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Haptic Wearable for Social Mediated Touch

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Preface

First and foremost, I would like to thank my supervisors Angelika Mader and Judith Weda for their support during this bachelor project. I am very grateful for all the effort and enthusiasm you showed in our weekly meetings. Thank you for all the feedback and motivation you gave me during this project.

I would also like to thank Edwin Dertien. He was kind enough to lend me his materials and knowledge on the pneumatic inflatables, which helped me greatly in creating the final prototype.

Last, I would like to thank all the participants that took part in evaluating my haptic wearable for social mediated touch. Your experience gave me new insights in my prototype, which I find very valuable.

Abstract

A social touch is any interpersonal touch with a communicative intent. Social touch has a lot of benefits and is related to social bonding, decreased level of loneliness, stress relief. It is also a way of communication. However, social touch is a close-proximity interaction and cannot be experienced over a distance. Now, in 2020, during the COVID-19 pandemic, everyone is advised to stay at 1,5 meter distance from everyone outside their household. This results in less social touch and less of its benefits are experienced. A haptic wearable for social mediated touch could be a solution, as it simulates a social touch over a distance.

Normally, friends and family members are greeted with a hug. During the pandemic, this is not always possible. Therefore, a haptic wearable that simulates a short hugging sensation is developed. This haptic wearable aims to make greetings a more pleasurable experience, while keeping the advised 1,5 meter distance from one another. First, the wearables automatically connect with one another, with the use of Bluetooth. Second, a hug is sent by touching two capacitive sensors on the sleeves of the wearable. Third, the hugging sensation itself is simulated with the use of silicone inflatables and vibration motors.

The wearable is created from an autoethnographic point of view. Furthermore, this bachelor thesis follows the Creative Technology Design Process, allowing quick iterations of the prototype. The wearable is evaluated using functional and systematic requirements. A user evaluation is conducted to see whether the functional requirements were met. The systematic requirements are evaluated by the researcher. Overall, the haptic wearable for social mediated touch was perceived positively and met almost all the established requirements.

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Chapter 1

Introduction

Social touch is an important part of human development and personal well-being. Throughout life, touch is used to communicate both positive and negative emotions. From infancy on, social touch has helped in development as it shapes social reward, attachment, cognitive communication [14]. Furthermore, social touch can help regulate psychological and emotional well-being [15] and encourage social bonding between individuals [16]. Moreover, social touch can also play a role in social loneliness and in regulating stress responses during short term challenges [15].

However, social touch is a close-proximity interaction between humans. When two individuals can not physically touch each other, this can result in less social bonding, increased loneliness and a lower stress buffer in stressful situations [15]–[17]. Therefore, maintaining a meaningful relationship and create a feeling of closeness over distance can be more difficult. Especially now, in 2020, social touch between individuals is minimised due to the COVID-19 pandemic. During this pandemic, it is essential to practice social distancing to stop the virus from spreading. According to the Dutch government, it is important to keep 1,5 meter distance from everyone outside of your household [18]. This means many social touch interactions are not able to take place and a lot of people do not experience the benefits of social touch.

A solution for this lack of social touch in society, could be a haptic wearable for social mediated touch. Social mediated touch allows for a sense of social touch over a distance. This means it lets one person, the sender, touch another person, the receiver, over a distance with the use of haptic technology. This means haptic wearables for social mediated touch can aid in increasing interpersonal well-being during this trying time of social distancing. Therefore, the goal of this bachelor project is to design a haptic wearable for social mediated touch, to allow a social touch while practising social distancing.

1.1 Research Questions

At the starting point of the project, a main research question is formulated:

How to design a haptic wearable for social mediated touch, to allow a social touch while social distancing?

To be able to answer this main research question, several sub-questions are composed. These sub-questions aim to gain insight in specific areas of haptic wearables for social mediated touch, such as touch type, state of the art and hardware and software components:

SQ-1 What is the state of the art for haptic wearables and social mediated touch technology?

SQ-2 What is a suitable context and scenario for a haptic wearable for social mediated touch?

SQ-3 What components, both hardware and software, are needed to design a haptic wearable for social touch?

1.2 Report Structure

This bachelor thesis contains all the knowledge gathered around haptic wearables for social mediated touch. Firstly, benefits of social touch, as well as social mediated touch are discussed in chapter 2: State of the Art. This chapter also contains possible hardware components that can be used and elaborates on projects in the same domain of haptic wearables for social mediated touch. This chapter aims to answer the first sub-question: What is the state of the art for haptic wearables and social mediated touch technology?

Secondly, in chapter 3: Methods and Techniques, the way this bachelor thesis is conducted will be elaborated. This bachelor thesis follows an autoethnografic design method. Furthermore, it utilises the Creative Technology design process as a guideline.

Third, the first concept idea is generated in chapter 4: Ideation, with the use of a mind map. After which, suitable contexts for the haptic wearable for social mediated touch are explored, using user case scenarios. In this chapter, the second sub-question is answered: What is a suitable context and scenario for a haptic wearable for social mediated touch?

In chapter 5: Specification, the concept is further specified. First, a list of the systematic and functional requirements are set up. Thereafter, the interaction is explained and an initial drawing of the design is generated. This chapter discusses which components are used in the design and why they have been chosen. Answering the third sub-question: What components, both hardware and software, are needed to design a haptic wearable for social touch?

Chapter 6: Realisation, further elaborates on how all the components are integrated into the final prototype. This chapter also showcases this prototype and explains the interaction between the components that make the haptic wearable fully function.

Thereafter, in chapter 7: Evaluation, this prototype is evaluated through a systematic evaluation and a functional evaluation. These evaluations are based on the requirements set up in chapter 5: Specification. To evaluate the functional requirements, a user test is conducted.

Chapter 9: Conclusion, aims to conclude the report by answering the research questions formulated in section 1.1.

Chapter 2

State of the Art

To be able to design a haptic wearable for social touch, some research is required to provide more insight on the subject. This chapter will focus on the benefits of social touch and how this touch can be perceived by different users. Moreover, a literature review is done to see whether these benefits of social touch are also present in social mediated touch technologies. Lastly, projects in the same domain of haptic wearables for social mediated touch, as well as frequently used components of wearables for social touch are explored. This chapter aims to answer the first sub-question: What is the state of the art for haptic wearables and social mediated touch technology?

2.1 Literature Review

An exploratory literature review is conducted, to provide an overview of social mediated touch and haptic wearable technologies. First, sense of touch and social touch are specified. Followed by the possibilities and limitations of haptic wearables for social mediated touch technology. The literature review mainly focuses on the following aspects of social mediated touch: Social bonding, level of loneliness, stress relief and communication. The literature review also explores what sensors and actuators can be used for haptic wearables for social mediated touch.

2.1.1 Sense of Touch

The sense of touch is the first sense that develops in the human embryo [19]. It allows humans to gain information about the world around them. With touch, humans can detect, discriminate and identify external stimuli. According to Haans and IJsselsteijn [20] and Huisman [21] the sense of touch can be further divided into kinesthetic and cutaneous senses.

The kinesthetic sense gives information about the position of the limbs in time and space. It is responsible for the awareness of the movement of the limbs. The kinesthetic sense helps to determine the size and weight of objects. Even without visual information, the kinesthetic sense provides awareness of the position through receptors in the limbs. [20], [1].

The cutaneous system refers to the receptors in the skin. Different types of nerve endings in the skin are receptive to different types of stimuli [20]. According to McGlone, Wessberg and Olausson [22], the cutaneous senses encompass pressure/vibration, temperature, itch, and pain. With the cutaneous system, it is possible to distinguish the texture, temperature and shape of an object.

2.1.2 Social Touch

Social touch is an interpersonal touch between people with a communicative intent, according to Cascio, Moore and McGlone [14]. Social touch can have positive and negative connotations, depending on the context of the situation. In this section the benefits of social touch are discussed.

Social touch has been related to social bonding, level of loneliness, stress relief and communication. Bonding between humans is partly based on physical interaction. According to Morrison [17] and Cascio, Moore and McGlone [14] social relations have been linked to the release of oxytocin in the bloodstream. Oxytocin is a hormone that plays a role in social bonding and aids in forming lasting relationships [15]. Furthermore, Huisman [21] states that higher amounts of this hormone have been found in individuals portraying frequent physical social contact with their partner. Therefore, social touch could be an indicator of the quality of the relationship between individuals [16].

Secondly, physical social touch could also aid in decreasing in social loneliness. According to a study by Tejada, Dunbar and Montero [16] participants that were exposed to a small amount of physical contact felt less neglected by their close relationships, compared to participants that received no physical contact. Amongst single participants, who generally received little physical contact in their daily lives, this neglect score was particularly low after receiving the physical touch. This suggests that there is a higher decrease in loneliness for single people, when receiving social touch. This study also reported a lower heart rate in the participants that received the physical touch, suggesting a positive effect on physiological well being.

Not only does social touch help against social loneliness, it can also help against stress. According to Morrison [17], social touch can act as a stress buffer, as it promotes the regulation of responses to acute stressors and other short term challenges. A study by Gallace and Spence [15], concurs with this statement. Their study showed that after receiving affectionate physical contact from a romantic partner, individuals had a decreased overall blood pressure and heart rate during a stressful event, when compared to individuals that received no physical touch.

Lastly, social touch also seems to play a role is communication. According to Hertenstein, Holmes, McCullough and Keltner [23], social touch enables the communication of positive and negative emotions and can intensify the display of emotion from the face and voice. Hertenstein et al. [23], conducted a study with 248 participants to see which emotions could be communicated through social touch of the forearm. [23] concluded that this study provides evidence that social touch can communicate several emotions. At least eight emotions could be distinguished: happiness, love, gratitude, sympathy, sadness, disgust, anger and fear.

These finding are further substantiated by a study by Kirsch et al. [24]. Their study also showed that multiple emotions could be communicated through social touch. While the study by [23] focused mainly on social touch of the forearm, this study allowed social touch of the whole body. With the whole body available for social touch, especially communications of sensual emotion , such as arousal desire and lust were easily distinguishable.

2.1.3 Perception of Social Touch

Social touch can have several benefits, but it is critical to discuss important factors that play a role in how social touch is perceived. There are individual differences when it comes to acceptance and meaning behind a social touch. Important factors to consider when discussing social touch are cultural, gender, age difference, type of relation and touch location.

Firstly, culture plays an important factor in how touch is perceived. According to [16], the amount of physical touch between close relations, as well as the meaning behind a physical touch can vary greatly between cultures. On the one hand, Green [25] states that some cultures experience a lot of social touch, often embracing, kissing or holding hands. While on the other hand, some cultures associate the need for physical contact with dependency or weakness, elaborate Tejada, Dunbar and Montero [16]. Furthermore, social touch practices in different cultures also depend on the type of relationship, gender and age [25].

Secondly, throughout life gender also plays a role in social touch between individuals. According to Green [25], on average women touch each other more, compared to men. This is likely due to less homophobia, lower competitiveness and more trust and intimacy between women. Furthermore, as a child, humans are more likely to touch same-gendered individuals, states [15]. During adolescence, however, social touch happens more often between cross-gender relationships. Thirdly, intensity of response to social touch also increases with age, according to [14]. Sehlstedt, Ignell, Wasling, Ackerley and Croy [26] add that the pleasantness of social touch also tends to increases with age.

Lastly, Huisman [21] adds that the way social touch is perceived also depends on the type of relationship between the communicating individuals. Positive effects on stress responses are higher during physical contact between spouses, compared to physical contact with a stranger. Furthermore, [21] adds that the the type of touch that is applied and the location of this touch are also important factors of how touch is perceived. Overall, it is important to remember the target group for which the haptic wearables for social mediated touch will be created. While designing a product for social mediated touch, the culture, gender and age of the user should be considered.

2.1.4 Social Mediated Touch

With the use of technology, social mediated touch allows a sense of social touching over a distance. Haans and Ijsselsteijn [20] explain that social mediated touch lets one person, the sender, touch another person, the receiver, over distance, though technology. The touch is recorded by the sender, after which it is send to the receiver through the internet, where it can be played again. To simulate the touch, the haptic wearable uses tactile or kinesthetic feedback. Tactile feedback stimulates the cutaneous receptors using electric current or vibrations, while kinesthetic feedback stimulates the kinesthetic receptors by applying force. By using one or both of these methods, physical interaction is emulated.

2.1.5 Hardware Components: Sensors and Actuators for Social Mediated Touch

To record and simulate a touching sensation, sensors and actuators are necessary hardware components for the haptic wearable. In this section, components that are often used when simulating social touch through technology are discussed.

2.1.5.1 Sensors

Different types of sensors can be used to detect touch from the sender. These sensors are called tactile sensors, as they are sensitive to touch, force or pressure. One of such a tactile sensor is a capacitive touch sensor [27]. When the user makes contact with the surface of the sensor, this closes the circuit. When the circuit is closed the capacitance changes. This change in capacitance can be measured and is converted into a signal. Capacitive sensors also come in the form of woven conductive fabric, which allows them to be easily integrated in a wearable.

Another tactile sensor which is often used in social mediated touch technology is the force sensor [28]. The resistance of the force sensor changes when force or pressure is applied on the sensor. This change in resistance is measured to give a reading of the force that is applied to the sensor. Force sensors can be very thin, making them ideal for wearables.

The last sensor often used in haptic wearables for social mediated touch are flex sensors [29]. This type of sensor can measure the amount of bending the sensor does. The flex sensor also uses change in resistance to measure the amount of bending that occurs. The resistance increases when the angle increases. The flex sensor is a thin and bendable sensor, making it unobtrusive in a wearable. In wearables, these flex sensors are usually placed in the sleeves of a wearable to see whether the arm is straight or bent.

2.1.5.2 Actuators

Actuators need to ensure a sensory equivalent to real time social touch. To recreate a simple touching and stroking sensations, mostly vibrotactile actuators are used, agree both [20] and [21]. These vibration motors are usually small, coin sized vibration motors. To create a stroking sensation, multiple vibration motors are placed in a row. Each vibration motor is activated after the other, creating the stroking pattern. Vibration motors are not able to perfectly emulate a feeling of a stroke, but allow a close technological resemblance to an actual stroking touch [20].

To produce a larger interaction, however, force actuators are used [21]. Such force actuators could be simple motors, pressing directly on the skin, creating a sense of touching in a small area. It could also mean, motors pulling the haptic wearable together to create a pressure sensation. By pulling the wearable together, a bigger surface is affected.

Another way to create the feeling of pressure is by using inflatable airbags. By inflating airbags in the wearable at different location, pressure can be exerted. The size of these airbags can vary, creating a small or larger area of touch. An example of such an inflatable can be found in [5] & [8]. They use silicone pouches that are inflated with air. These silicone pouches can be modelled into any shape using the silicone. Silicone is an ideal material for haptic feedback technology, as it has a skin-like feel.

Lastly, an actuator which is often overlooked, is a temperature regulator, such as a Peltier element [30]. These elements can convert electricity into heat. Peltier elements can be used to produce warmth to a specific temperature [31], [32].

Real life touch is often warm, therefore adding this to a haptic wearable for social touch could aid in creating the feeling of a real life touch. One thing to keep in mind, however, is that temperature regulators need some time to heat up and cool down. This means that a temperature actuator is not able to react real time. Therefore, when simulating touch real time, temperature actuators might not be ideal.

Overall, all of these sensors and actuators can be useful when creating a haptic wearable for social mediated touch technology. Each component has a different purpose. Therefore, first the goal of the haptic wearable needs to be clear, to see which components should be integrated in the design.

2.1.6 Considerations

The fact that the physical interaction is emulated with the use of technology, results in some differences when comparing it to real-life social touch. Firstly, Huisman [21] explains that social mediated touch technology is not always mutual and thus could be one sided. This means that the sender does not always have the opportunity to also receive a touch. Secondly, Huisman [21] continues, mediated touch does not have to be real-time. The touching sensation could also be recorded by the sender, to be played at a later time by the receiver. Lastly, Haans and IJsselsteijn [20] add that mediated touch does not feel similar to actual touch in terms of sensory richness. This is due to the fact that the sense of touch has to be simulated through technology.

2.1.7 Benefits of Social Mediated Touch Technology

Social mediated touch technology is being developed to simulate the sensation of touch between two individuals over a distance. However, as mediated social touch is still not able to accurately replicate actual physical touch, Huisman [21] argues that it might not have the same positive effects that real-life social touch has. Some studies [31], [33] state that the sense to feel closer with their partner through social mediated touch is the main goal of the technology. However, little articles can be found to substantiate whether social mediated touch actually helps in creating a stronger bond between two individuals over a distance.

Stress relief from social mediated touch, however, has been researched. A study by Nunez, Hirokawa, Persuquia-Hernandez and Suzuki [34], as well as a study by

Nakanishi, Sumioka and Ishiguro [32] show that mostly mediated hugs are shown to have a positive effect on an individual's mental stress relief. However, other social mediated touch applications have been effective in reducing stress as well, according to Haans and Ijsselsteijn [20]. Furthermore, the use of warmth can be an important factor in stress relief when it comes to social mediated touch technology [21]. Nakanishi et al. [32] states that this stress relieving effect of social mediated touch might even be the reason why individuals have a better impression of hearsay information.

Lastly, Huisman and Frederiks [35] tested if a tactile sleeve for social touch could communicate emotions through touch at a distance. The result of their study provides some evidence to suggest that emotions can be successfully expressed using social mediated touch technology. Overall, the participants of this study felt moderately confident when expressing an emotion using the tactile sleeve. More information on the tactile sleeve for social touch is provided in section 2.2 Products and Projects.

2.2 Products and Projects

There are some products and projects that make use of haptic wearables for social mediated touch. In this section of the thesis, some these products and projects are explored. Projects that vary in use of sensors and actuators, as well as in type of social touch are selected.

2.2.1 The TaSST: Tactile Sleeve for Social Touch

The Tactile Sleeve for Social Touch (TaSST), is an arm sleeve that was designed to allow communication over distance [1]. The TaSST enables social mediated touch of the forearm between two users. According to [1], the forearm was chosen, as this location is easily reachable and an appropriate location for social touch. Furthermore, the forearm is sensitive to vibrotactile stimulation. The sleeve is attached to the forearm with the use of Velcro straps. When the sender touches the sleeve on their forearm, this sensation is felt by the receiver. As both users have an arm sleeve, the touch can be reciprocal. The TaSST can be seen in figure 2.1.

