or textile sensors - **capacitance or resistance measurement.** The basic construction of most textile pressure sensors consists of two fabric layers, sandwiching a pressure-sensitive material made of either a dielectric or highly electrically resistive material. As the application of pressure deforms the fabric, the electrodes are brought closer to each other, changing the capacitance or the resistance recorded (Hughes-Riley et al., 2019).

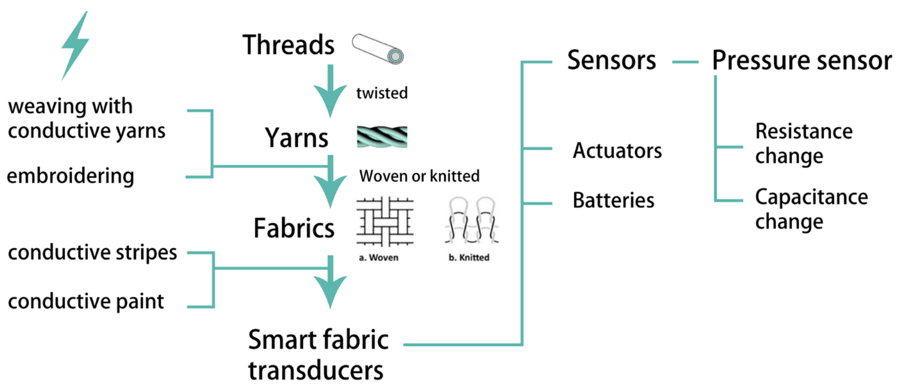


Figure 2.2.11 Overview of the construction of smart fabric.

The advantages and disadvantages of the capacitive and resistive sensors are described in the literature. Hughes-Riley et al. (2019) say that capacitive sensors provide an average pressure load, while the resistive sensors provide a peak pressure value. Castano & Flatau (2014) claims that capacitive fabric sensor outputs are typically non-linear, with regions of approximate linearity. Capacitive fabric sensor is also found more sensitive to humidity compare to resistive fabric sensor. The effect of humidity on capacitance is significant. Thus, an open-structured sensor is prone to errors of this origin. (Hughes-Riley et al., 2019). The result is summarized in Figure 2.2.12

While it also differs from different structures under the same working principle. For detailed examples, refer to Appendix A.

Capicitance	**Resistance**
average pressure load	peak pressure load
approximate linearity	open- structured sensor can cause shoricircuits
more sensitive to humidity	

Figure 2.2.12 Comparing capacitance sensing and resistance sensing

Six general types of Capacitive fabric sensors. (1996- 2020)

The working principle of the capacitive fabric sensor is the pressure change causes the deformation of a dielectric spacer, which lead to capacitance change between the two conductive layers on each side of the spacer.

The capacitance at the pressing point (C) can be calculated by Equation,

$$C_{sensor} = \varepsilon_0 \varepsilon_r \frac{A}{d_0}.$$

A, electrode area,
d, dielectric thickness,
ε0, a constant for the dielectric permittivity of vacuum
εr, the permittivity of a dielectric.

The variations in the permittivity of dielectric layers also contribute to a change in capacitance, as shown in Equation (2), where εair = 1 and εPET = 3.3. The sensitivity increases when the volume of the air gaps decreases. The decrease in dielectric thickness (d) and the increase in permittivity (εe) under pressure together contribute to the increase in the textile capacitance sensor's sensitivity.

Figure 2.2.13 summarized six types of sensor structure from literature (1996 until 2020). It shows the parameters: responsivity and sensing range (Atalay & Kennon, 2014), advantages and disadvantages of each structure. For detailed information, refer to Appendix A, B.

1. Single element sensor: The sensor as a single sensing element can only sense pressure change at one point. (Thomas Holleczek, 2010) used silver-coated textile and PCCR spacer to sense the pressure on the feet of athletes. The sensor shows a sensing range of 30N/cm2, but it started to peel off after the outdoor experiments, and it is not machine washable. (Meyer, Arnrich, Schumm, & Troster, 2010) uses single electrodes on one side of the spacer as an array, and the other side consists of one common electrode. The sensor is used for sensing pressure distribution on the seat. The research found that the sensor can be used to detect accurate pressure values.

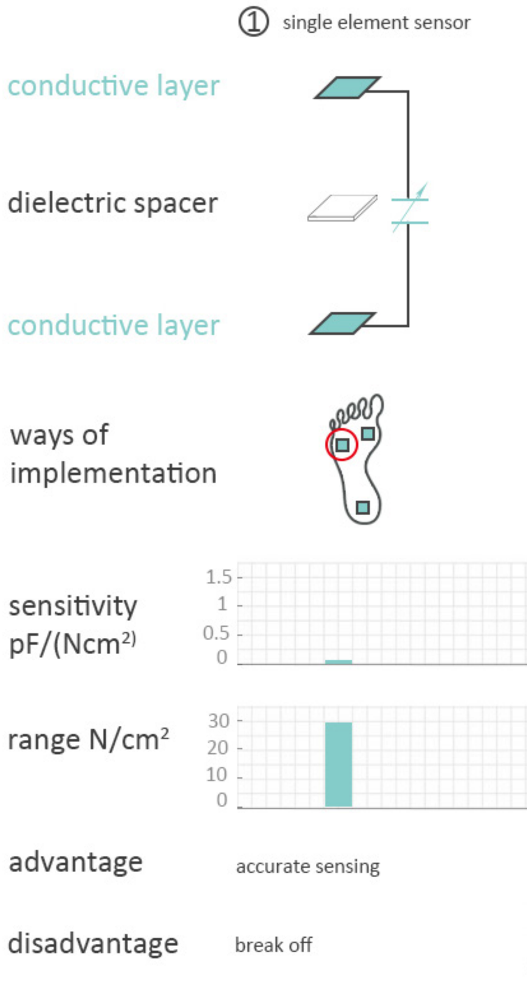
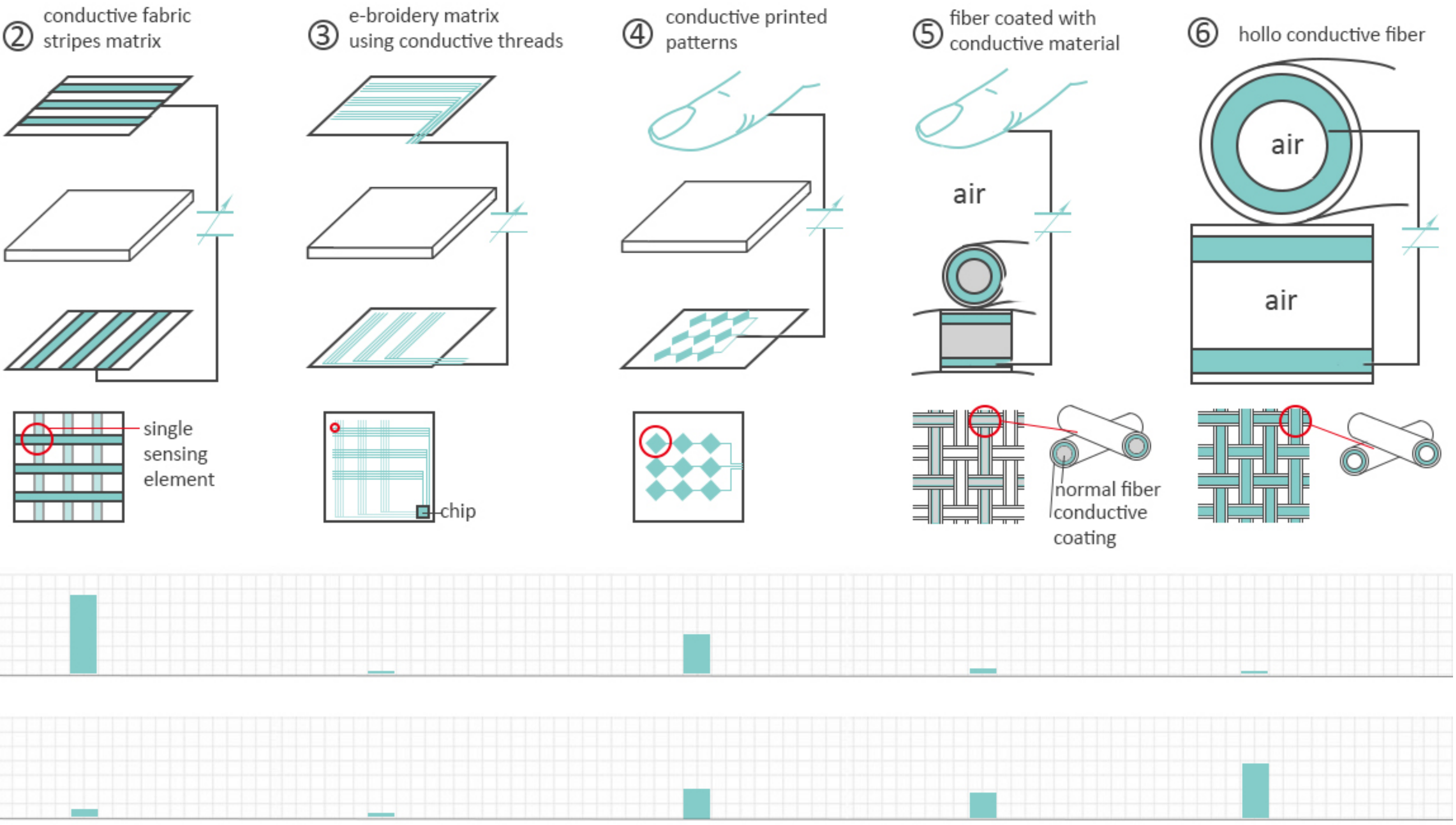


Figure 2.2.13 Overview of the sensor structure based on ca



no significant hysteresis stable	robust	allow scale and reduction, used in ECG	large area sensing	robust and stable
less sensitive with thinner spacer	not function when wet	printing quality affected by thickness of fabric	more touch sensing	more touch sensing

pacitance change

2. Conductive fabric stripes: The conductive elements are fabric stripes knitted or woven by conductive yarns. The stripes can reduce the extra material for electrodes, as the yarns act as both structure of the fabric and the conductive electrode. The stripes are mapped out perpendicularly to form a matrix, which can sense pressure change in the crossing point of the two conductive layers. (Hughes-Riley et al., 2019) uses silver yarns knitted in the fabric as electrodes and Fibrous spacer structure. The senor has low hysteresis. In (Wu et al., 2019), using Ag NF yarns and 3D penetrate fabric as spacer shows good stability with more than 20000 testing cycles.

3. E- broidery: Conductive yarns are embroidered on the fabrics. (E. R. Post, 2000) says the sewn circuit elements are robust. However, the sensor will not function when wet, as the yarns are not insulated. (Sergio et al., 2003) shows that the sensor is suitable for not only pressure sensing but monitoring pressure distribution. It is also widely used as a connecting measure(E. R. Post, 2000). Also, (M. Sergio, 2002) mentioned that the mechanical flexibility of the fabric is expected to worsen.

4. Printed patterns: The conductive ink is printed on the fabric, forming small sensing elements. These two structures can be used for scaled production at a low cost. (Cao et al., 2018) verified the robustness of the print after washing. The printed patterns are used a lot in ECG monitoring (Acar et al., 2019)

(Achilli, Pani, & Bonfiglio, 2017; Xu, Luo, He, Guo, & Yang, 2019). It has high sensitivity in touching (Vu & Kim, 2020). While the sensing range varies in different researches as the spacers used are different.

5. Coated fiber: The fabric is knitted or woven by specially coated fiber, using the capacitive change of the two fibers to detect pressure change. Therefore, the fabric function as on a single layer instead of 3 layers. In research (Seiichi Takamatsu, 2011), the specially coated fiber can be used in large-area sensing (1.2m*3m). At the same time, the fabric is more of a touch sensing instead of pressure sensing. Research (Takamatsu, Kobayashi, Shibayama, Miyake, & Itoh, 2012) also described a low sensing range (9.8N/cm2) of this sensing structure. The poor elastic recovery of a single-layer fabric pressure sensor prevents its use in prolonged applications (M. Sergio, 2002).

6. Hollo structured fiber: The fiber uses the air in the hollo inside the fiber as a spacer. It is researched in (Kim et al., 2018) and has a high requirement of the fibers. The sensor maintains its function after 1000 times of repeated sitting and washing with detergent.

Touch sensing

The capacitive sensor method toggles a microcontroller, sends a pin to a new state, and then waits for the receive pin to change to the same state as the send pin. A variable is incremented inside a while loop to time the receive pin's state change. The physical setup includes a medium to high value (100 kilohms) resistor between the send pin and the receive (sensor) pin. The receive pin is the sensor terminal. When the send pin changes state, it will change the state of the receive pin. The delay between the send pin changing and the receive pin changing is determined by an RC time constant, defined by R * C, where R is the value of the resistor and C is the capacitance at the receive pin, plus any other capacitance (e.g., human body interaction) present at the sensor (receive) pin.

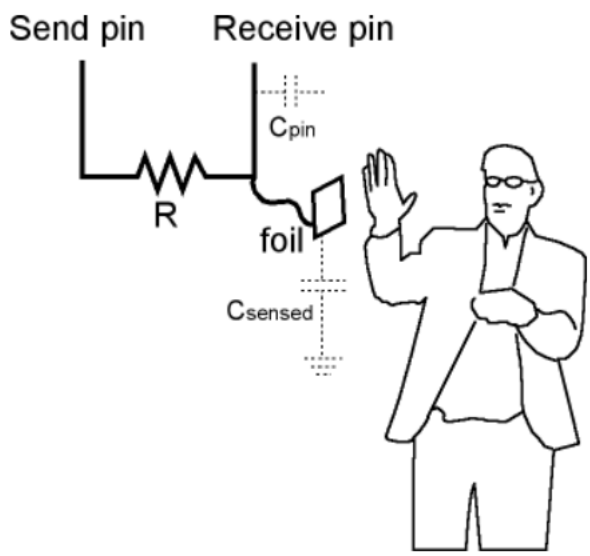


Figure 2.2.14 Working principle of the touch sensor (Capacitive Sensing Library. n.d.)

Pressure sensing

To reduce the effect of parasitic capacitances, the two-port measurement method is applied. With this method, parasitic capacitances are connected to the ground. The capacitance between the electrodes is measured separately from the ground potential. (Jan Meyer 2010) Each Arduino capacitance meter relies on a property of resistor-capacitor (RC) circuits- the time constant. The time constant of an RC circuit is defined as the time it takes for the voltage across the capacitor to reach 63.2% of its voltage when fully charged:

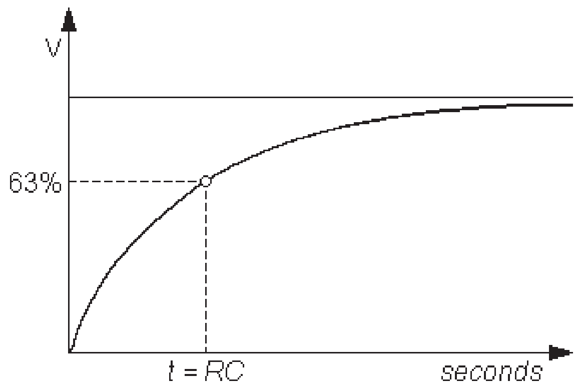


Figure 2.2.15 Working principle of pressure sensor (Basics, C. 2020,)

Larger capacitors take longer to charge, and therefore will create more astronomical time constants. The capacitance in an RC circuit is related to the time constant by the equation:

$$TC = R \times C$$

$TC:$ *Time constant of the capacitor (in seconds)*
$R:$ *Resistance of the circuit (in Ohms)*
$C:$ *Capacitance of the capacitor (in Farads)*

Six general types of Resistive fabric sensor (2011-2020)

As shown in Figure 2.2.16, six types of structure based on resistance change are summarized. The resistive fabric sensor has more variations of its structures. The main difference from the capacitive structure is that the "dielectric layer" is changed into a conductive layer, changing its resistance when pressure changes.

1. The "easy- to- build" single element sensor: Like the capacitive sensor, the single element sensor based on resistance change is capable of sensing one point and can be made within 15 minutes using only standard office tools (Pizarro et al., 2018). The resistive change material in the middle is low-density polyethylene (LDPE) with a carbon sheet.

2. Piezoresistive: Using piezoresistive film as a middle layer is a commonly used method [05]. (Maurin Donneaud, 2017)conducted some necessary testing with the sensor with coins, and the thin sensor allows it to be draped over the body, which is suitable for wearables.

3. Screen-printed patterns combined with other structures: In (Zhou et al., 2018), researched the screen-printed patterns combined with coated cotton as a middle layer. The deform of the conductive cotton leads to resistance change. The fabrication process is facile, economical, and suitable for large scale production.

4. E- broidery. Similar to the capacitive sensor, e-broidery ca also be used in resistive sensors. It is still only used for touch sensing as keyboards or switches. (Roh, 2013)

5. Tooth structured: conductive foam is also a new way of forming textile sensors. In (Y. Wang et al., 2011), the foam is made as a tooth shape with the strain sensing film in the middle. By adjusting THE Yong's modulus of the two foam layers, and the geometrical of the tooth shape, the sensing range and sensitivity can be changed.

6. Nanofiber: As a future direction in a micro-level, matrix made from nanofiber also shows a fast response speed and stability. (Qi et al., 2020)

Other structures mentioned in the literature. For a detailed reference, refer to Appendix B.

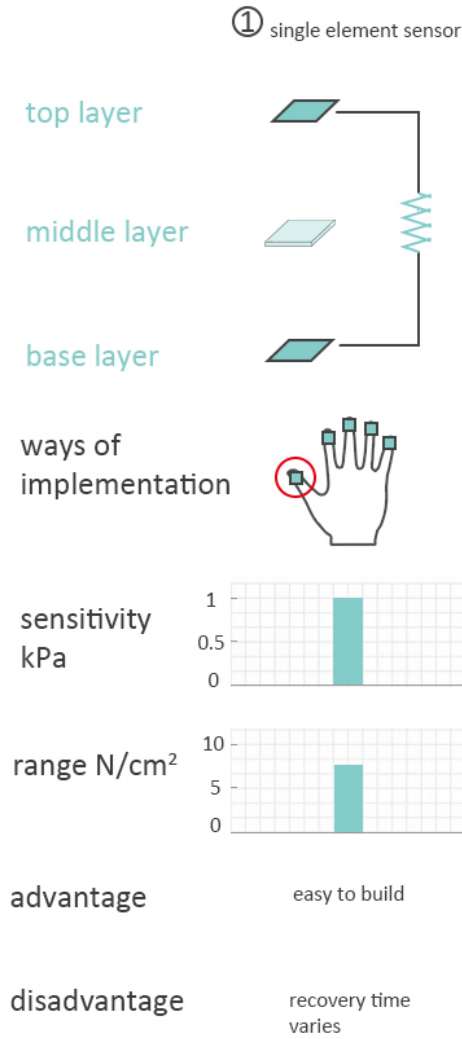
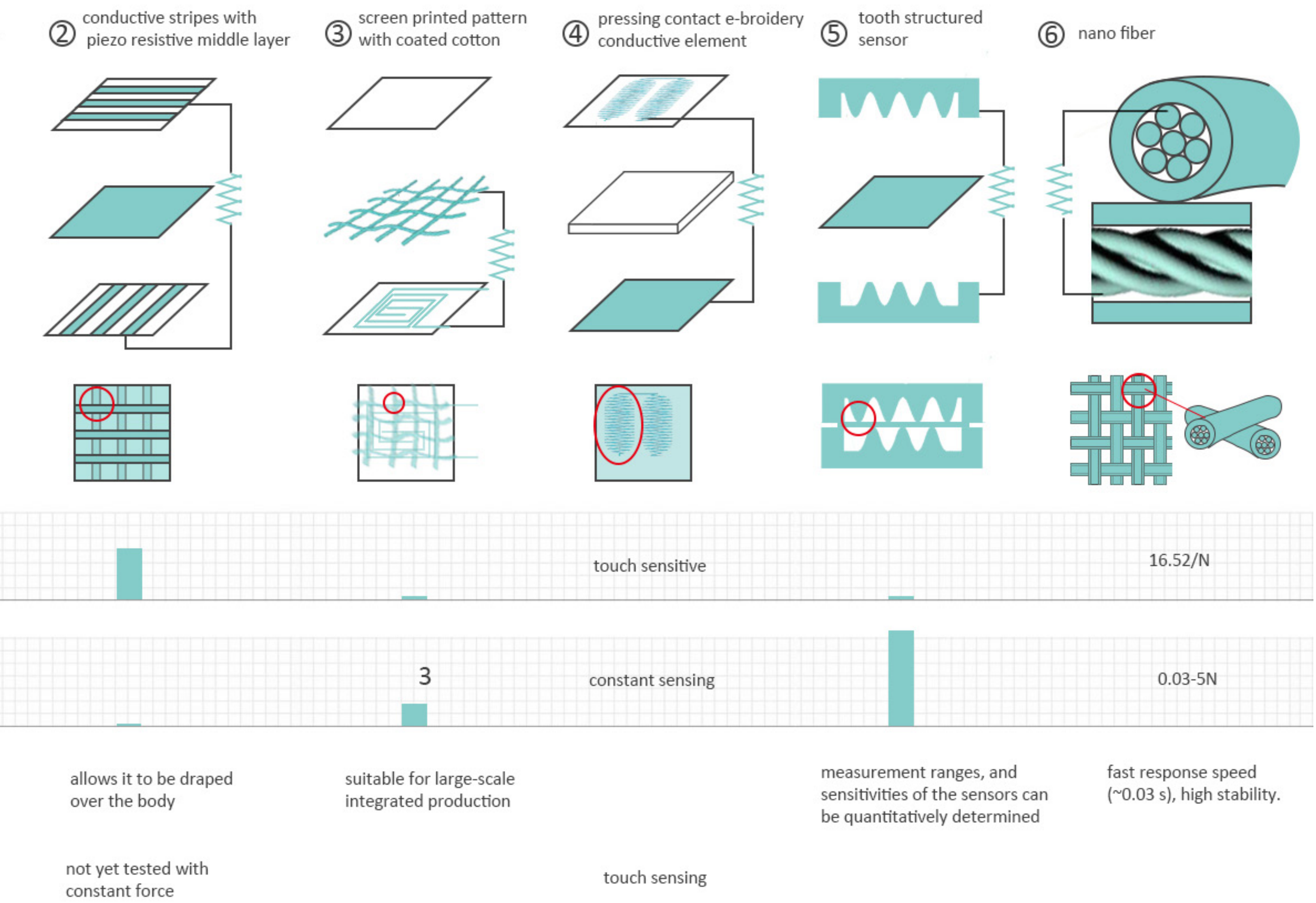


Figure 2.2.16 Overview of the sensor structure bas



ed on resistance change

2.2.4 Yarns and spacers

For choosing the material, types of yarns and spacers are also explored as shown in Figure 4. (Detailed reference in Appendix C)

Yarns:

Yarns act as electrodes and structure the entire circuit. There is currently a wide range of yarns from companies and self- made ones for testing. Shieldex yarn is commonly used in researches (Hughes, Oliveira, & Dias, 2019; Meyer et al., 2010; Pizarro et al., 2018) because of its good conductivity and stability. However, the structure is multifilament yarn coated with silver. Its insulation performance needs to be tested. Conductive ink, like CNT (carbon nanotubes), is also used in printed sensors. The ink is toxic to the skin and requires other materials like silver powder as cover. (Vu & Kim, 2020)

In order to start testing more quickly, the knitting samples started with existing yarns in the lab. Silver coated yarn from WEARIC is suitable for knitting. The strength of the yarn is also robust enough. However, the silver can get oxidized during long time use (Ag2O). Stainless steel yarn from kiwi electronics is highly conductive. The disadvantage of stainless steel is that it is not solderable. As the car interior has effects on the sensor’s performance, insulated yarns can protect the sensor from shortcuts and dirt. Elektrisola insulates is tested for sewing. The yarn is fragile and easy to break, which is not ideal for knitting. It needs to be knitted with another yarn.

Spacer:

The spacer between the electrodes defines the pressure range and the resolution of the sensor (Viera, Petra, Havelka, & Marcela, 2018). Polyurethane foam, nonwoven, and 3D knitted spacer fabrics are commonly used as padding (in the middle layer) in car seats cover. (Viera et al., 2018). The 3D spacers show better mechanical durability and water vapor permeability than PU foam. Therefore, the 3D spacer is recommended be used in the testing sensors. Foams shows more hysteresis than other 3D fabric spacers, but negligible long- term drifting and creep. (Castano & Flatau, 2014) There is a change in capacitance between wet and dry spacers. The thickness of the spacer significantly impacts the sensitivity and sensing range of the fabric sensor. (Hughes-Riley et al., 2019). The 3D knitted spacer produced by Müller Textil, Germany is used in research (Meyer et al., 2010). The CrosliteTM, also referred to as Proprietary Closed Cell Resin (PCCR), is used as a spacer material in the sport socks to work under a higher pressure. Some material from the lab - the spacer knit with different thickness is also used for testing. The spacers under microscope are shown in Figure 2.2.19.

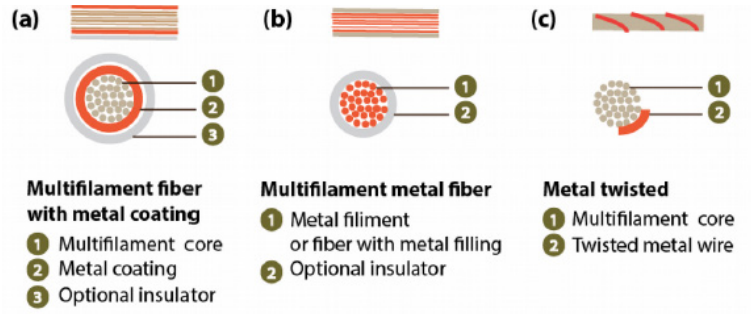


Figure 2.2.17 Structure of conductive yarn (Poupyrev et al., 2016)

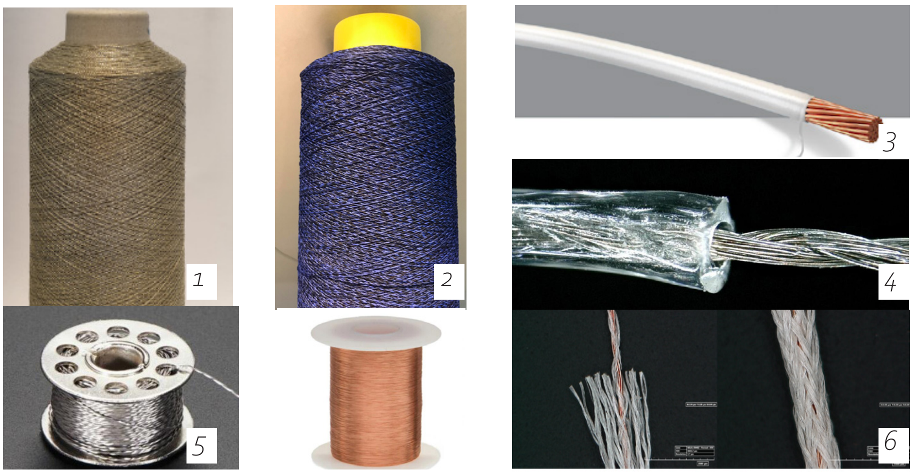


Figure 2.2.18 Yarns. 1. Silver coated yarn 2. Blue yarn 3. Elektrisola insulates (Conditions / Basics. (n.d.) 4. Shieldex® TPU Yarn (Shieldex TPU Yarns. 2020) 5. Stainless steel yarn 2ply 6. Jacquard yarn(Poupyrev et al., 2016)

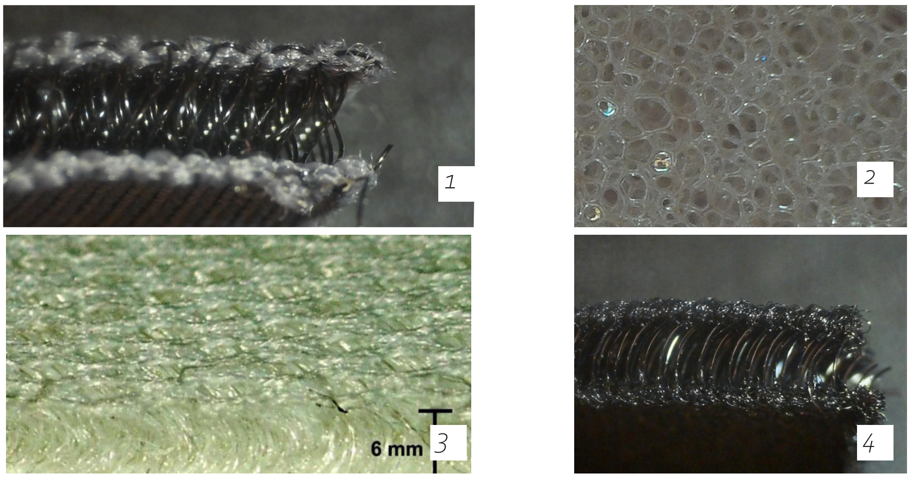


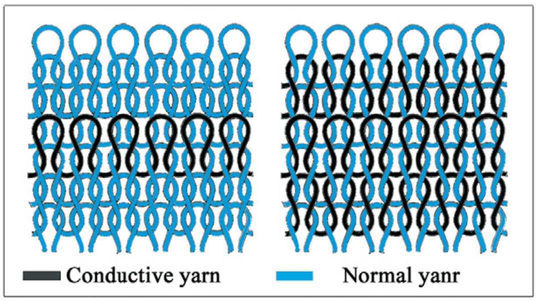
Figure 2.2.19 Spacer structure under micrscope. 1,4. Spacer knit 2. Foam 3. 3D knitted spacer in Müller Textil, Germany (Meyer et al., 2010)

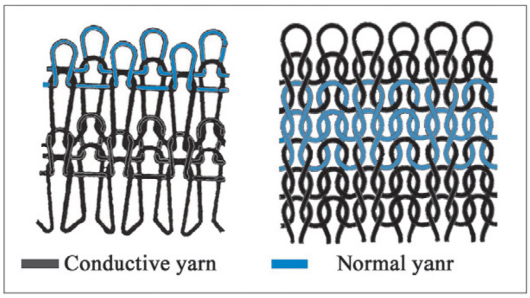
2.2.5 The knitting machine.