In the top left corner of figure 2.1, the input layer, output layer and control box

Figure 2.1: The Tactile Sleeve for Social Touch [1]

can be seen. The input layer consists of a 4 by 3 grid of Lycra pads. These pads are filled with a conductive wool. When this wool is compressed, it changes the resistance of the wool. This is how the forearm sleeve senses the touch. The advantage of conductive wool is that it can easily be integrated into a piece of clothing. The output layer consists of eccentric mass vibration motors, also in a grid of 4 by 3. How strong these motors vibrate depends on the amount of force that is put on the wool conductive sensor. The actuators are 40 millimeters apart from each other, because this enables relatively accurate single-point identification, according to [1]. Different types of touching sensations can be distinguished and transferred: poking, hitting, pressing, squeezing, rubbing and stroking. These touches can be seen in figure 2.2.

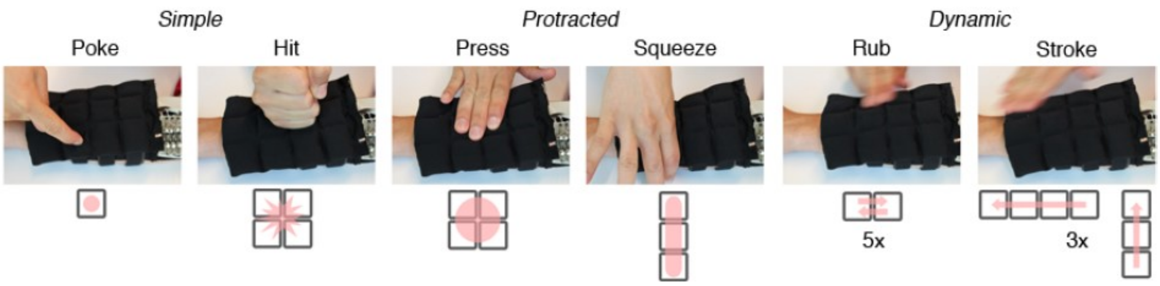


Figure 2.2: The types of touches the TaSST can distinguish and transfer [1]

To test the capability of the tactile sleeve, a user study was conducted. Beforehand, the different types of touches were recorded. During the study, the user would receive a variation of these recorded touches. The participants were then asked to imitate the touch on their own sleeve. Overall, the touches that were felt most clearly by the participants were the protracted touches press and squeeze. Furthermore, simple touches were also imitated quite accurately, but dynamic touches were most difficult.

In another paper by Huisman and Frederiks [35], the expression of emotions with the Tactile Sleeve for Social Touch were investigated. The study had 16 participants test this capability the TaSST sleeve. The participants were asked to express an emotion using the tactile sleeve. Overall, the study gave some evidence that the emotions could successfully be expressed, according to Huisman and Frederiks. [35].

2.2.2 HaptiHug

The HaptiHug is created by Tsetserukou [2] to mimic a hug similar to a real-life hugging interaction. With the HaptiHug, Tsetserukou wants to enhance social interaction and increase the emotional involvement of the users. The device makes use of a 3D virtual environment, called Second Life. When two avatars in the virtual world hug, the HaptiHug reproduces this hugging feeling. The HaptiHug can be seen in figure 2.3

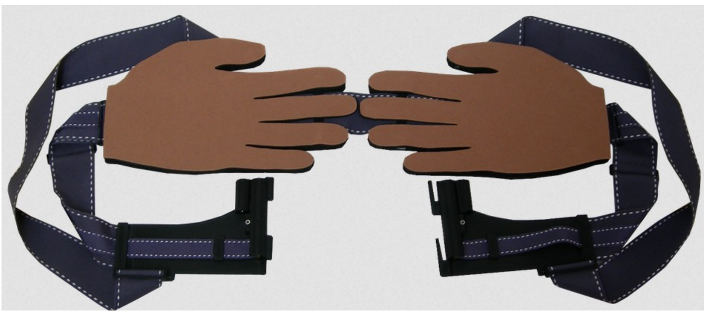


Figure 2.3: HaptiHug [2]

The HaptiHug consists of two soft hands that lay on the user's back. These hands are connected to a belt. At the chest side of the belt two rotating motors are able to pull the belt together, tightening the hug. The soft hands are sketched from real human hands to create an authentic hugging feeling. Furthermore, the Haptihug has two shoulder straps to support the weight of the device. To start a hugginh sensation, the Haptihug does not use sensors as input, but turns emoticons or text sent in the virtual world into a hug. There are three types of messages that correspond to a hug. The three types of messages correspond to different levels of hugging pressure and duration.

The HaptiHug was tested with over 300 users during several conferences. According to the majority of these users, the system realistically resembled a real life hug. Furthermore, adding the HaptiHug interaction to the animation of hugging in the virtual world caused a feeling of surprise and happiness in many participants. Tsetserukou adds that the device was able to fit users of any size, due to the adjustable belt straps.

2.2.3 Huggy Pajama

The Huggy Pajama is an interaction system for parents and children [3]. With the Huggy Pajama, the user can send a hug to the pajama through the internet. The goal of the system is to increase communication value between parents and their children. Parents can reach their children by (video) calling, but this type of communications lacks physical interaction between parent and child. The Huggy Pajama does not aim to replace actual hugging between parent and their child, but could be a valuable addition to the relationship, according to Cheok. The Huggy pajama makes use of two objects: a hugging interface in the form of a small doll and the pajama. The sender hugs the doll to record the hugging sensation. This recording is sent over the internet to the pajama, which will play the hugging sensation. An overview of the system can be seen in figure 2.4

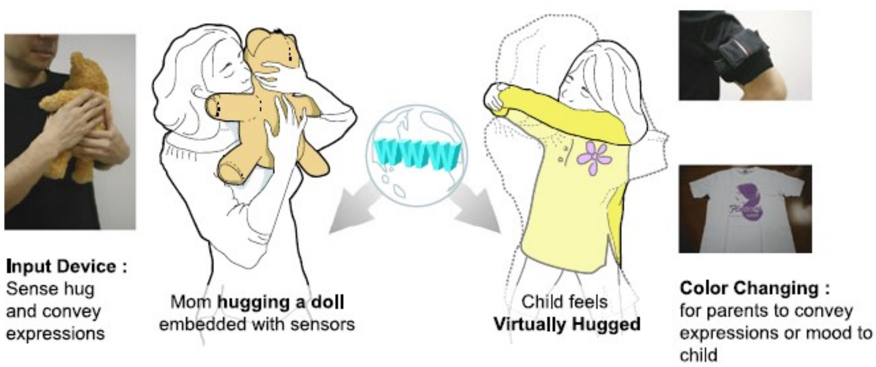


Figure 2.4: Huggy Pajama [3]

The doll contains touch and pressure sensors. In total there are 12 of these touch and pressure sensors in the doll. These sensors sense the amount of pressure that is executed on the doll as well as where this pressure is situated. This information is digitized and sent to the pajama through the internet.

The Pajama simulates the touch that was recorded. It does this by inflating airbags at the touched location, based on the amount of pressure that was recorded on the doll. In total, the Huggy Pajama contains 12 air pouches that can be inflated independently. Each pouch corresponds to a touch and pressure sensor in the doll. Furthermore, the pajama has a temperature control system, using one Peltier module. This enables a warming sensation in the pajama during the hugging interaction.

According to the study by Cheok [3], the interaction created by the Huggy Pajama created a similar response to real life physical touch. Overall, the interface was easy to use and most participants felt positive about using the interface. Furthermore, the hugging sensation felt realistic compared to an actual hug for 80%. Moreover, 90% of of the participants thought the Huggy Pajama creates a useful interaction to increase the sense of presence of a loved one.

2.2.4 Kissenger Machine

The Kissinger Machine is an electrical machine, developed by Cheok and Zhang [4] for remote kissing.The Kissenger Machine is an attachment for mobile phones, which transmits a sense of kissing over over distance over the internet. The goal of the Kissinger Machine is to increase emotional connection and intimacy during digital communication. The machine can sense the lip pressure and sends these haptic sensations of the kiss to a partner with the same device. An image of the Kissenger Machine can be seen in figure 2.5.

The Kissinger Machine consists of a flexible lip surface with three force sensors and captive linear stepper motors. The force sensor resistors register the pressure put on the lip-like surface and the system transmits this information to the other device. The captive linear stepper motors of this other device then simulate this motion, creating a sense of kissing. Cheok and Zhang [4] created a compatible mobile phone application that allows using the kissing system while video calling. The application uses real-time

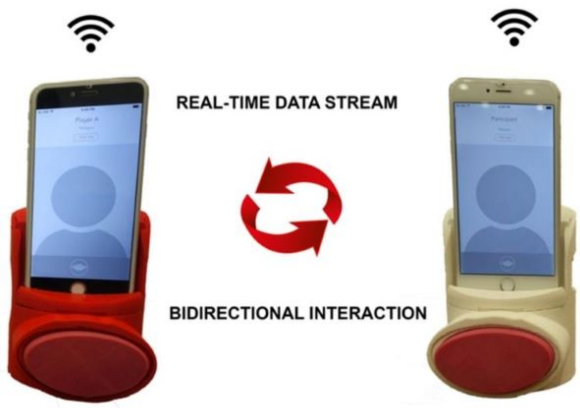


Figure 2.5: The Kissenger Machine [4]

data transmission, to enhance the sense of real-time kissing. The three experiments conducted with this device had positive results. The Kissinger Machine showed similar pleasure, arousal and user experience ratings compared to real-life kissing. Furthermore, couples experienced an increase in relationship satisfaction as well as stress relief when using the machine for a week.

2.2.5 FleXo: Flexible Exoskeleton for Therapeutic Touch

The FleXo: Flexible exoskeleton for therapeutic use, designed by Setty [5], uses silicone inflatables to mediate touch for the use of physiotherapy. It provides a mediated touch through pressure on twelve points on the body. The twelve points of pressure are located on the back and are derived from acupressure points. The goal of the haptic wearable, is to provide remote physiotherapy. Therefore, the wearable is controlled by a physiotherapist. The FleXo can be seen in figure 2.6

The FleXo consists of the wearable as well as a haptic interface. The wearable has 12 silicone pockets that can be inflated placed on the back. The wearable is worn by the therapeutic patient. The therapist controls the haptic interface. Whenever the therapist presses a key, the silicone inflatable at that point will be inflated, exerting pressure on the back of the patient.

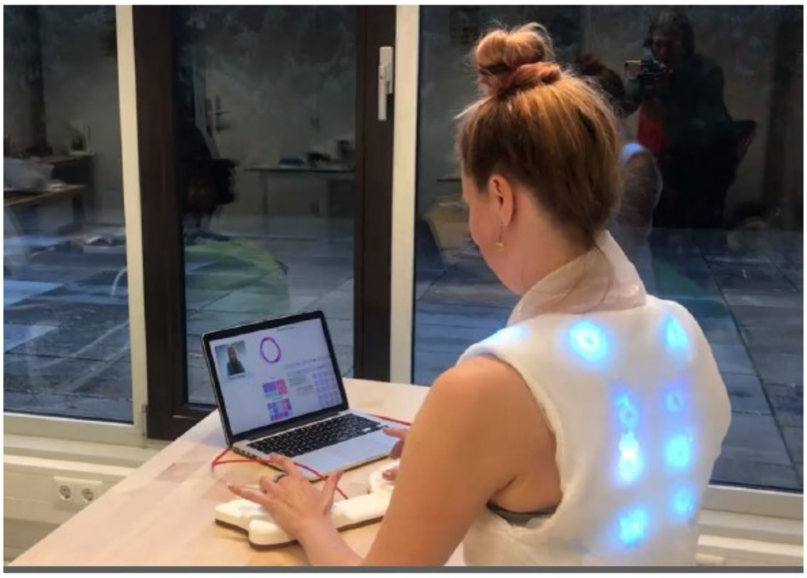


Figure 2.6: FleXo: Flexible Exoskeleton for Therapeutic Touch [5]

2.2.6 The Hug Shirt

The Hug Shirt enables one user to send a hug to another user [6]. The Hug Shirt was developed by CuteCircuits. The shirt connects to an application on the phone of the use via Bluetooth. The HugShirt App lets the user record a hug, which can then be delivered to another user. The hug is immediately transmitted to the other Hug Shirt. According to CuteCircuits, it is possible to hug friends in real time all over the world. What the shirt looks like can be seen in figure 2.7.

The Hug Shirt has digitally printed concentric circle areas. These areas show the positions of the sensors and actuators. These areas is were the Hug Shirt can be touched to record the hug. The hug will also be played in these areas, with the use of actuators. What sensors and actuators are specifically used in the design is not specified by CuteCircuits.

2.2.7 Hey Bracelet

The Hey Bracelet is a product by FeelHey [7]. It is a bracelet that sends a touch, between two users, over the internet. The Hey Bracelet is a one to one bracelet. This means it is possible to link to only one person. The goal of the Hey Bracelet is to keep a sense of togetherness over a distance. The Hey Bracelet can be seen in figure 2.8.

Figure 2.7: The Hug Shirt [6]

The Bracelet uses a sensor surface to detect touch. This touch is sent to a mobile phone application via Bluetooth. This application, the Hey app, then sends the touch to the other user over the internet. The Hey Bracelet has a small motor, which pulls part of the wristband into the casing. This produces a gentle squeeze of the wrist.

2.2.8 AWElectric

According to Neidlinger et al., awe is a complex emotion, with a mix fear and wonder. It is a sensation of a shudder in combination with goosebumps, often experienced during outstanding experiences. It is a sensation that is hard to be shared, says [8]. AWElectic, is a wearable that is able to detect this sensation of awe, enhance it and share it with another person.

To sense the feeling of awe, the electro-dermal activity, breath rate and heart rate variabily are used. These sensing choices were based on physiological changes that occur during the feeling of goosebumps. At the moment of feeling awe, there is a peak in heart rate, a gap in respiration rate and an increase in electro-dermal activity.

Silicone pneumatics are used to amplify the emotion of awe. The silicone inflatables have a skin-like texture, ideal to mimic the exited skin. The silicone pouches are inflated using small SMC 070 series pneumatic valves. LED lights were also added, to further

Figure 2.8: Hey Bracelet [7]

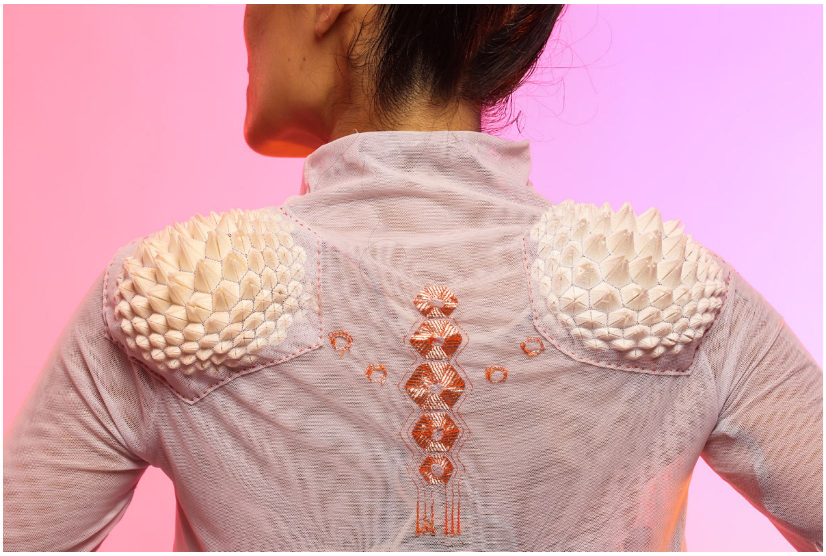


Figure 2.9: AWElectric [8]

enhance the extimacy. Lastly, AudioTactile fabric was added to the wearables. This fabric is essentially an embroidered speaker. By playing low frequencies on the skin, it creates a tickling sensation, further increasing the feeling of awe.

There is a bluetooth connection between the two wearables, using a HC-06 Bluetooth - serial module. This connection is half-duplex. One wearable holds the sensing part, while the other can only receive the sensation of awe. The sending wearable reads the emotional peak. When an emotional peak is reached, this wearable starts the inflation of the silicone modules and speakers on the back start to vibrate. The sensation is also sent to the other wearable. Upon receiving the sensation of awe, this wearable also inflates the silicone modules, and vibrates the AudioTactile fabric.

2.3 Conclusion

In this chapter, the state of the art of haptic wearables for social mediated touch has been discussed. This was done by conducting an exploratory literature review and exploring product and project in the domain of haptic wearables for social mediated touch.This chapter aims to answer the second research question: *What is the state of the art for haptic wearables and social mediated touch technology?*

In the first section of this chapter, section 2.1: Literature Review, touch and social touch are explained. This section aims to explore the possible benefits of social mediated touch technologies. Social touch has been related to social bonding, decrease of loneliness level, stress relief and communication. Whether these benefits are also attainable using haptic feedback for social mediated touch is not yet investigated fully for all factors.

Little studies show any increase in stronger bonding between two individuals over distance when using a haptic wearable for social mediated touch. If the level of loneliness decreases with social mediated touch technology is also unclear. On the other hand, two factors that have been proved beneficial in haptic wearables for social mediated touch are stress relief and communication. For the former, stress relief, mostly mediated hugs have been seen to have a positive effect on creating a stress buffer for the user. For the latter, communication, a study found that up to eight emotions could be successfully expressed using a haptic wearable for social mediated touch. This haptic wearables uses mediated touch of the forearm.

This section also provided an overview of hardware components that are often used in the design of a haptic wearable for social mediated touch. Over all, common sensors used for haptic wearables for social mediated touch are capacitive touch sensors, force sensors and flexing sensors. Actuators that are often used are vibration motors, force actuators, inflatables and temperature regulators.

The last section, section 2.2, explores products and project using social touch technology in haptic wearables. This section shows the wide range of opportunities for haptic wearables for social mediated touch. The projects and products vary not only in the type of social touch they try to emulate, they also vary in components that are used to simulate this touch. Many of the projects discussed were still in its early stages, but show great promise in supporting social mediated touch. Overall, most of the projects and products discussed aim to create a sense of closeness to the other user.

Noticeably, almost all of the projects and products use the haptic wearable for social mediated touch over a longer distance. Only the AWElectric [8], uses short distance communication of the social touch, with the users in visible distance of each other. Furthermore, there are no projects and products found that aim to use social mediated touch as a solution for decreased social touch, during the COVID-19 pandemic. However, with this pandemic being such a recent occurrence, this is understandable. Overall, with this chapter, the second sub question, about the state of the art of haptic wearable for social mediated touch technology, has been answered.

Chapter 3

Methods & Techniques

3.1 Autoethnografic Design Method

This bachelor thesis follows an autoethnografic design method approach. According Tetnowski and Damico [36], the autoethnografic studies have been written by a member of the group under investigation. This is contrary to traditional ethnography, where the researcher tries to study the rules, norms and acts of a certain group as an outsider, continues Hughes [37]. In an autoethnographic design method the researcher is already an insider. The purpose of this autoethnografic design method is to consider what the important factors are to the designer themselves, constantly reflecting using personal experience.