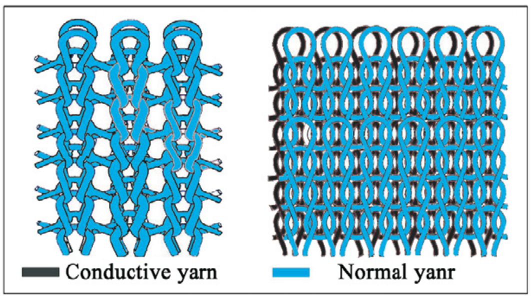
The two main methods, compared to the amount of produced materials, are weaving and knitting. While weaving is simply the interlacing of weft and warp yarns, knitting is done by the interleaving of loops. The Stroll knitting machine can do knitting fabrics. Structures of woven and knitting fabrics are shown in Figure 2.2.20.

For the creation of textile sensors that measure physiological signals, the 2x2 rib stitch and the full needle stitch are preferred because of their elasticity. Tubular stitch can also be used to separate conductive yarn. Compared to the plating stitch, the tubular stitch exists of two layers. (Daan 2020)

Figure 2.2.21.The knitting machine used (STOLL. n.d.)







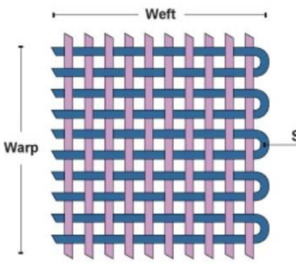


Figure 2.2.20. Fabric structures 1. Woven fabric () 2.Jersey stitch and color striping stitch. 3. Full milan double stitch and 2 × 2 rib stitch. 4. Full needle stitch and tubular stitch. (Li et al, 2009)

2.2.6 Textile used in automotive industry

Textiles have become the most widely used material in seat coverings and are beginning to be used in other areas of the seat in place of polyurethane foam. (W.F. Fung, 2001)

The essential requirements of car seat cover fabric are high abrasion resistance and resistance to UV degradation.

The products that would meet the criteria: abrasive wear, high lightfastness, were usually unexciting fabrics, probably piece dyes, which offered little design potential.(W.F. Fung, 2001)

Conductive fabrics knitted from conductive yarns also need to fulfill this requirement in order to be able to put on the market.

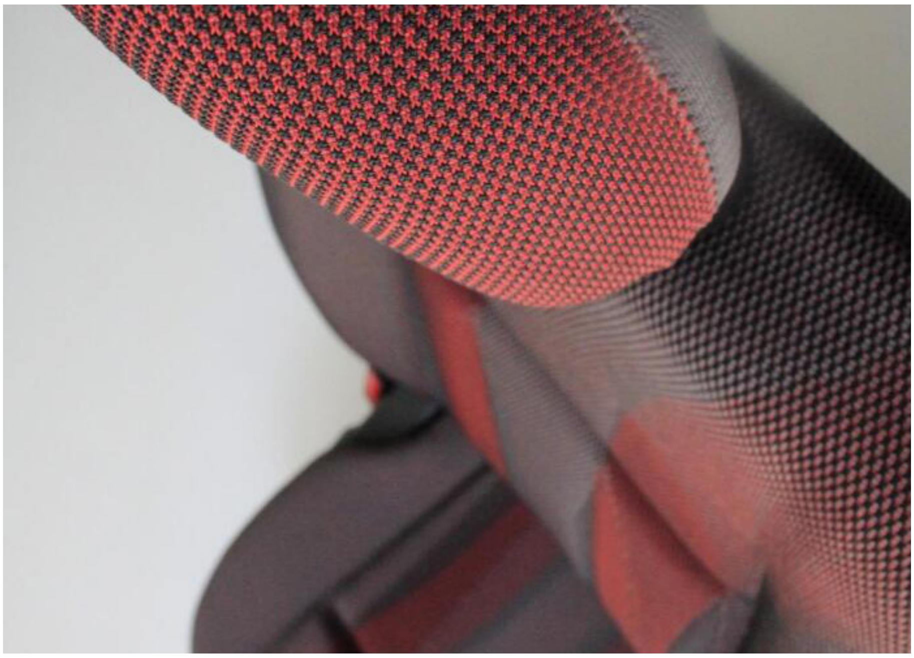


Figure 2.2.22 Fabric on the car seat.

2.2.7 The list of requirement

As the design is under the stage of exploration in lab, some requirements required in the using context are researched but will be wishes instead of requirements.

Requirements

1. Sensing range.

1.1 A pressure range of 0-25kPa for seating pressure sensing, based on the research on wheelchair users. (Hughes-Riley et al., 2019)
1.2 Pressure induced by sitting has been measured as up to 3N/cm2 in the pelvic bone region. (Meyer et al., 2010).

2. Material.

2.1 The sensing mat is made completely put of textile, with no or limited amount of plastic material.

3. Performance.
3.1 The sensor is able to detect at least 3 obvious posture change
3.2 A pressure distribution map is more important than the accuracy of each sensing element. This means all the sensors need to have a similar output when adding the same pressure.
3.3 Stability of the sensor. The fluctuation of the sensor value need to be within a range of 10 units.

Wishes

3. Automotive requirements.
Fulfilling the automotive requirements is the main challenge of smart textile. In particular, environmental tests may be a hurdle for smart-textile systems at the moment. The upper and lower limits of the parameters of temperature, humidity, vibration, and mechanical shock are defined in the specification book. [A]Some basic requirements for car interiors are listed below.

3.1 Temperature range: -40 to 105c
3.2 Humidity Up to 85%
3.3 Vibration: Depends on location, typically 20 g (RMS)
3.4 Mechanical shock: Typically 50g
3.5 Perform the ‘Coke’ test if implemented on the seat, which means functions should not be affected when a soft drink is spilled. (Wagner, 2013)

Key insights of 2.2

From analysis, the performance of electrode fabric should not be affected by water. As the sensors based on resistance change require open conductive electrodes, it can not be used to fulfill the wishes to be used in aurtomotive context without adding an insulation layer. Capacitive sensors can be affected by humidity, but there are still possibilities to have outputs. Making the effect in a durable range is a wish in this project.

Capacitance change sensors are chosen as a priority in the preliminary tests. The working principle is based on two layers pressure sensing. The structure used is the conductive stripes as it can be easily done by the knitting machine with enough width of the conductive stripesto ensure the contact area.

As mentioned in chapter 2.2.4, 3D knitted spacer fabrics are commonly used as padding (in the middle layer) in car seats cover and it shows better mechanical durability and water vapor permeability than PU foam. The 3D spacer is recommended be used in the testing sensors. As the spacer knit fabric has similar structure as the 3D spacer knit and is avaliable in the lab, the spacer knit material, foam, and cotton are chosen to test as spacer materials.

2.3 The added value of a new design

Considering the future development of the textile pressure sensor, a roadmap is concluded in Figure 2.3.1. For the market trends, "health on wheels" is considered necessary since 2000. This trend also led to the implementation of smart textiles in healthcare like ECG seats. Pressure sensing fabrics were also used to help wheelchair users to prevent the formation of an ulcer(Cherenack & van Pieterson, 2012). The trend of the interior design changes from "visible technology into "shy tech", pushing the technology into the background. (Heijboer, Schumann, Tempelman, & Groen, 2019) Smart textiles find value in this trend as the electrodes can be seamlessly knitted into the fabric and function without being realized.

Concerning the technology of the smart textile itself, there are three distinct generations to integrate electronics into textiles.
1. Adding electronics or circuitry to a garment
2. Functional fabrics such as sensors and switches
3. Functional yarns.

Most of the smart textile products are in the second generation. For example, the XSENSOR can provide accurate data for testing, with robustness and stable performance. Other aspects like the power source are one of the show stoppers of implementing smart textiles due to size, inflexibility, and not washable(Castano & Flatau, 2014). The adoption of E-textiles will depend on the cost. The development of graphene technology and carbon nanotubes is beginning to show some promise. (Hughes-Riley et al., 2019)

Many products are focusing on pressure sensing while making use of the data in daily life is still a challenge. The new product aims to make the smart textile sensor used in the long term, providing skin-friendly material to the user. Also, as a sensor entirely made from fabric, it shows the potential of the technology itself.

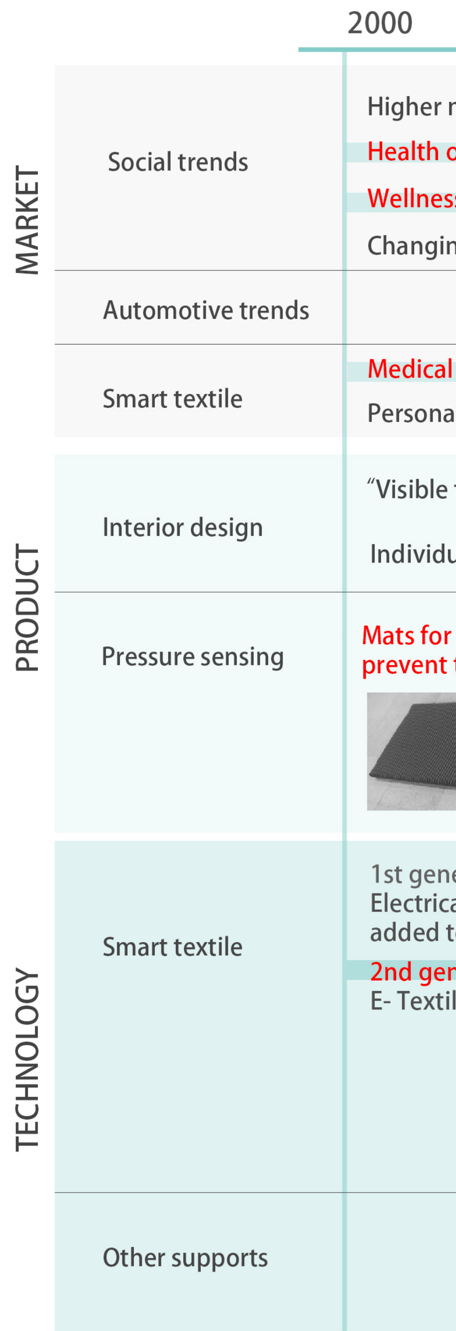


Figure 2.3.1 Technology road map

2010 2020 2030

mobility of people

Sustainability

on wheels

s on wheels

g age structure

Autonomous driving

Shared driving

care

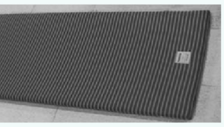
l safety

technology"

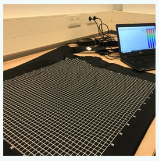
"Shytech"

alization

wheelchair users to
the formation of ulcer



XSENSOR



eration
al circuits or electronics
o garments.

neration
es

Use mobile phones as interface

3rd generation
Functional yarns

Incorporate all of the required
electronic systems within textile

Carbon nanotubes

Graphene technology

Power source

3. Preliminary Tests

After choosing the sensor structure used for testing, a set of tests is conducted to verify the sensors' performance.

The tests start with a single sensing element, changing the contact area and the spacer, to see how the electrode size and the dielectric properties affect the sensor.

- Test 1. Comparing the performance of a single-element capacitive sensor with different spacers. - Decide on the dielectric and compression property of the spacer.

- Test 2.Comparing the performance of a single-element capacitive sensor with different areas. - Decide on the electrode size

- Test 3. Checking the performance of the fabric sensing matrix. - Test the coding and make it work for the sensing matrix.

3. Preliminary Tests

3.1 Test 1

Comparing the performance of single element capacitive sensor with different spacers.

Method
Apparatus:
Hardware: Seeeduino Lotus.

Software: Arduino code for capacitance meter. (Basics, C. 2020,) Fabric Sensor: The sensor itself is based on the single sensing element structure. As a conductive layer, the Shieldex NoraDell woven fabric sheet with glue at the back is ironed on one 40 *40 mm cotton fabric. The contact areas of the conductive fabrics are 10*10, 20*20, 30*30 mm.

Different dielectric spacers are put between the conductive fabrics. The size of the spacer is 40*40mm. Eight spacer samples are chosen- foam with a thickness of 5.5 mm, 8.5mm and 50mm, cotton knitted fabric, spacer knit with a 2mm, and 3 mm thickness. The detail of the samples is shown in Table 3.1. Standard wires are tapped on the conductive fabric using copper tape. The sensor is then connected the sensor to Seeeduino.

Sensing principle:
The sensing element is sensing the capacitance change with two layers, as mentioned in Chapter 2.2.3. The Arduino will measure the voltage at the capacitor and record the time it takes to reach 63.2% of its voltage when fully charged (the time constant). The resistance value of the Arduino board is already known (28.48 ohm). The capacitance can be calculated by the formula

$$TC = R \times C$$

$$\begin{aligned}
&TC: \ Time\ constant\ of\ the\ capacitor\ (in\ seconds)\\
&R: \ Resistance\ of\ the\ circuit\ (in\ Ohms)\\
&C: \ Capacitance\ of\ the\ capacitor\ (in\ Farads)
\end{aligned}$$

Arduino, as a cap meter, is capable of sensing the capacitance change from 470 uF to 18 pF.(Basics, C. (2020,) After testing with a normal compactor, the code can measure the capacitance of 33pF with an accuracy of 90%. For the Arduino code refer to Appendix K. The code used in this test will also be used in the sensing matrix.

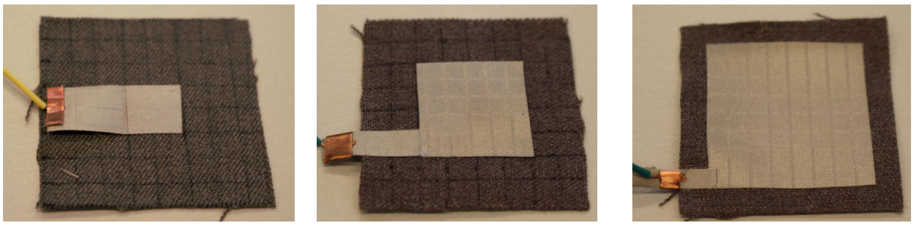


Figure 3.1 The testing samples with contact area of 10x10, 20x20,30x30.

foam	foam	shape memory foam	knitted cotton
Sample 1	Sample 2	Sample 3	Sample 4
			
20*20	20*20	20*20	20*20
8.5 mm	5.5 mm	50 mm	2 mm

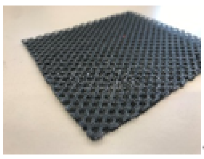
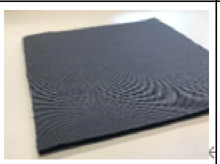
cotoon	spacer knit	spacer knit	spacer knit
Sample 5	Sample 6	Sample 7	Sample 8
			
20*20	20*20	20*20	20*20
5.5 mm	2mm	3mm	2 mm

Table 3.1 The property of the spacer samples

3. Preliminary Tests

A special container is constructed to put weights and apply a controlled and uniform pressure over the sensor (Pizarro et al., 2018). The container is constructed using a 3D printer, fed with standard polylactic acid (PLA) filaments. The dimension of the container is 40*40 mm2, the same as the size of the samples. For a detailed dimension of the container, refer to Appendix F. From requirement 3.2, the pressure range is from 0-3N/cm2 (30kPa). The weight required is calculated by the formular

$$p = \frac{F}{A}$$

p is the pressure (N/cm2)
F is the magnitude of the normal force (N)
A is the area of the surface on contact (cm2)

The required weight range is 0-4.8kg. Standard weights from 0-5kg are put in the container. Each sample is tested three times. Detailed testing data refer to Appendix G.

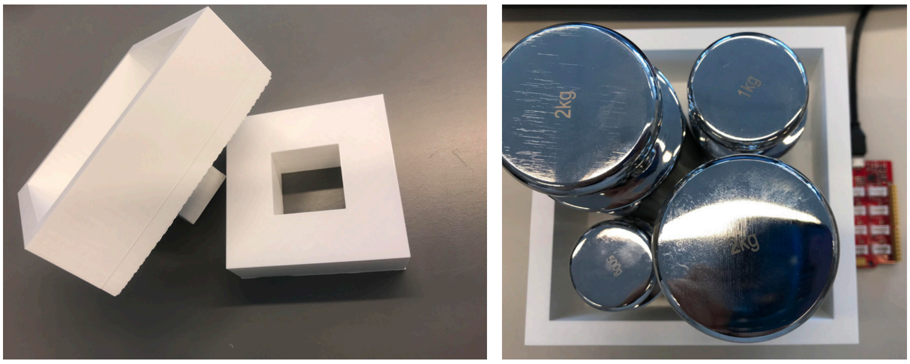


Figure 3.2 The special container made for adding pressure on top of the samples.

The measured capacitance of a single electrode is from 1 to 3pF of the 10*10 and 20*20 sample, 2-16 of the 30*30 sample when adding pressure from 0- 35kPa.
The testing result of the contact area 10*10 is shown in Figure 3.3. Sample 2 covers the most extensive capacitance range when adding pressure from 0-35 kPa. Sample 6, Sample 1, and Sample 3 show linear capacitance change compare to the other four samples. Sample 7 and 8 have a particular property with a sudden "crash" when adding pressure, leading to a sudden capacitance change. Sample 7 is thicker than Sample 8.
In Figure 3.3, it is hard to see sudden capacitance change in Sample 7. Sample 8 shows a capacitance change when the pressure is 20kPa.

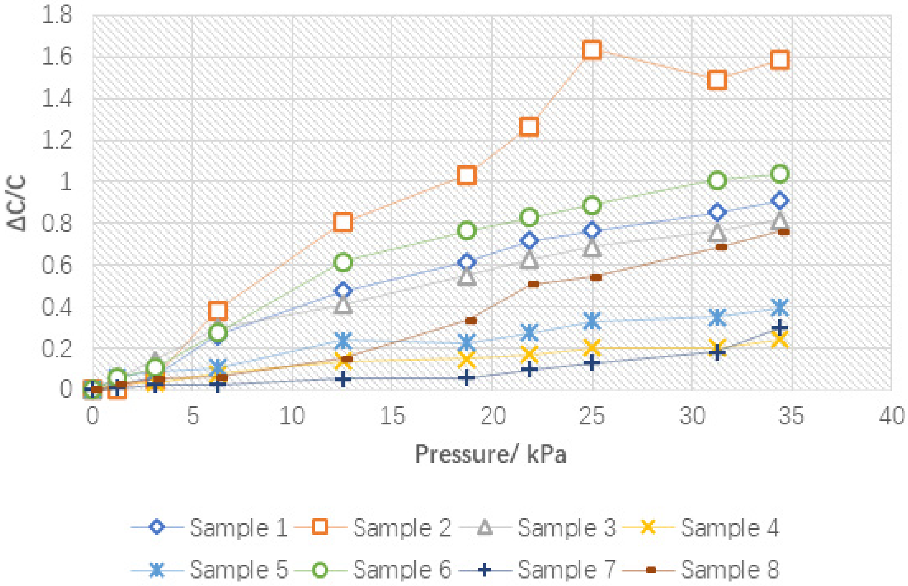


*Figure 3.3 The testing result of the contact area 10*10*

The testing result of the contact area 20*20 is shown in Figure 3.4. Sample 3 covers the most extensive capacitance range. Sample 2 and 3 also show a broad change of capacitance. A sudden capacitance change of Sample 7 happens when the pressure is 20kPa. It happens when the pressure is 22kPa in Sample 8.

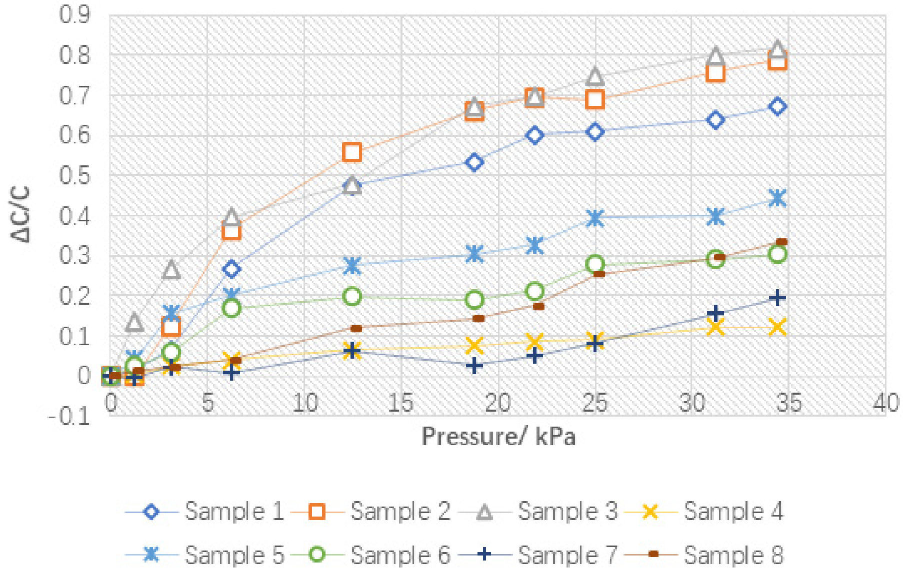


*Figure 3.4 The testing result of the contact area 20*20*

3. Preliminary Tests

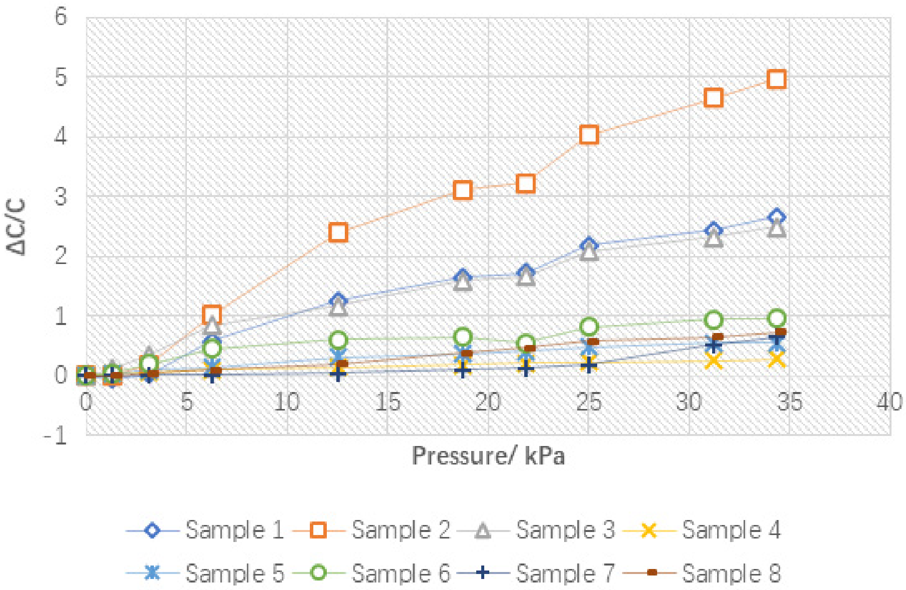


*Figure 3.4.2 The testing result of the contact area 30*30*

The testing result of the contact area 30*30 is shown in Figure 3.4.2 Sample 2 covers the most extensive capacitance range. Sample 1 and 3 show a similar capacitance change. A sudden capacitance change of Sample 7 happens when the pressure is 25kPa. Sample 8 did not show noticeable capacitance change.

From the test, it can be concluded that Sample 2, the foam spacer with 5.5mm thickness, shows the widest capacitance change when adding pressure from 0-35kPa. It is chosen for further testing.

Sample 1, the thick foam with 5 mm thickness, and Sample 3, the shape memory foam with 10mm thickness, shows a similar capacitance change performance. The dielectric property can be one of the reasons which lead to this result. Sample 1 is chosen for further testing because it is thinner, saving more space as a fabric sensor.

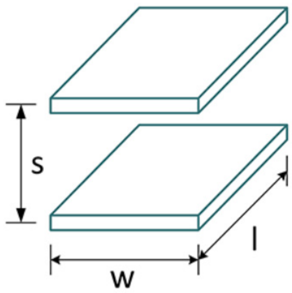
Sample 7 and 8 are chosen for further testing to check if the unique property in compression is reflected in the capacitance change.

A comparison of the same spacer sample with different contact areas is discussed in Test 2.

Test 1.5

The capacitance of two rectangular parallel plate can be calculated by the formula

$$C = \frac{\epsilon_0 \epsilon_r w l}{s}$$



Permeability of free space:

$$\mu_0 = 4\pi \times 10^{-7} \approx 1.25663706 \times 10^{-6} \text{ H/m}$$

The permittivity of air:

$$\varepsilon_0 = \frac{10^{-9}}{36\pi} \approx 8.8541878176 \times 10^{-12} \text{ F/m}$$

In Test 1, the w and l can be assumed as constant values. The relative permittivity of the spacer and the distance between the two conductive layers s are the parameters that can affect Test 1. Assume the ε_0 will not change when compressing, this Test 1.5 aims to find out how the s of the spacer changes when adding pressure. This change will be calculated through Yongs modular. The spacer sample Sample 1, 2, 7, 8 from Test 1 are chosen for this test.

Sample 1	Sample 2	Sample 7	Sample 8
			

Table 3.2 The chosen spacer for the further test

3. Preliminary Tests

The DMA Q800 V21.3 Build 96 is used for the compression test. The samples are cut into a cylinder with a diameter of 10mm. Each sample is compressed for three times. The instrument keeps compressing until the sample can not be compressed.

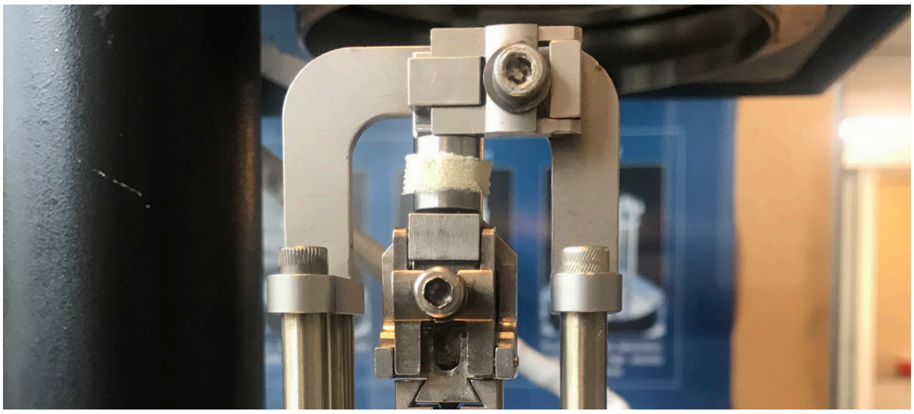


Figure 3.5 Machine used for the compression test

As shown in Figure 3.6, all four samples show two stages of compression—Young's modular increases when the displacement reaches a certain range. Sample 7 shows the effect of a crash in the graph, with a sudden decrease in displacement. Sample 8 did not show the crash effect. Sample 1 and 2 have similar Youngs modular on the two stages. Sample 1 is thicker than Sample 2, and the thickness leads to a bigger displacement. The applied pressure in Test 1 is from 0-35Kpa, which in this test is equal to the force range of 0-2.74 N (under the blue line). It means the spacers have not reached or juts reached the second stage of deformation. The displacement s is linear for Sample 7 and 8 and can show an increase in Sample 1 and 2 when the force reached 2N. (2.54N/cm2)

In conclusion, Sample 2 is chosen for further tests, as it shows similar performance as Sample 1, and its thickness is enough to cover the required sensing range of seating. Sample 7 is still kept as an exploration for further testing. For the testing data refer to Appendix M.