An advantage of this method is that it causes authentic views of the participant itself, which would not happen with other methodologies. Furthermore, this design method speaks to the intrinsic motivation, as the design is created based on personal context [38]. Another advantage of the autoethnografic design method is the accessibility of data [39]. As the data is based on the designer itself, small and focused design experimentation can be executed. This in turn, allows for quick adaptations to the design. It is important to note that the autoethographic design method could also pose some limitations. As data is mostly gathered from the point of view of the designer, this data can be rather limited in its conclusions, states Mendez [39]. By designing from own experiences, it can be hard to extend the design to a wider audience.

On the topic of designing a haptic wearable for social touch, this means the researcher designs the wearable based on their own context. Furthermore, the design is tested and adjusted according to their own reflection and experiences. As the goal of the wearable is to simulated social touch, the designer has to test the prototype with a second user. Therefore, the context and experience of this second user should also be taken into account. Personal testing is, however, only the first step in the design process. Later the product should be tested on a larger user group of the target audience. This results in a design that can be used by a larger range of people.

3.2 Creative Technology Design Process

To develop the haptic wearable for social mediated touch, the Creative Technology Design Process will be utilised [9]. The overview of this design process can be seen in figure 3.1. The design process consists of four stages: Ideation, Specification, Realization and Evaluation.

After the introduction and the state of the art, there is a general concept of the project, creating a haptic wearable for social mediated touch that can be utilised while social distancing. The ideation phase aims to create a more defined project concept. This is done through a brainstorm of different social mediated touch ideas. With this idea, the user is further explored through user case scenarios. The ideation phase can be found in chapter 4: Ideation.

In the specification phase, the concept from the ideation phase is further specified. Components that can be used are specified. Furthermore, initial tests of these components are executed to check their performance. This phase holds the first iterations for the design of the haptic wearable. During the specification phase, a list global requirements of the system are also set up. This phase is described in chapter 5: Specification.

During the realization phase, the requirements that were specified in the previous phase will be used to develop the final prototype. The individual components selected in the specification phase are integrated in the prototype. This will result in the haptic wearable for social mediated touch developed for this project. The realization phase of the creative technology design process can be found in chapter 6: Realization.

During the evaluation phase, the prototype will be evaluated to see whether it meets the requirements set up in the specification phase. With the evaluation, prospective recommendations will be able to set up, to continue work on the haptic wearable in the future. The evaluation of this project is described in chapter 7: Evaluation.

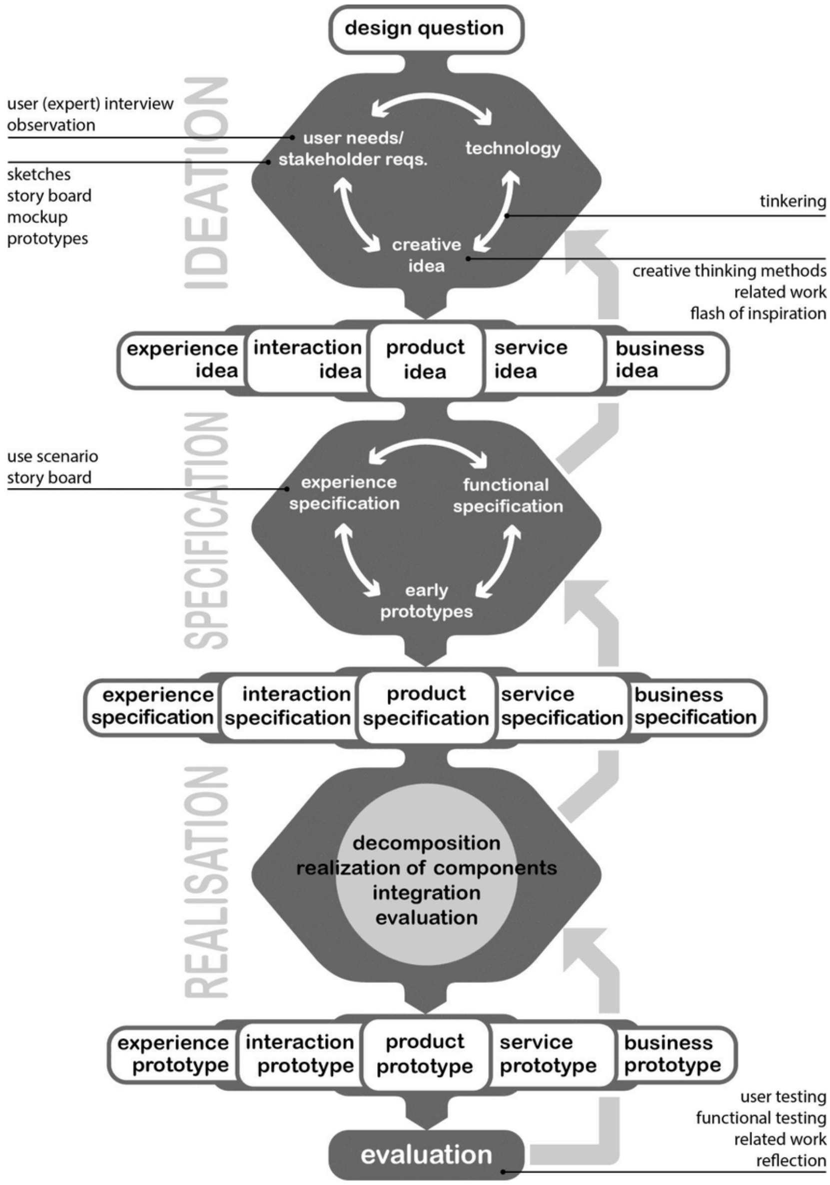


Figure 3.1: Creative Technology Design Process [9]

Chapter 4

Ideation

In this chapter, several design options are explored. Thereafter, a global project idea will be chosen. The context of this project idea is further explored through user case scenarios. This chapter aims to answer the second sub-question: What is a suitable context and scenario for a haptic wearable for social mediated touch?

4.1 Mind map

To identify multiple possible design options for a haptic wearable for social mediated touch, a mind map is created to brainstorm different ideas. The mind map can be found in figure 4.1. At the start of the brainstorm session, different context situations where social touch is a common interaction are explored. These contexts are highlighted in yellow.

After this, the mind map is further elaborated with the the actual social touch interactions that would occur during such a situation. These are the social interactions that are appropriate for these contexts. These interactions are marked green. Due to the COVID-19 pandemic, most of these interactions are unable to take place between people outside the same household. Therefore, a haptic technology feedback solution could be found for these interactions.

Therefor, a few social mediated touch technology solutions were thought out. These social mediated touch solutions aim to simulate the social touch interactions that are appropriate for the explored contexts, using haptic feedback technology. These possible technological solutions are highlighted in blue. These possible solutions are based on the component discussed in section 2.1.5 of chapter 2 :State of the Art.

From this mind map an initial project idea is derived. As this project makes use of the autoethnographic design method, a project idea the designer is most interested in, is chosen. This initial idea is described in section 4.2.

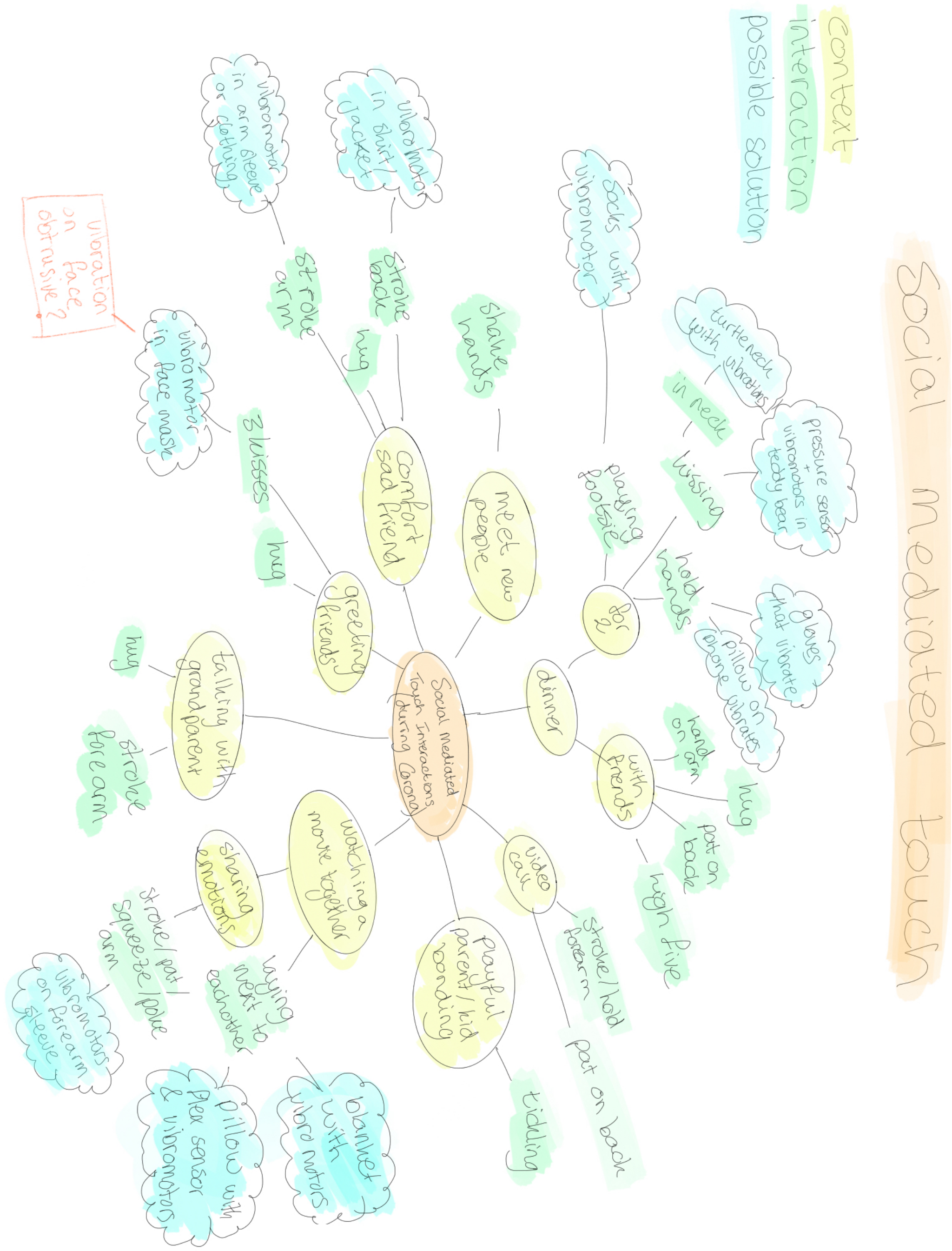


Figure 4.1: Mind Map of Social Mediated Touch Possibilities

4.2 Initial project idea

During the COVID-19 pandemic, it is essential to practice social distancing to stop the virus from spreading. To do this, it is essential to keep 1,5 meter distance from everyone outside your household, according to the Dutch government [18]. This means many social touch interactions are not able to take place. One of such an interaction is the hug.

When greeting friends and family members, it is common practice to give them a short hug. Now that social distancing is the norm, due to the COVID-19 pandemic, hugging is often not a possibility anymore. Therefore, new greeting methods are explored. However, these often results in greetings that feel somewhat unnatural. An example of such an unnaturally feeling greeting, is the elbow bump. This interaction can be seen in figure 4.2. Although the elbow bump is safer than a handshake, it is still not contact free. Furthermore, it momentarily places two people within the advised 1,5 meter of each other.

Figure 4.2: The Elbow Bump Greeting [10]

By creating a haptic wearable for a social mediated hug, greeting of friends and family members while social distancing can become a more pleasant experience. Therefore, the initial project idea of this project is to create a haptic wearable that is able to simulate a short hugging interaction between two individuals, at 1,5 meter distance. This will enable greeting friends and family outside of your own household with a hug, at a safe distance.

The wearable aims to overcome the unnatural greetings now often experienced during the COVID-19 pandemic. The haptic wearable for social touch should make greetings a more pleasurable experience, by simulating a hug. Therefore, the wearables should be able to communicate with each other, while the users can see each other. This allows the users to practice social distancing, but still experience social touch and the benefits of it.

4.3 Hugging

There are multiple circumstances under which hugging occurs. According to Forsell and Aström [40], hugging is not only part of a greeting behaviour, it can also be a display of empathy and/or gratitude. The greeting behaviour between to individuals, greatly depends on their relationship. Forsell and Aström [40] state, that among good friends, a natural greeting is hugging. It is a closer and more affectionate greeting when it is compared to handshaking.

There are some benefits connected to hugging. Receiving a hug from a partner has been linked to higher levels of plasma oxytocin, norepinephrine, cotrisol, and blood pressure. These effects were more significant in women compared to men. With frequent hugs of a partner, linked to higher oxytocin levels, lower blood pressure and lower heart rate in premenopausal women, says Light, Grewen and Amico [41]. Light et al. even hypothesises that this enhanced oxytocin activity, during a touch, can be a physiological mediator of the health benefits of emotional support.

This is further substantiated by Cohen et al. [42], who state that a hug is a way of conveying empathy caring and reassurance. They state that it is a means of communicating affection and concern, which has an influence against the effects of stress. A likely explanation is that hugs are often involved as a way of resolving conflict, or to combat related emotional after effects.

Cohen et al. also claims that people who receive regular hugs, are slightly more protected from infections and illness-related symptoms. However, this could also be due to the physical nature of a hug, exposing one to pathogens that provide immunity during further exposures. Overall, hugging can help with a psychological sense of well-being, and is usually an overall positive emotional experience. While practicing social distancing during the COVID-19 pandemic, many people are often unable to experience hugs and these benefits of hugging.

4.4 User case scenarios

To provide a clear overview of the type of interaction that needs to be simulated, some user case scenarios are created. These scenarios describe specific situations where a hug would normally be a suitable interaction. Now, however, these interactions are not possible, due to the COVID-19 pandemic.

4.4.1 Scenario 1

Nina is a student at the University of Twente. She lives alone in an apartment. During the COVID-19 pandemic she studies from home. When the national regulations allow it, from time to time, some friends come to visit her. She wants to follow the advice of the government and keeps to the 1,5 meter distance rule. This means she never hugs or even touches her friends in social situations. Furthermore, when she visits her parents she is careful to keep safe distance as well. Overall, this means Nina has not felt any type of social touch for a while. She feels the need for a social touch, but because of social distancing there is no opportunity for it without breaking the rules.

4.4.2 Scenario 2

Johnny is 14 years old. Today, Johnny is visiting his grandmother with his parents. As an elderly, his grandmother is in the risk group for the corona virus. Therefore, his parents want him to keep a safe distance from his grandmother. Normally, it would make his grandmother light up when he burst through the door to give her a hug. Before the COVID-19 pandemic, he would hug her immediately, but today he knows he is not able to. This makes Johnny especially sad, because he knows how much his grandmother loves hugging her grandchildren. Now he just stands in the doorway and awkwardly waves at his grandmother. He hopes he can give her a hug soon again, but his parents tell him this might still take a while.

4.4.3 Scenario 3

Emily is a 38 year old accountant. Yesterday she received some particularly sad news. She calls a friend over to comfort her. While telling her friend what happened, Emily feels the need for a hug or a stroke on her back. She wants to be comforted, but also wants to abide to the 1,5 meter social distancing rule during this COVID-19 pandemic. She feels conflicted and eventually settles for a quick pat on the back from her friend. He tells her "I wish I could give you a hug right now". This does not feel like enough, but there is not a lot more she can do. When her friend leaves he wishes her good luck. For the next several days, she still feels the need for a hug, but there is nothing she can do.

4.4.4 Scenario 4

Ricardo is 18 and lives with his parents. His mother has a respiratory illness, which means she is part of the risk group for the corona virus. Therefore, he feels the need to be careful. At the beginning of the pandemic, his friends would meet online. After a while, however, his friends started to meet in person again. Ricardo still stayed at home for his mom's safety, but started to feel left out of his friend group. Eventually, he decided to meet his friends again. He notices that it is hard to keep a proper social distance of 1,5 meter from his friends. Especially because the rest of the group does not particularly mind breaking the rules a little. Therefore, he and his mother decide that they need to keep their distance in the house, to try and minimize the risks. Before the COVID-19 pandemic, Ricardo would hug his mom every night before she went to bed. For her best interest they do not hug anymore. Ricardo feels bad that he misses this moment of social bonding, but he still wants to see his friends too.

4.5 What does an actual hug look like?

To be able to simulate a hugging sensation, it is important to note what an actual hug looks like. The figure 4.3 shows what a real life hug looks like. A hug is a sensation of two hands wrapped around the back, with two hands pressing on the back. This pressure is often accompanied by a hand stroking up and down on the back. This is the sensation that the haptic wearable for social mediated touch, developed during this bachelor project, should simulate. This sensation will be recreated using haptic feedback technology.

Figure 4.3: Drawing of a hugging interaction

4.6 Conclusion

The goal of this chapter was to answer the second sub-question: What is a suitable context and scenario for a haptic wearable for social mediated touch? By going through the ideation process this question has been answered. Due to the COVID-19 pandemic, everyone is advised to stay at 1,5 meter distance from everyone outside of their household. Therefore, many social touch interactions can not take place anymore. With the use of a mind map, these interactions were explored. With the results of this mind map, a suitable context for social mediated touch is chosen. This is done from an autoethnographic point of view.

The context for the haptic wearable for social mediated touch, is a new greeting method. Most greetings are unable to take place in a regular fashion, during the COVID-19. This results in greetings that feel somewhat unnatural. Therefore, a new, more pleasurable and socially distant solution is desirable. With the use of a haptic wearable that is able to simulate a mediated hugging sensation, this can be achieved. To further elaborate during which scenarios such a haptic wearable could be used, user case scenarios were presented. These scenarios could all benefit from a haptic wearable for social mediated touch, as it would allow for a socially mediated hug, over a distance.

Overall, with the ideation phase of this bachelor thesis, the initial project idea is set up. This bachelor project will focus on developing a haptic wearable that is able to simulate a hugging sensation, for greeting purposes. In this way, greeting one another, while social distancing, can be a more pleasurable experience. Next, the hardware and software components that are necessary to complete such a wearable will be discussed in chapter 5: Specification.

Chapter 5

Specification

With the findings of the ideation phase in chapter 4, it is now possible to further specify the interaction of the users and the components of the wearable. Furthermore, the prototype requirements are listed. This chapter aims to answer the third sub-question: What components, both hardware and software, are needed to design a haptic wearable for social touch?