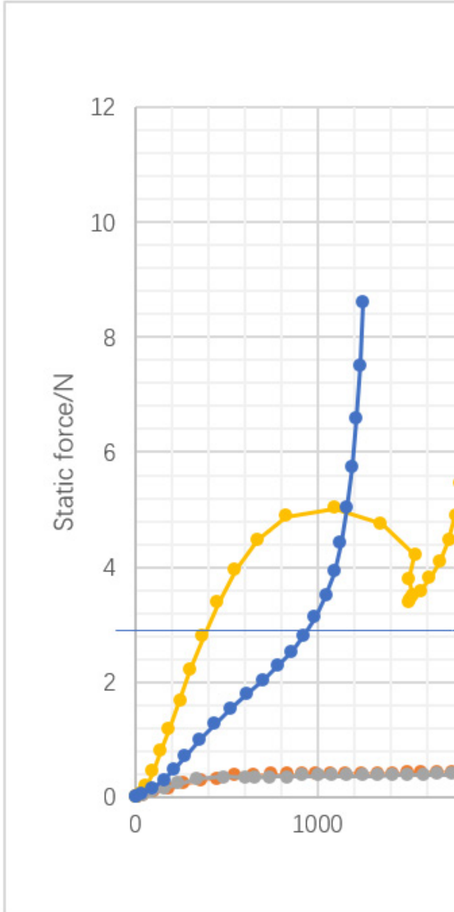
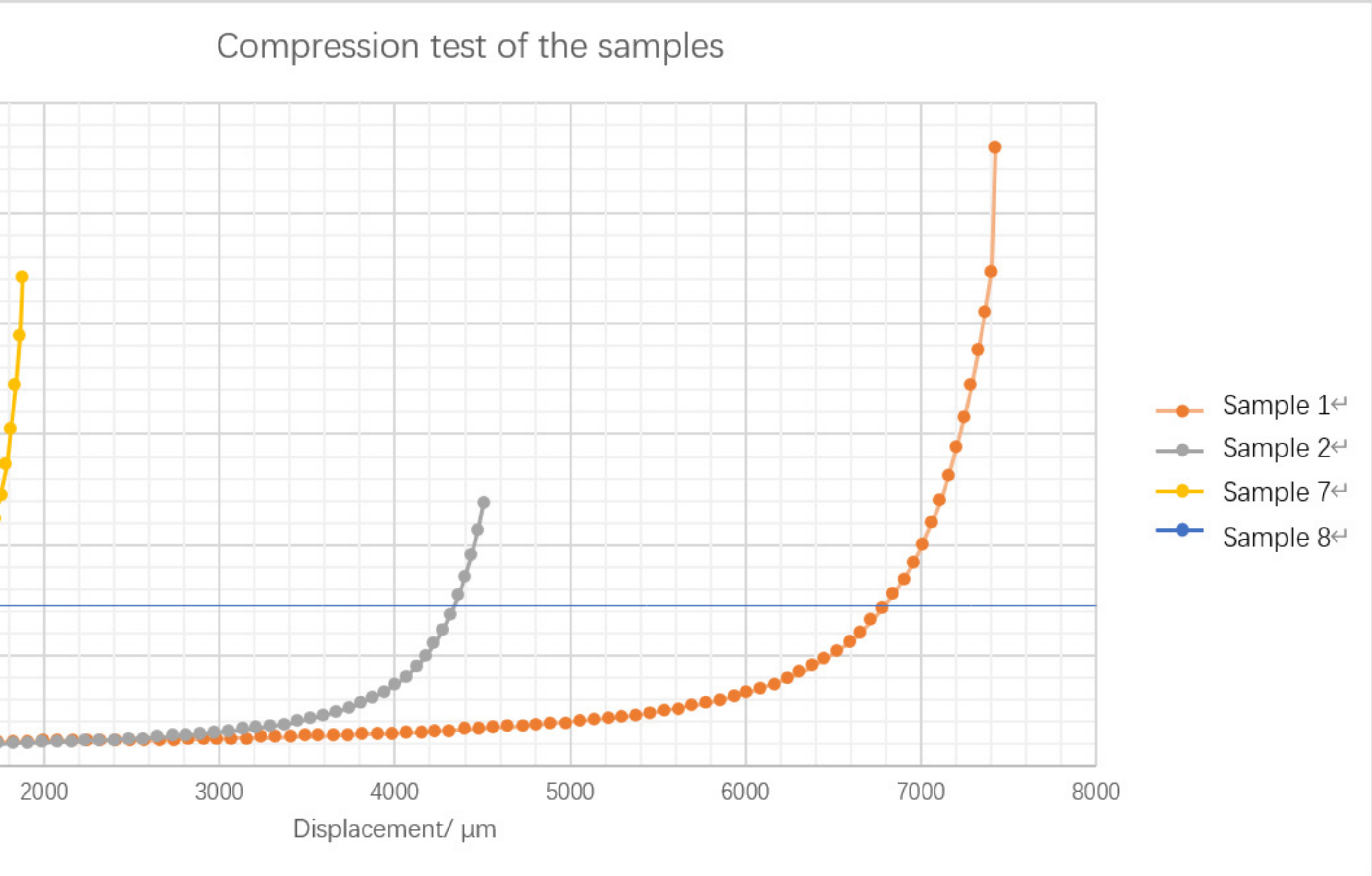


Figure 3.6 The property of different spacers after co


Compression test of the samples
2000
3000
4000
5000
6000
7000
8000
Displacement/ µm
Sample 1
Sample 2
Sample 7
Sample 8

mpression

3.2 Test 2

Comparing the performance of single element capacitive sensor with different areas.

The area of conductive material is another parameter that needs to be decided. The test aims to check the performance of different contact areas to decide the fabric pressure sensor's final pattern.

Research (J.Meyer 2010) shows that the smallest part of the buttock, back, legs, and upper arms (bone at the buttock) can be recognized with a resolution of 30 mm *3 0mm. The research used the electrodes of 20mm*20mm. The needle defines the grid distance of 2.7 mm during the embroidering process. Research (03 M. Sergio 2002) used the width of 8mm of each sensing stripe, which is about the same as the tactile resolution of human back skin. Research (Theodore Hughes Riley 2019) included five complete 12 mm wide knitted silver conductive electrodes, separated by 12 mm.

From the researches, the effect of the contact area and the gap between the stripes are not further researched. However, the size of the contact area and the gaps are affected by manufacturing aspects and ergonomic aspects.

The chosen contact area ranges from 8mm* 8mm to 30mm*30mm, and the gaps are from 2.7mm to 12mm.

Smaller contact areas (8mm) are used as a demonstrator of touching, and bigger ones (20mm) are used for seating.

For the testing samples, three primary contacting areas are chosen for texting: 10mm*10mm, 20mm*20mm, 30mm*30mm. Spacer sample 2 and sample 7 are used.

Figure 3.7 shows the capacitance change of samples with spacer Sample 2. There is not a big difference in capacitance with contact area 10*10 and 20*20. When the contact area increases to 30*30, the capacitance increases. Based on the formula in Test 1.5 $C = \frac{\epsilon_0 \epsilon_r w l}{s}$

The increase of contact area (w and l) should result in an increase of capacitance in proportion. However, it is not reflected in the testing data.

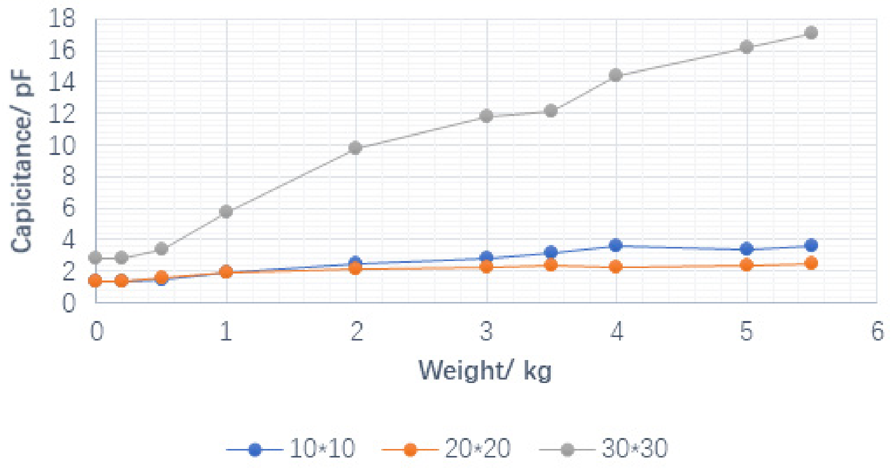


Figure 3.7 The capacitance change of samples with spacer Sample 2.

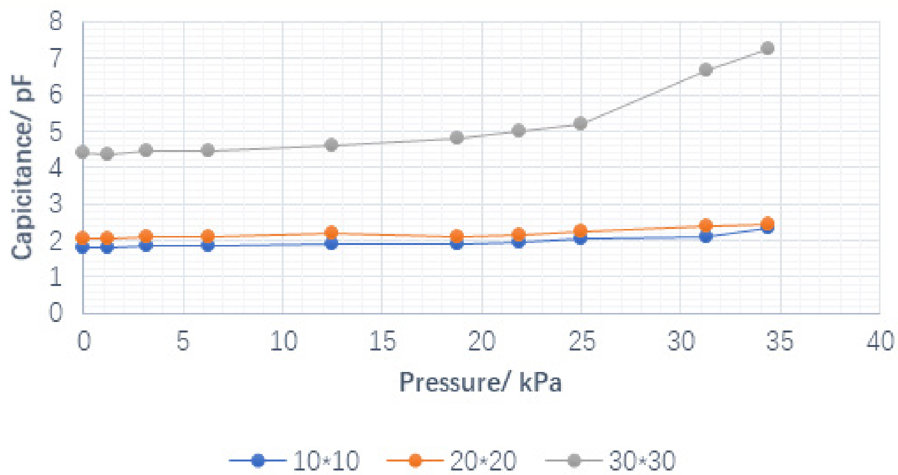


Figure 3.8 The capacitance change of samples with spacer Sample 7.

Figure 3.8 shows the capacitance change of samples with spacer Sample 7. The contact area of 30*30 shows a visible capacitance increase when the pressure reaches 25kPa, which matches the result in Test 1.5. The crash effect of Sample 7 also happens under the pressure of 2.54N/cm2 (25.4kPa).

Like Sample 2, the contact area of 10*10 and 20*20 does not show a big difference in capacitance. The data of contact area 30*30 did not show a proportional increase of capacitance. The reason can be that the container used for adding weight leaned on one side of the sample, which affects the accuracy of pressure. It can also be that the capacitance change is too small, and the accuracy of the capacitance meter is not enough. A further test is required to decide on the contact area.

3.3 Test 3

Checking the performance of fabric sensing matrix.

After testing with a single sensing element, the feasibility of the sensing matrix is tested. The principle of the sensing matrix is shown in Figure 3.9. The sensing matric structure can refer to the conductive stripe matrix in Chapter 2.2.3.

Each capacitor has been made with the coupling capacitance between two conductive strips separated by a dielectric spacer. When the dielectric layer between a given row and column of electrodes is squeezed, as pressure is exerted over the corresponding fabric area, the coupling capacitance between the two increases; by scanning each column and row, the image of the pressure field can be obtained. (M. Sergio, 2002)

A lot of existed demos from Arduino Blog are based on one side capacitance sensing- which can be used for touch sensing mat (Team, 2019).Their approach shows that it is possible to take turns sensing the capacitance between rows and lines. Researches like (Hughes-Riley, Oliveira, Morris, & Dias, 2019) are conducted based on two sides sensing, using software like Agilent 4192A LF independent ananalyzer. Arduino is not usually used as a sensing software in researches but more in DIY websites. The coding in this project also refers to the code from (Basics, 2020a) and ("Pressure matrix code + circuit,"n.d.).

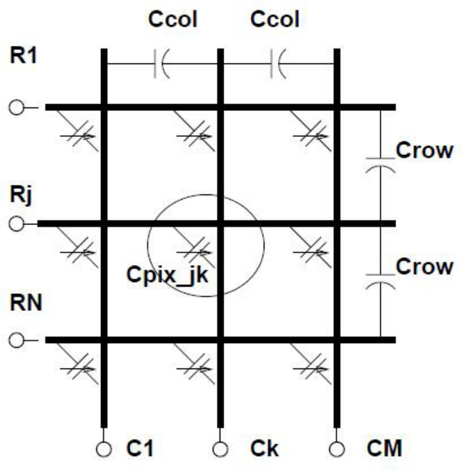


Figure 3.9 Sensing matrix (M. Sergio, 2002)

A fast prototype is made from the cotton fabric and Shiedlex NoraDell woven fabric used in Test 1 and 2. Four conductive stripes with 10mm wide are ironed on a piece of 80*80 mm cotton fabric. Standard wires are connected to the fabric using copper tape (Figure 3.10).

The sensing matrix has four cols and four rows. The spacer Sample 2 and 7 are used for testing.

The board Seeduino Lotus is used. The data output from Arduino is transferred into greyscale colour change using Processing. Processing is a software that is fast to download and easy to operate.

After some testing iterations with the coding, the fabric sensor can show the colour change when a finger presses it. (a higher pressure leads to a more significant capacitance and a darker square in the picture).

The result proves the code working. Further developments are based on this code. At the same time, some problems need to be solved:
1. The sensing data can be affected by the touch sensing principle as the finger is also conductive.

2.The output is not stable and disappears after a few seconds.
These problems will be solved in further testing.

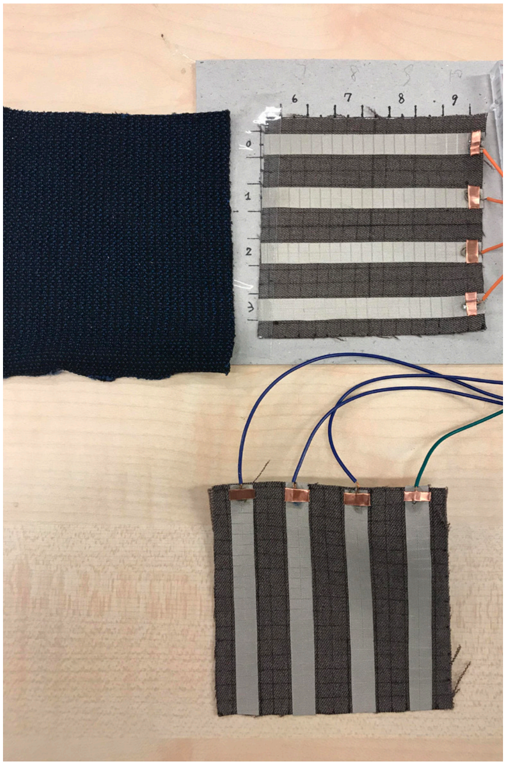


Figure 3.10 The sample used for testing the sensing matrix

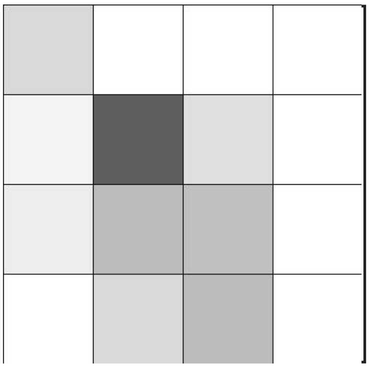


Figure 3.11 The pressure map of the 4x4 matrix sample

3.4 Key insights

The three tests helped with making some decisions about the fabric sensor. The four crucial aspects that need to be decided are the property of spacer, the dimension of conductive stripes(the contact area of the conductive layer), the code for the sensing matrix, and the knitting &sewing technique to make the fabric pieces. An overview of all the tests is shown in Figure 3.12.

Test 1 narrowed down the number of spacers that can be used. Spacer **samples 1, 2, 7, 8 are chosen to do further testing.** Test 1.5 goes deeper into the compression performance of the spacer materials to see how the compression affects the capacitance change. In conclusion, **Sample 2 - the foam spacer is chosen for further tests. Sample 7, the spacer knit material, is still kept as an exploration for further testing.**

Test 2 compares the capacitance of the same spacer with different conductive contact areas. **More tests are required to determine why the capacitance does not show an increase from the contact area 10*10mm to 20*20mm.** One reason can be that the capacitance is in pF, which is very small; the accuracy of the Arduino capacitance is not able to sense the difference.

Test 3 **made the code of sensing matrix works and visualize the pressure distribution by grayscale color change.**

The knitting samples are not made yet in this stage. The tests are conducted using conductive stripes ironed on top of a cotton fabric. The knittng is tested in the next stage. The simple prototype already makes a start for the fabric pressure sensing. The hardware and software are both ready for the next stage. The sensor is further developed under the second stage - prototype iteration, which will be discussed in Chapter 5.2 and 5.3.

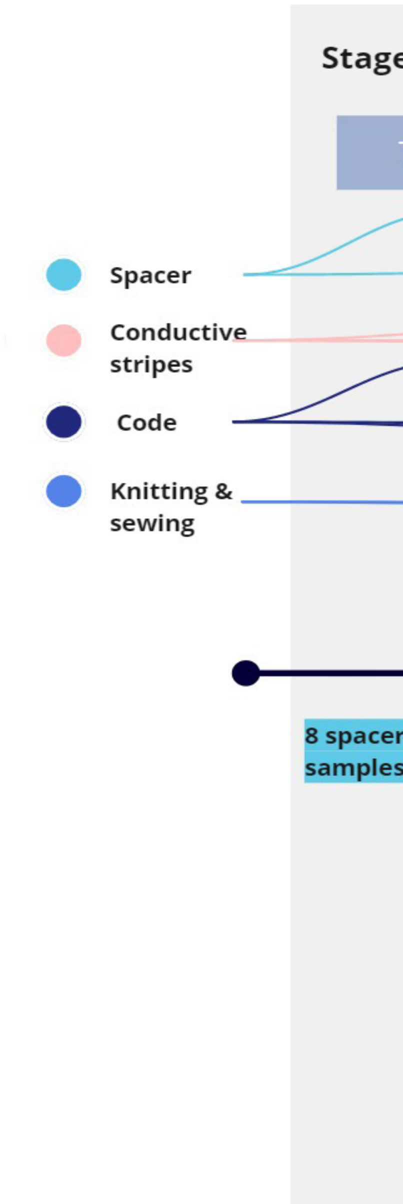
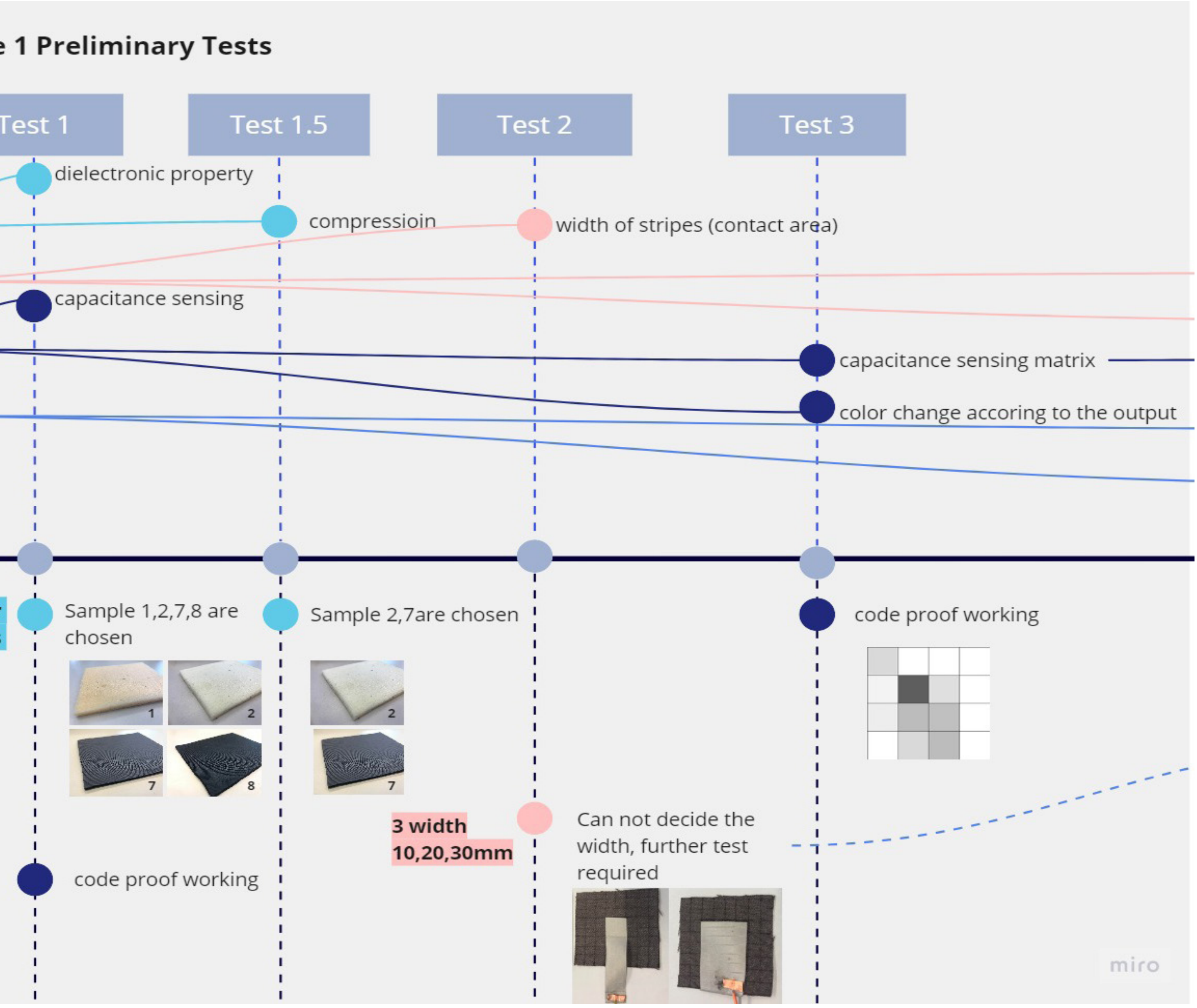


Figure 3.12 Overview of the preliminary tests


e 1 Preliminary Tests
Test 1
Test 1.5
Test 2
Test 3
dielectronic property
compressioin
width of stripes (contact area)
capacitance sensing
capacitance sensing matrix
color change accoring to the output
Sample 1,2,7,8 are chosen
Sample 2,7are chosen
code proof working
3 width 10,20,30mm
Can not decide the width, further test required
code proof working
miro

4. Synthesis

After analyzing the user's need, checking the working principle of the pressure sensor, a narrowed place in the car interior- the car seat is chosen as a more specific place to use the textile pressure sensor.

In the synthesis phase, the structure of a car seat is researched. It helps to determine where and how to put the pressure sensor.

Then, two concepts are generated. The two concepts have two target groups. The lumbar support focuses more on the driver, while the sliding seat focuses more on the passengers. There is no ideation in the synthesis phase, as the underlying user needs are analyzed, and the problem is reframed:

Doing nothing in the car - seating comfort - people are physically unware of the interior support and can relax without worrying about adjusting the interior - monitor the pressure in an ideal pressure distribution.

Singing in the car - boredom - free dwelling in the car - use feedbacks and interaction.

The fabric pressure sensor finds its way of application through these two concepts.

After analyzing the strength and weaknesses of the two concepts, the first concept, the lumbar support, is chosen for further development.

4. Synthesis

4.1 Structure of the seat

The traditional method of seat making involves cutting and sewing of panels of the seat cover laminate (face fabric/foam/scrim) into a cover, which is then pulled over the squab (seat back) and cushion (seat bottom) and then fixed in place using a variety of clips and fastenings.

The first element of the seat is the frame, composed of a backrest and a cushion, slides for depth adjustment, and posture and adjustment mechanisms. The covering of the frame is divided into two parts, a polyurethane foam cushioning and a cover material. The cover can be made by three layers - surface polyester fabric (weaving, knitting, AlcantaraÒ, leather), polyurethane foam, and polyamide knitting. This structure makes it easy to insert sensors into the car seat. (Drean, Schacher, Adolphe, & Bauer, 2008). As shown in Figure 4.1, the textile pressure sensor can be added into the cover as a part of the seat, or under the cover, along with the cushion layer. It can also be a seperate product which connects to the seat. The cushion layer is soft and provides more freedom in adding electronics.

Figure 4.1 Exploded view of a typical modern car seat, BMW 3 Series 328i (A2mac1 2014) (Jakob Steinwall, 2014)

4.2 Concepts

From the analysis phase, three key players are concluded, and the design focus more on the user - the driver and the passenger. Their user needs are analysed, and the meaning of doing nothing refers to a comfort feeling. The posture- pressure - movement is concluded as the relatiionship of the seating comfort. The two concepts focuses on two key stakeholders: **The driver and the passenger**. The health problem of the driver, and the bordem of the passenger are the two questions need to be solved.

Based on the vision of providing a comfort environment to make the user "free dwelling in the car", at the same time , using pressure sensor as a core technology, as shown in Figrue 4.2, two concepts are generated.

The first one focus on the driver and posture, as a poor posture is the direct cause of the health problem of the driver. The second one focuses on the passenger and movement, as the movement is one way to reduce the discomfort caused by long time sitting. At the same time, movement as a way of interaction with the context can bring more fun elements to the passenger.

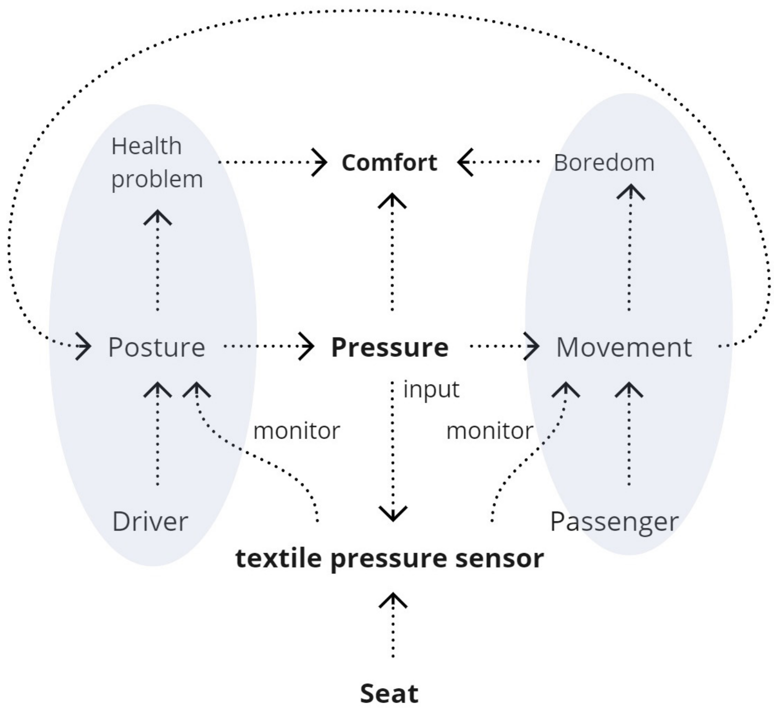


Figure 4. 2 Overvew of the idea generation

Concept 1 Lumbar support

Lumbar supports are conventional methods to improve the seated postures in health care. Use of a lumbar support pillow that allows space for the posterior pelvic bulk significantly decreased lumbar flattening during sitting in healthy individuals. (Diane E Grondin John J Triano, 2013). Research shows that back and leg pain were significantly reduced when sitting with a lordotic posture. Referred pain shifted towards the low back—in general, sitting environments a lumbar roll results in
1) reductions in back and leg pain;
2) centralization of pain.

The idea is to design a Lumbar support, which is as one part of the car seat. Use the advantage of the textile pressure sensor in large area sensing. As shown in Figure 4.3, the Lumbar support has pressure-sensing textile covered on the surface, measuring the pressure input of the lower back. The shape of the support will change according to the pressure input, maintaining the pressure of the lower back in the ideal pressure range. The aim is to provide privacy and protected feeling to the user. The support functions as a modular part of the seat. It is connected with one cable for power and can be washed separately.

The added value of this support is
1. It senses pressure change in a large area, providing pressure distribution on soft surfaces.
2. It uses textiles as the pressure sensing method in daily life, not only in the testing phase or short-time use.
3. It provides personal support through measuring specific people and can change the support over time when people are doing other tasks.
4. The driver is the one who is always in the car. The lumbar support also "forced" him or her to sit in a healthier posture, which improves the driver’s health in the long term.
5. The support is integrated into the car seat as part of the interior, which also prevents the third company from making separate lumbar support. It also shows a brand image of caring about "health on the wheel" and value the well-being of users.