5.1 Requirements

With the initial project idea explored, a list of requirements for the wearables is set up. These requirements are split into systematic requirements and functional requirements. The systematic requirements list the technical requirements of how the wearable should operate. The functional requirements list what is expected from the wearable from the end user's perspective. This list of requirements is later evaluated in chapter 7.

5.1.1 Systematic Requirements

The haptic wearable should...

- Be mobile
- Be integrated in a wearable
- Be able to interact with another haptic wearable at 1,5 meter distance
- Be able to be turned on and off by the user

5.1.2 Functional requirements Requirements

The haptic wearable should...

- Make greetings a more pleasurable experience while social distancing
- Simulate a hugging sensation
- Imitate the feeling of two hands pressing on the back
- Imitate the feeling of a hand stroking the back
- Be intuitive to use
- Be non-intrusive for the user

5.2 Initial Design

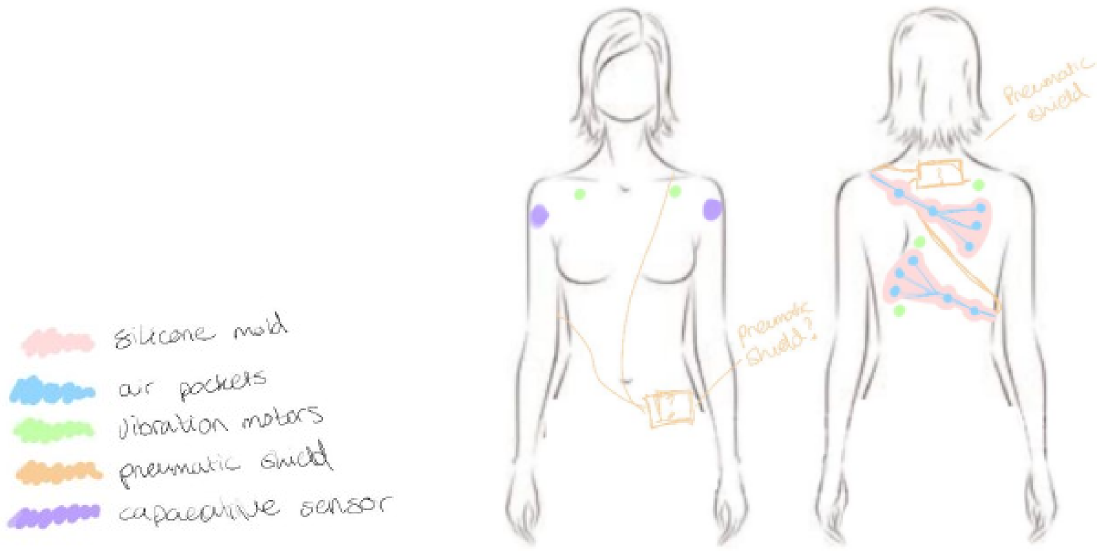
The layout of the components in the wearable are drawn as an initial concept design. This drawing can be seen in figure 5.1. This drawing shows where the components will be placed, to sense and simulate the hugging interaction. The components that are chosen to be used, are based on the findings of section 2.1.5 of chapter 2: State of the Art.

5.3 Interaction Specification

The goal of this project is to allow two individuals to greet each other with a hug at a distance of 1,5 meter, through a haptic wearable. This means a wearable should be able to sense a hug, simulate a hug, and send a hug to another wearable. This means two wearables need to be able to interact with each other. The interaction between two users takes place in three phases: 5.3.1 Connect the Wearables, 5.3.2 Record the Hug, and 5.3.3 Receive the Hug. These phases are depicted in figure 5.2

5.3.1 Connect the Wearables

Two wearables should be able to communicate with each other over a distance of around 1,5 meters. This communication can be set up automatically by the wearables. By



(a) Legend of components (b) Drawing of component placement

Figure 5.1: first project concept

letting the two wearables connect automatically when they are in close vicinity of each other, there is no set up for the user and a hug can be sent almost immediately. This makes the overall experience more user friendly.

A component that allows this automatic communication between two wearables at 1,5 meter distance, is a Bluetooth module. By integrating a full duplex Bluetooth module, the wearables are able to both send a hug to another wearable and receive a hug from another wearable. Thus, the interaction can go both ways. A full duplex Bluetooth module that is able to do this, is the HC-05 Bluetooth module. The HC-05 Bluetooth uses the 2.4GHz frequency band. The data can transfer between the two modules at a range of up too 10 meters. This means the Bluetooth module is ideal for the purpose of giving hugs at 1.5 meter distance.

Bluetooth networks make use of the master/slave model to control when and where devices can transmit data. In such a network, the master can send and request data from any of its slaves. Slaves are only capable of receiving data from their master and sending data to their master. The HC-05 Bluetooth modules can be set as both master and slave, allowing two HC-05 modules to interact with each other, both sending and receiving information.

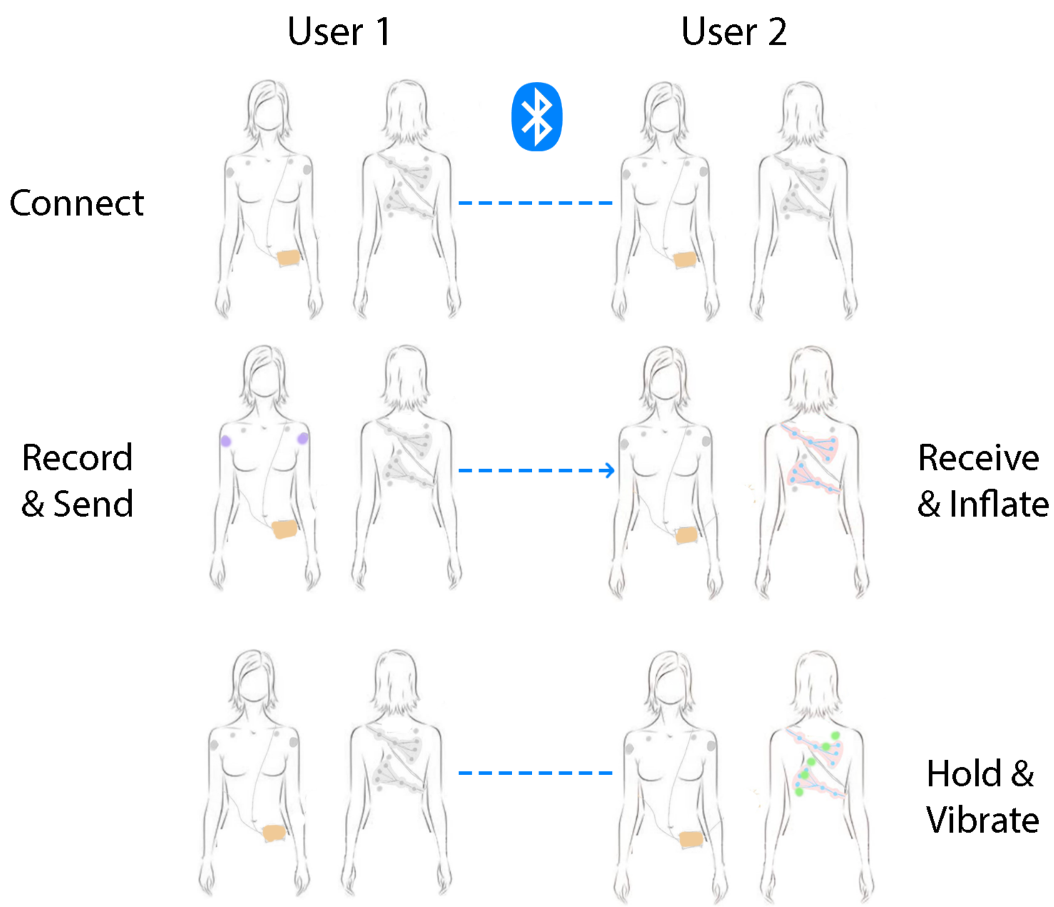


Figure 5.2: Interaction between two wearables

5.3.1.1 Configuring Module to Master Mode

The HC-05 Bluetooth modules are initially set to slave mode. In order for the two HC-05 Bluetooth modules to connect with each other, one of the two modules needs to be set to a master mode. This only needs to be done once. To do this, the module first needs to be able to communicate using the serial monitor. This can be enabled by connecting the HC-05 Bluetooth module to an Arduino Nano and running the HC-05_AT_MODE_01 sketch. The sketch can be found in appendix H.

After running the sketch, AT mode needs to be activated. In the AT mode, settings of the Bluetooth module can be changed. To activate the AT mode, the small button switch on the module needs to be pressed while powering on the module. After the module is powered, the button switch can be released. The LED light on the module should now be blinking every couple of seconds to indicate that the AT mode is activated.

While in AT mode, the module can be set to master by entering "AT+ROLE=1" into the serial monitor. Then, to allow it to pair with any other module, enter "AT+CMODE=1". Now the module is set to master and can be paired with the other HC-05 module. After successful pairing, the Bluetooth modules can work in full duplex mode. This means the two wearables can both send and receive data. With the Bluetooth modules, the wearables are able to communicate with each other over the desired distance of 1.5 meter. The Bluetooth modules will automatically pair with each other if they are placed within 10 meters of each other.

5.3.1.2 Testing Connection Speed and Communication Speed

After the connection between the wearables has been set up, the speed of communication between the two wearables is tested. The wearables should be able to communicate real-time with each other. Thus, the connection speed and the communication speed between the wearables should be fast enough to enable this. For this test, the two HC-05 Bluetooth modules are placed at a distance of 5 meters from each other. After which, both of the Bluetooth modules are turned on. The time it takes for the modules to connect is measured. Thereafter, a series of characters are send from one Bluetooth module, to the other Bluetooth module. This is done through the serial port of the Arduino. Again, the time it takes to receive a character from the first Bluetooth module is measured. This experiment is repeated three times in order to produce accurate results.

Test	Connection Speed	Communication Speed
Test 1	11 seconds	<1 second
Test 2	14 seconds	<1 second
Test 3	9 seconds	<1 second

The results of the test show that it takes the Bluetooth modules between 9 and 14 seconds to connect, after they have been turned on. As an interaction can be sent after this connection has been established, the users would have to wait around 12 seconds before sensing a hug. Furthermore, the communication speed between the two Bluetooth modules was almost instant. After a character was sent from serial port of the first Bluetooth module, the second Bluetooth module received this character almost immediately. These results were similar during all three of the tests. With these results, it can be concluded that the interaction between the two Bluetooth modules is almost real-time. However, it does take around 12 seconds for the two modules to establish the connection.

5.3.2 Record the Hug

During a real-life hug, the arms of the first person wrap around the second person. While keeping 1,5 meter distance, wrapping the arms around the other person is not possible. However, this movement can be emulated to start the hugging interaction. By emulating the movement of a real-life hug, initiating the hug feels most intuitive for the user. Therefore, to send a hug to the second wearable, the user can wrap their arms around themselves, touching their upper arms. This will look like giving oneself a hug in order to send a hug. Figure 5.3 shows what this would look like.

Figure 5.3: Giving oneself a hug [11]

By placing two sensors on the upper arms, this deliberate hugging movement can be registered and the hugging sensation can be initiated. When the two sensors are touched, the first user records a hug and sends it to the other wearable. A sensor that is ideal for registering a touch, is the capacitive sensor. When the capacitive sensor is touched, the capacitance of the sensor changes. These changes can be measured, allowing the wearable to register when it has been touched.

Capacitive sensors also come in the form of conductive fabric. Conductive fabric is ideal when working with wearables. Conductive fabric is soft an malleable, while being able to conduct electricity. The fabric can be sown onto a clothing item using conductive thread. This means the sensors will not be felt by the user, making the sensing components unobtrusive. Furthermore, by using two capacitive sensors, the user is less likely to initiate the interaction accidentally. Only when both capacitive sensors are pressed, the wearable will send a signal to start the hug.

To test the performance of the capacitive fabric, a piece of capacitive fabric is placed on the sleeves of the sweater of the researcher. This piece of capacitive fabric, is then covered with a thin layer of regular fabric. The capacitive sensor is connected to an Arduino, through a 10MΩ resistor with conductive thread, to allow a reading of the capacitance value of the fabric. These sensor pin readings show that the capacitive sensor is very sensitive to touch, as the capacitive value shoots up when the sensor is touched. There is a clear distinction between when the capacitive sensor is touched and when it is released. These clear distinction is ideal, as a threshold value can be used to allow the wearable to recognise if the sensors are touched. If the capacitance threshold value in both of the capacitive sensors are reached, the wearable sends a signal to the other wearable to start the hugging interaction.

5.3.3 Receive the Hug

The second user will receive the hug, starting the hugging interaction. During a real-life hug, two hands are pressed on the back and the back is often stroked in an up and down motion. These two sensations will be simulated by the wearable.

5.3.3.1 Pressure of Two Hands on the Back

To recreate the feeling of two hands on the back, pressure needs to be exerted on the back. This can be done by using silicone inflatables. Silicone inflatables are silicone pouches that can be filled with air to put pressure on the skin. These silicone pouches can be modelled to take any form. This means, these silicone pouches can be modelled after two hands, creating the feeling of two hands pressing on the back.

These silicone inflatables are based on the inflatable wearable technology by [8].

The silicone inflatables are modelled after adult human hands. For this, Ecoflex 00-30 [43] is used. Ecoflex 00-30 is a skin-like silicone, which is flexible enough to inflate, but strong enough so that it does not tear.

To recreate this sensation of a hand on the back, the silicone inflatables are modelled after a hand. Specifically, five pressure points of the hand are taken into account. Firstly, pressure of the lower and upper hand palm should be included in the design. These two areas execute the most pressure on the back during a hug. Secondly, to further give the sensation of a hand, three out of five finger tips pressure points are added to the design. Due to the weight of the silicone, three fingertip inflatables are chosen in stead of five. The silicone material can be quite heavy. Therefore, using less silicone is preferable. The pressure points of the hand that are chosen to be integrated into the design of the silicone inflatables are shown in figure 5.4.

Figure 5.4: Pressure points on the hand that will be integrated into the design of the silicone inflatables

The silicone inflatables need to be pumped with air to be inflated. For this, the pneumatic shield developed by de Jong is used [12]. The pneumatic shield can be seen in figure 5.5. It is a compact and fully controllable shield with four output valves. This means the shield is able to inflate four different inflatables.

The shield is controlled by an Arduino Nano. There are female headers on the shield for easy attachment of the Arduino Nano. The shield uses one side of the

Arduino Nano, leaving space on the shield for the attachment of external sensors and actuators. The shield can be externally powered by a power supply. The valves and pump of the shield take up current up to 2A. Therefore, an external power supply of 5V/2A is needed.

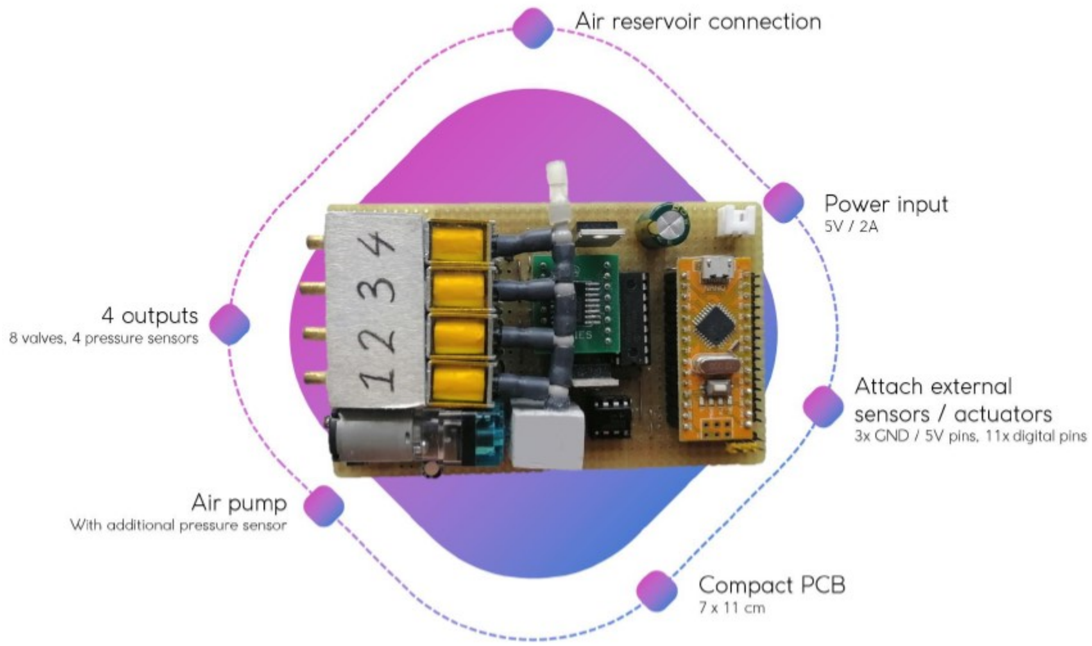


Figure 5.5: Pneumatic Shield with Labels [12]

An Arduino library has been made for easy control of the shield. It has functions that allow full control of the valves and pumps. This means the shield can be easily programmed to inflate the two silicone hands for the haptic wearable.

5.3.3.2 Stroking the Back

While receiving a hug, one's back is often stroked. A stroking sensation can be simulated by creating a apparent haptic motion. Apparent haptic motion is a continuous moving sensation of the skin, using haptic actuators such as vibration motors [13]. According to [44], this apparent haptic motion occurs when two different stimuli occur sequentially on the skin, creating a stroking sensation. Each stimulation slightly overlaps with the previous stimulation to create this sensation of movement on the skin.