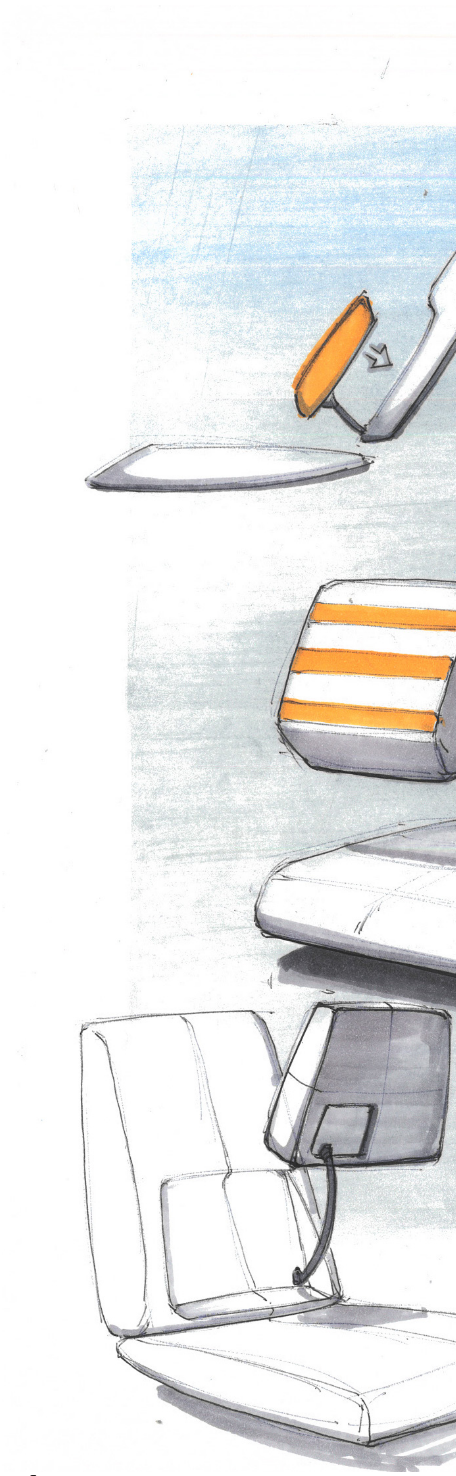
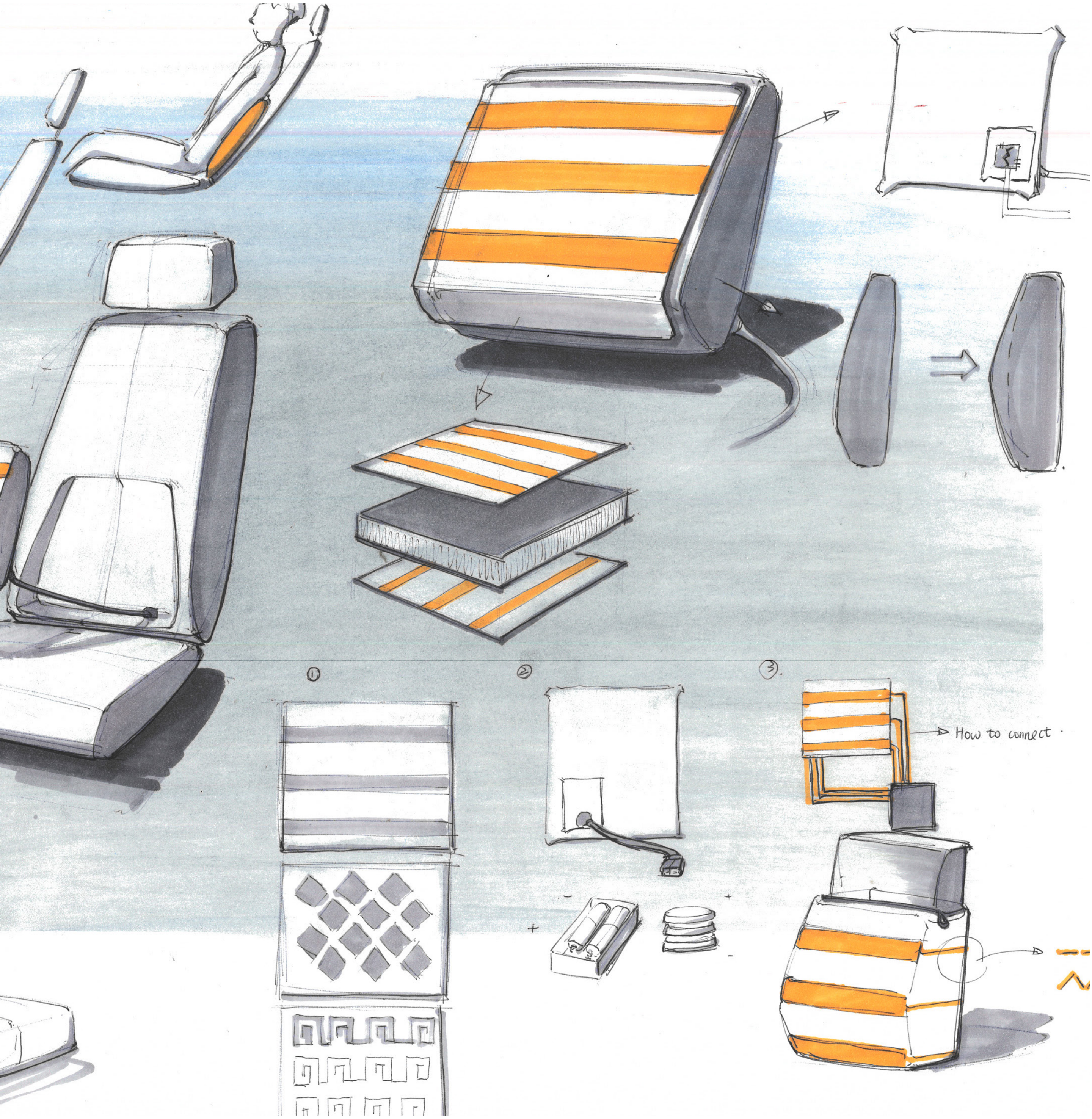


Figure 4.3 Concept 1


How to connect

Concept 2 Silding seat

The second concept focuses on passengers. As the rear seats have more freedom of moving, the movement can play a more critical role. Inspired by the camping chair shown in Figure 4.4, the pressure changes when people want to relax, and leaning backward can be an input for the chair to slide down. The no driving-related interaction makes use of the pressure change and provides more movement to people. The adding movement can reduce the health problem caused by long time seating.

As shown in Figure 4.5, as the sliding mechanism is for passengers, it also adds interaction between the passengers when more than one person is sitting at the car's back seat. They can "wave" up and down, promoting fun activities. The interaction also reflects the condition of the passenger through his or her posture. For example, when the passenger would like to rest and do not want to be disturbed, they can "slide down." This interaction does not require any buttons or extra control, and the seat can adjust the angle according to the pressure change.

The added value of this concept is making use of the posture change lead to pressure change. Use the seat's movement as feedback, creating an interaction in which technology plays a role as a background, and showing the feeling of humanity. The interaction between passengers through posture change and movement of the seat can not only add fun but also a way of communicating. It can show the feeling of the passenger. The pressure-sensing mat is put both at the bottom and the back of the seat, measuring the pressure change to predict the user's posture. The sensing mat is fixed as part of the seat. If the car is equipped with seat covers, the performance of sensing will be affected. A textile sensing mat also shows its value in do not require extra protection and being able to be robust enough to stand the daily use in the car. As it is made from textile, it is air permeable and friendly to the skin.

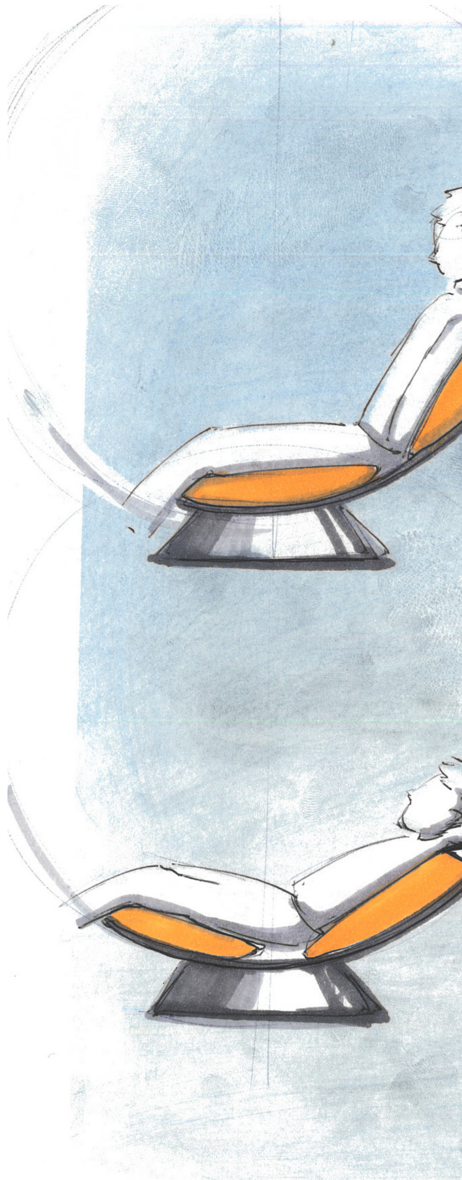


Figure 4.4 The camping chair

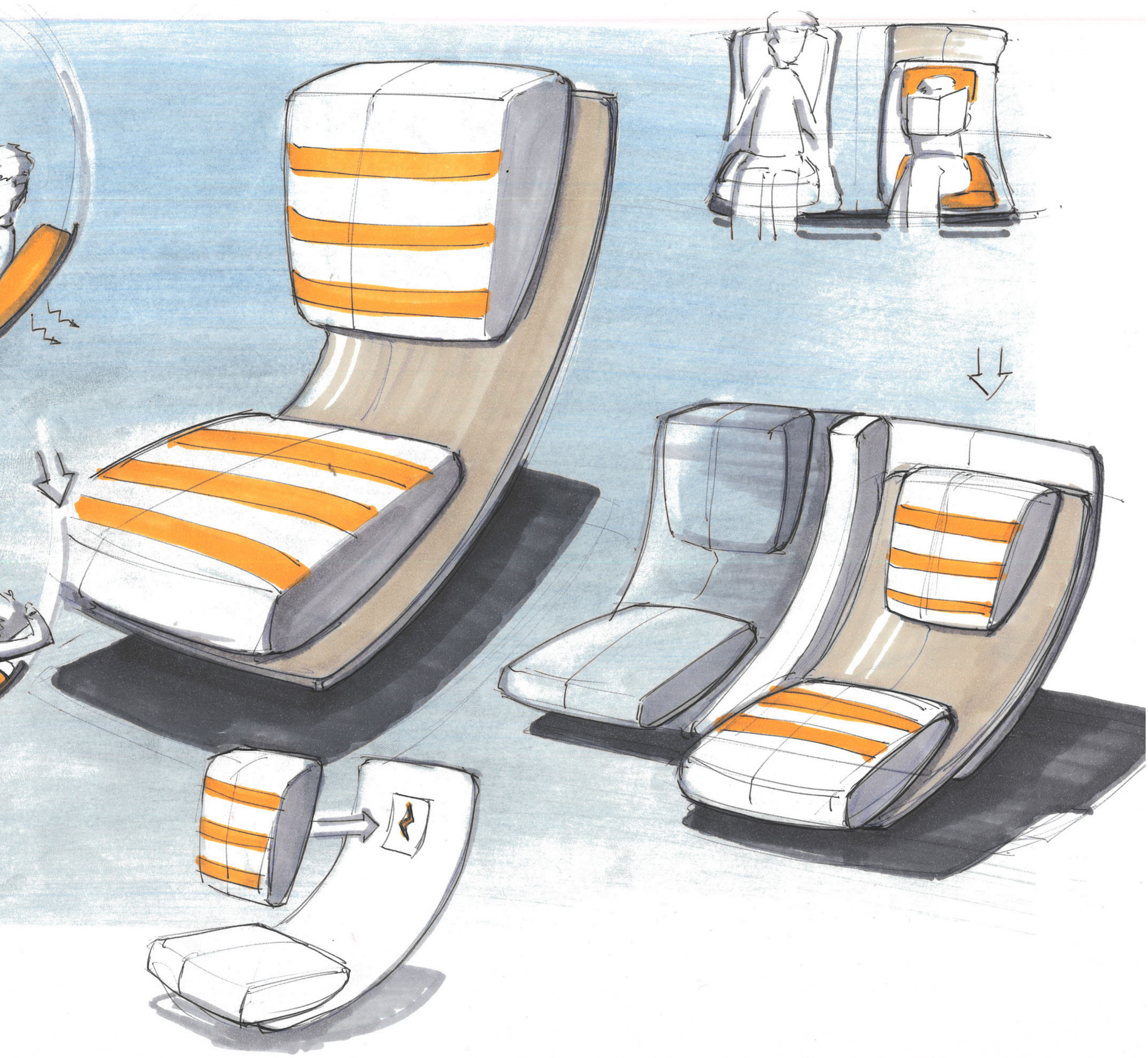


Figure 4.5 Concept 1

How -Tos

There are several "How-Tos" that need to be considered for the prototyping and the final product.

1. How to vary the pattern. If the user wants a different pattern for aesthetic reasons, will the change of pattern?

2. How to connect the fabric into conventional electrodes. Copper tape is used in the Preliminary tests. However, it is not robust enough for daily use.

3. The fabric pressure sensor will be in the end, look like a mat. How the layout should be, and how to connect the stripes to power?

The How-tos are explored in the embodiment phase. Some tests are conducted to make decisions.

4.3 Concept selection

As the first goal of this project is to make the textile sensor work, choosing a concept that needs to be made in an early stage so that the exploration can go deeper into the prototyping phase. Simultaneously, as described in the co-evolution model, the chosen concept will be further elaborated.

The PMI(Plus - Minus - Interesting) method is used to choose from which concept goes further. The positive, negative aspects are listed. What makes the concept interesting is also considered. The project aims to demonstrate the possible implementation of the textile pressure sensor; being able to make a working prototype is also considered as criteria.

As shown in Figure 4.6, the PMI is generated for both concepts. The second concept shifts the focus of the sensor itself into the entire seat structure. Considering the aim of the project is to make the sensor working in context, the first concept shows a more definite direction of how the sensor as a stand-alone technology can be used in the seat. Also, the driver's focus is more representative as the driver's role is always necessary for both ordinary and autonomous cars. Therefore, Concept 1 is chosen for further development.

	Concept 1- Lumbar support	**Concept 2- Sliding seat**
Plus	+ Driver is the one who is always in the car. A lumbar support can be widely used + Has small change in the car interior	+ Detecting big posture change has lower requirement of the pressure sensor than measuring pressure distribution. + The sensed data is directly used as a means of feedback
Minus	• Requires more accurate output from the sensor. • There are existing supports on the market that can fulfill some of the user needs.	• Requires more changes in the car interior, including car seats and other structures. • For showing a working prototype, the focus is not only on the pressure sensing but also the sliding mechanism.
Interesting	• Combining the pressure measuing and shape changing technology. Make use of the soft property of the fabric sensor.	• Adding interactions between users, providing another way of communicating.

Figure 4.6 Comparing the two concepts

5. Embodiment

The technical part of the pressure sensor and the concept of implementation are developed parallel during the embodiment phase.

For the technical aspect of the fabric pressure sensor, further tests are conducted in Chapter 5.2 to knit the conductive fabric pieces and conduct a pilot test the sensor with people.

Chapter 5.3 goes more in-depth to solve the problems that occurred during the pilot and iterate on the prototype. The problems like insulation, connecting the power, calibration, and basic sewing techniques are included. The sensor samples are finally tested with five people (2 male, 3 female).

For elaborating on the concept, some further researches are conducted regarding the knowledge of ergonomic - where is the lumbar region. Also, the benchmark lumbar support products are analyzed.

After considering the car company, which is also a key player in the stakeholder analysis, the chosen concept is elaborated. Athesitics aspects like pattern and shape of the product are considered. A primary concept of service of the product is generated.

5. Embodiment

5.1 Further research

Where is lumbar region?

The lumbar region (lower back) of the spine consists of five vertebrae labeled L1 through L5. The lower back region contains large muscles. When the muscles spasm or become strained, the back pain will happen.

To make the sensing matrix that covers the lumbar region, the size of the sensing matrix need to be decided to fit the area of a lumbar support.

As the area of the lumbar region differs a lost from individuals, some existing lumbar supports on the market are used for deciding the size of the sensing mat. The sensing mat is only used for sensing pressure from one direction, and a support with a smilple shape is chosen (Matchu Sports Back-Sand Lumbar support,n.d.) as shown in Figure 5.10.

The support is used for a rough size reference. To cover the area of lumbar, the fabric sensor needs to be at least 30cm long and 25 cm wide. The sensing mat for seating is measured based on the seat of a BMW car. The size to cover the seat is 40*40 cm. The width of the sample depends on the pattern- the number of strips, the width of each stripe and the gap between stripes. It is explored in Test 1.

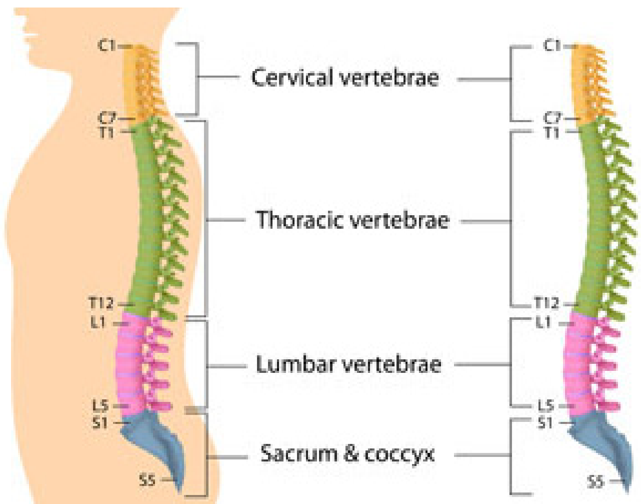


Figure 5.1 The lumbar region

5.2 Further tests

Test 4 Test the way of knitting using the knitting machine.

For the prototype, this project aims to make the sensor entirely out of fabrics. Knitting the stripes with conductive yarns and ordinary yarns must be tested to make the final sensing mat.

The samples are made with the same dimension and pattern as the matrix in Test 2. The conductive yarns are silver conductive yarn, and the non- conductive one is blue cotton yarn. The stitch is the interlocking stitch. The knitting machine used is STOLL CMS 530.

The reason for choosing the interlocking pattern is to keep the conductive pattern on one side of the fabric. A test is done in the knitting machine knit the conductive stripes only on one side. The result was not ideal and some jump wires happens. Conductive yarn broke during the knitting. A final decision is made to use the interlocking pattern still and knit the conductive stripes on both sides of the fabric. The testing sample is 80*80 mm, with four 10mm width conductive stripes. The gap between the two conductive stripes is also 10mm. A fabric piece under the microscop is shown in Figure 5.3.

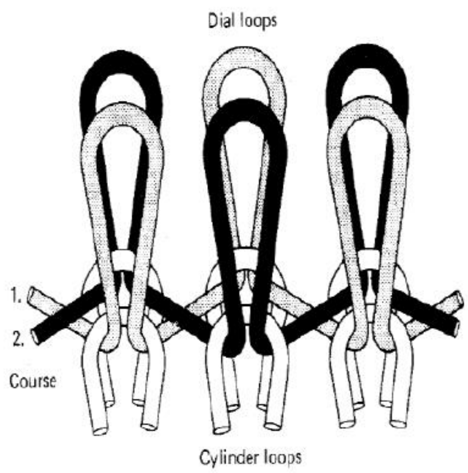


Figure 5.2 The interlocking stitch

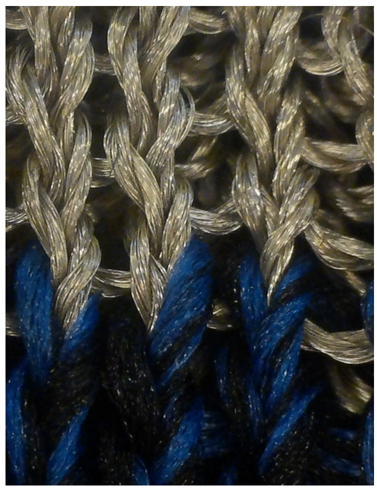


Figure 5.3 The knitted sample under microscope

5. Embodiment

The new sample is with the interlock stitch is robust and ideal as a demonstrator. Bigger samples are knitted for testing. Based on the estimation in Chapter 5.1., fabric pieces with patterns shown in Figure 5.5 are knitted. A normal piece of cloth is stitched around the fabric to form a "bag" to put the spacer. The silver conductive yarn is also used as a function of wire as shown in Figure 5.4
In conclusion, it is recommended to use an interlock stitch and straight stripes pattern at the start of the prototyping. The silver yarn is also possible for stitching in a regular stitching machine. It is also recommended to knit one stripe first and measure the width. The size is not scalable by changing the number of the stitch. Always measure before knitting the final product. The number of stitches used in each sample can be found in Appendix M.

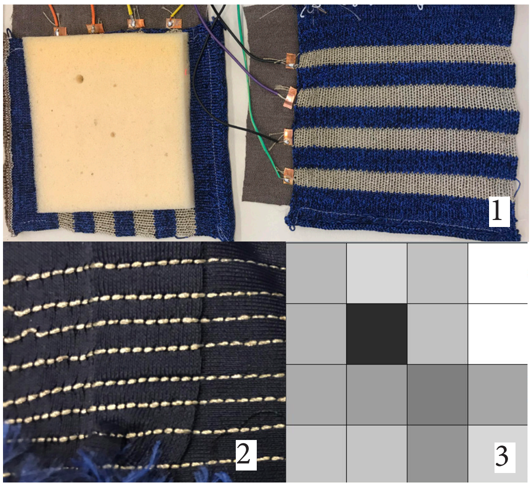


Figure 5.4 1.Testing a small piece of knitting sample 2.Stitching with silver coated yarn 3. Output of the sensing matrix

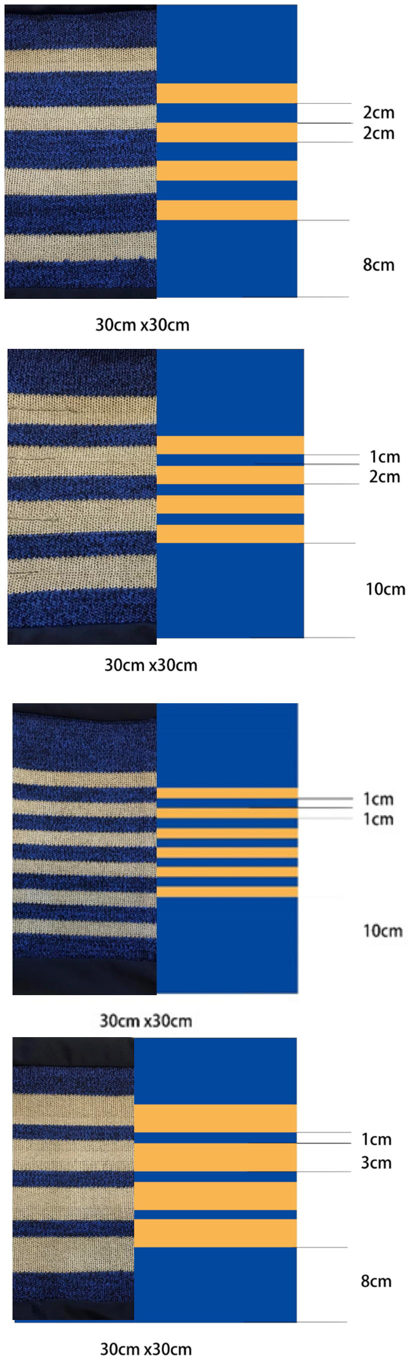


Figure 5.5 Knitting sample with four different patterns

Test 5 How to connect the fabric with normal electrodes?

Connecting the textile threads with normal electrodes is always the hard part. There are different ways of connections in researches. Crimping, soldering, epoxy glue are usually used for connection. The difficulty of this matrix is that it requires a lot of connecting points for every stripe within a limit space. Research (Maurin Donneaud, 2017) in Figure 5.6 used normal PCB piece to connect the threads and use a plastic film as insulation. The research also made a ribbon and use embroidery to connect the stripes. As shown in Figure 5.6. The embroidery create robust connection and is stretchable.

Considering the instrument in the lab a normal stitching is possible. Soldering, copper tape and conductive glue are tested for ways of connection. Crimping method is also tested as shown in Figure 5.7.

The copper tape and conductive glue are not robust enough and the wire quickly pills off after a few times of moving. The glue can lead to shortcuts as the liquid drop flows and is hard to control before it dries. Soldering with silver yarn cannot be done as the yarn gets burned and the connection is lost.

The crimping method is chosen for connection as it is able to form strong connection and will not lead to shortcut between the yarns.

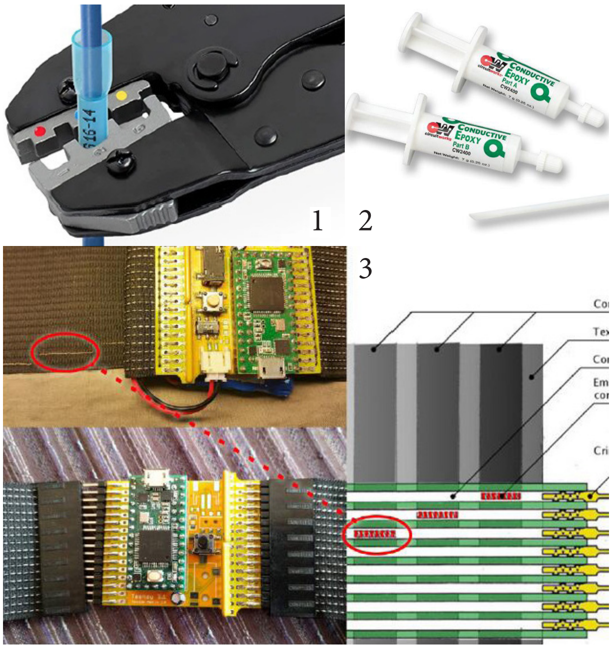


Figure 5.6 Ways of connection. 1.Crimping (Demo product, 2016) 2.Conductive glue.(CircuitWorks Conductive Silver Epoxy, n.d.) 3. Emboridery (Maurin Donneaud, 2017)

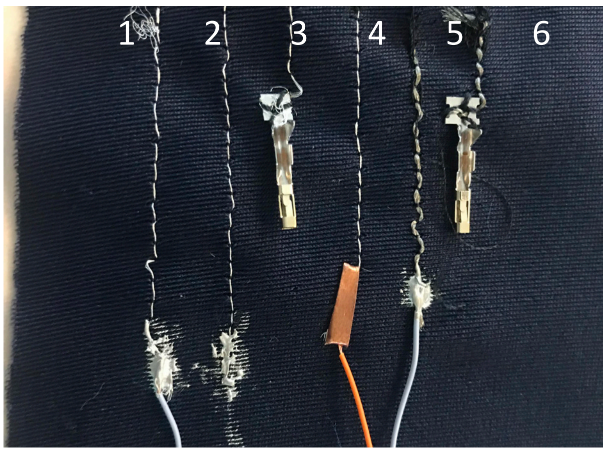


Figure 5.7 Connect the insulated yarn and thin flexible wire using conductive glue. 3, Connect the insulated yarn and crimp by stitching. 4, Conncet the insulated yarn and thin flexible wire using copper tape. 5, Conncet silver conductive yarn and thin flexible wire using conductive glue. 6 Connect the silver yarn and crimp by stitching

Figure 5.8 The crimping connection used in the samples

Test 6 Test the fabric pressure sensor with people.

To evaluate the textile pressure sensing system, a test is conducted to see if the knitted fabric pressure sensor with different patterns can detect valuable pressure distribution data compare to XSENSOR. The recorded pressure distribution map will be used for the classification of 6 sitting postures. The tested samples have conductive stripes with different thickness and gaps. (Shown in Figure 5.5)The test result will be used to choose a suitable sample for the final product.

Research question:
1. What is the most suitable knitting pattern for the fabric pressure sensor on the lumbar support
2. If the fabric pressure sensor can detect pressure distribution with different seating posture, compare to XSENSOR.

Method:
Apparatus:
As shown in Figure 5.10, a Matchu Sports Back-Sand Lumbar Support is covered with the fabric pressure sensor. The support will be put on a car seat in the lab. The tested sensing mat (30*25 cm) will be used to cover the lumbar support and fixed with velcros. Seeeduino lotus and Arduino Mega and a laptop will be used for collecting the pressure distribution map. XSENSOR mat, as a reference, will also be put on the same lumbar support under the same context. The XSENSOR mat has 48*48 sensing elements and accuracy of 5%. Another bigger sensing mat with 40*25 cm will be put on the seat. XSENSOR mat will be put under the sensing mat to collect the same data output. A laptop and the XSENSOR Auto mode will be used for collecting the pressure distribution.

Figure 5.9 One testing sample

Figure 5.10 Lumbar support used in the test. (Matchu Sports Back-Sand Lumbar support, n.d.)

Participants:
One male and one female participant will be invited to sit on the car seat.

Stimuli:
The force stimuli are used to trigger the required output response ranging from 0 to peak value of 3 N/cm2, which is the maximum pressure of people sitting. (Requirement 1.1)

Procedure:
The fabric pressure sensor or XSENSOR will be put on the lumbar support. The participants will be invited to sit on the car seat after explaining to them about the sensing mat. They are asked to perform five postures: sit normal- upright position for short term traveling, lean front, lean right, lean left, a slightly relaxed seating. (Ümit Kilincsoy, 2014). Each posture will last for 10s. A laptop will monitor the pressure distribution and capacitance change. In each round, each position beside the home position has been taken once. After each testing all postures, the participants are asked to fill in a questionnaire. The questionnaire includes basic data of their weight, height, and age. The test will take around 30 min. A video will be taken with permission from the participant. The concent form can be found in Appendix Q.

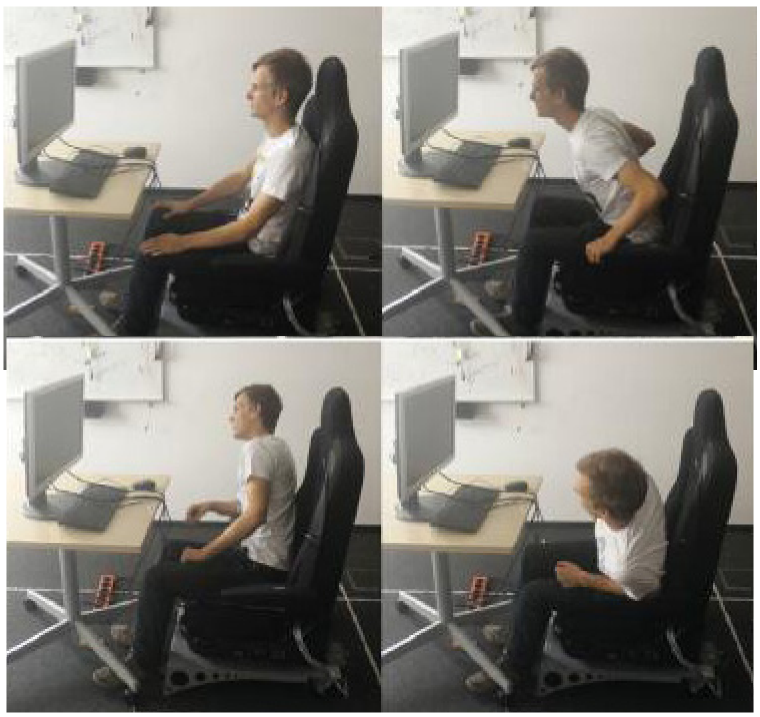


Figure 5.11 Four postures from the research(Cheng, Sundholm, Zhou, Hirsch, & Lukowicz, 2016)

Data collection:
1. Pressure distribution map of both knitted fabric sensors and XSENSOR.
2. Data on the capacitance change in different postures. (both sensors)
3. The weight, height, and age of the participant.

Data analysis:
The pressure map of the two sensor mats will be compared to check if the knitted fabric sensor can show comparable data as XSENSOR in a low resolution.

The capacitance data will be used to check the accuracy of the knitted fabric sensor. The data of height and weight from the participants will be used to check the sensor mat's sensing range.

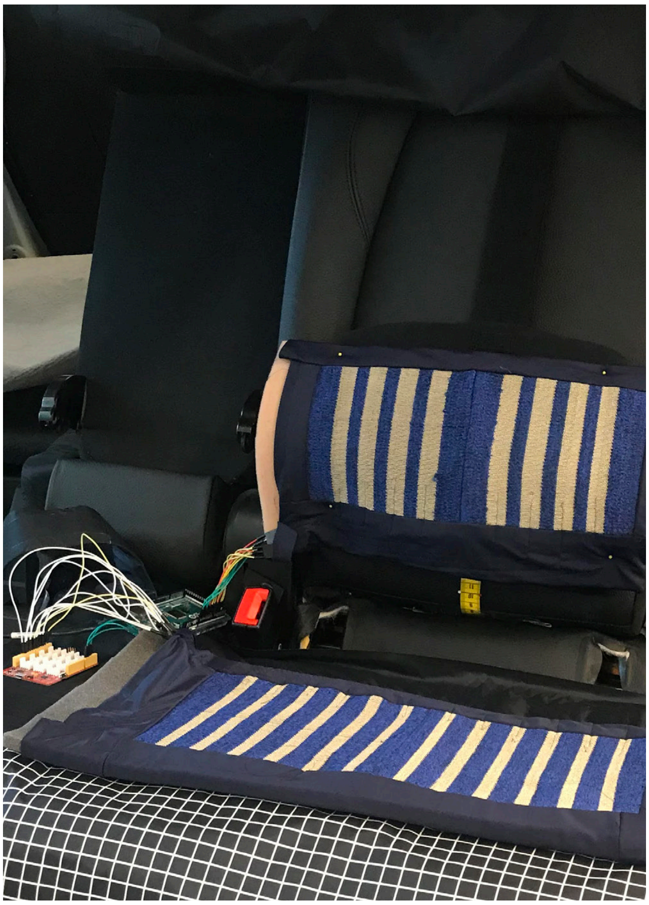


Figure 5.12 Test setup

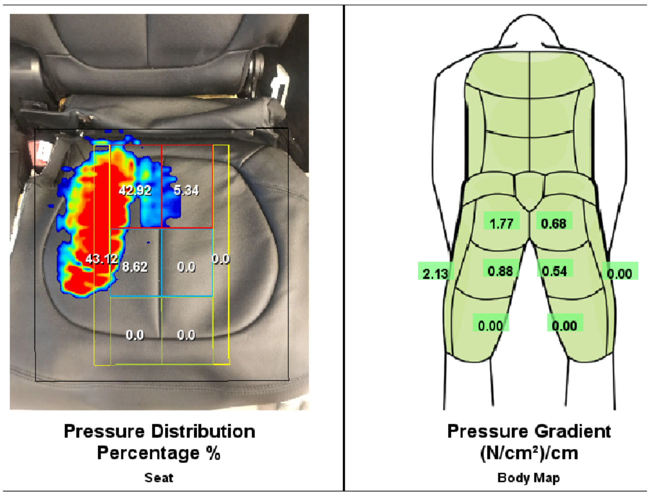


Figure 5.13 The pressure distribution of XSENSOR in auto seat mode. Posture: leaning right

A pilot test is conducted to check the output of the pressure sensing mat. The test procedure is the same as Test 5, but only the seating mat is used.

The 4*4 stripes can show pressure change. However, the resolution of the pressure distribution is low. The sensing stripes are in the middle of the support, and the size of the mat is not big enough to cover both left and right when people change posture.

The bigger sensing mats for seating has 12 rows and 4 cols of conductive stripes. The number of cols and rows in the coding can be changed into 12 rows and 4 cols, and the output will change accordingly.

Because of the limitation of the number of Analog pins in Seeduion (A0-A5), and A4, A5 can have different output from the other pins. ("8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash", n.d.) The first test iteration is using the Digital pin of Seeduion as the output of 12 rows. The accuracy of both boards are acceptable, XSENSOR is put under the sensing mat, as shown in Figure 5.12.

The result shows a colour change in the seating mat, and it can detect the pressure distribution when the people are leaning on one side (right in Figure 5.14). However, after a few seconds, the output disappears, and the first row always shows a darker color compared to other rows. For detailed testing data, refer to Appendix I

To prevent the change of accuracy caused by the output from digital pins, Arduino Mega with 16 Analog pins is used instead for the lumbar support. The pins support the 16 outputs of the 16 stripes.

Another problem happens in the test. The pins that are connected to the sensing mat gets loose when the participant changes posture. The way of connection needs to be improved.

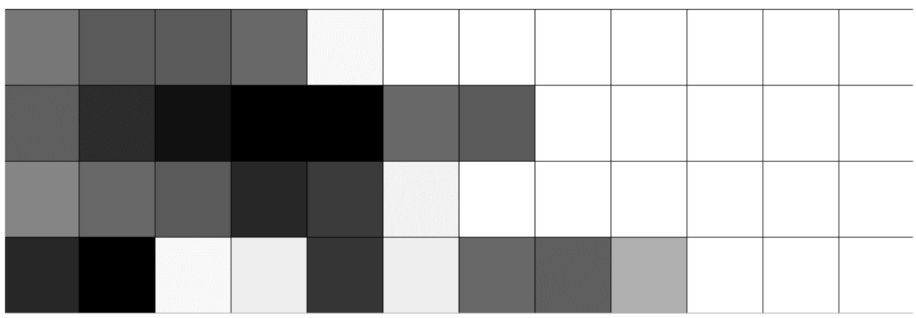


Figure 5.14 The output from the tested sample on the seat. Posture: leaning right

5.3 Prototyping iterations

Insulation

As described in 5.1.2 Test 1, the conductive threads are also used as wires to connect the fabric to conventional electrodes. The threads are stitched close to each other. The capacitance between threads is estimated to check if it will affect the performance of the pressure sensor.

$$C = \frac{2\pi l \varepsilon_0 \varepsilon_r}{\cosh^{-1}\left(\frac{s^2 - r_{w1}^2 - r_{w2}^2}{2 r_{w1} r_{w2}}\right)}$$

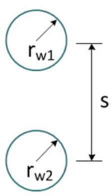


Figure #3 most used posture

The r of the silver yarn is estimated to be 0.3 mm; the gap between two yarns is estimated to be 3mm, the length of the yarn is 20cm. The estimated capacitance caused by the yarn is around 3pF. From the Test 1 in Chapter 3, the capacitance change of the sensing elements is also in the range of 1- 6 pF. Therefore, the effect of the yarn is not negligible. Insulation is needed to prevent the yarns from shortcuts and reduce the effect of capacitance change caused by the yarns.

The heat transfer paper from Silhouette is used for insulation, as shown in Figure 5.16. The number 1 and 2 are the same material with different colors. It is ironed on top of the stitched threads to form a thin layer of insulation. The 3 is another insulation foam with glue on the backside. The advantage of 3 is that it can be directly taped on the threads without ironing.

Figure 5.15 Stitching with conductive yarns

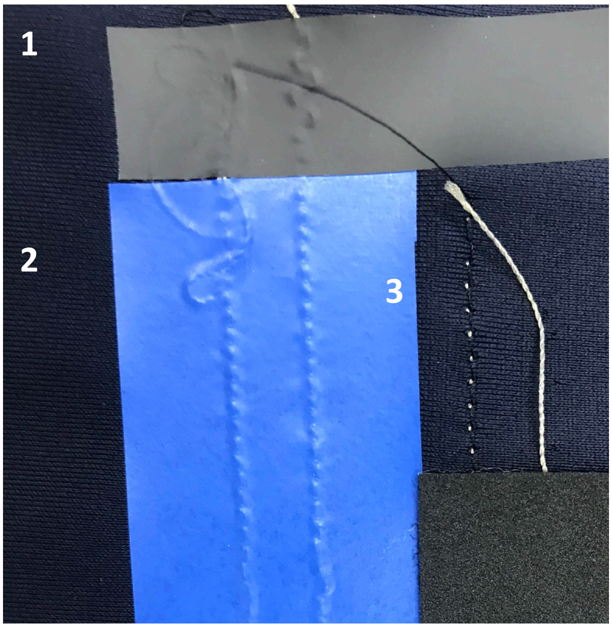


Figure 5.16 Different ways of insulation. 1, 2 Heat transfer material silhouett with different color 3. Thin foam tape

Ironing can cause oxidation of the silver yarn and affects the conductivity. As another option, the stainless conductive yarn is used as it has smaller resistance. The stainless thread is also not easy to oxidize. It is essential to mention that both yarns are not able to be soldered.

Iteration on hardware and software

To discover the cause of the unstable output, some improvements are made in both the hardware and the software.

As the spacer is not fixed inside the fabric "bag," it can move when the participant changes posture. The fabric will not be closely contacted to the spacer, and there will be air in between the conductive and the spacer layers. Some more stitches are made to fix the spacer inside, as shown in Figure 5.17.

Figure 5.17 Top stitch to fix the spacer material

Using the serial plotter in Arduino; it can be seen in Figure 5.18 of the output before changing the code. The output increases and decreases regularly. That explains why the sensed data in the test disappears after a few seconds. According to research (Pourjafarian, Withana, Paradiso, & Steimle, 2019), different sensing frequencies affect the output. After testing, the frequency of sensing is then increased into every ten milliseconds.

Another problem regarding the darker color of the first row is solved by defining each pin as an output. After the change with the coding, the output is shown in Figure 5.19. There is still one high value of output, but other values are stable, and the code can detect the pressure of different pins. For detailed code, refer to Appendix K.

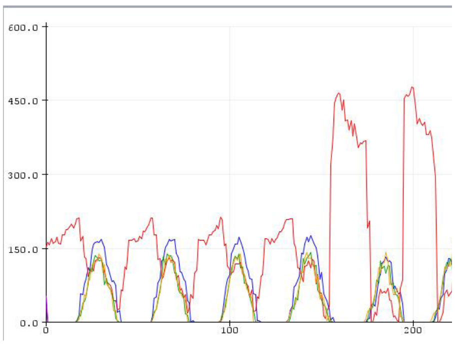


*Figure 5.18 The output of a 4*4 matrix before changing the code*

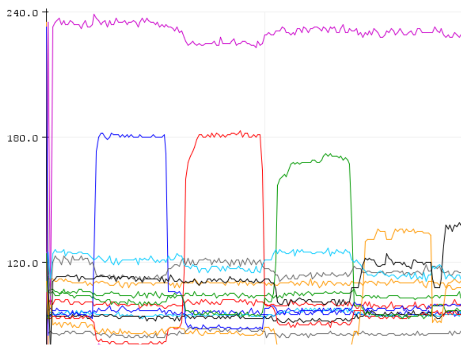


*Figure 5.19 The output of a 4*8 matrix after changing the code*

Connection

During the pilot test, the connection from the sensor mat to Arduino gets loose when the participant moves, which affects the sensor output. Some iterations are made to solve this problem. Two ways are of connections are considered.

1. Stitch the conductive yarns and make knots on the PCB board. Solder a ribbon cable connection, as shown in Figure 5.20. The PCB board is then stitched on top of the fabric to form a strain release effect.

2. Cut the crimping end of standard wires, make a knot through the wholes, and crimp the yarn. The ends are put into the shell and stitched on to the fabric to form a strain release effect. When the connection gets pulled, the knots will not get loose as the added stitch is holding the strain. The second way of connection is shown in Figure 5.21. with black insulation layer. The difference between the second connection and the connection used in Test 5 is that the crimping end in Test 5 was not fully plugged in the shell, causing a no firm connection.

The two methods are both tested. The advantage and disadvantages are listed.

Figure 5.20 Testing with ribbon connection

Figure 5.21 Crimping connection with the conductive yarns stitched in a wider gap.

The first method has a firm connection. The ribbon wire enables a one-time plugin. It is easy to connect and robust. It is suitable for a sensor with more than ten conductive stripes. Different yarn lines need to be stitched close to each other, with a 2-3mm gap to fit the PCB size. The small fluffy threads cause short circuits between connections. (as shown in Figure 5.23). The thread ends results in a resistance of around 100-300 ohm between two stripes. The sensor will show an error as a large capacitance is monitored. The pressure sensor will not work.

The second method performs well in connection. It is a robust connection. The different yarns can be stitched with a broader gap from 3mm to 5mm, as shown in Figure 5.22. A wilder gap will prevent short circuits. A short circuit can still happen if the yarns are stitched too close to each other, as shown in Figure 5.22. It is suitable for a sensor with less than or around ten conductive stripes as it has enough space for the yarn lines to be stitched wider. The disadvantage of this method is that it still needs regular wires to connect from the shell to the board. The connection from the shell to the board is more robust than Test 5, but it can still get loose if there is a big movement. Some of the problems mentioned above can be solved during industrial manufacturing. The first method has a more significant potential to fit the sensor with more sensing stripes if the short-circuit problem can be solved.

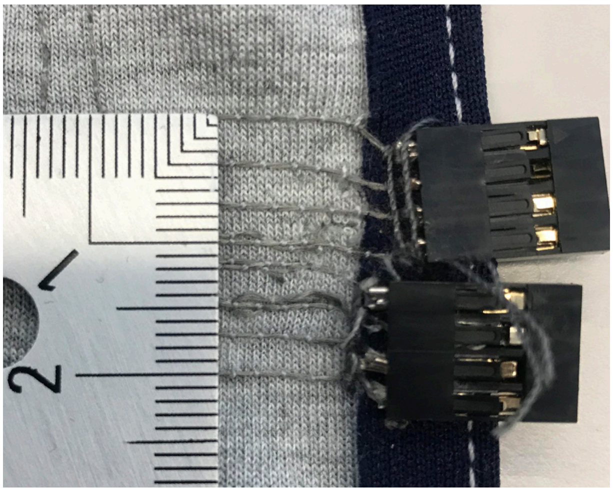


Figure 5.22 Crimping connection with the conductive yarns stitched in a small gap.(can lead to short curit)

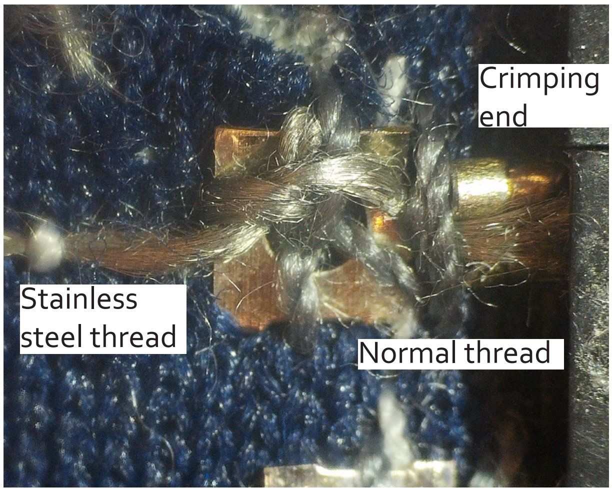


Figure 5.23 Connection under microscope. The small yarn ends which can lead to short circuit.

To prevent the short-circuit, insulation of the yarns is needed at the end of each connection so that the small yarn ends will not touch each other. One solution is to use the flexible wire, as shown in Figure 5.24. The wires have a diameter of 1mm, with copper core and insulation. The Zigzag stitch is used to fix the wires on top of the fabric. The end of the wire can be soldered on top of the PCB board, as shown in Figure 5.25.

By using the flexible wire and soldering, the short-circuits are prevented. Also, this method does not require the wires to be stitched separately. On the contrary, the wires can be stitched close to each other, saving more space for the design. The wires also have smaller resistance compare to conductive yarns.

The disadvantage of this method is that the thin wires can be broken after stretching or long-time use. Sharp points can easily damage the insulation layer. The wire itself is not as robust as the conductive yarns.

It is recommended to try insulated yarns Shieldex TPU Yarn for further development. The yarn is insulated and has the property of conductive yarns. More tests need to be done to check the feasibility.

Figure 5.24 Zigzag stitch to fix the flexible yarns on top of the fabric

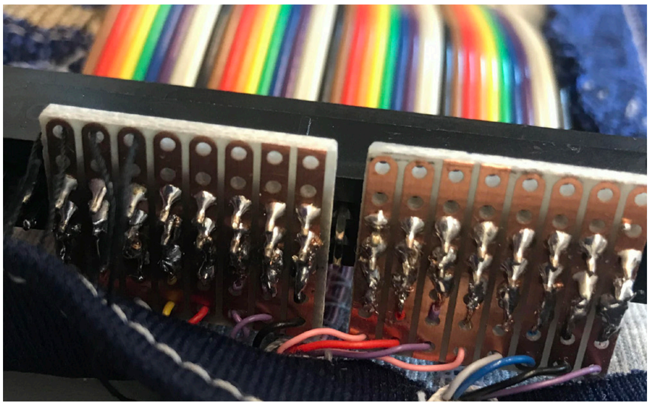


Figure 5.25 Soldered end of the flexible yarn on the PCB.The other side is connected to the ribbon wire.

Tips and techniques used in prototyping.

The regular fabric used in the sensing mat is Neoprene fabric (as shown in Figure 5.26). It is a structure with two Jersey layers knitted together, containing a thin spacer knit. The fabric is robust, and is hard to get wrinkled. It is not recommended to use thin and stretchy Jersey fabric as the stitch can lead to the shape change of the fabric during stitching as the conductive fabric sample uses an interlock stitch, with a thickness of around 1mm. Fabric with similar thickness is better for stitching.

Topstitch is used to prevent the bump on the fabric connection (as shown in Figure 5.26).

The conductive yarns for connection are stitched as a base yarn. The recommended tension and gap of the stitching are tension 5 gaps 3. A Jersey needle should be used to avoid the top yarn going through the conductive yarn.

The knitted fabric has a fluffy edge. It also happens after cutting the fabric. Stitch on edge, as shown in Figure 5.27, is used to clean the edge. This way of stitching also helps to prevent shortcuts caused by the threads in the conductive stripes.

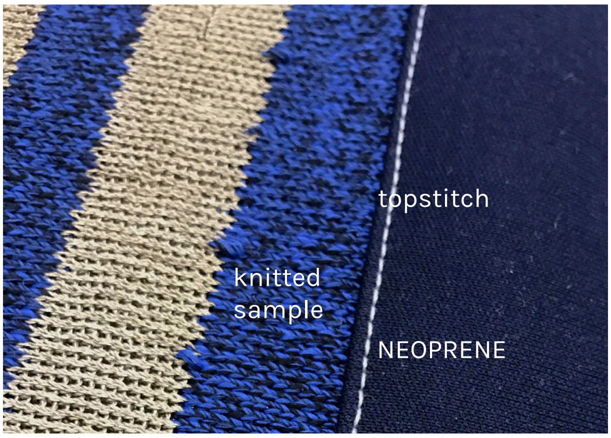


Figure 5.26 Top stitch at the edge of the fabric

Figure 5.27 Cleaning the flufy end of the knitted sample

Calibrate the sensor mat

As shown in Figure 5.29, there is a high output of one sensing element. Also, the sensing elements show different capacitance when adding the same pressure.
From requirements 3.2 of the sensing mat, the pressure distribution is more important than the sensor's accuracy. Therefore, calibration is needed so that the sensing elements have similar output when adding similar pressure.

Some data are collected to check if the sensing elements are showing a similar linear change of output when adding pressure. A calibration method can then be decided. The sample with 4*4 stripes, the width of 30mm is used to collect the data. The weight from 0.5- 5kg is put on top of the container used in Test 1 of Chapter 3 to apply pressure. The setup can be seen in Figure 5.28. The output of all sensing elements is measured. The capacitance/ weight graph is shown in Figure 5.29. All sensing elements, including the one with high value, show similar capacitance changes when adding pressure. The output is shown in Figure 2.29.2.
After analyzing the data, (for detailed data, refer to Appendix J), the initial value when no pressure is put on top of the sensor has a big influence on the output as the rest of the increase on capacitance is based on the starting value.

Figure 5.28 Set up of the manual calibrate

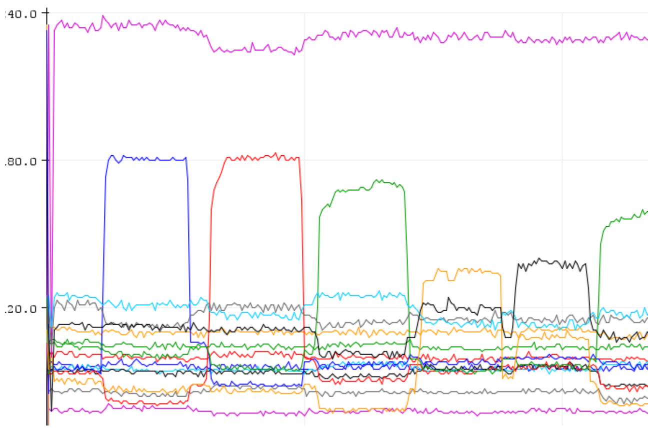


*Figure 5.29 The output of a 4*8 matrix after changing the code*

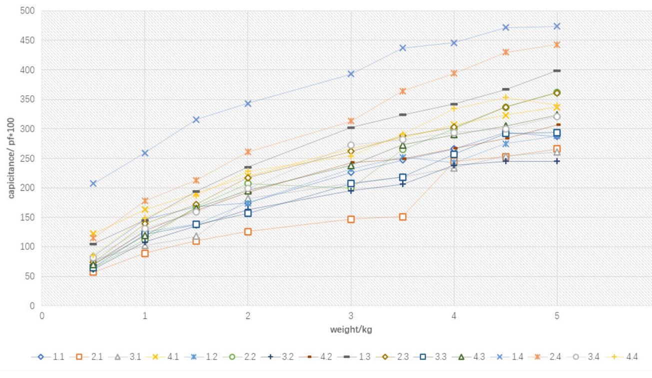


*Figure 5.29.2 The output of a 4*4 matrix when applied weights*

The normalize method is chosen in the end for calibration. It requires the minimum and maximum value of the sensor.

The minimum value used is the initial value when no pressure is added to the sensors. The maximum value used is the output when the weight is 5kg. The formula used is

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

As shown in Figure 5.30, the output shows a similar trend of capacitance change when more weights are added. The manual calibration is done through all sensor mats. Another test with people is conducted. However, the output is not as ideal as the calculated data. As the initial value of the same sensor can be different due to some small changes in the environment. A pilot is conducted but the high value still exists. **In conclusion, a function of auto-calibration is needed to have a uniform output.**

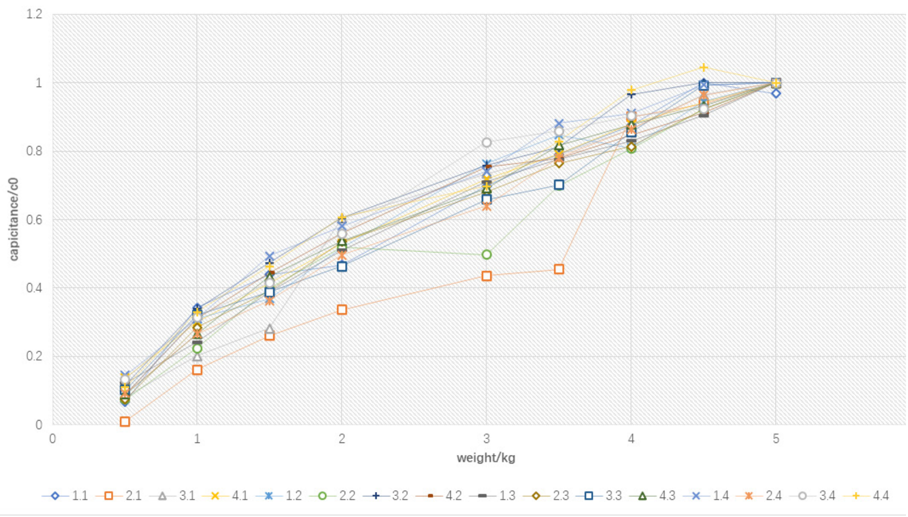


*Figure 5.30 The capacitance change of different sensing elements on a 4*4 sensing matrix after normalized.*

The auto-calibration function is defined in Arduino. The sensor will sense the initial output in the first 5 seconds when starting the code. The rest of the data will be mapped in the range of the initial sensed value and a calculated maximum value. The output will then be converted into a number from 0 to 255. As the sensor shows similar pressure trends, the maximum value can be estimated based on the minimum value.
In this calibration function, the maximum value is calculated by the formula

amax = amin + maxweight* 60

The output of the calibrated sensor is shown in Figure 5.31. Compare to the previous version in Figure 5.29, the data all starts from around 0-5 and shows a more even capacitance change when putting the same pressure on the top. There are still some sensing elements that provide a higher or lower output but the sensing mat is ready for testing. Due to time constraints, the calibration cannot be further explored. It is recommended to calibrate the sensor further so that all the outputs are the same when adding the same pressure.

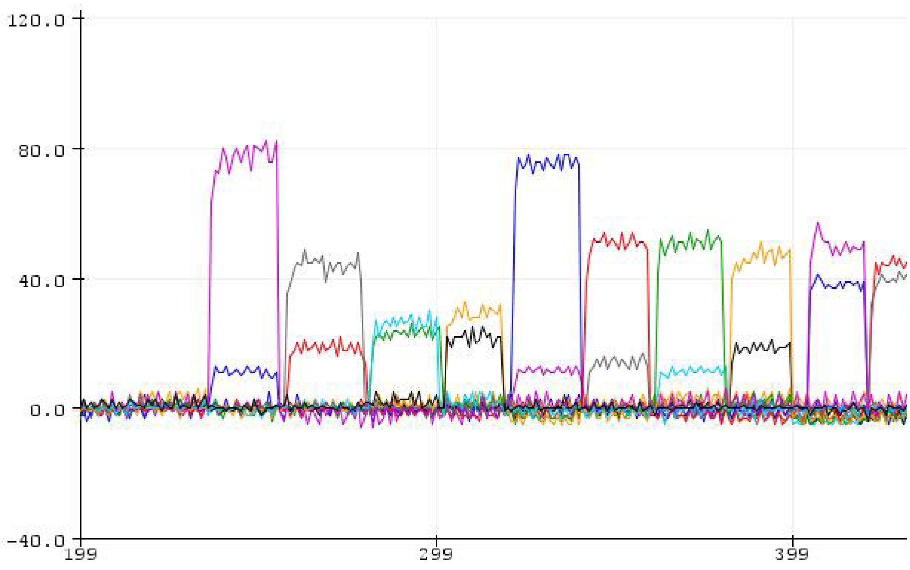


Figure 5.31 The output after auto calibration

Final test with people

A final test is conducted with one male participant and two female participants. Some data of P1 is not collected because of the problem in the recording. The data of P2 and P3 are used for analysis. The data of P1 is also used as a comparison when necessary. For all the testing data, refer to a seperate folder containing all the testing videos.

The testing procedure is the same as Test 2 in Chapter 5.1.2.

As shown in Figure5.32, the testing samples can show a clear pressure map. Although it is in a shallow resolution, the postures' difference can be distinguished from the pressure distribution of the seating pad.

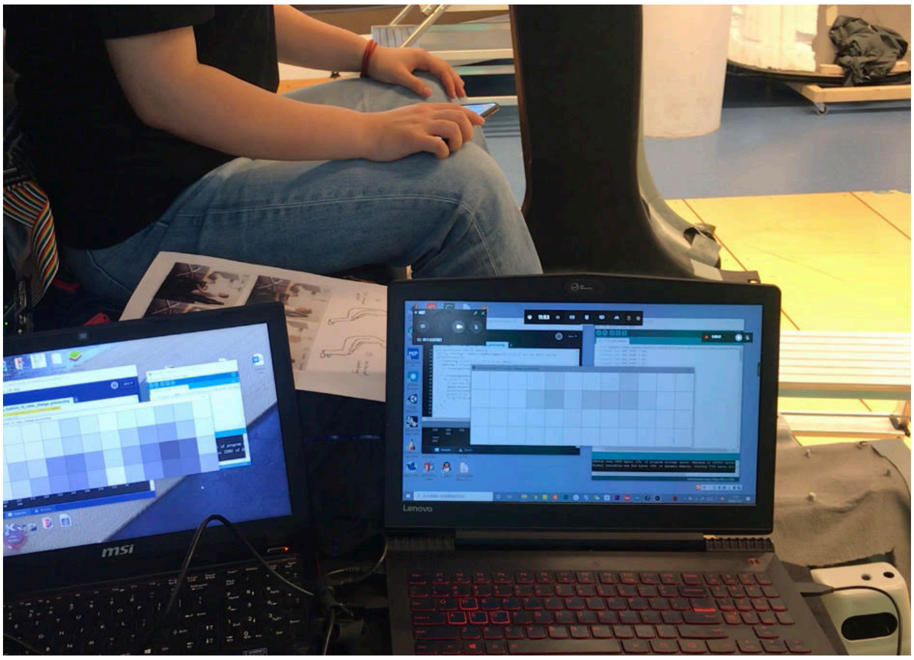


Figure 5.32 Picture taken during the final test

For lumbar support, the pressure depends on individuals. The three participants recline in different ways when performing the postures. Therefore, the output is not comparable. The lumbar support sample can show pressure change when the participant reclines with different postures, especially leaning left and right. For standard seating and relaxed seating, the XSENSOR and the test sample shows a different output. The pressure of the standard seating in XSENSOR is smaller than the relaxed seating. At the same time, it shows an opposite result in the testing sample. The postures defined in the test did not specify to the joints of the participants. That affects the result. It is recommended to define the posture in more detail.