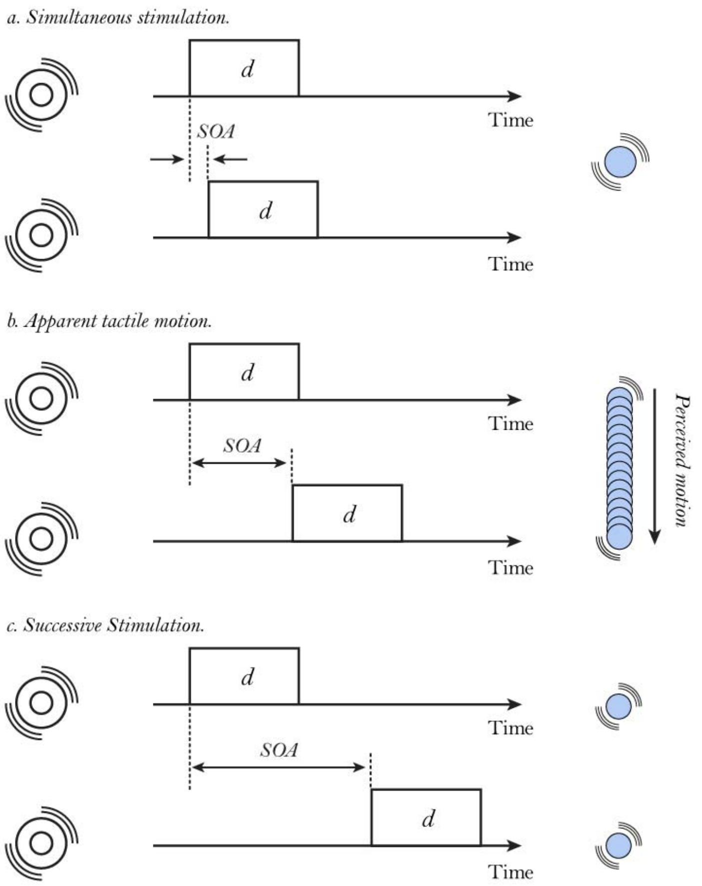


Figure 5.6: Apparent haptic motion as a function of the onset of subsequent vibration motors [13]

To create the stroking sensation on the back, vibration motors will be used. Several vibration motors in a row can be used to give realistic stroking sensation. According to Israr and Poupyrev [13], to give the sensation of an apparent motion, the correct stimuli onset asynchrony is needed. The activation of the vibration motor should slightly overlap with the previous vibration motor. The time between activation of subsequent vibration motors is important in creating the stroking sensation. If there is not enough time between the onset of subsequent vibration motors, it would feel as if only one point is stimulated. This can be seen in figure 5.6a. Oppositely, if the onset time between two vibration motors is too large, it would feel as a series of stimuli instead of an apparent motion. This can be seen in figure 5.6c. Therefore, to create an apparent haptic motion, the vibrations of two subsequent vibration motors should overlap slightly, as can be seen in figure 5.6b [13].

5.3.3.3 Pleasantness of Vibration Location

It is important to find the correct placement for the vibration motors. Therefore, the pleasantness of the vibration motors of certain parts of the body are investigated. As the goal is to simulate a hug, only locations on the upper body are tested.

The vibration motor is taped onto the body of the researcher at different locations. The vibration motor is activated every second. After receiving the vibration several times, the pleasantness of a vibration at that location is notated. The result of this initial test of locations can be found in figure 5.7. Each unpleasant location was marked red, while the pleasant locations were marked in green.

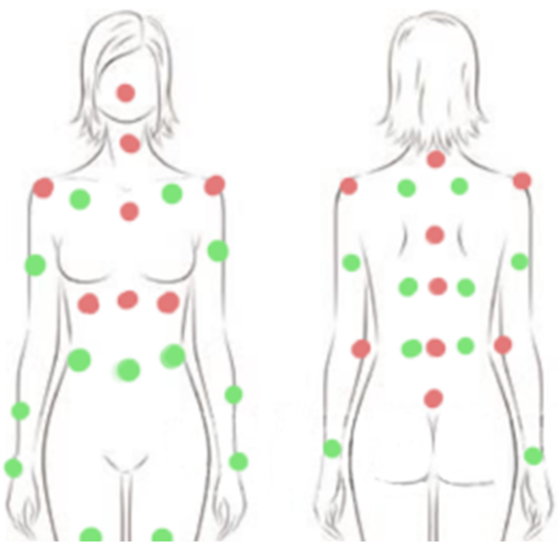
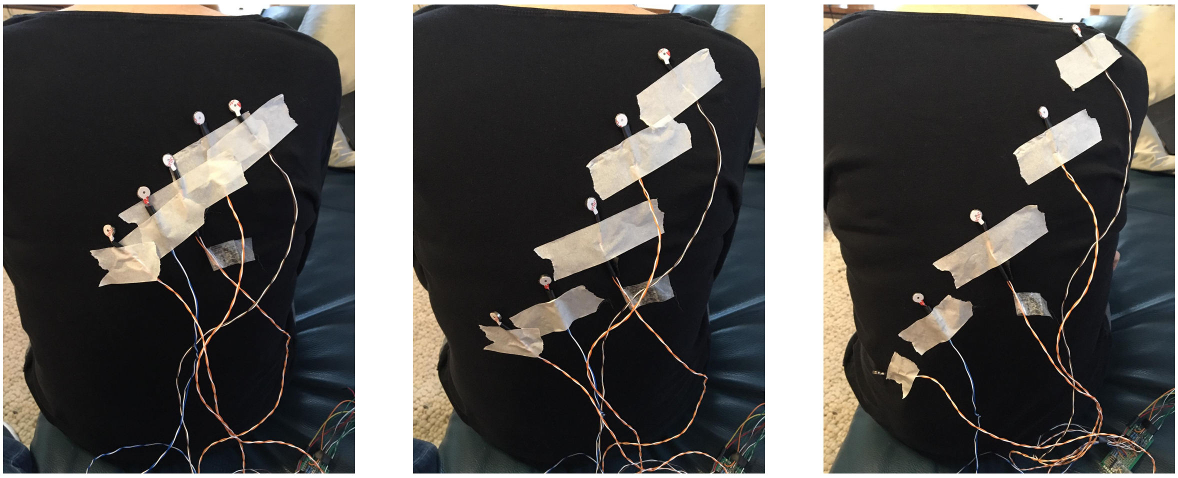


Figure 5.7: Pleasantness of vibration motor locations. Red = unpleasant, green = pleasant

From this test, it can be concluded that mostly areas with bones close to the surface, such as the spine, are perceived as unpleasant locations for vibration. Whereas areas with deeper laying bones are perceived as pleasant. It is important to take these findings into account when choosing a location for the vibration motors in the final design. Placing the vibration motors at locations marked in red should be avoided.

5.3.3.4 Distance between Vibration Motors

Israr and Poupyrev [13] placed the vibration motors 2,5 inches (or 6.35 cm) apart on the back. Whether this is also the ideal distance between vibration motors was investigated by the researcher. To test the ideal distance this, five vibration motors were placed on the back of the researcher. First the theoretical placement of 6.5 cm, close to the suggested 6.35 centimetre of Israr and Pouyrev [13], is explored. Then, a smaller distance of 4 cm apart. Lastly, a larger distance of 8 cm is tested. Placing the vibration motors more than 8 cm apart from each other would leave too little room for all the motors to be placed on the back of the wearable.



(a) 4 cm apart (b) 6.5 cm apart (c) 8 cm apart

Figure 5.8: Comparing three different distances between vibration motors

While the vibration motors are placed on the back, they are activated subsequently while slightly overlapping. The uppermost vibration motor is activated first, subsequently moving to the lowest placed vibration motor. Here the motion is turned around, and the activation goes from bottom to the top again. At the top, this pattern is repeated. This was done for all the different distances of vibration motors.

From this spacing test, it was concluded that the described 6.5 cm distance between the vibration motors works best. This distance is long enough to allow full coverage of the back, but not reach too far down. This distance gave a pleasant experience overall. When placing them closer together, it was harder to distinguish the up and down pattern of the vibrations. Placing them further apart, on the other hand, was perceived as less pleasant, as the vibration motors were too close to the sides. By placing them 8 centimetres apart, the vibration motors also reached onto the lower back, which was too far down when comparing it to a real-life stroke on the back. This means a distance of 6.5 centimetres between the vibration motors will be used in the final design.

With the distance of 6.5 cm between each vibration motor, the speed at which these vibration motors should be activated can be investigated. To do this, five vibration motors are taped on the back with the chosen 6.5 centimetres between them. Then, the vibration motors are activated at three different speeds. First, an slower activation speed of 10 centimetres per second was tested. After which an activation speed of 25 centimetres per second was tested. Lastly, the vibration motors were activated at 50 centimetres per second.

From this activation speed test, it was concluded that an activation speed of 25 centimetres per second was perceived as most pleasant. The slower activation speed, of 10 centimetres per second, moved too slow to be perceived as an apparent haptic motion. It felt as if the vibration motors were activated one after another, even with the activation of the vibration motors overlapping slightly. The faster activation speed of 50 centimetres per second moved too fast .

Therefore, an activation speed of 25 centimetres per second of the vibration motors will be used in the design. This means the each vibration motor should be activated about 200 milliseconds, slightly overlapping with the previous vibration motor.

5.4 Arduino Nano

To control the sensors, actuators and Bluetooth modules, an Arduino Nano is used [45]. The Arduino Nano is a small board, which is ideal for integrating it in a wearable. A sketch can be uploaded onto the Arduino Nano, after which this code is active while the Arduino is powered. To realise the interaction between the components, the Arduino Software is used [46]. With the open-source Arduino Software, a code can be written and uploaded to the Arduino Nano, allowing the components to interact with each other as desired.

The pneumatic shield used holds space for an Arduino Nano to be added. The pneumatic shield uses one row of the Arduino to control the shield itself. This means there are fifteen pins available for external components. These pins are RX/TX, RST, GND and D2 to D12.

5.5 Wearable

Now that the components that will be used to records, send and simulate the hug are specified, they should be integrated into a wearable. The type of wearable that is chosen, is a sweater vest with a zipper.

A sweater also allows for enough room for all the components. The capacitive sensors will be placed on the upper arms. Therefore, a long-sleeved wearable is necessary. Furthermore, the pneumatic shield and power bank require quite a bit of space. By using a sweater vest, these components can be hidden away by placing them in the pockets at the front of the vest.

By using a sweater vest with a zipper, the wearable can also easily be put on. A sweater vest can also be worn over the regular clothing items of the user. This means the wearable can be quickly put on, without the use of a full wardrobe change. It is important to note that the silicone inflatables should be able to exert enough pressure on the back to be properly felt. Therefore, a somewhat tight fitting sweater vest is chosen, based on the clothing size of the researcher. In this way, the chances of properly feeling the pressure of the silicone inflatables are increased.

5.6 Conclusion

In this chapter, the components needed to make a haptic wearable for social mediated touch have been discussed. In particular, a haptic wearable that is able to simulate a hug at 1,5 meter distance, to make greetings while social distancing a more pleasurable experience. With this knowledge the third sub-question can be answered: What components, both hardware and software, are needed to design a haptic wearable for social touch?

To realise a haptic wearable for social mediated touch, three things are needed: An input, an output, and communication method between two devices. Firstly, input, or sensors, that will be used to sense the touch, are two pieces of capacitive fabric. If the user touches both of these sensors, a hug will be sent to the other wearable. Secondly, the output, or actuators that are added to the wearable, to simulate the hugging sensation. For this, two different types of actuators are used, silicone inflatables and vibration motors. The silicone inflatables aim to recreate the feeling of two hands pressing on the back, while the vibration motors create a stroking sensation. Third, two wearables should be able to communicate with each other at a distance of 1,5 meters. For this, a Bluetooth module is used, that will automatically connect to the Bluetooth module of the second wearable when they are in close vicinity of each other.

Lastly, these components all need to interact with each other. For this an Arduino Nano is used. A script can be uploaded to this Arduino, enabling the sensing, communication and simulation of the hug. To write and upload this script, the open-source Arduino Software is used. With each of the components that will be used explored, the haptic wearable for social mediated touch prototype can now be built. The realisation of this prototype will be discussed in the next chapter, 6: Realisation.

Chapter 6

Realisation

With the components specified in chapter, the haptic wearable for a social mediated hug can be build. This chapter elaborates how these components are integrated into the wearable.

6.1 HC-05 Blueetooth module

The Bluetooth module is used to make a connection with another wearable, to be able to send a mediated hug. The Bluetooth module requires two digital pins of the Arduino Nano, D2 and D3. The RX pin of the bluetooth module is connected to pin D3 through a voltage divider, using one 1kΩ and one 2kΩ resistor. Figure 6.1 shows the schematics of the HC-05 Bluetooth module connected to the Arduino Nano.

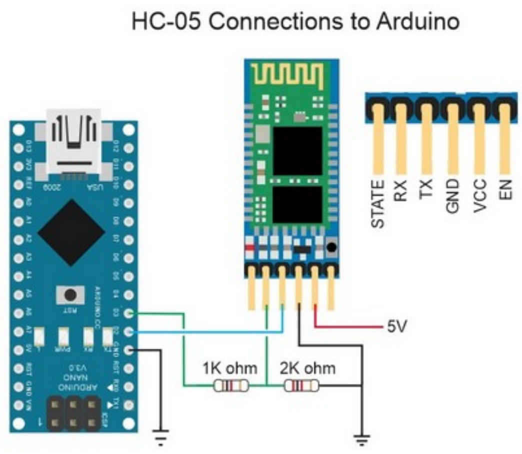


Figure 6.1: HC-05 bluetooth module connections to Arduino Nano

6.2 Capacitive Sensors

To be able to initiate a mediated hug, two pieces of conductive fabric are place at the on the upper arm, creating two capacitive sensors. When the user touches both of these capacitive sensors, the hugging interaction is initialised.

The conductive sensors are sown onto the sleeves of the wearable. This is done with conductive thread, as can be seen in figure 6.2a. Conductive thread can be used to create a circuit, as it can carry current just as a wire. This means a flexible circuit can be created with conductive thread. In this way, the wires are not felt by the user.

One thing important to keep in mind when using a capacitive sensor, is to not let the user touch the capacitive sensor directly. This can cause the system to short-circuit and destabilise the signal. To avoid this, a piece of regular fabric is sown over the capacitive fabric, as can be seen in figure 6.2b. This fabric also shows the user where the capacitive sensors are. On the inside of the wearable, the conductive thread is also covered with regular fabric.

(a) (b) (c)

Figure 6.2: (a) Capacitive fabric sown onto the wearable, using conductive thread, (b) Capacitive sensor covered with regular fabric, (c) conductive thread on the inside covered with regular fabric.

One capacitive sensor utilises two pins of the Arduino Nano, a send pin and a receive pin. A 10MΩ resistor is connected between the send pin and the receive pin. The capacitive fabric is also connected to the receive pin. The schematics of the connected capacitive sensors to the Arduino Nano can be seen in figure 6.3. The capacitive sensors use a total of four digital pins of the arduino: D4, D7, D8 and D12.

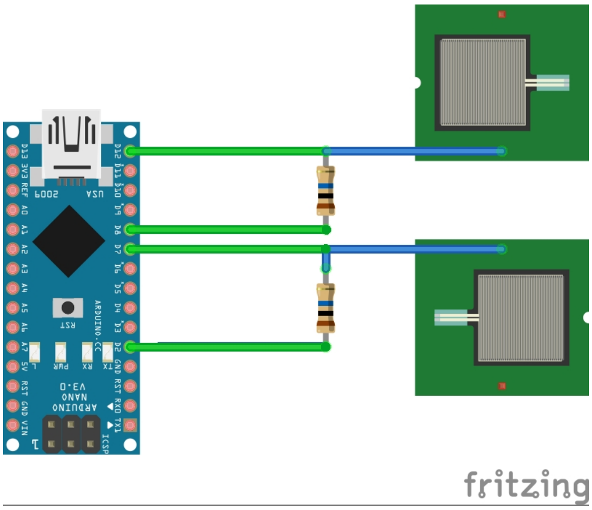


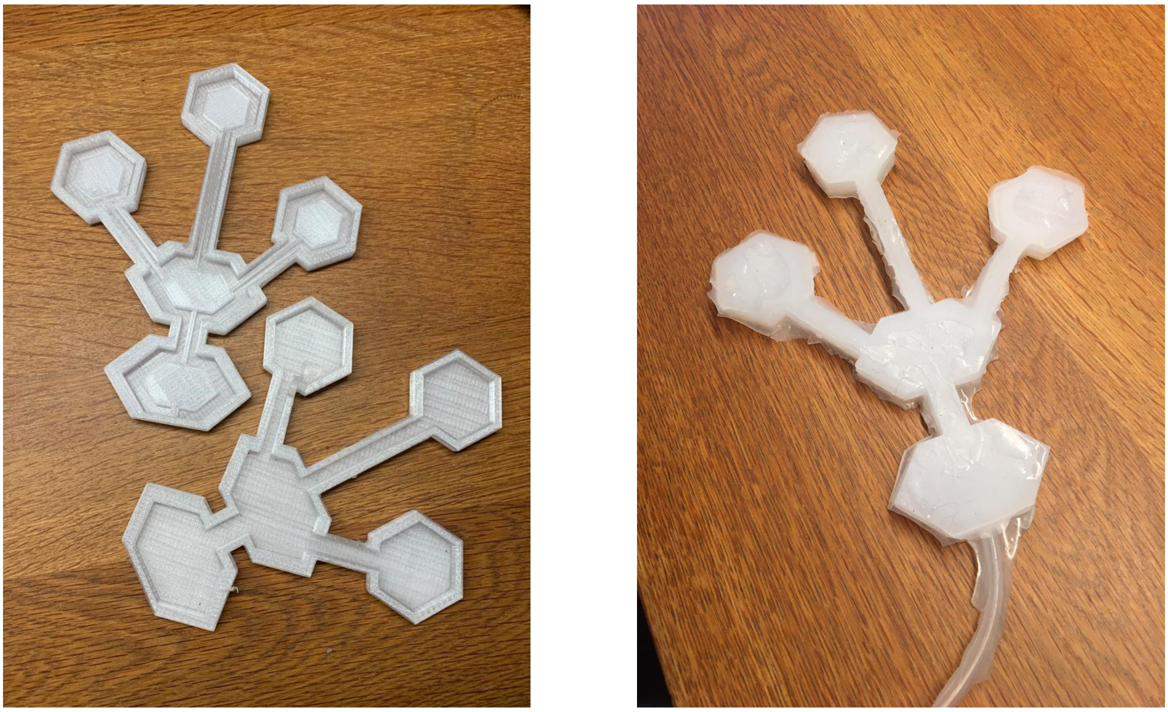
Figure 6.3: Two capacitive fabric patches connected to the Arduino Nano

A capacitive sensing library [47], is used to require the sensed capacitive values of the two pieces of capacitive fabric. When the two capacitive sensors are touched, these values reach a certain threshold. This threshold will give the signal to start the interaction.

6.3 Silicone Inflatables

Silicone inflatables are used to emulate the feeling of two hands pressing on the back during a hug. The inflatable will therefore be modelled after an adult human hand, keeping roughly the same size. To recreate the sensation of a hand, five pressure points of the hand are taken into account. Firstly, pressure of the lower and upper hand palm should be included in the design. These two areas execute the most pressure on the back during a hug. Secondly, to further give the sensation of a hand, three out of five finger tips pressure points are added to the design. Due to the weight of the silicone, three fingertip inflatables are chosen in stead of five. The silicone material can be quite heavy. Therefore, using less silicone is preferable.