Comparing different patterns, the lumbar support pattern wth 4*8 stripes, stripe width 20mm, gap 10mm shows the widest color range and is able to cover the lumbar area. The seating pad with pattern of 10mm conductive strip, gap of 20mm is able to sense the seating pressure and show clear pressure map. The spacer material used in the samples is foam with 10mm thickness.

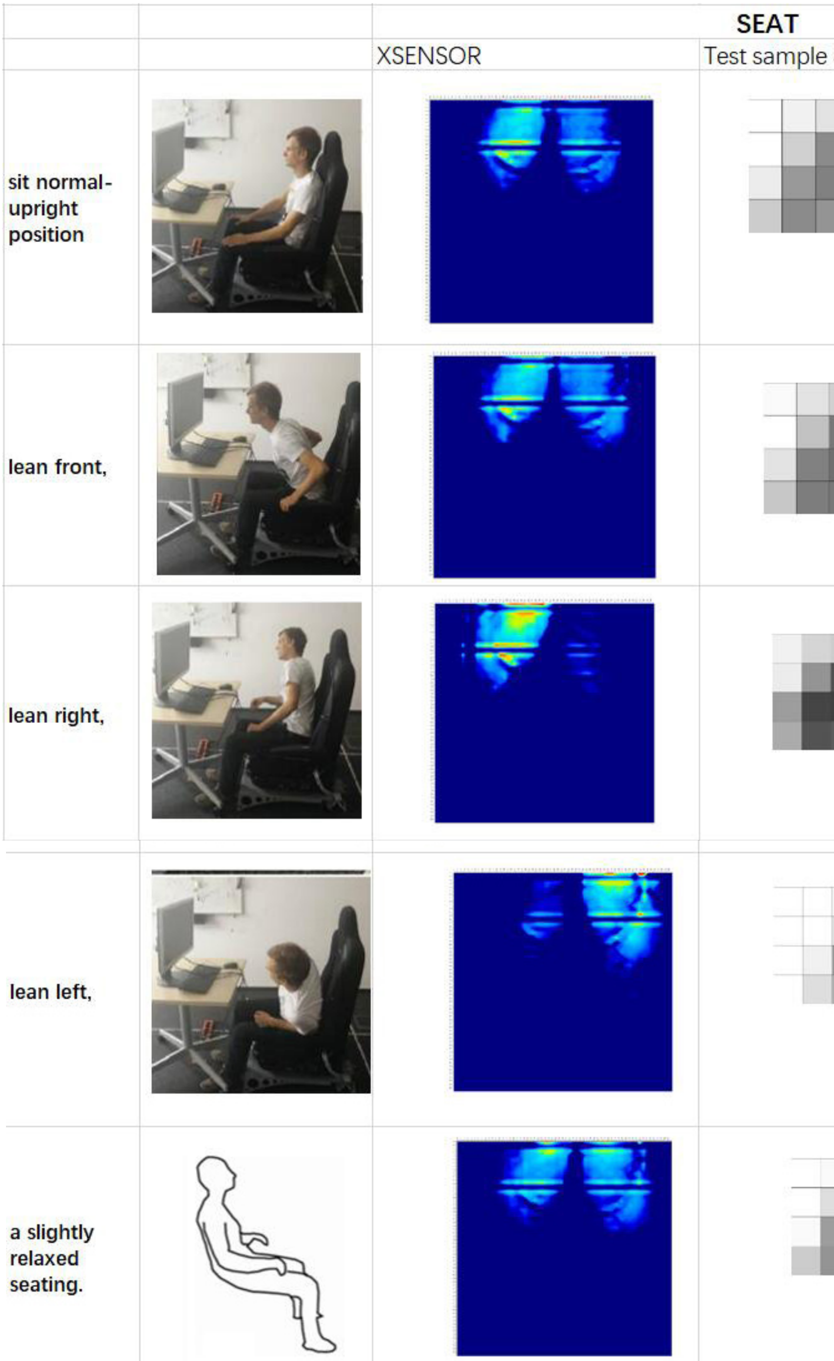
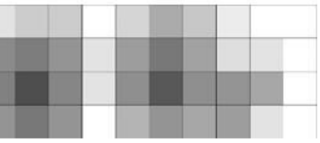
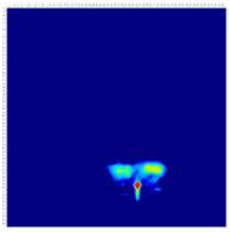
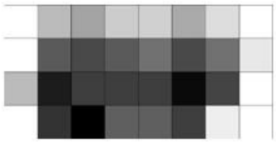
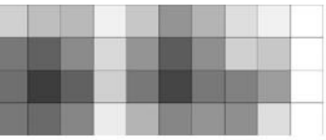
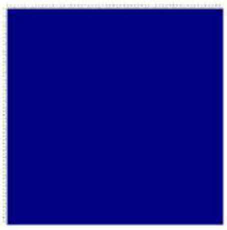
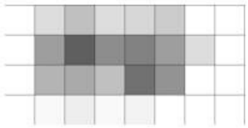
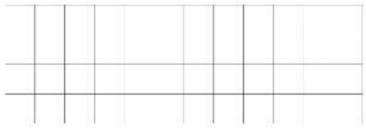
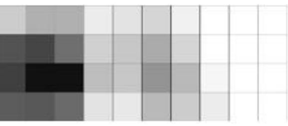
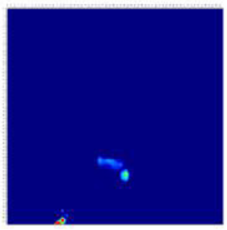
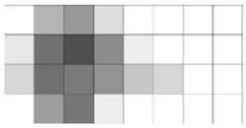
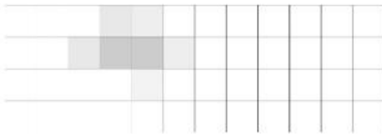
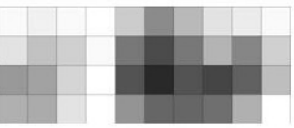
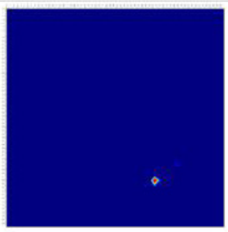
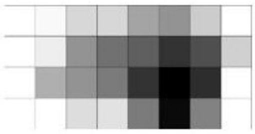
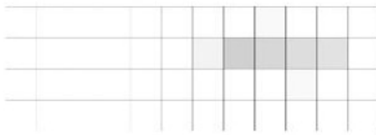
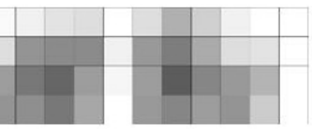
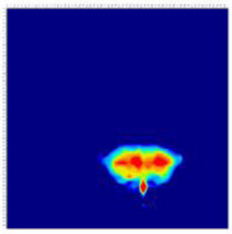
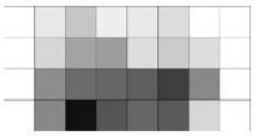
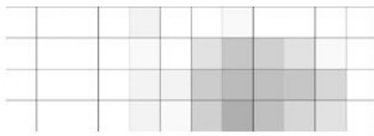


Figure 5.33 Testing result of the second participant. A comparation of the XSENSOR and the testing sample with different patterns

	Lumbar support		
4_12_10	XSENSOR	Test sample 4_8_20	Test sample 4_12_10
			
			
			
			
			

5. Embodiment

As shown in Figure 5.34, the output from different samples. The auto-calibration is proof of working as the outputs all start from around 0. The 4*4*30 sample shows an average positive output. While the rest three samples all have one or more negative output. The negative values cannot be shown in the pressure map. For the range of the output, different samples show different capacitance range. The ways of connection also affected the output as the samples using crimping shows more significant capacitance change than the samples.

From the conclusion of the test, another iteration is conducted to change the testing procedure and specify the participant’s postures.

Another testing round is conducted. The data is also put in a seperate folder.

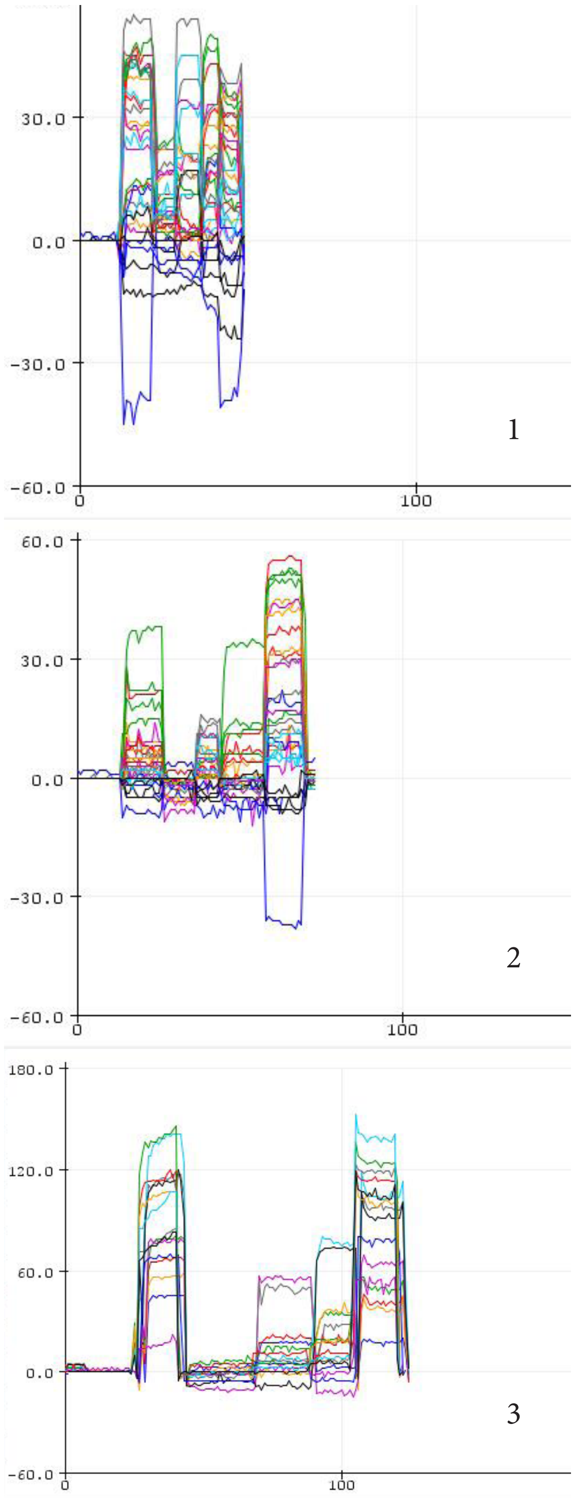


Figure 5.34 Capacitacne output from different samples.
*1. Sample 4*8, 20 mm, Participant 2*
*2. Sample 4*8, 20 mm, Participant 3*
*3. Sample 4*4, 30mm, Participant 2,*

Some small changes are made to conduct anothertest iteration.

For the posture, the joints of the participant are more clearly defined as shown in Figrue 3.35. This helps to avoid misunderstanding and make the postures more comparable.

The sensing mat sample used for seating is put in the same place of the seat- against the backrest. It is observed in the test that the sening mats changes place when the participant changed their postures. For the lumbar support, as the support is not fixed on the seat, the position also changes under different posture. Measuring the height of the support during the normal sitting upright posture is not applicable to other pistures. It also shows that the support needs to have some free areas for the height when the user changes his posture.

Another adjustment is the coding. As the capicitance range of different samples are different, some sensors shows very light color change under the same color scale. From the data monitored in Plotter, different color scales are defined to make all the sensors be able to show a n obvious pressure distrubtion map. For detailed data refer to the folder of testing data.

After the adjustments mentioned above, another round of testing is conducted with one male and one female participant. The result is discussed on the next page.

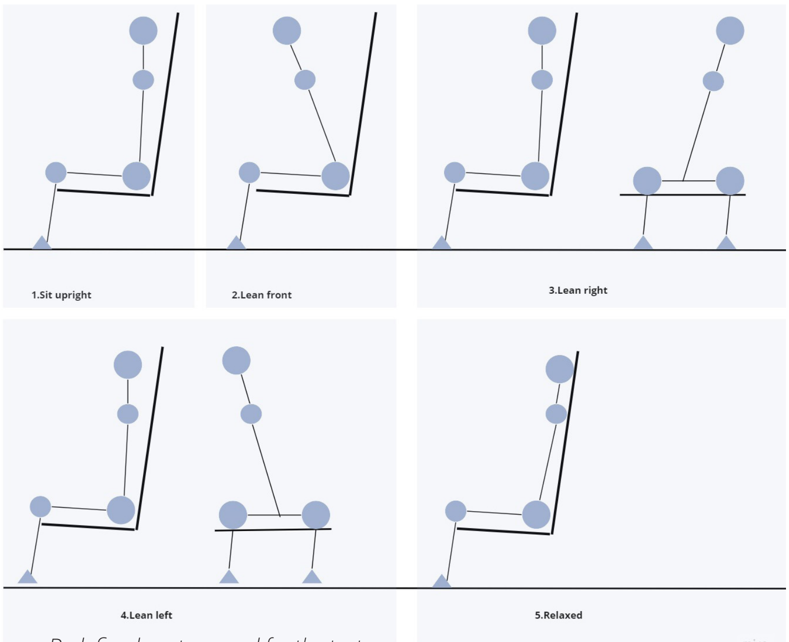


Figure 5.35 Redefined posture used for the test

From the result shown in Figure 5.36, The sensors samples are able to show a clear greyscale color change after changing the color scale. The 4*8 sensor for lumbar support still shows the most widest color range.

In conclusion, the pressure map of all the sensor mats will can show a pressure distribution map. From the map the seating mat and the lumbar support are both able to destinguish leaning right and leaning left. The sitting upright and relaxed posture shows no big difference just by looking at the pressure map. Comparing to XSENSOR, the postures of sitting upright and relaxed seating also did not show a big difference. However, from the Pressure Gradient, it can be seen that the relaxed posture shows more area where the pressure is higher than the ideal pressure range.

The capacitance data will be used to check the accuracy of the knitted fabric sensor. The data of height and weight from the participants will be used to check the sensor mat's sensing range.

Research (Meyer et al., 2010) used Naive Bayes classifier for classifying the postures. It requires the following features for classification:

1) sensor value from each sensor element;
2) center of force;
3) pressure applied to 4 and 16 equal aggregated areas of the seating area.

It is recommended to test with more postures and use the classifier to compare the accuracy of detecting the postures.

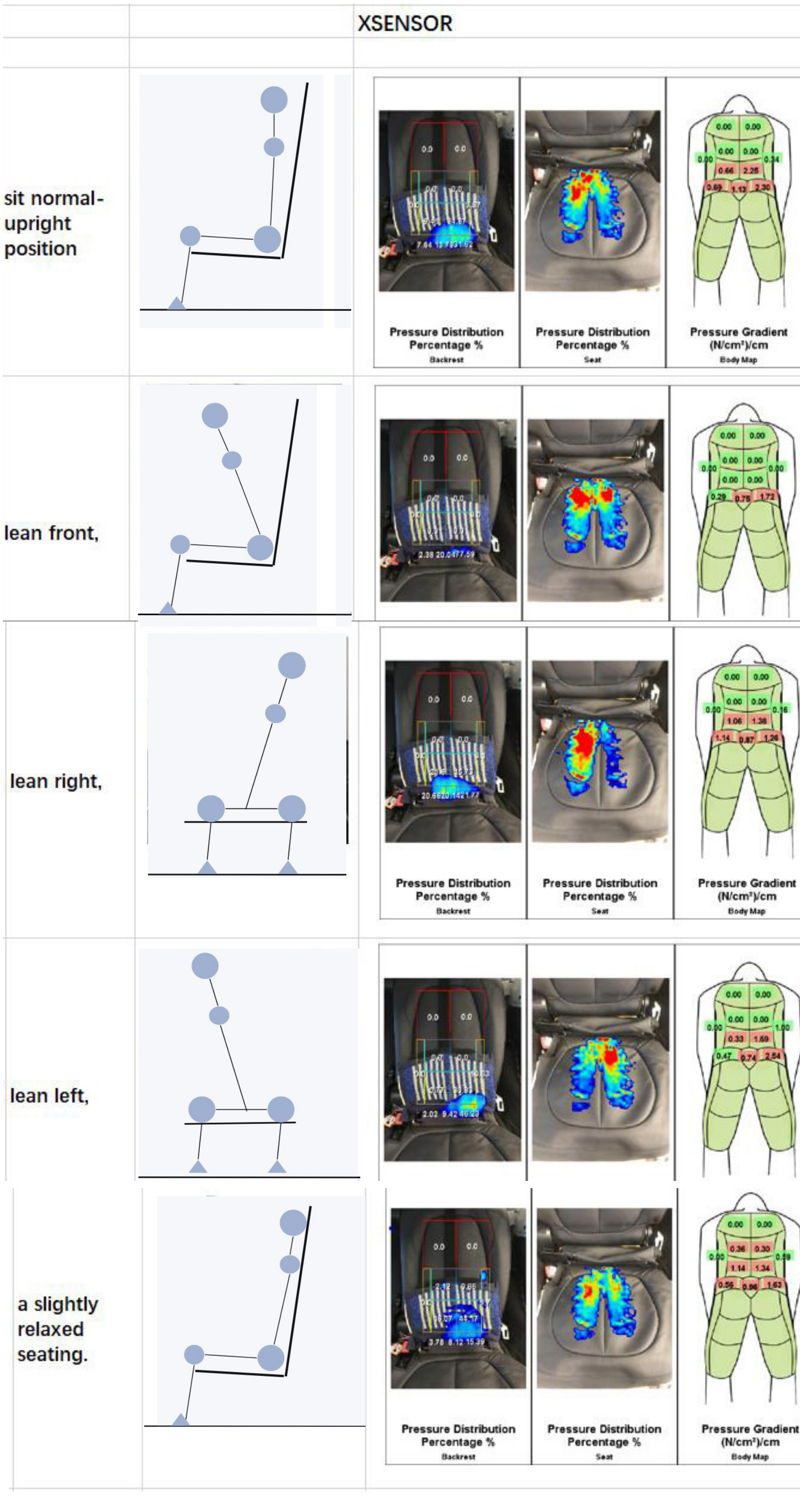
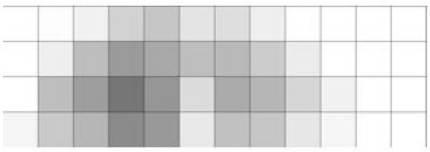
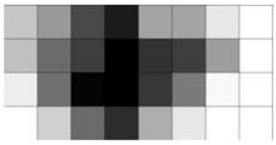
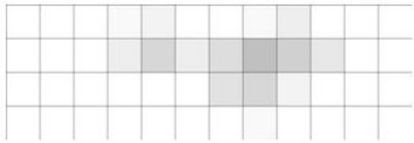
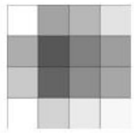
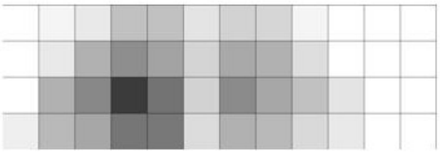
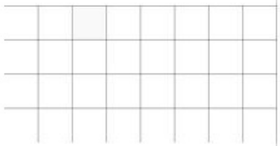
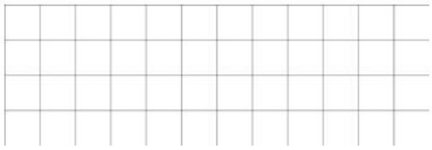
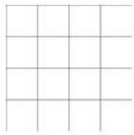
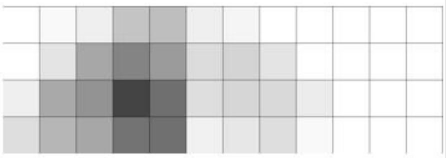
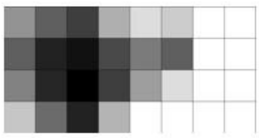
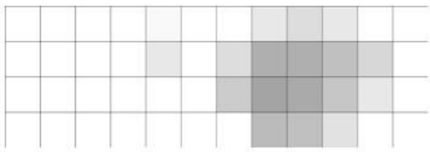
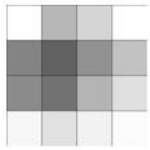
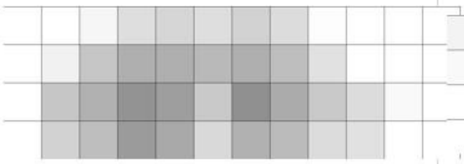
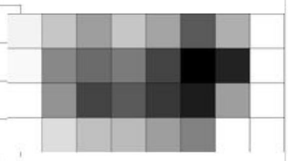
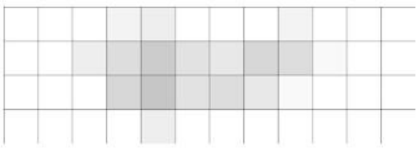
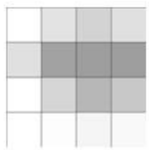
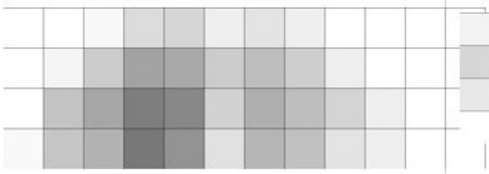
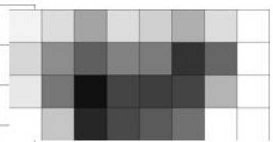
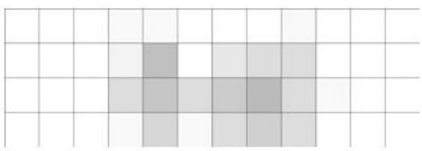
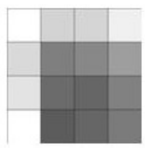


Figure 5.36 Testing result of the fourth participant. A comparation of the XSENSOR and the testing sample with different patterns.

SEAT	LUMBAR SUPPORT		
Test sample 4_12_10	Test sample 4_8_20	Test sample 4_12_10	Test sample 4_4
			
			
			
			
			

Key insights 5.2&3

As the second stage, the prototype iteration, the four crucial aspects of the preliminary test are further explored.

Test 4 made decisions on the knitting fabric- using an interlocking pattern, knit with silver-coated yarn for conductive stripes. Four patterns with different width and gaps of the conductive strips are knitted to decide on the most suitable pattern.

Test 5 is a pilot test with people to find out the problem of the sensing mat. Connection problems and the unstable output needs to be solved in order to do further testing.

The Ho- Tos are tried and iterated. In the first iteration, The way of connection, using crimping and ribbon cable, is tested. The code is modified about the sensing frequency and defining pins. Another pilot is conducted to test with people. The problem that not all the sensors have the same starting capacitance. A calibration function is needed

In the second iteration, calibration is done manually by putting weights on the sensor. One more test is conducted. The manual calibration does not work as the environment changes affect the sensor.

In the third iteration, auto-calibration is defined in the code, and the output is improved. The testing procedure is also improved by defining the posture in more detail.

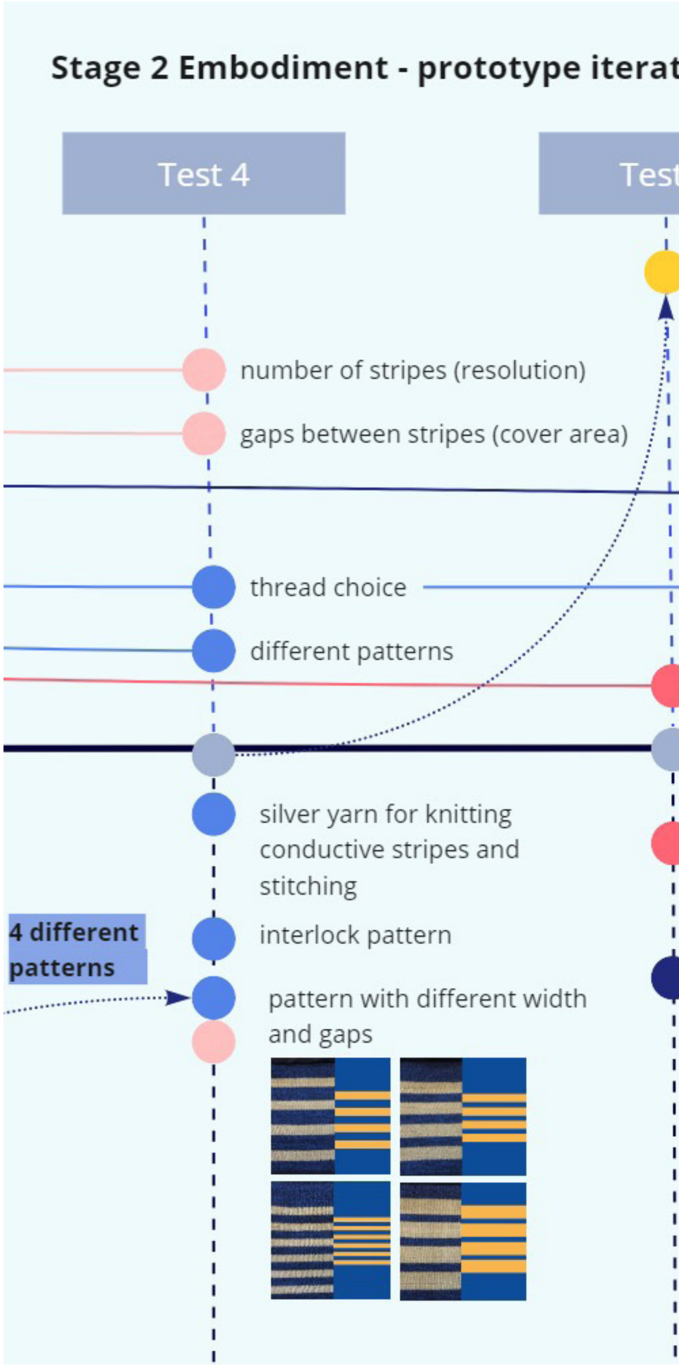
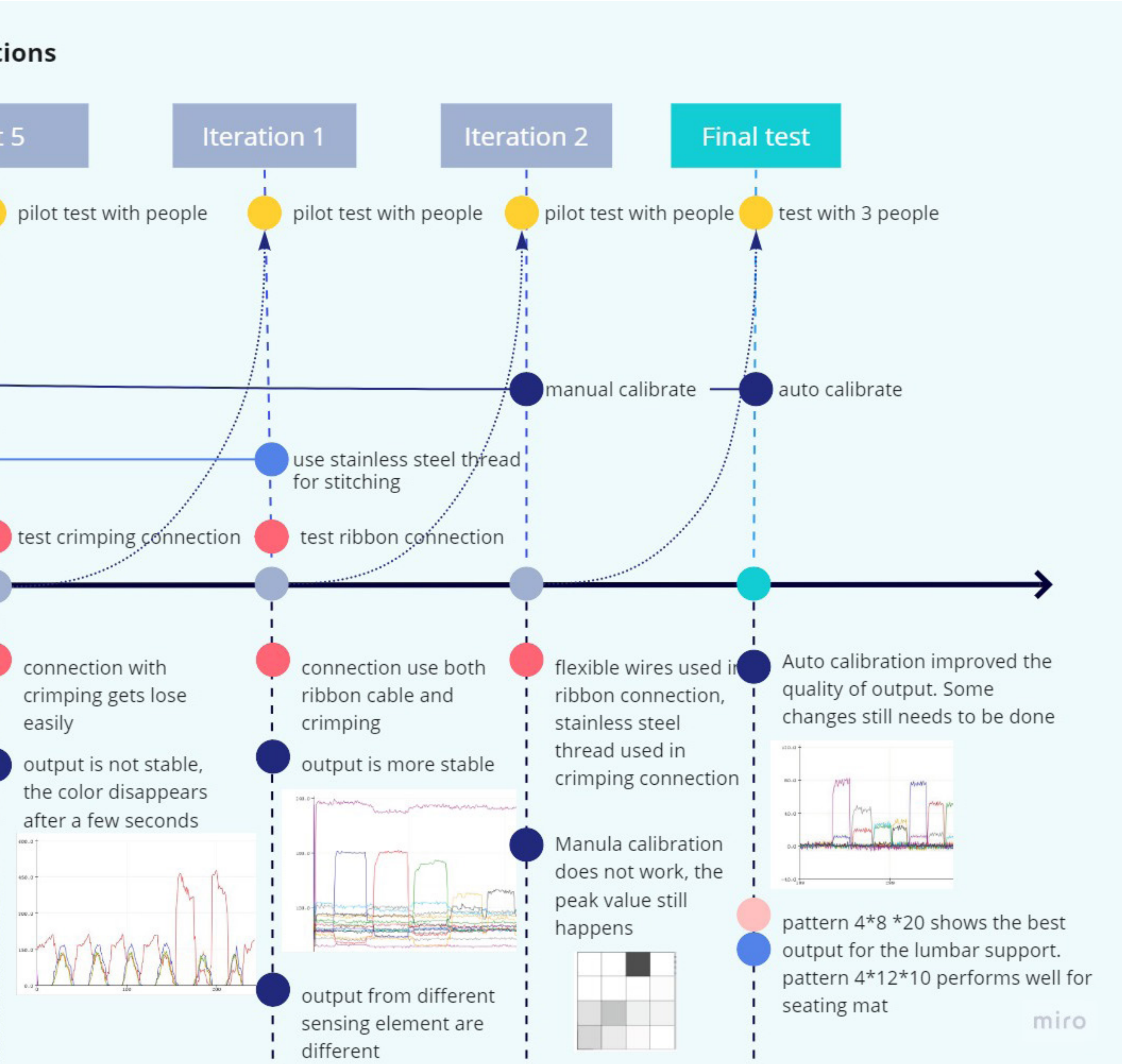


Figure 5.37 Overview of the prototyping iterations


tions
t 5
Iteration 1
Iteration 2
Final test
pilot test with people
pilot test with people
pilot test with people
test with 3 people
manual calibrate
auto calibrate
use stainless steel thread for stitching
test crimping connection
test ribbon connection
connection with crimping gets lose easily
output is not stable, the color disappears after a few seconds
connection use both ribbon cable and crimping
output is more stable
output from different sensing element are different
flexible wires used in ribbon connection, stainless steel thread used in crimping connection
Manula calibration does not work, the peak value still happens
Auto calibration improved the quality of output. Some changes still needs to be done
pattern 4*8 *20 shows the best output for the lumbar support. pattern 4*12*10 performs well for seating mat
miro

5.4 Existing lumbar supports

Benchmark A - Good Monday Zero Gravity Upright Posture(ZGUP) Cushion

ZGUP cushion is a seating pat that can help the user to sit more upright. The principle is by helping people sit 108 degrees (hip angle, as shown in Figure 5.38). It changes the posture differently from lumbar support. It is a new way of sitting to the body, which can affect the spines, discs, groins, legs, and more.

The memory foam of the ZGUP cushion is claimed to provide 97% of restoration or resiliency even after 80,000 times of Seating Durability Test. (Zero Gravity Upright Posture Cushion. n.d.)

The premium double-layered mesh cover fixes common problems like getting dirty fast and heating up. It has anti-microbial and anti-bacterial properties while keeping the user cool while seated.

Price: 35 dollars

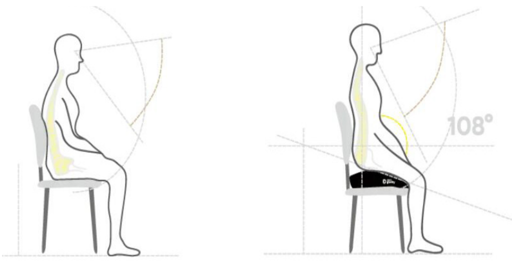


Figure 5.38 Posture change claimed by the company.(Zero Gravity Upright Posture Cushion. n.d.)

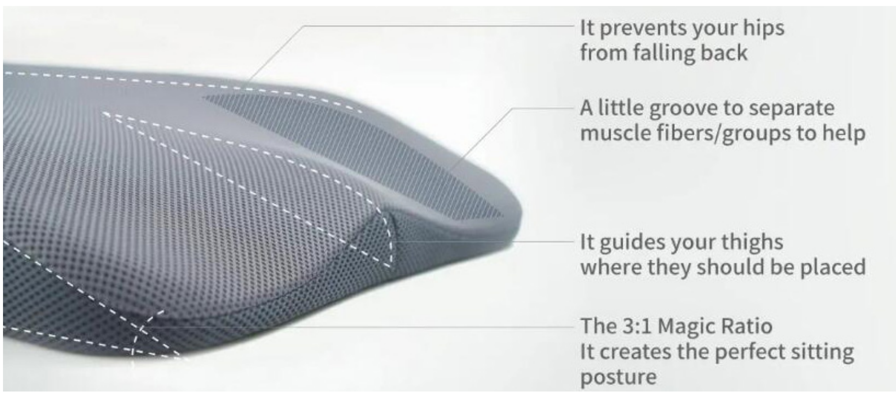


Figure 5.39 How can the mat help people sit 108 degrees (Zero Gravity Upright Posture Cushion. n.d.)

Benchmark B - EmbraceAIRPlus

EmbraceAIRPlus was designed with the help of Chiropractors and Physiotherapists and scientific proof. The patented design enables the user to determine the firmness of the support and its exact position. The user can change the firmness with the push-button valve and easy squeeze bulb.

The property creates changes in weight distribution and circulation patterns within the back. It is a simple solution for the user to adjust the support into the shape that fits himself the most.

Price: 120 dollars

Figure 5.40 How the support looks like (Innotech Rehabilitation Products Inc. n.d.).

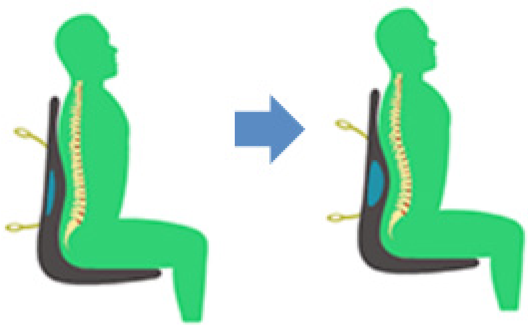


Figure 5.41 Shape change of the support that helps with the postue.(Innotech Rehabilitation Products Inc. n.d.).

Benchmark C - Kia Optima: Lumbar support

Kia Optima DL3 2019-2020 owners manual (Kia Optima - Seat - Safety features of your vehicle. n.d.) shows a way of using buttons to adjust the lumbar support. It can adjust both the depth and the position of the support. As shown in Figure 5.42, the lumbar support can be adjusted by pressing the lumbar support switch on the seat's side.

The adjustments have limitations.
1. From the manual, drivers are warned never to attempt to adjust the seat while the vehicle moves. The adjustment could result in loss of control of the vehicle. To adjust the seat support manually while moving will distract the driver and adding risks of driving.
2. It is not recommended for the user to sit on aftermarket seat cushions or sitting cushions. The passenger's hips may slide under the lap portion of the seat belt during an accident or a sudden stop. A separate product from aftermarkets can cause safety risks if the cushion does not fit the seat.

Thus, the new lumbar support functions as real-time monitoring of the pressure and automatically adjusts the lumbar support. The automatic adjustment does not require any attention to the driver, especially when driving. If the driver changes his or her posture, the support does not require extra adjustments.

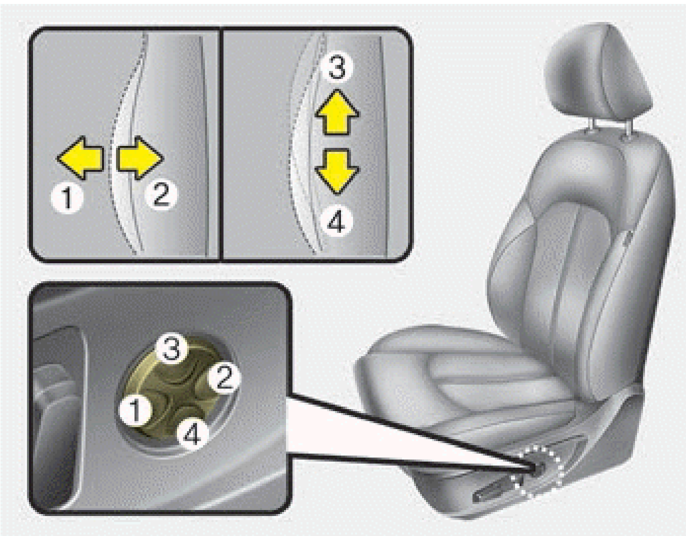


Figure 5.42 How to change the position of the support in Kia Optima (Kia Optima - Seat - Safety features of your vehicle. n.d.)

Comparing the different products

As shown in Figure 5.43, the three products are mapped out based on their price and technology. The seat in Kia Optima integrates the adjustment function into the car interior. The price of the specific function can not be defined. The ZGUP cushion has the lowest price, more like other types of lumbar support. The innovation of ZGUP is that it improves the lumbar condition by changing the way of seating. It is inspiring that the comfort of different areas of the body is connected. By changing one part, the whole body can be affected. The Embrace AIR Plus shows its advantage in adjusting the lumbar support's shape at an affordable price. However, compared to the other two products, in terms of price and technology, the Embrace Air Plus is not the ideal choice.

The grey dot shows the goal of where the new product can put itself. Having a higher price than Kia Optima, and a significant advantage in the technology. As the product is integrated into the seat, its effect depends more on the price of the car itself. The product needs to be first implemented into a car with a higher price, and use the technology as a selling point.

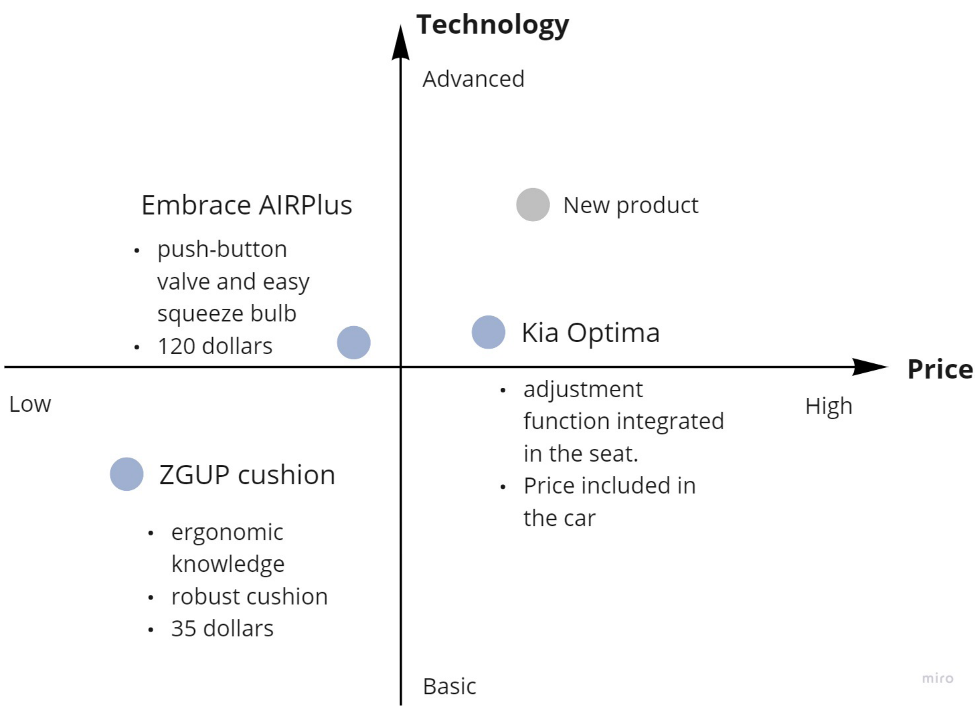


Figure 5.43 Comparing the different products.

5.5 Elaborate on the concept

"I have tried the lumbar support a number of times but it is too big for my back. This gives me even more back pain than I already had. This is not recommended for a short back."

This is a quote from the comments under a lumbar support product (Matchu Sports Back-Sand Lumbar support,n.d.). The comment is inspiring as there is a need for the user to choose proper lumbar support.

As the product is only validated in the lab, a lot of work must be done afterward to put it into the market. The original concept was to develop a fabric sensor and a shape-changing structure. The two technologies are both popular in researches. From the stakeholder analysis, another key player - the car company is considered in this iteration.

The body fitter used a kiosk to provide suggestions to the consumers on the most suitable mattress. This way of providing a product and service is one way of providing feedback to the user. The suggestion not only benefits the consumer but also benefit other stakeholders, like the mattress company. As there is a user need to decide which lumbar support to buy, there are also many existing lumbar support products on the market; there needs a role to give personal suggestion to the user which kind of support is better.

That is where another iteration of the concept happens. To give more freedom to the user, also keep the company focus on investigating time on putting a textile sensing product on the market, the function of pressure sensing can be separated from the shape-changing structure and become a stand-alone product—the feedback changes from the shape-changing structure into a suggestion of which lumbar support to use. The car company can also cooperate with some lumbar support company to produce the support fits in the specific car.

Another aspect considered is that the product cannot be copied or used easily by a third company. The requirement determines that the sensing mat should be integrated into the car seat, instead of an add on product.

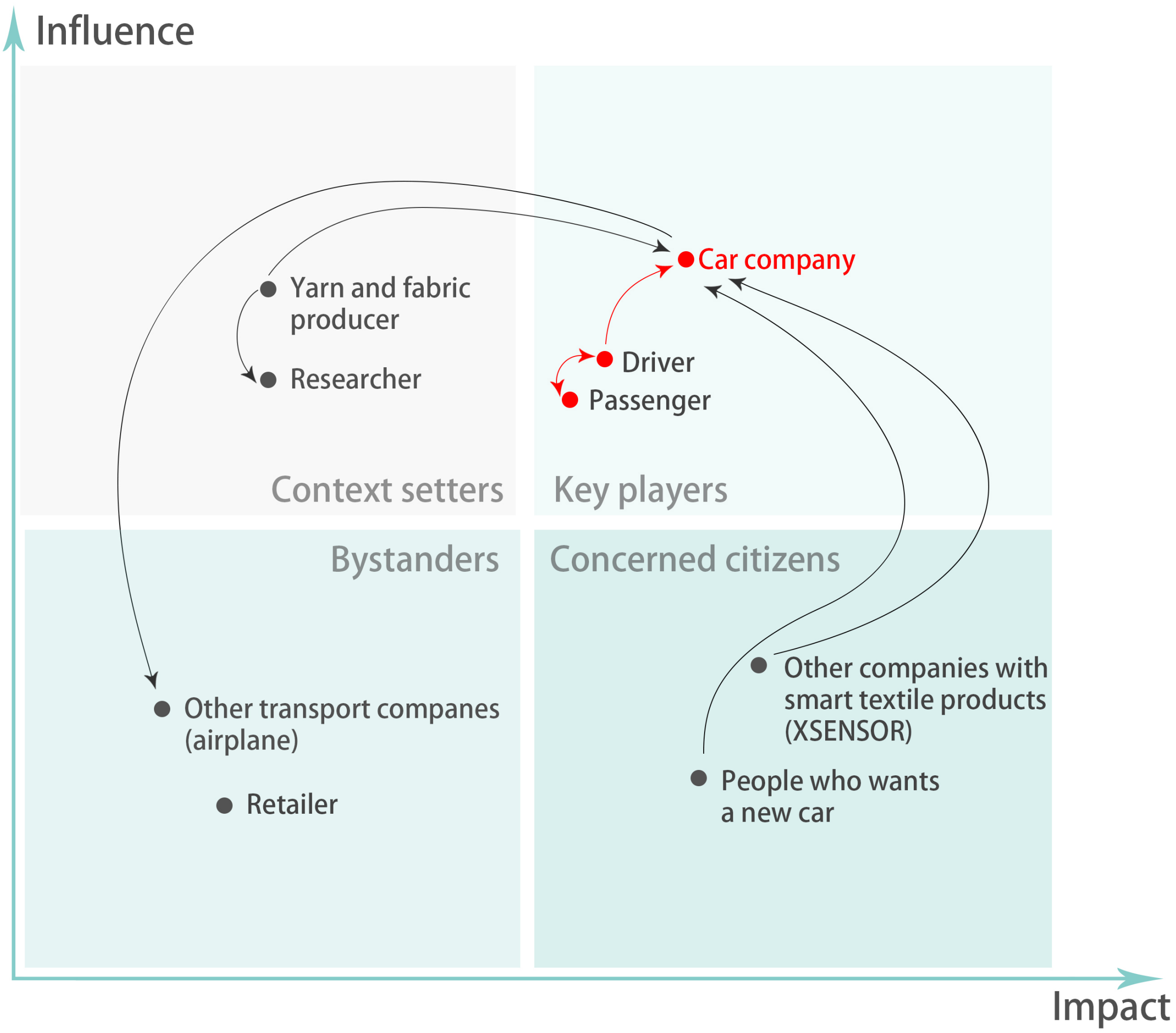


Figure 5.44 Stakeholer map

5. Embodiment

The original concept, on the other hand, will be a product in the later stage.

As shown in Figure 5.4.5, the function of the sensing mat and the shape-changing pillow are separated. The sensing mat is part of the seat's cover, and it is plugged into the seat for power connection. A zipper is used to fix the surface on top of the seat. There is a groove in the cushion of the backrest, where the pillow can fit in.

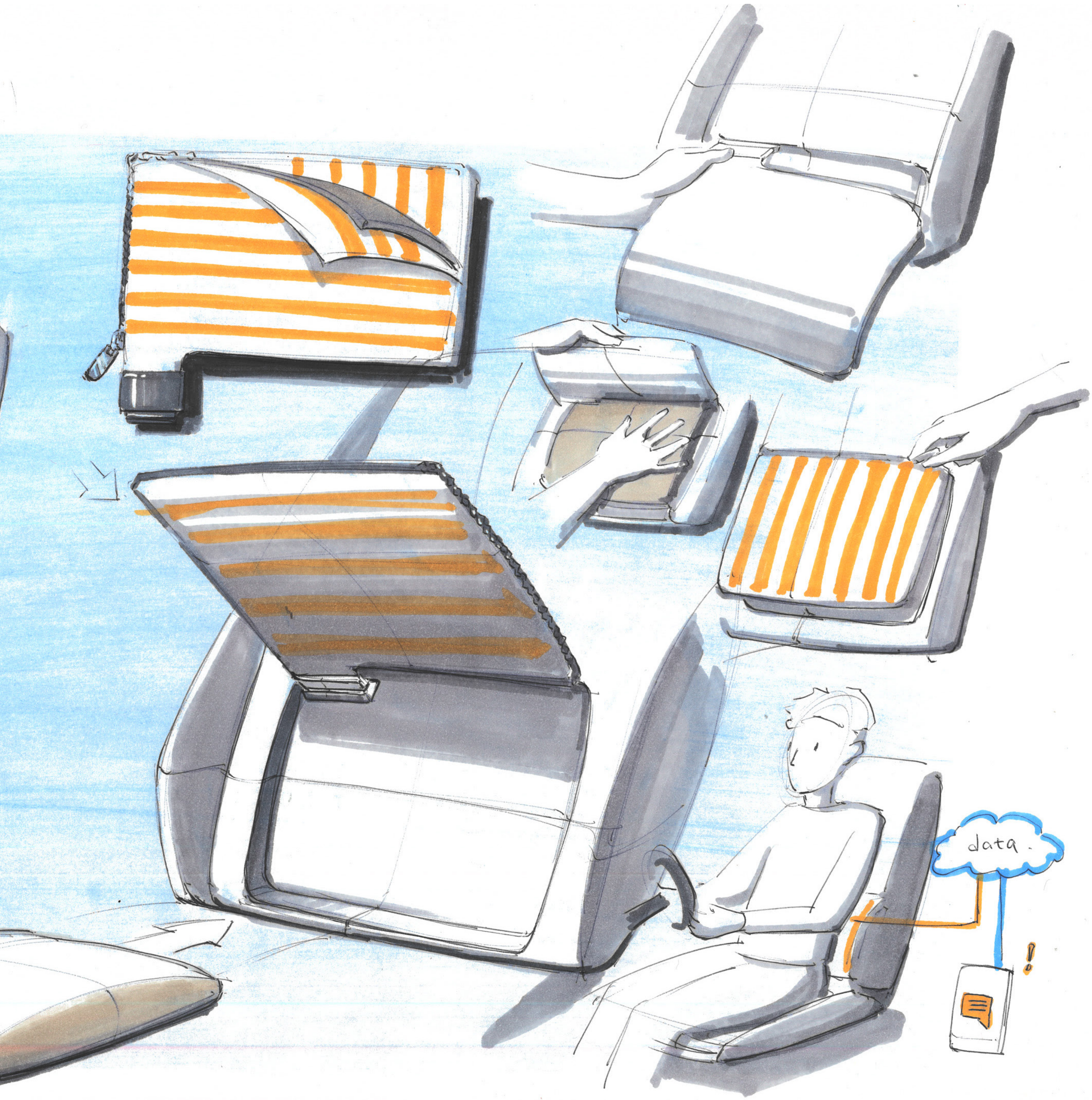
Standard support is put in the groove at the beginning when the user buys the car. When the driver sits on the seat, the pressure distribution is monitored. The data is then stored. After some period of driving, some suggestions for buying lumbar support and which ones can choose.

Advantage

For the car company,
Can put the effort more on the fabric pressure sensing mat. The shape-changing function can be added in a later stage.
It is integrated into the car seat. Not easy for other sensor companies to produce a similar product.

For the driver,
Provide freedom to the driver to choose some existing lumbar support.
Give personalized recommendations based on the sensed data.

Figure 5.45 Sketch of the iterated concept


data

Feedback and user interaction

Like the Body fitter, a service is also provided along with the sensing mat. The car itself is also a "kiosk" for the driver.
As shown in Figure 5.46, a mockup of how the software could look is generated based on the template of iCare.

The detailed procedure could be:

1. Enter your height, gender, and weight
2. Use the sensing mat and the lumbar support for testing
3. Generate pressure map, give recommendations to which lumbar support is suitable.
4. Monitor the pressure regularly.
5. Reminds the user a new lumbar support is needed

The service is available from the company, and the driver does not need to go to any service points to get his pressure map and ask for suggestions. The map itself is also scientific proof of the suggestions given to the user.

Figure 5.46 How the in car service could look like

Pattern of the fabric sensor

Considering the pattern of the sensor, it highly relies on the design of the seat. However, as there are many requirements on the conductive fabric- the contact area, preventing shortcuts between stripes, the freedom of pattern design is reduced.

Figure 5.48 shows some trends and pattern examples in the car seat. The advantage of the fabric sensor is that by changing the conductive and regular yarn's color and pattern, the electrodes can be seamlessly merged into the seat.

Research (Bredies, 2017) explored a wide variety of knitted and woven techniques. As shown in Figure 5.49 (1), the samples are knitted and claimed to reflect on pressuring change. It is also mentioned in the literature that this sensor sometimes does not work as there are small shortcuts between yarns when the fabric is stretched or moved. Therefore, the complicated pattern is not stable for a fabric sensor compared to the samples made in this project.

Figure 5.48 Patterns from different car seats.(C. (2018)

On the other hand, the literature shows the potential of how far the pattern could vary from fabric pressure. To create the atheistic value when remaining the function of pressure sensing.

Figure 5.49 (2) shows the woven technique. The fabric is also used for pressure sensing. Use the knowledge of knitting and weaving, the fabric sensor can vary a lot in its shape and colour. Embroidery is also an approach to create an add on the pattern on the fabric using conductive yarns. The embroidery technique is also tested in this project at the beginning, with a contact area of 10*10 mm, as shown in Figure 5.49.3, the sample can show a similar output as the knitted samples.

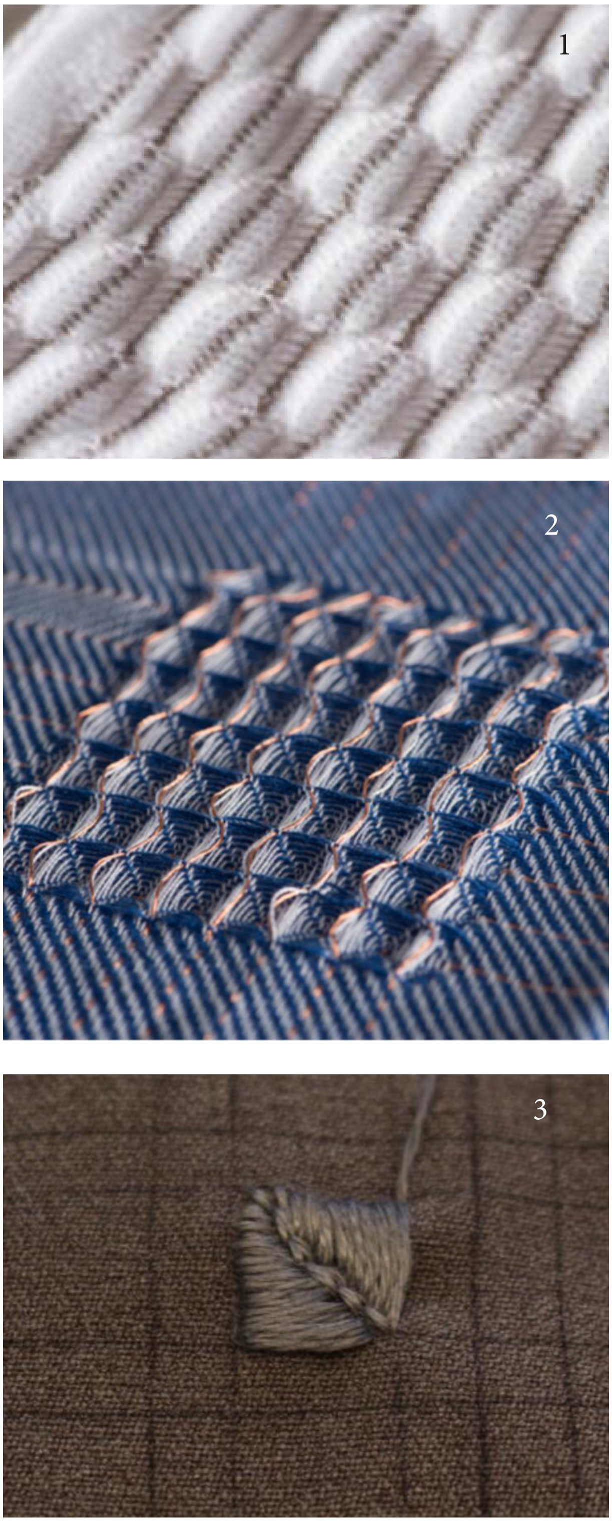


Figure 5.49 Patterns from different car seats. 1. Shadow view of the final pressure matrix sample. 2. Closeup of the woven pressure sensor matrix with copper threads on the long floats. (Bredies, 2017) 3. Embroidery sample made at in the project.

Cost estimation

The cost of the product is also estimated based on the material used in the prototype. As the material of the prototype might not be used for the final product, the estimation is not accurate. It is just used for a company to get an overview of how much the product will cost.