In order to create the silicone inflatables, two 3D moulds need to be created. Figures of these moulds can be found in figure 6.4a. The first mould includes a raised section at the the five pressure points. These raised sections ensure an empty pouch that can be filled with air. These are the parts where the silicone hand will inflate. The second mould has the same shape as the first mould, without the raised pouches. Ecoflex 00-30 silicone is added to both moulds, creating the two sides of the silicone inflatable. After these silicon parts have dried, they are glued together, creating the inflatable. A pneumatic tube is placed in between these two layer, to allow airflow into the pouches. One of the inflatables can be seen in figure 6.4b.



(a) (b)

Figure 6.4: (a) 3D moulds for the silicone inflatables, (b) Silicone Inflatable

The silicone inflatables are then added to the wearable. They are positioned to line up with the placement of the two hands during a real-life hug, similar to figure 4.3. The silicone inflatables are sown onto the wearable with the use of a piece of fabric. This fabric is light and stretchy enough as to not limit the inflation of the silicone pouches.

The silicone inflatables are inflated with the use of the pneumatic shield. The pneumatic tube attached to the inflatables are each connected to their own output valve on the shield. Therefore, two of the four output valves of the pneumatic shield are used for the inflation of the two silicone inflatables. The shield itself is hidden in one of the front pockets of the sweater vest. The inflation of the silicone inflatables

Figure 6.5: Close up of the silicone inflatables sown onto the wearable

can be seen in figure 6.6.

The pneumatic shield requires a power supply of 5V and at least 2A. De Jong also states that not all power banks worked reliably [12]. Therefore, several power banks were tested. A 5V/2.4A power bank worked best while controlling multiple valves. The power bank is connected to the pneumatic shield and placed in the other front pocket of the wearable. This way, the power bank can be easily swapped out or charged when necessary.

6.4 Vibration Motors

The vibration motors aim to give a stroking sensation on the back. As the ideal placement and distance between the vibration motors has already been tested, the vibration motors can be sown onto the inside of the wearable. The vibration motors are placed around 6.5 centimetres apart from each other. Furthermore, placement on bony structures of the back, such as the spine or the scapula are avoided. The

(a) (b)

Figure 6.6: Filling of the inflatables with (a) Empty inflatables, and (b) Filled inflatables

placement of the vibration motors on the wearable can be seen in figure

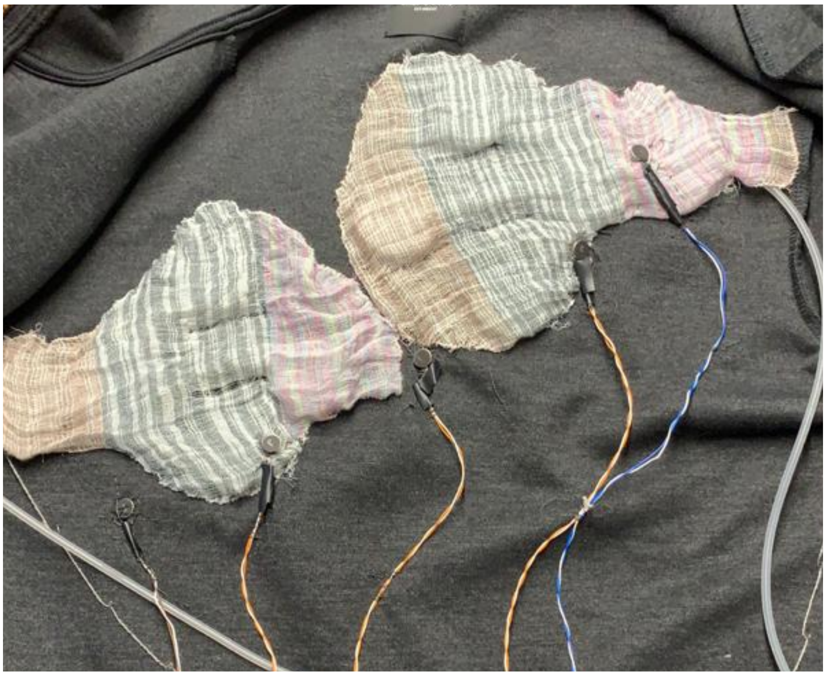


Figure 6.7: Placement of the vibration motors sown onto the wearable

The vibration motors are connected to the Arduino Nano through a 2N3904 transistor and a 1kΩ resistor. The schematics of the vibration motors connected to the Arduino Nano can be seen in figure 6.8. The vibration motors use pin D5, D6, D9, D10 and D11. Only Pulse Width Modulation (PWM) pins are used. The speed of the vibration motors is directly proportional to the voltage applied to the motor. Therefore, by using PWM pins, this allows for precise control of the speed of the vibration motors.

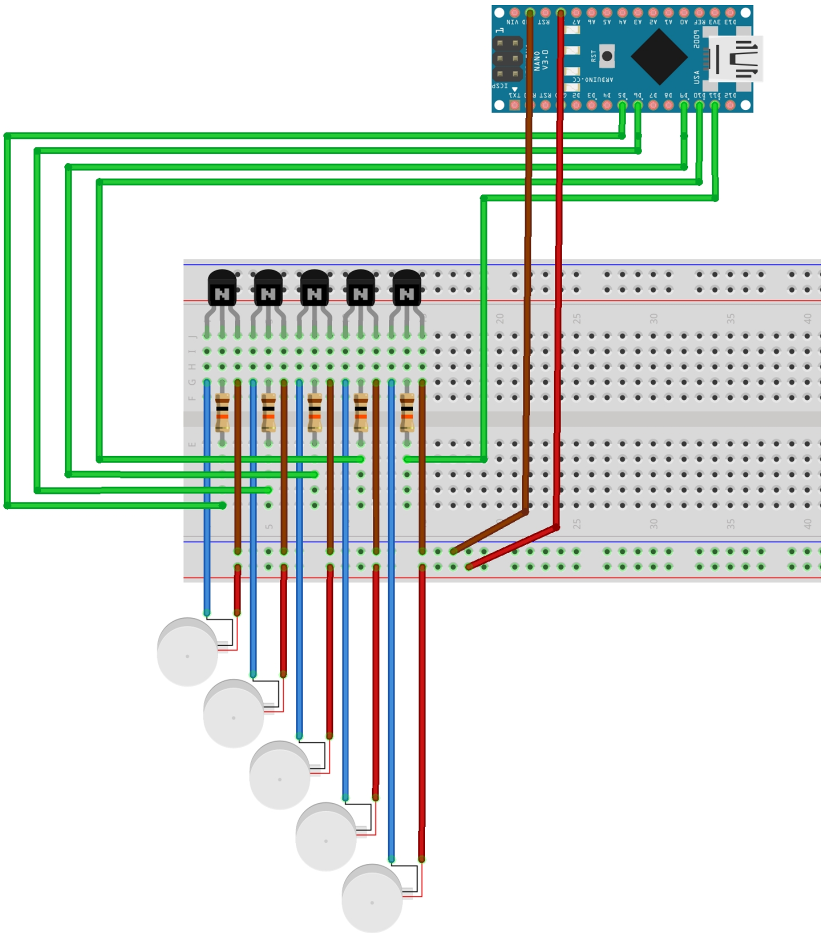
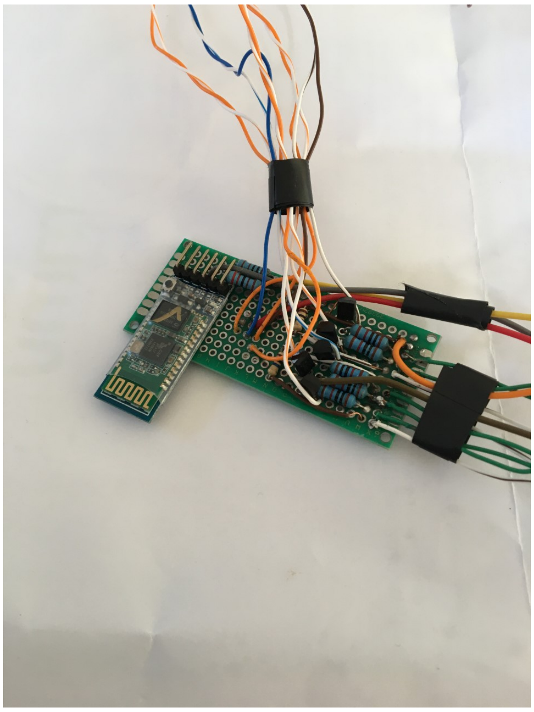


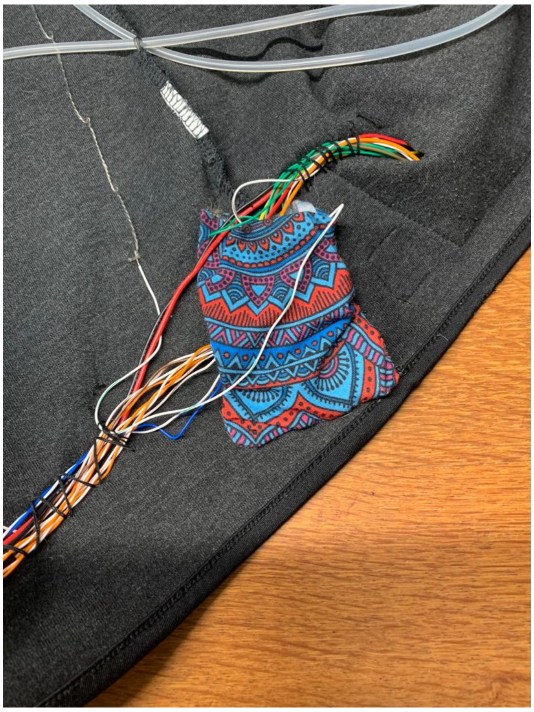
Figure 6.8: Sketch of the vibration motors connected to the Arduino Nano

6.5 PCB

The resistors and transistors mentioned to complete the circuit of all the components, are soldered onto a PCB plate. The HC-05 Bluetooth module that will form the connection between the two wearables is also soldered onto this plate. The PCB plate can be seen in figure 6.9a. This PCB plate is placed in a fabric pouch. This pouch sown onto the inside of the wearable, as can be seen in figure 6.9b.



(a)



(b)

Figure 6.9: (a) PCB with resistors, transistors and HC-05 Bluetooth module, (b) Fabric pouch covering the PCB sown onto the wearable

6.6 Prototype

All the components are now added into the sweater vest, almost completing the haptic wearable for social mediated touch prototype. The outside of the prototype can be seen in figure 6.10. The wearable looks like a regular sweater vest, with two patches of fabric on the sleeves. These patches are the capacitive sensors, that will sense when the user wants to send a hug. The inside of the wearable, with the actuators sown into it, can be seen in figure 6.11. Now that the components are integrated in the wearable, the interaction can be set up. The sensors, actuators and Bluetooth modules are all connected to an Arduino Nano. The schematics of the circuit with all components integrated can be found in appendix A.

6.6.1 Interaction with Components

When User 1 decides to send a hug, they touch both capacitive sensors that are sown onto the sleeves of the wearable. Once both the capacitive sensors are touched, the

(a)

(b)

Figure 6.10: (a) The wearable from the front. (b) The wearable form the back.

Bluetooth module will tell the wearable of User 2 to start the hugging interaction. Almost immediately the silicone inflatables will be inflated. To fully inflate the silicone pouches takes around six seconds. Once the silicone pouches are fully inflated, they will hold for another six seconds. During these six seconds, the vibration motors will start to vibrate. The vibration motors vibrate one after each other, slightly overlapping in activation with the previous vibration motor. After the six seconds of holding the inflatables, they start to deflate. Once the silicone pouches are fully deflated, the vibration motors are stopped as well. The interaction has ended.

While User 2 is receiving the hugging sensation, they are able to reciprocate the hugging interaction by initiating a hug of their own. User 2 can do this by also touching the two capacitive sensors on the sleeves of the wearable. Now the wearable of user 1 will start with the hugging sensation.

When the two capacitive sensors are touched and a hug is sent, no new interaction can be sent for the next 30 seconds. This ensures that only one hugging interaction is sent at a time. To realise this interaction, an Arduino sketch is created and uploaded

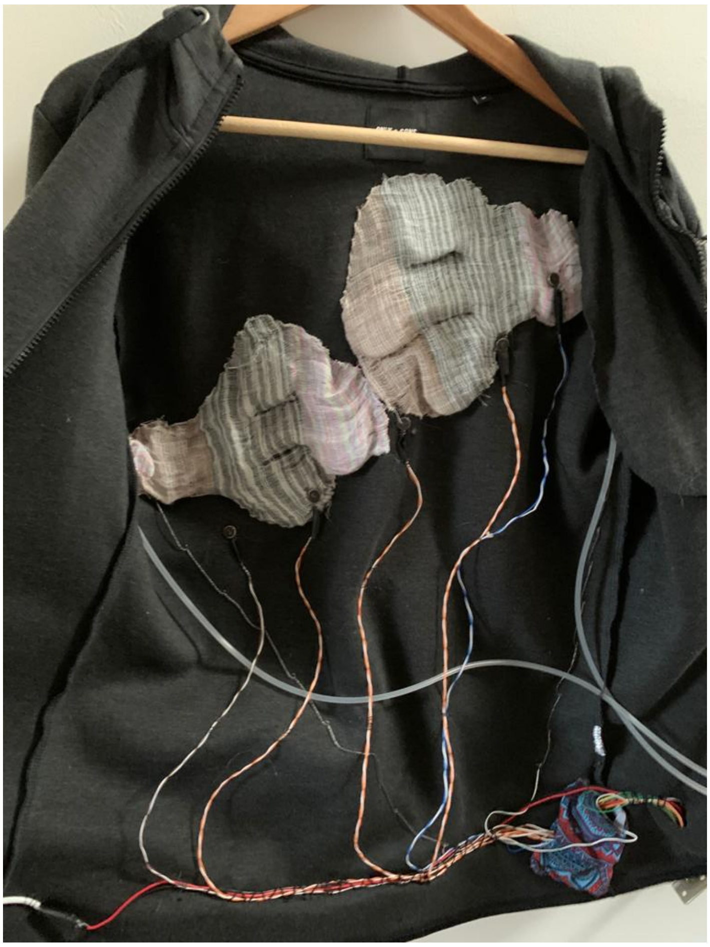


Figure 6.11: The inside of the wearable, showing the inflatables and the vibration motors

to the Arduino Nano. The full sketch can be found in B. A flowchart of the interaction with the components can be found in appendix C.

Chapter 7

Evaluation

This chapter aims to evaluate how well the wearable functions as a new greeting method, by simulating a hug through haptic feedback. In this chapter, the requirements set in chapter 5 are evaluated. First, the functional requirements are evaluated with a user test. Second, the systematic requirements are evaluated by the researcher.

7.1 User Evaluation

A user evaluation will be conducted. The goal of this user test is to evaluate the quality of the user's experience. This evaluation consists of several factors: Intuitivity of the design, ease of learning and subjective satisfaction. The user evaluation checks whether the following functional requirements set at the end of chapter 4: Ideation have been met:

- Make greetings a more pleasurable experience while social distancing
- Simulate a hugging sensation
- Imitate the feeling of two hands pressing on the back
- Imitate the feeling of a hand stroking the back
- Be intuitive to use
- Be non-intrusive for the user

7.1.1 Participants

For the user evaluation, a total of seven participants are recruited. Only adults, who are capable of giving consent will be selected. Other than this, there are no specific restrictions or requirements for the participants to take part in this study.

7.1.2 COVID-19

It is important that the user evaluation follows the COVID-19 guidelines of the Dutch government [18]. Therefore, only already existing face-to-face contact will be utilised. This means contact the researcher would already have with their participants. For this reason, roommates, family members and planned visitors will be contacted to participate. A distance of 1,5 meter will be kept at all times with members outside of the household. Furthermore, the researcher will conduct a user evaluation with one participant at a time.

The items both the researcher and the participants have to touch will be disinfected before and after they were used. Face masks can be kept on during the research. New masks will be provided, if the participant does not have their own.

7.1.2.1 Considerations

Due to the COVID-19 pandemic, social contact is limited to roommates and a maximum of one visitors per day. For this reason, only roommates, family members and planned visitors are able to participate in the user evaluation of the haptic wearable. Thus, some participants might already be aware of the project and some of its content. This could potentially affect the evaluation of the prototype, as they are already aware of some of its functionalities. If possible, participants have not received information about the project are selected. However, this is not always possible.

Furthermore, as the participants are close to the researcher, the participants feel they need to positively evaluate the haptic wearable. To try and minimise this problem, the participants are all asked to answer as truthfully as possible, even if they feel negatively about the haptic wearable or one of its functionalities. Overall, this participant selection is not ideal. Nevertheless, it is the best option in the current state of the COVID-19 pandemic. Moreover, the user test are still useful in evaluation the current prototype.

7.1.3 Data Collection

During the user test, observational notes will be taken and audio and video footage will be recorded. This audio and video footage allow the researcher to analyse the interaction after the user test. Furthermore, the answers of the questionnaire will be collected.

7.1.4 Procedure

The research procedure will take place in three phases. First, the participant is informed about the wearable. Second, the participant is asked to put the wearable on and perform interaction tasks. Lastly, the participant is asked to fill in an questionnaire about their experience.

7.1.4.1 Phase 1

The goal of the first phase is to inform the participant about the wearable and the setup of the user test. First, a brochure is provided, which explains the background, research information and purpose of the design. This brochure can be found in Appendix D.

After the participant has read the brochure, the context in which the haptic wearable prototype would be used is explained. This is done, because the perception of how the social mediated touch is perceived would highly depend on the context in which it would be used. The context is explained as follows:

During the COVID-19 pandemic, it is essential to practice social distancing to stop the virus from spreading. To do this, the government has advised to keep 1,5 meter distance from everyone outside your household [18]. This means many social touch interactions are not able to take place. One of such an interaction is the hug.

When greeting friends and family members, it is common practice to give them a short hug. Now that social distancing is the norm, this results in a greetings that can feel somewhat unnatural. For that reason this haptic wearable has been designed.

The haptic wearable can simulate a short hug between two individuals, at 1.5 meter distance. Allowing the user to greet their friends and family members at a safe distance, with a mediated hug.

Before continuing to the second phase, the participant is asked if they have any questions or objections about the user evaluation.

7.1.4.2 Phase 2

During the second phase, the participant will interact with the wearable. This phase will be audio and video recorded. This will allow the researcher focus on conducting the user test, as they can analyse the recorded footage afterwards. The researcher will wear a second wearable to which the interaction can be send by the participant. This wearable will also send a mediated hug to the participant, to allow them to feel the hugging sensation.

First, the participant is asked to put the wearable on. The researcher will provide verbal help when necessary. When the participant has put the wearable on correctly, they will be asked to perform a series of tasks:

1. Turn the wearable on
2. Send a mediated hug to the other wearable

After the participant sent a mediated hug, they will receive a hug. The researcher will send a hugging sensation, by touching the two capacitive sensors on their wearable. After the 30 seconds cool-down period of the wearables, another hug will be send to the wearable of the participant.

Now the participant can take off the wearable and the user evaluation moves on to phase three.

7.1.4.3 Phase 3

During this phase, the participant is asked to fill in a questionnaire about their experience with the wearable. During the questionnaire, the participant is able to elaborate on problems, improvements and performance of the product. The full questionnaire can be found in Appendix E. For multiple choice answer options, the Likert scale is used.

The questionnaire is split up into different sections, each elaborating on one part of the interaction.

7.1.4.3.1 COVID-19 pandemic The first section of the questionnaire aims to give an overview of the current situation of the participants. This can clarify if there is a need for a haptic wearable that is able to simulate a hug at a distance. In this section, they are asked if they experience less physical interaction since the pandemic. Furthermore, they are asked how they greet their friends and family while social distancing. Whether such a greeting feels unnatural to them is also investigated.

7.1.4.3.2 The Wearable This section formulates some questions about the wearable itself. The participants are asked if the wearable is easy to put on, turn on and comfortable to wear. They are also asked if the wearable has a pleasing look.

7.1.4.3.3 Hugging Interaction Next, the hugging interaction is investigated. First, the user is asked whether it is easy to send a hug to another wearable and if the wearable is intuitive to use. Secondly, the sensation of the hugging interaction is questioned. These questions aim to answer if the hugging sensation is a pleasant one and if it gives a feeling of closeness to the other person. How similar the hugging sensation is to a real-life hug is also investigated. At the end of this section, the participants are asked to describe the hugging sensation they received.

7.1.4.3.4 Silicone Inflatables This section of the questionnaire investigates how well the silicone inflatables are felt by the participants. Furthermore, whether the pressure on the back is pleasant, and if it resembles the feeling of two hands pressing on the back is asked.

7.1.4.3.5 Vibration motors Similar to the silicone inflatables section, this section investigates the performance and experience of the vibration motors. The vibration motors aim to give a stroking sensation on the back. Whether this stroking sensation is felt and if it is a pleasant sensation is investigated.

7.1.4.3.6 Overall Experience Lastly, the participants are asked to comment what they liked and what they did not like about the wearable and the experience interacting with it. They are also asked if they would use the wearable and with whom.

7.1.5 Results

The full list of results of the user evaluation can be found in Appendix F. With these results, the requirements set for the user evaluation have been met.

7.1.5.1 COVID-19 Pandemic

To see if there is a need for the haptic wearable, the participants were asked about their current way of greeting. All seven participants experience less physical interaction during the COVID-19 pandemic. All of the participants also agree (4) to strongly agree (3), that greeting friends and family members while social distancing feels unnatural. Five participants greet their friends and family by waving from a distance.

7.1.5.2 The Wearable

The 7 participants all agreed that the wearable was easy to put on. However, whether the wearable is comfortable to wear showed mixed results. This was mostly due to the heaviness of the wearable and because some of the components could be felt on the back. One participant also mentioned that it did not feel like wearing normal clothes. However, most participants did agree that the wearable had a pleasing look.

7.1.5.3 Hugging Interaction

First the participants were asked if the wearable is easy to turn on. The wearable is currently powered by a power back and this power bank also functions as the ON/OFF switch. The results of this varied. Five participants did agree that it was easy to turn on, while one disagreed and the last neither agreed nor disagreed. The participants were also asked if it was easy to send a hug to another wearable and if the wearable was intuitive to use. Overall, six out of the seven agreed to these statements.

Furthermore, several questions about the hugging sensation were asked. Six participants agreed that they enjoy the hugging sensation of the wearable. The last participant neither agreed nor disagreed. However, according to the results, the hugging interaction did not feel similar to a real-life hug. Only two participants agreed that it felt similar. Three participants disagreed.

The hugging sensation was mostly described as a stroke, tingling or light caressing of the back. One participant commented that the experience "felt nice as a replacement for the real thing, but needs tweaking. Felt too robot like".

7.1.5.4 Silicone Inflatables

This section evaluates the performance of the silicone inflatables. Six participants were able to feel the pressure of the inflatables of the back. However, this pressure did not feel like two hands pressing on the back to all participants. Three of the participants disagreed with this statement. Overall, the pressure on the back was perceived as pleasant by six out of the seven participants.

7.1.5.5 Vibration Motors

This section evaluates the performance of the vibration motors. All participants were able to feel the vibration motors. Furthermore, to most participants (5) it did feel like a stroking sensation on the back. Six of the participants strongly agreed that the vibration motors gave pleasant experience. The other participant disagreed with this statement.

7.1.5.6 Overall Experience

Overall, six of the seven participants had a pleasant experience interacting with the wearable. All of the participants could think of a situation in which they would use the wearable. However, not all of them agreed that they would like to use the wearable again. Five participants agreed with this statement. Whether the hugging sensation of the wearable gave a feeling of closeness to the other person varied between the participants. One strongly agreed, two agreed, two neither agreed nor disagreed and two disagreed. Most participants would use the wearable with their close family members. Some of the participants (3) would also use it with their other relatives. Three participants would use the wearable with their friends.

Furthermore, the participants were asked what they liked and did not like about the wearable. To the former question, participants mostly answered about the ease of use of the wearable. They also commented about the pleasant experience and the feeling of closeness they felt when receiving the hugging sensation. The answers to what the participants did not like about the wearable varied. Two participants noted that they were not fully able to feel the pressure. Another participant did not like the sensation of the vibration motors.

7.2 Conclusion

The evaluation aims to see if all the requirements set up at the end of chapter 4: Ideation have been met. The conclusion of the functional requirements are based on the results of the user evaluation. The systematic requirements are evaluated by the researcher.

7.2.1 Functional Requirements

The conclusion of the functional requirements is based on the results of the user evaluation. The following table aims to evaluate to what extend these requirements have been met.

The requirements are categorised as follows:

++ Requirement is fully met

+ Requirement is mostly met

+- Requirement is partially met

- Requirement is not met

The haptic wearable should...	Comment	
Make greetings a more pleasurable experience while social distancing	most had a pleasant experience with the wearable, but not all of them would use them again.	+
Simulate a hugging sensation	The hugging sensation did not feel similar to a real-life hug for all participants.	+ -
Imitate the feeling of two hands pressing on the back	The pressure was not felt by all participants. The pressure did not really feel like two hands pressing on the back.	-
Imitate the feeling of a hand stroking the back	The vibration motors were perceived as pleasant and did feel like stroking on the back.	+ +
Be intuitive to use	Almost all participants agreed that the wearable was intuitive to use.	+ +
Be non-intrusive for the user	The wearable is still quite heavy and the components can be felt. However, participants did find it easy to put on	+ -

Overall, most functional requirements have been met at least partially. The requirement that has not been met is imitating the feeling of two hands pressing on the back. According to the users, the pressure exerted on the back by the silicone inflatables was not enough to be properly felt. Some participants of the user test did not feel this pressure at all. Those that did feel the pressure of the silicone inflatables however, did experience the pressure positively.

The extend to which participants were able to feel this pressure on the back, also depended on how tightly the sweater vest fit around the back. For some of the participants, the haptic wearable was rather large. This meant there was more room between the back of the participant and the inflatable. These were also the participants that said they were not able, or not fully able to feel the silicone inflatables. How well the vibration motors were felt, on the other hand, did not seem to depend on how tight the vest was around the back of the participants.

Another reason for the participants not being able to feel the pressure, could be the sensitivity of the back. Nerve endings in the skin sense the feeling of touch. Pressure receptors and touch receptors are able to distinguish pressure and touch on the skin. Some areas of the body, however, are more sensitive than others, because they have more nerve endings. According to [48], the back is less sensitive when it comes to pressure and touch, as the back holds less of these nerve endings. The ability to discriminate two points on the back lies at 39 millimetres. Especially the sensitivity threshold for males is higher when it is compared to the sensitivity threshold of females.

Furthermore, the hugging sensation created by the wearable did not feel like a real-life hug to most participants. However, they did enjoy interacting with the wearable and would like to use it again. For the purpose of making the greeting experience a more pleasant one while social distancing, exactly simulating a hug using haptic technology is less important than the willingness to use the product. Currently, the components of the wearable can still be felt. The participants of the user test said this is what makes the wearable somewhat uncomfortable.

7.2.2 Systematic Requirements

To see if the prototype meets the systematic requirement, it is tested by the researcher and designer. This is done by checking whether the systematic requirements set at the end of chapter 4: Ideation have been met. This evaluation is done by the researcher.

The haptic wearable should...	Comment	
Be mobile	All the components are powered by a power bank, making it fully mobile	✓
Be integrated in a wearable	Everything is sown onto a sweater vest	✓
Be able to interact with another haptic wearable at 1,5 meter distance	The Bluetooth modules with automatically connect when they are within 50 meters of each other	✓
Be able to be turned on and off by the user	Currently turning the wearable on/off is done by switching the power bank to on/off	

Almost all systematic requirements of the haptic wearable are met, except for the last one. Currently there is no ON/OFF button directly on the wearable itself, this is done by the power bank in the pocket. This is not a problem at this stage of the prototype, but should be integrated into a later version of the wearable. One function of the power bank, however, did seem to be useful. The power bank automatically turned off after about five minutes. As the interaction of one wearable only takes about 30 seconds, the total interaction of two users will not be longer than a minute or two. Therefore, letting the wearable automatically turn off after about 5 minutes felt like the perfect time. When adding an ON/OFF button to the wearable, this could also be integrated.

Chapter 8

Discussion

This chapter elaborates on recommendation when continuing the project. Several additions or changes to the prototype can be made in the future to make it improve in functionality and user friendliness. Furthermore, the possibilities for the haptic wearable for a social mediated hug, after the COVID-19 pandemic are discussed. It will explain other options for the wearable when there is no need for social distancing anymore. Lastly, an ethical report is set up to discuss the ethical considerations regarding a haptic wearable for social mediated touch.

8.1 Recommendations

With this bachelor project a first prototype of the haptic wearable for a social mediated hug has been developed. This prototype has been tested through a usability test. The results of this user test can be used to formulate several recommendations for further iterations of a haptic wearable for a social mediated hug, used for greeting purposes.

8.1.1 Redesign of Inflatables

Firstly, the user evaluation showed that the silicone inflatables were not properly felt by all users. Currently, the silicone inflatables seem to press away from the back, in stead exerting pressure on the back. Therefore, the overall design of the inflatables should be adjusted in a prospective iteration of the wearable. This problem can be resolved by placing a firm casing, around the back of the inflatables. This ensures that the inflatables push into the back, rather than pushing away from the back.

8.1.2 Connection Notification

Secondly, the haptic wearables connect automatically with each other, through the HC-05 Bluetooth module. To connect the two wearables, they should both be turned on. When the wearables are turned on and within range of each other, the wearables can connect. Setting up this connection takes about ten seconds. Currently, the users are not notified by the wearable when this connection has been formed. This makes the users unsure of when they are actually able to send a hug. Therefore, a notification should be added when the Bluetooth connection has been made between the two wearables. This could be in the form of a quick, but noticeable vibration by the vibration motors on the back.

Another way the users can be notified, is by adding an LED to the wearable. Be emitting light from, for instance, the location of the touch sensors, the users are able to see when they can send a hug. However, if a LED is used to indicate the connection of the Bluetooth modules in a next iteration of the wearable, the ideal placement of such a LED should be investigated firs.

8.1.3 Wearable Sizes

Third, as concluded from the user evaluation, the performance of the haptic wearable was based on the clothing size of the participant. The wearable should fit somewhat tightly on the back to be able to fully experience the silicone inflatables and the vibration motors. This should be taken into account when developing a future product.

Realising different wearable sizes can be done in several ways. First, a similar wearable such as this sweater vest can be used. If this is the case, multiple sizes of the sweater vest should be created to service a large spectrum of body types. Second, a completely new wearable can be created, making it adjustable in size. Thus, the same wearable can be adjusted to properly fit each user. One way this can be done, is by adding straps to the wearable. By doing this, a one size fits all model of the wearable is created.

8.1.4 Personalising the Hug

Lastly, this iteration of the haptic wearable only has one type of social mediated touch simulation. Each hugging sensation is exactly the same every time. In the future, hugs that are sent could be made more personal by the users. Varying the time the capacitive sensors are touched could give different outputs results of the actuators, instance. A short touch could result in a short interaction of the vibration motors. A longer touch, on the other hand, could sent a more stronger hugging sensation. Making the hug both longer and more intense. The intensity of the hug can depend on the length the silicone inflatables are inflated and the strength of the vibration motors. Furthermore, personalising the hug allows for further experimentation with different types of vibration patterns.

8.2 After COVID-19

This haptic wearable has been designed as a new greeting method during the COVID-19 pandemic. Presently, the regulations around the COVID-19 pandemic urge everyone to keep 1.5 meter distance from each other. Most likely, however, this pandemic will end at some point and people will be able to greet one another with a hug once again. This does not mean that the haptic wearable for a social mediated hug becomes irrelevant.

Firstly, the wearable as is, can be used whenever people still need to keep their distance from one another. When someone is vulnerable or sick, for example, the wearable can still be used to give a short social touch to that person. Secondly, the haptic wearable can easily be adjusted for other purposes. The Bluetooth modules now connect to each other whenever they are close to each other. However, these Bluetooth modules can also connect to other Bluetooth devices, such as a mobile phone or a computer. If these devices are connected to the internet, the wearable can be used over any distance. The wearable could be used to greet someone during a long distance video call, for example.

Alternatively, by connecting the wearable to a mobile phone, a hug can be send at any time to a loved one, similar to the Hug Shirt [6].To realise this, an mobile phone application should be developed in which two people can connect to send a hug. Such an application would enable multiple people to connect with each other. Allowing multiple people to which the user can send a hug, and from which the user can receive the hug. Such an iteration would not solely have the goal of sending a hug as a greeting. Thus, deviating from the current context. Therefore, if in the future, hugs can be send at any time, more research should be done on the type of contexts such a haptic wearable would be used in.

8.3 Ethical Considerations

As part of the Reflection course of the Creative Technology graduation semester, a reflection report has been set up. This reflection report holds the ethical considerations that should be taken into account when developing a haptic wearable for social mediated touch. This ethical reflection report can be in G.

Chapter 9

Conclusion

The goal of this bachelor project was to design a haptic wearable for social mediated touch. At the beginning of the project the main research question had been formulated. This chapter aims to answer this main research question.

How to design a haptic wearable for social mediated touch, to allow a social touch while social distancing?

In order to answer the main research question, the sub-questions should be answered first.

SQ-1 What is the state of the art for haptic wearables and social mediated touch technology?

This sub-question was answered in chapter 2: State of the Art. To answer this question, social touch itself should first be discussed. Any interpersonal touch with a communicative intent can be categorised as a social touch, according to Cascio, Moore and McGlone [14]. Depending on the context, this social touch can be perceived as positive of negative. Overall, however, social touch does have a lot of benefits. It has been related to social bonding, decreased loneliness, stress relief and communication. If social touch is not a possibility, these benefits can not be experienced.

During the COVID-19 pandemic, the Dutch government advises everyone to stay at 1,5 meter distance from everyone outside their household [18]. This mean a lot less social touch interactions are occurring. A solution for this lack of social touch, could be a haptic wearable for social mediated touch. Haptic wearables for social mediated touch enable a sense of touch over a distance. These wearables use haptic feedback technology to simulate a social touch. This haptic feedback technology consists of different types of sensors and actuators. The sensors aim to record the social touch, while the actuators simulate the social touch. Sensors commonly used in haptic wearables for social mediated touch are capacitive touch sensors, force sensors and flex sensors. Actuators commonly used are vibration motors, force actuators, inflatables and temperature regulators.

Projects and products in the same domain of haptic wearables for social mediated touch were also investigated. There are many different types of haptic wearables for social mediated touch. Each haptic wearable discussed serves a different purpose and varies in context. They all use the haptic feedback technology in for different purposes and in different combinations. None of the projects and products was specifically designed for the COVID-19 pandemic, which this bachelor project did aim to do. This, however, is understandable, as the COVID-19 pandemic is a recent occurrence. Furthermore, almost all of the wearables discussed are meant to be used at a longer distance, where the users are unable to see each other. Only the AWElectic [8] uses two wearables at a small distance connect with each other.

With the first sub-question answered, the second sub-question can be discussed.

SQ-2 What is a suitable context and scenario for a haptic wearable for social mediated touch?

With the knowledge gained in chapter 4: Ideation, this sub-question can be answered. During the COVID-19 pandemic, less social touch is experienced. Haptic wearables for social mediated touch, could aid in experiencing more social touch, while still practising social distancing. To explore what contexts and scenarios could be relevant to introduce such a wearable into, a mind map was created. From this mind map a relevant and interesting context for the researcher was chosen.

Normally, friends and family members are greeted with a hug. Currently, however, greetings can feel somewhat unnatural, while keeping the advised 1,5 meter distance from one another. A haptic wearable for social mediated touch, could make these greetings a more pleasurable experience again. Enabling greeting friends and family members with mediated hug. Therefore, this bachelor project focuses on created a haptic wearable that is able to simulate the feeling of a hug, for greeting purposes. Several user case scenarios were explored, to provide a clear overview of the type of context in which such a wearable can be used.

SQ-3 What components, both hardware and software, are needed to design a haptic wearable for social touch?

Chapter 5: Specification, discusses the components that are needed to make this haptic wearable for a social mediated hug. The haptic wearable should be able to connect with another wearable, record a hug and simulate a hug. The wearables should be able to automatically connect with one another at 1,5 meter distance. For this, a Bluetooth module is chosen, as these modules can automatically connect within 10 meters of each other.

To record the hug, two capacitive sensors are used. These capacitive sensors are in the form of conductive fabric, which is sown onto the sleeves of the wearable. When the user touches both of these capacitive sensors, a hug is sent to the second wearable. Conductive fabric is malleable and feels somewhat similar to regular fabric, making it ideal for a wearable.

In order to simulate the hug two types of actuators are used: silicone inflatables and vibration motors. The goal of the inflatables is to recreate the feeling of two hands pressing on the back. Therefore, the silicone inflatables are modelled after a human hand. These silicone inflatables are inflated with the use of a pneumatic shield. The vibration motors aim to create stroking sensation on the back. The best placement and activation speed of these vibration motors are tested before they are added to the wearable.

The Bluetooth modules, capacitive sensors and silicone inflatables are all connected to an Arduino Nano. The sketch to allow these components to interact with each other is uploaded onto this Arduino Nano. All the components are added to a sweater vest to complete the haptic wearable for social mediated touch.