The price of the XSENSOR mat is 20000 euros / piece. The poduction cost of the new sensor mat is estimated to be 153.6 euros /piece. The normal price in store is estimated to be 700 euros /piece. The cost on different aspectes are shown in Table 5.1. As the estimation is based on the material used for the prototype, some costs like the Investments and allowances are roughly estimated. The price of the material is based on the price on the market. For detaile cost estimation, refer to Appendix N. **Comparing to the XESNSOR mat, the sensor shows its advantage in the price. Also as the product is integrated in the seat, the cost is inclused in the cost of a car. The technology can be used as a unique selling point.**

Product series:	2000
Material costs	€49.4
Material processing costs	€3.3
Investments	€0.2
General allowances	€0.5
Bought components	€7.3
Bought electronics	€20.0
Assembly costs	€23.4
Total production costs	**€153.6**

Assembled production price for internal calculation:		**€153.6**
Overhead factor for general operating costs	15%	**€23.0**
Overhead factor for sales	5%	**€7.7**
Profit factor (unexpected costs are paid for from the profit)	50%	**€76.8**
Total factor = product of (Each of the factors + 1) - 1	81.13%	**€124.6**
Price when collecting the product from the factory		**€385.6**
Profit margin for the wholesale (e.g.: import, wholesale, distributor)	20.00%	**€77.1**
Wholesale price		**€462.7**
service-oriented retailer in a beautiful building in a prime location. Strategy with a view to competition	25.00%	**€115.7**
Netto price (excluding VAT)		**€578.4**
VAT	21.00%	**€121.5**
Normal price in store		**€699.9**

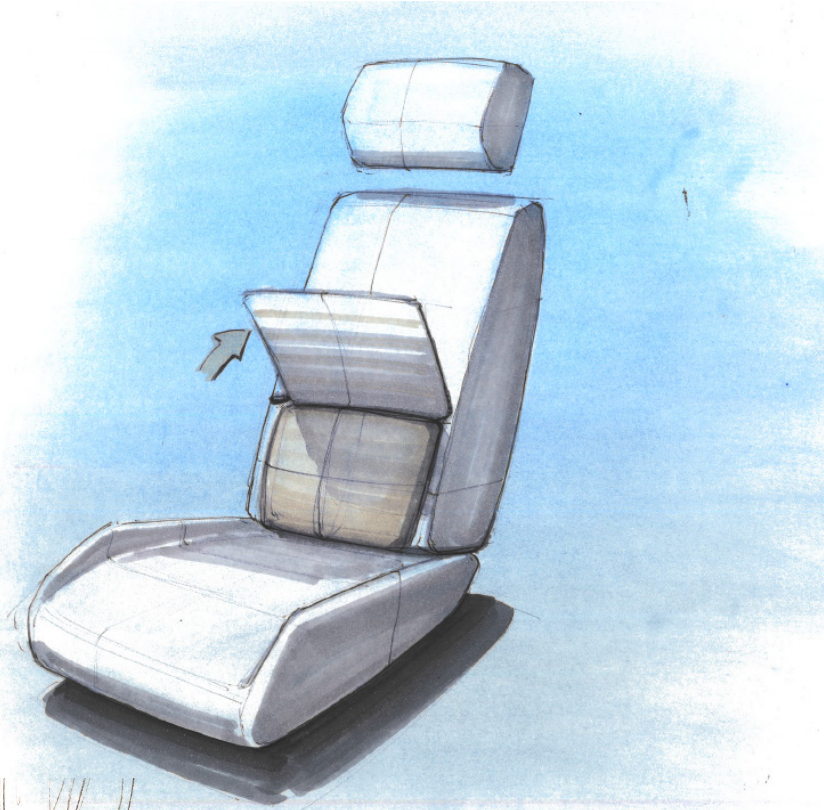
Figure 5.1 Cost estimation

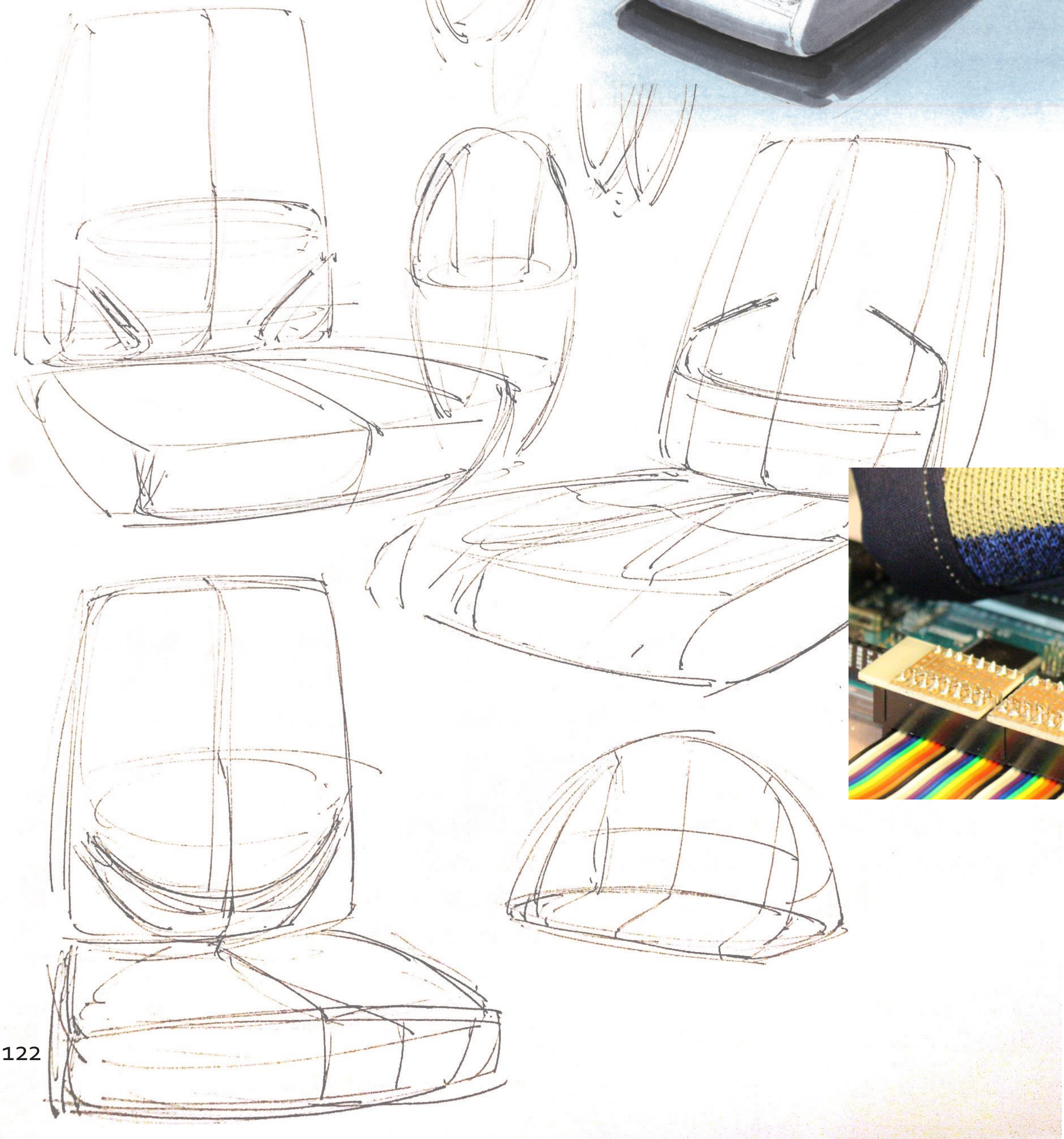
Sketch and picture of the final prototype

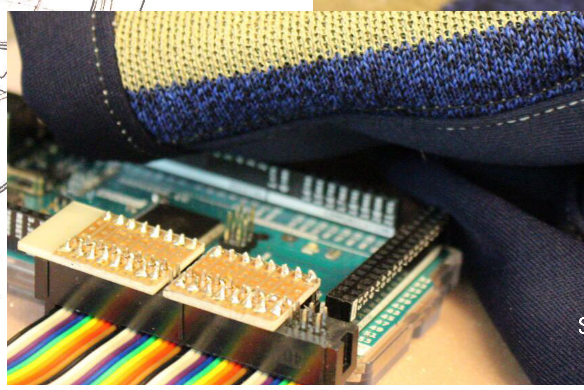
Some sketches of the concept and pictures of the final prototype is shown in this page.

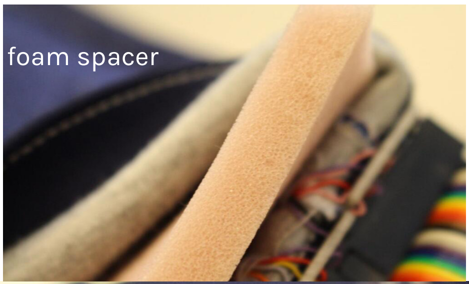
The sketch shows some thoughts on how the sensor could be put on the seat surface in different shapes. Rounder shapes are considered.

The picture show an overview of the prototype.

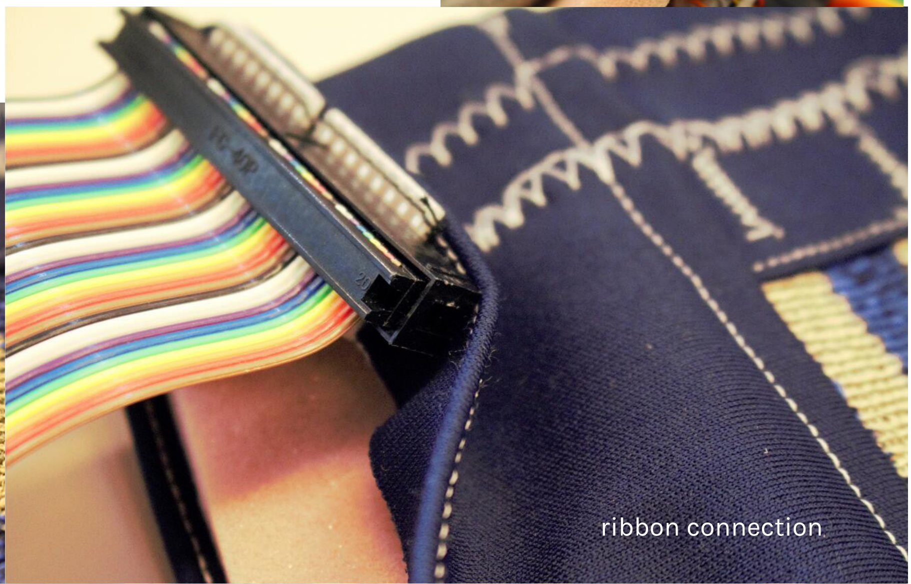






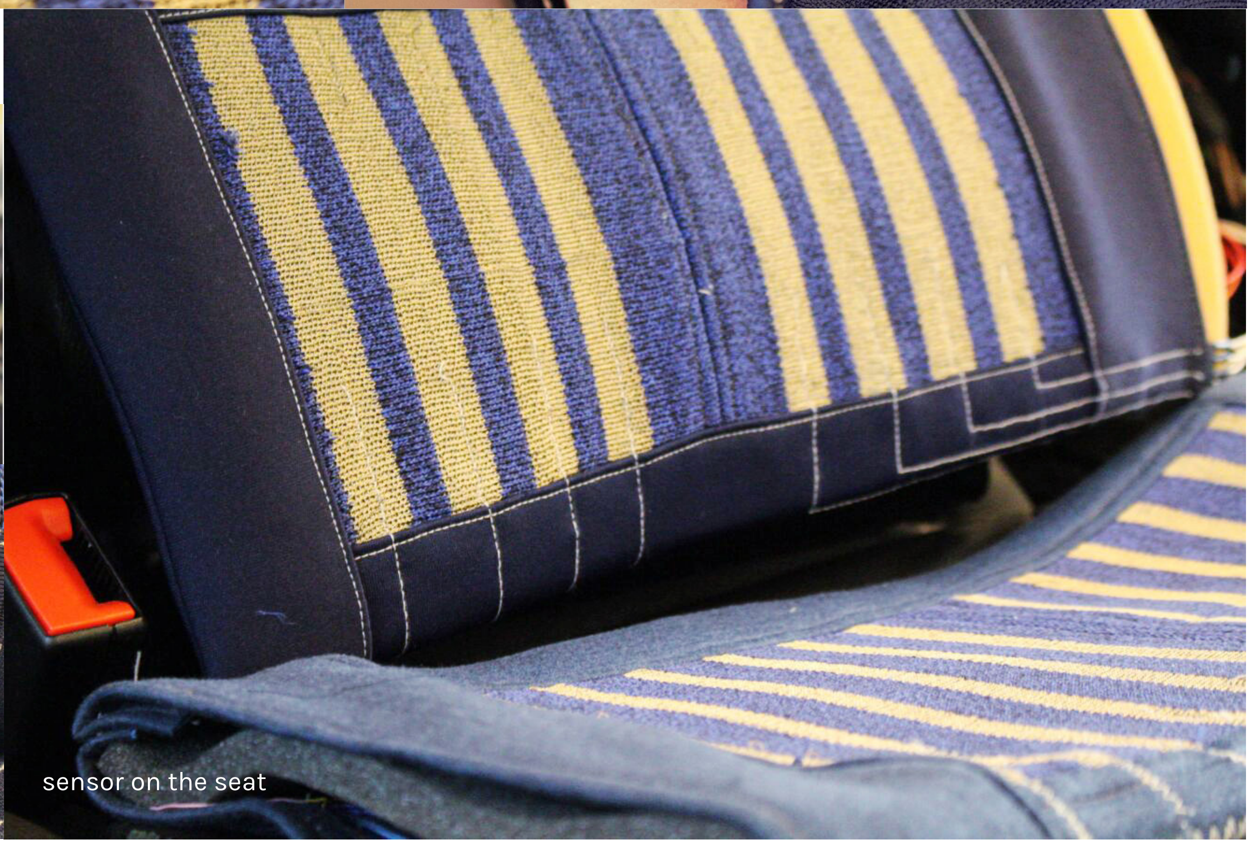

foam spacer


zigzag stitch


ribbon connection


nductive lines


Soft fabric


sensor on the seat

6. Evaluation

Requirement checklist

In the evaluation phase, the requirements are checked. As shown in Table 6.1, the fulfilled requirements are marked with a green dot, and the unfulfilled ones are marked with red. Yellow ones are not fulfilled, but some solutions are generated as recommendations.

No.	Description	Level of fulfillment
1.1	The sensor is able to sense pressure from 0-3 kPa	🟢
2.1	The sensing mat is made completely put of textile, with no or limited amount of plastic material.	🟡
3.1	The sensor is able to detect at least 3 obvious posture change	🟢
3.2	A pressure distribution map is more important than the accuracy of each sensing element. This means all the sensors need to have a similar output when adding the same pressure.	🟢
3.3	Stability of the sensor. The fluctuation of the sensor value need to be within a range of 10 units.	🟢
3.4	The sensor should be able to show outputs under wet condition.	🔴

Table 6.1 Requirement check list

Four out of six requirements are fulfilled. Requirement 2.1 is not fulfilled as the spacer material is foam instead of fabric. Recommendations are provided to use the 3D knitted fabric from the company Müller Textil, Germany. Requirement 3.4 is not tested yet. While it is checked that if there are short circuits between two yarns, the sensor will not work. It is recommended to use insulated yarn for knitting. For the detailed recommendations refer to Recommendations in this chapter.

6. Evaluation

TRL level check

The Technical readiness level is used to evaluate how far this project goes. The system and subsystem are defined. For the detailed figure, refer to Appendix#.

As shown in Figure 6.1, the subsystems are evaluated from TRL level 1 to level 9. The gray blocks indicate the starting of each system. The blue ones refer to the end level after this project. The fabric sensing mat is proofed working, and the connection is also validated in the laboratory situation—the support material of the sensing mat like the unconducive fabrics and yarns. In general, the sensing mat itself reached TRL 4, laboratory validation.

For the boards used in this project, the Seeeduion lotus and Arduino mega are already elaborated hardware. No improvement is made under this system.

There are some validated Arduino codes from websites for touch sensing matrix and capacitance measuring for the software. The processing code for touch sensing can be directly used after some small changes. Therefore, the software started from TRL 2 and reached TRL4 in this project, enables the sensor to provide primary output.

For the lumbar support and service concept, the level started from TRL1 and reached TRL4 with a working prototype. A lot of embodiment work is still required in order to put the product on the market.

In general, this project sets the start of the implementation of the textile pressure sensor, from technology in researches to a working prototype validated in the laboratory.

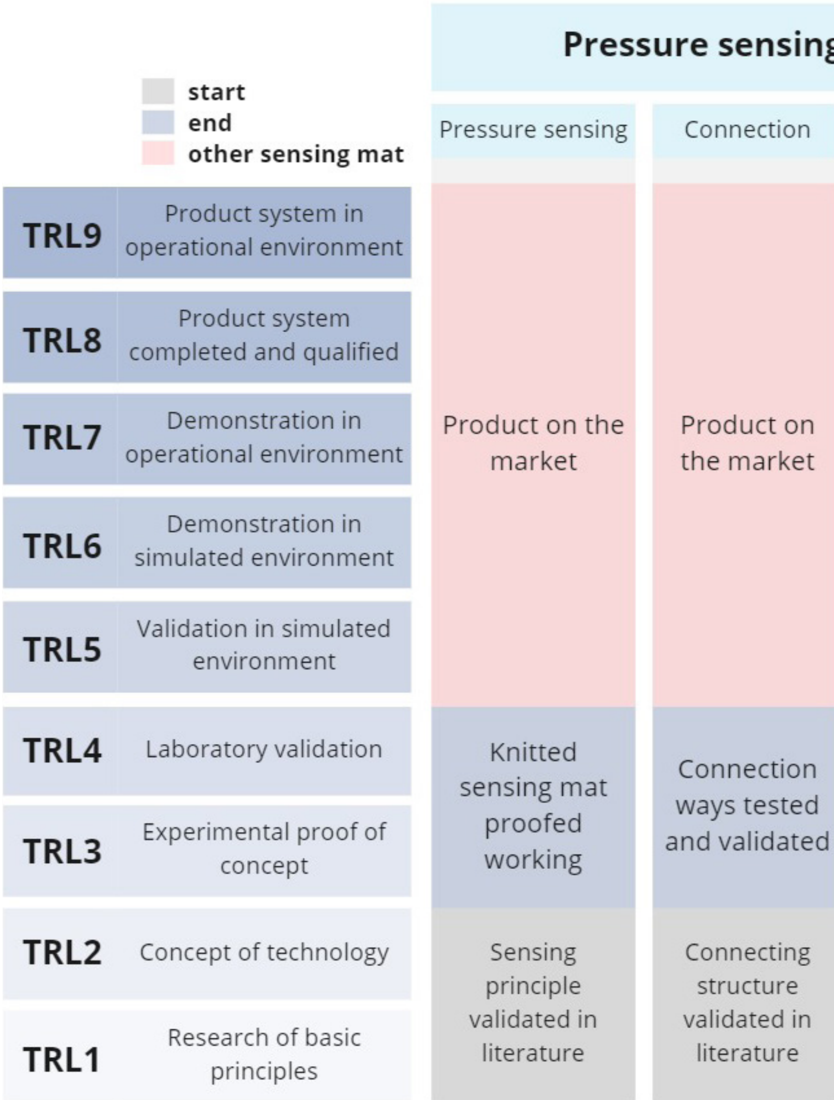
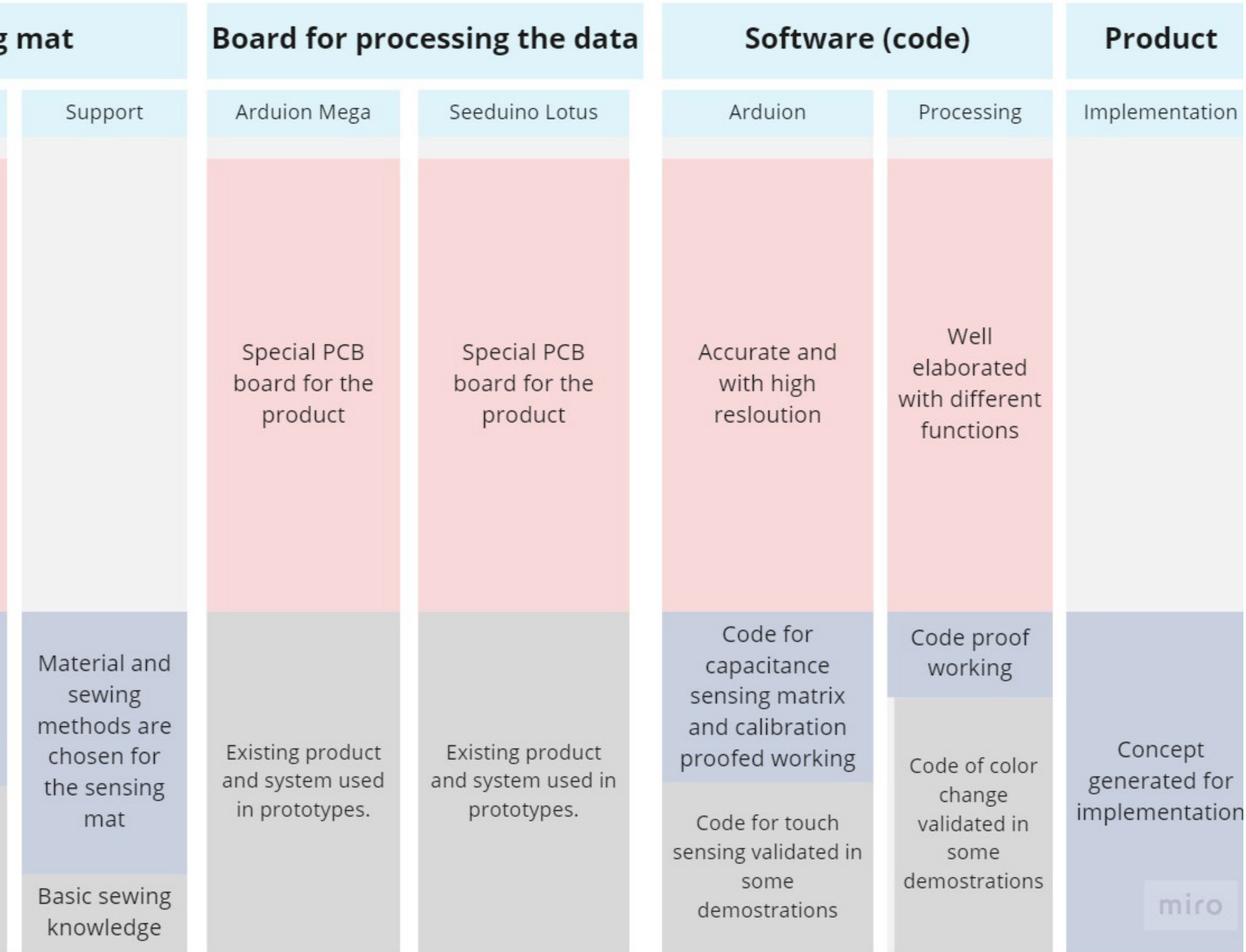


Figure 6.1 TRL level


g mat
Board for processing the data
Software (code)
Product
Support
Arduion Mega
Seeduino Lotus
Arduion
Processing
Implementation
Special PCB board for the product
Special PCB board for the product
Accurate and with high resloution
Well elaborated with different functions
Material and sewing methods are chosen for the sensing mat
Basic sewing knowledge
Existing product and system used in prototypes.
Existing product and system used in prototypes.
Code for capacitance sensing matrix and calibration proofed working
Code for touch sensing validated in some demostrations
Code proof working
Code of color change validated in some demostrations
Concept generated for implementation
miro

6. Evaluation

User test- Story telling

As the prototype is only about the pressure sensing part, it is not a complete product that can be used for user testing. Therefore, the storytelling method is used along with the prototype.

The participant is asked to read through a story. After reading, the prototype and a sketch of the final product are shown to the participant. A short interview is then conducted to ask them about their opinion on the new product. The questions including:
1. What do you think is the advantage of this product?
2. What is the disadvantage of this product?
3. Do you have any suggestions for this product?
4. Do you have any other questions?

The story and notes from the interview can be found in Appendix #. Six people joined the test. In general, participants are very interested in this new technology. They also think along with the story and provided many valuable suggestions. Some queots are listed below about their suggestions on the concept.

Disadvantage:

"It is just for one - time use. If the driver does not feel uncomfortable, the pressure sensor is useless "

"It is only for monitoring one driver."

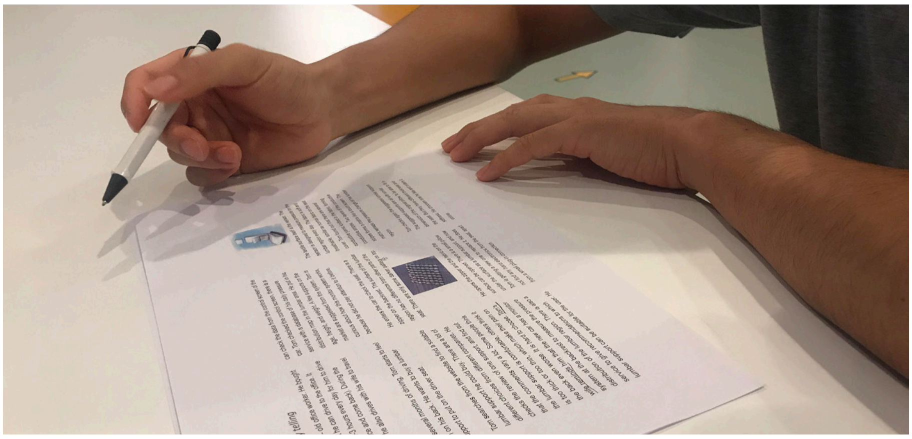


Figure 6. 2 Participant reading the story

" Which kind of car are you going to put the sensor? Will it be very expensive?"

"Some car seats are already very comfortable. There is no direct feedback after monitoring."

Suggestions:

"The pressure will increase during the crash, maybe that can be another function of the sensor."

"Maybe the data collected can be used for the company to design its own lumbar support for the car."

" The angle and the position of the seat also needs to be considered. People adjust it sometimes, and then the pressure will be different."

Two participants mentioned the first disadvantage - the sensing mat is only for one-time use. If the driver did not feel any discomfort, there is no other feedback. The users are expecting more forms of feedback. At the same time, some of the supports on the market cannot fit inside the room left inside the seat. As a solution, the car company is recommended to provide its own lumbar support with different depths and stiffness. The collected data can be used as a guide to choose the lumbar support made by the company.

The shape-changing function, as direct feedback, is desired from the user as it can provide direct feedback.

Another suggestion regarding the seat angle is also worth considering. The seating angle is another parameter that can affect the pressure distribution. More research needs to be done to determine the relationship between the seating angle and the pressure distribution of the seat so that the pressure sensor can make the right analysis of the sensed output.

Recommendations

Yarn and spacer choice:

As the sensor stripes are not insulated, it can still be affected by people touching it. As the finger is also conductive and the human is regarded as a big capacitor. To fulfill the requirement of insulation and being able to use the sensor under the automotive context, it is recommended to try insulated yarns Shieldex TPU Yarn for further development. As shown in Figure 6.4, the yarn is insulated and has the property of conductive yarns.

For the spacer material, it is recommended to test further the 3D knitted spacer produced by Müller Textil, Germany. It is validated in research and can be used as an improvement version of foam.

Connection choice:

For the connection, instead of ribbon connection, which is hard, Textile Cabling produced by the company, ohmatex, is recommended in Figure 6.3. Their softness and strength characterize the yarns.The textile ribbon, with insulated yarns in the middle, is suitable to both be soldered and stitched. It is suitable for both small and large amounts of conductive stripes.

Software:

Processing in this project can show the pressure change in a greyscale. There are more options to make the figure of pressure distribution look nicer. The code from Github called multitouch kit has an elaborated processing code, enabling a more nice-looking output.

For the calibration, the code used for

Figure 6.3 Textile Cabling

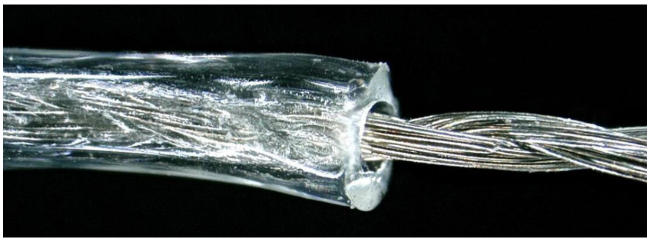


Figure 6.4 Shieldex TPU Yarn

Figure 6.5 3D knitted spacer in Müller Textil, Germany (Meyer et al., 2010)

auto-calibrate needs to be improved as the sensing elements still shows some different values when adding the same pressure. It would be better to add pressure using a machine instead of weights. The accuracy of the sensor can also be improved.

Suggestions on the concept:

The concept of the lumbar support can be described in a short- term and long- term version.
As analyzed in the TRL level, the sensor still requires a long way of developing and testing to reach the market.
In the short term (5 years), the company is recommended to develop the pressor sensor first and provide self-made lumbar support. The lumbar support made by the company can be designed with different depths and stiffness. The pressure sensor's collected data can be used as a guide to choose the lumbar support made by the company.

In the long term (10 years), as the user still favors the real-time feedback, it is recommended to also invest in developing the shape-changing technology and provide a shape-changing sensing mat.

Another suggestion regarding the seat angle is also worth considering. The seating angle is another parameter that can affect the pressure distribution. More research needs to be done to determine the relationship between the seating angle and the pressure distribution of the seat so that the pressure sensor can make the right analysis of the sensed output.

Prototyping:

It is recommended to use an interlock stitch and straight stripes pattern at the start of the prototyping. More possibilities can be explored as discussed in the chapter of pattern.

It is also recommended to knit one stripe first and measure the width. The size is not scalable by changing the number of the stitch.

It is not recommended to use thin and stretchy Jersey fabric as the stitch can lead to the deform of the fabric during stitching. Choose the fabric with similar thickness as the knitted sample.

For sewing conductive threads, it is recommended to use Jersy needle as it has a rounder end. Normal needle with sharp ends can stitch through the middle of the yarn and the stitch is smooth.

6. Evaluation

Reflection

This is the first project that I make planing and organize meetings by myself. I learned a lot as being a stand-alone designer.

What I feel the most important in the graduation project is to balance what I want to explore and what I can explore in a certain amount of time. As the final project of Master, it is usual that I want to make everything "perfect." It is right on the one hand, as I am pushing myself to improve. On the other hand, it leads to so engaged in one problem and spend a lot of time to solve it. For example the way of connection when prototyping. To make the samples look nice, I spent two weeks on remaking all the samples. Another week is then used to identify short circuits. For the report writting, it also takes some extra time as I keep adding parts into it. I should have set a limit of how far I should go.

The project is highly technical focused, and the concept generation is more of an assist aspect. For the project approach, I tried the co-evolution method and generate concepts without ideation. I tried to analyze the problem from different elements, define the underlying user needs. Then the solution is right there. Look back at my analysis, the arguments are convincing but also lack of innovation. More effort need to be put in critical thinking and put more logical arguments.

From the technical aspect, I am excited about the prototype when it finally works. Watching it gradually gets to the point I want gives me a feeling of accomplishment. On the other hand, I think I did not go more in-depth to ask why, especially the working principles of electronics, in some situations. It is also a doing and learning progress. When the sensor shows outputs, I no longer go deeper into the accuracy and sensitivity of the sensor. It is, on the one hand, due to time constraints, on the other hand, these aspects mentioned in the literature requires a deep understanding of the material used, like the property of the conductive yarn. The essay is not the only source of knowledge. Asking experts and peer students, also search in general from the websites are also helpful.

I also benefit from participating in other user tests from other students. It is not a waste of time. I learned about how other people approach some similar questions. For example, the posture in my test is not defined using the joints of people. Participants have their own understanding of the postures even though they are given reference pictures. I learned about a more specific way of defining postures by joining another test.

In general, it is an unforgettable experience. I felt nervous and excited when sending the invitation.

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