With the answers on the sub-questions, the main research question can be answered.

How to design a haptic wearable for social mediated touch, to allow a social touch while social distancing?

With the use of the Creative Technology Design Process [9], a haptic wearable for social mediated touch has been developed. This haptic wearable simulates a hugging sensation, to make greetings while social distancing a more pleasurable experience. With the wearable, a hug can be recorded and send to another wearable. Each wearable can also simulate the sensation of a hug. It does this by inflating two silicone inflatables and five vibration motors on the back.

Whether this new greeting method was perceived as a more pleasurable experience, was tested by several users. The results of the evaluation showed, that most participants had a pleasant experience interacting with the wearable and would like to use it again. However, some adaptations should be made when continuing the work on this haptic wearable for social mediated touch.

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Appendix A

Schematics

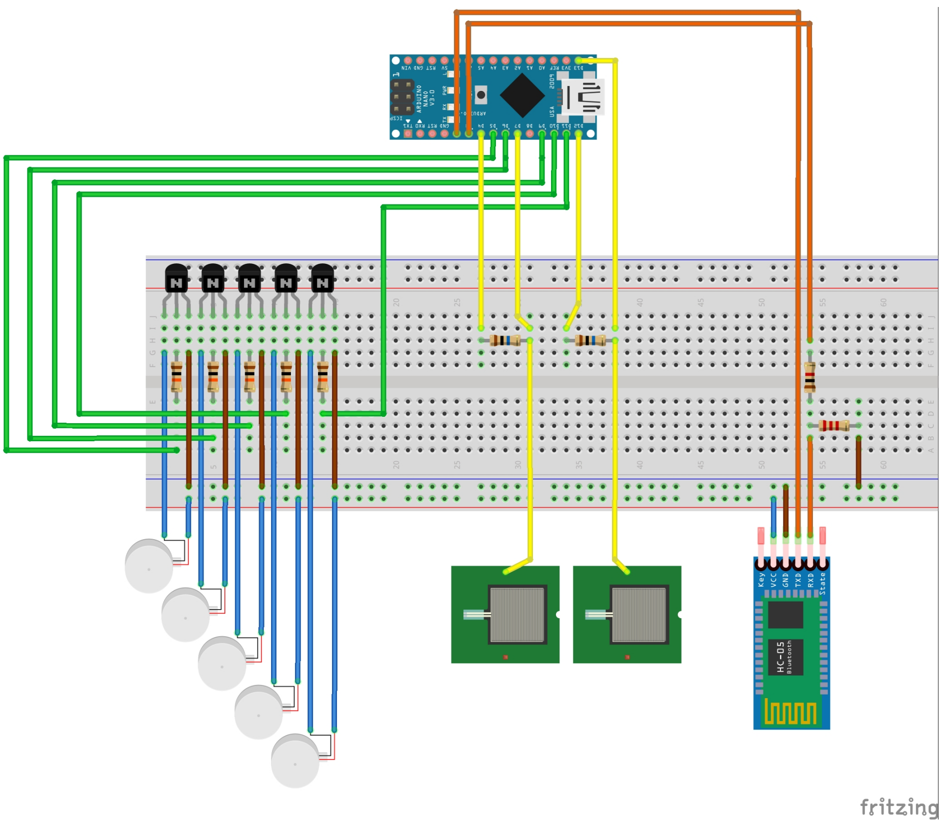


Figure A.1: Schematics of the components connected to the Arduino Nano

Appendix B

Arduino Code

```
/* This is the script for the haptic wearable for a social mediated touch
   With this script an hugging simulation can be sent from one wearable to
   another using the bluetooth connection. The hugging interaction is initiated
   by touching two capacitive sensors. The hugging sensation is simulated by
   inflating two silicone inflatables and sequentially activating several
   vibration motors.
   This script was written by Esmarie Jonkergouw - s1739840 for her bachelor
   thesis on haptic wearables for social mediated touch.
*/

//Include libraries for non-blocking delay
#include <BufferedInput.h>
#include <BufferedOutput.h>
#include <loopTimer.h>
#include <millisDelay.h>
```

```
#include <SafeString.h>
#include <SafeStringReader.h>
#include <SafeStringStream.h>

//include library for the capacitive sensor
#include <CapacitiveSensor.h>

//include library for the bluetooth modules
#include <SoftwareSerial.h>    //library for bluetooth module

//include library for the pneumatic shield
#include "Board.h" //library for pneumatic shield
BOARD board; //initialize board

// 10 megohm resistor between pins 4/8 & 7, pin 4&8 are sensor pins to which capacitive fabric is connected
CapacitiveSensor   cs_7_8 = CapacitiveSensor(7, 8);        // 10 megohm resistor between pins 7 & 8, pin 8 is sensor pin to which the capacitive fabric is connected
CapacitiveSensor   cs_7_4 = CapacitiveSensor(7, 4);        // 10 megohm resistor between pins 7 & 4, pin 4 is sensor pin to which the capacitive fabric is connected

// Connect the HC-05 TX to Arduino pin 2 RX.
// Connect the HC-05 RX to Arduino pin 3 TX through a voltage divider.
SoftwareSerial BTserial(2, 3); // RX | TX //bluetooth module is connected to pin 2 and 3
char c = ' ';   //initialize characted that will be sent/received from bluetooth module

```

```

unsigned long StartTimeInfl; //Initialize timer for inflation
unsigned long StartTimeCap;  //Initialize timer to hold input capacitive sensor


//initialize vibration motor pins, motor pin state and vibration delay
int motorPin1 = 5; //vibrationmotor on PWM pin 5
int motorPin2 = 6; //vibrationmotor on PWM pin 6
int motorPin3 = 9; //vibrationmotor on PWM pin 9
int motorPin4 = 10; //vibrationmotor on PWM pin 10
int motorPin5 = 11; //vibrationmotor on PWM pin 11

int state;   //state of statemachine for vibration sequence
boolean forward; //vibration motors states set to move forward

millisDelay vibrationDelay; //initialize non-blocking delay for vibration motor sequence
millisDelay vibrationOverlap; //initialize non-blocking delay for overlap time of vibration motors


void setup() {
  Serial.begin(9600);
  Serial.println("Remember to select Both NL & CR in the serial monitor");  //needed for bluetooth modules to connect
  BTserial.begin(9600); //set to match your BT module

```

```
  StartTimeInfl = 0;  //timer for inflatables is not running
  StartTimeCap = 0;   //timer for capacitive sensor is not
     running

  board.init([] {board.readSensors();}); //initialize
     pneumatic shield

  //Set vibration motors to output
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(10, OUTPUT);
  pinMode(11, OUTPUT);

  state = 1; //statemachine begins in state 1

  vibrationDelay.start(200); //delay between vibrationmotors
     set to 200 ms
  vibrationOverlap.start(100); //delay for overlap between
     vibration motors is set to 100ms
  forward = true;
}

void loop() {
  long capsensor1 = cs_7_4.capacitiveSensor(30); //values for
      capacitive sensor one (left)
  long capsensor2 = cs_7_8.capacitiveSensor(30); //values for
      capacitive sensor two (right)

  delay(100); // arbitrary delay to limit data to serial port

```

```
// Keep reading from HC-05 Bluetooth module and send to
   Arduino Serial Monitor
if (BTserial.available())
{
  c = BTserial.read();
  Serial.write(c);
}
//Inflatables and vibration motors will start on other
   Arduino when 'B' is received
if (c == 'B' ) {
  StartTimeInfl = millis(); //Start the timer for
     inflatables
}


if (StartTimeInfl > 0)   {      //Timer is running
  // for 5 seconds fill inflatables & start vibration motor
      state machine
  while (millis() - StartTimeInfl >= 0 && millis() -
     StartTimeInfl <= 10000) {
    board.setPump(true);               // Turn the pump on
    board.setValve(1, 2);              // Set output 1 to
       FILL(2)
    board.setValve(2, 2);              // Set output 2 to
       FILL(2)
    //RUN_STATEMACHINE();                // Start running
       the state machine for the vibration motors

  }
  // for 5 seconds hold inflatables & keep running
     vibration motor state machine
```

```
    while (millis() - StartTimeInfl >= 10000 && millis() - StartTimeInfl <= 15000) {
      board.setValve(1, 1);           // Set output 1 to HOLD (1)
      board.setValve(2, 1);           // Set output 2 to HOLD (1)
      board.setPump(false);           // Turn the pump off so it will only make noise during inflation
      RUN_STATEMACHINE();             // keep running the sate machine for the vibration motors

    }
    // release the inflatables for 5 seconds and turn off vibration motors
    while (millis() - StartTimeInfl >= 15000 && millis() - StartTimeInfl <= 22000) {
      board.setValve(1, 0);         // Set output 1 to RELEASE (0)
      board.setValve(2, 0);         // Set output 2 to RELEASE (0)

      //turn off all vibration motors
      digitalWrite(motorPin1, LOW);
      digitalWrite(motorPin2, LOW);
      digitalWrite(motorPin3, LOW);
      digitalWrite(motorPin4, LOW);
      digitalWrite(motorPin5, LOW);
    }

    //if inflate, hold, release sequence is complete, set the timer for the inflatables back to 0
```

```
    if (millis() - StartTimeInfl >= 22000) {
      StartTimeInfl = 0; // Stop the timer for the inflatables
    }
  }

  //if the capacitor sensors are pressed, it will send a signal to the other wearable to start the interaction
  //No new interaction can be started for 30 seconds.
  if (capsensor1 >= 3000 && capsensor2 >= 3000 && StartTimeCap == 0) {
    c = 'B';
    BTserial.write(c); //sends character 'B' to other board via bluetooth to start the initiation
    StartTimeCap = millis(); //start the timer
  }

  //for 30 seconds no new interaction can be started
  if (millis() - StartTimeCap >= 3000) {
    StartTimeCap = 0; // stop the timer
  }


  if (Serial.available()) // Keep reading from Arduino Serial Monitor and send to HC-05
  {
    c =  Serial.read();
    BTserial.write(c);
  }
}

```

```
//This is the statemachine for the vibration motors. They
    turn on one after the other, each vibrating for 300 ms
void RUN_STATEMACHINE(void)
{
  switch (state) {

    //first state: after vibration delay has finished: motor
        1 ON, motor 2 OFF --> move to state 2
    //flip boolean forward to !forward to move through states
         backwards
    case 1:
      if (vibrationDelay.justFinished() && state == 1) {
        vibrationDelay.repeat();
        analogWrite(motorPin1, 200);
        if (vibrationOverlap.justFinished()) {
          digitalWrite(motorPin2, LOW);
          vibrationOverlap.repeat();
        }
        forward = !forward;
        state = 2;
      }
      break;

    //second state: after vibration delay has finished: motor
         2 ON, motor 1 & 3 OFF -->  if forward  --> move to
        state 3
    //                -->  if not forward --> move to state 1
    case 2:
      if (vibrationDelay.justFinished() && state == 2) {
        vibrationDelay.repeat();
        digitalWrite(motorPin2, HIGH);
```

```
        if (vibrationOverlap.justFinished()) {
          vibrationOverlap.repeat();
          digitalWrite(motorPin1, LOW);
          digitalWrite(motorPin3, LOW);
        }

        if (forward) {
          state = 3;
        }

        else if (!forward) {
          state = 1;
        }
      }
      break;

    //second state: after vibration delay has finished: motor
        3 ON, motor 2 & 4 OFF -->  if forward  --> move to
       state 4
    //                       -->  if not forward --> move to
       state 2
    case 3:
      if (vibrationDelay.justFinished() && state == 3) {
        vibrationDelay.repeat();
        digitalWrite(motorPin3, HIGH);
        if (vibrationOverlap.justFinished()) {
          vibrationOverlap.repeat();
          digitalWrite(motorPin2, LOW);
          digitalWrite(motorPin4, LOW);
        }
        if (forward) {
```

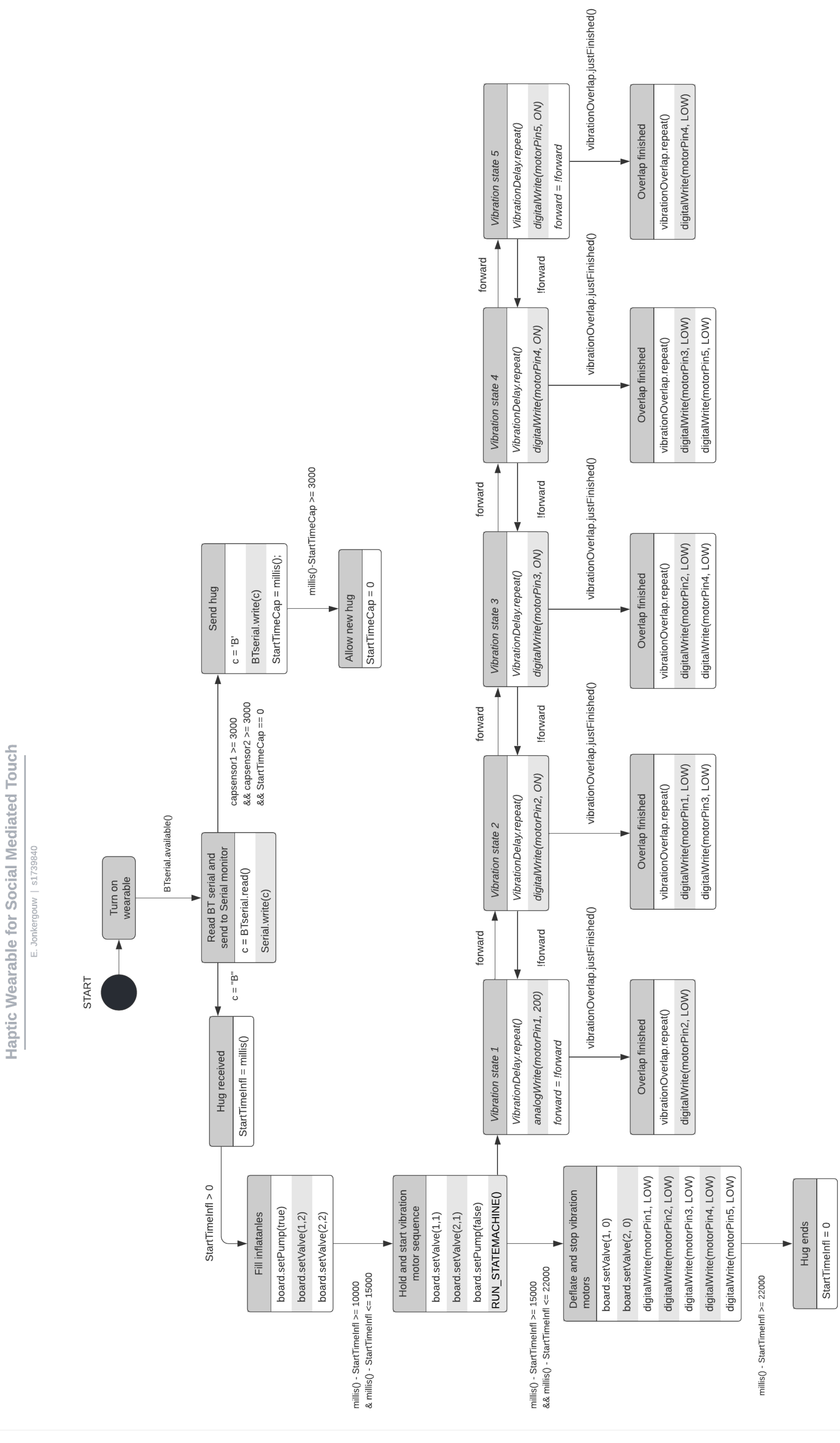
```

          state = 4;
        }
        if (!forward) {
          state = 2;
        }
      }
      break;

    //second state: after vibration delay has finished: motor
        4 ON, motor 3 & 5 OFF --> if forward --> move to
       state 5
    //                   --> if not forward --> move to state 3
    case 4:
      if (vibrationDelay.justFinished() && state == 4) {
        vibrationDelay.repeat();
        digitalWrite(motorPin4, HIGH);
        if (vibrationOverlap.justFinished()) {
          vibrationOverlap.repeat();
          digitalWrite(motorPin3, LOW);
          digitalWrite(motorPin5, LOW);
        }

        if (forward) {

          state = 5;
        }
        if (!forward) {
          state = 3;
        }
      }
```

```
      break;

    //first state: after vibration delay has finished: motor
       5 ON, motor 4 OFF --> move to state 1
    //flip boolean forward to !forward to move through states
        backwards
    case 5:
      if (vibrationDelay.justFinished() && state == 5) {
        vibrationDelay.repeat();
        analogWrite(motorPin5, 150);
        if (vibrationOverlap.justFinished()) {
          vibrationOverlap.repeat();
          digitalWrite(motorPin4, LOW);
        }
        state = 4;
        forward = !forward;
      }
      break;

    //default state
    default:
      digitalWrite(motorPin1, LOW);
      digitalWrite(motorPin2, LOW);
      digitalWrite(motorPin3, LOW);
      digitalWrite(motorPin4, LOW);
      digitalWrite(motorPin5, LOW);

      break;

  }
}
```

Appendix C

UML Flowchart

To explain the interaction of the haptic wearable, a UML flow chart is created. With this flow chart all the possible interactions are explored.


Haptic Wearable for Social Mediated Touch
E. Jonkergouw | s1739840
START
Turn on wearable
BTserial.available()
Read BT serial and send to Serial monitor
c = BTserial.read()
Serial.write(c)
c = "B"
Hug received
StartTimeInfl = millis()
capsensor1 >= 3000
&& capsensor2 >= 3000
&& StartTimeCap == 0
Send hug
c = 'B'
BTserial.write(c)
StartTimeCap = millis();
millis()-StartTimeCap >= 3000
Allow new hug
StartTimeCap = 0
StartTimeInfl > 0
Fill inflatanles
board.setPump(true)
board.setValve(1,2)
board.setValve(2,2)
millis() - StartTimeInfl >= 10000
& millis() - StartTimeInfl <= 15000
Hold and start vibration motor sequence
board.setValve(1,1)
board.setValve(2,1)
board.setPump(false)
RUN_STATEMACHINE()
millis() - StartTimeInfl >= 15000
&& millis() - StartTimeInfl <= 22000
Deflate and stop vibration motors
board.setValve(1, 0)
board.setValve(2, 0)
digitalWrite(motorPin1, LOW)
digitalWrite(motorPin2, LOW)
digitalWrite(motorPin3, LOW)
digitalWrite(motorPin4, LOW)
digitalWrite(motorPin5, LOW)
millis() - StartTimeInfl >= 22000
Hug ends
StartTimeInfl = 0
Vibration state 1
VibrationDelay.repeat()
analogWrite(motorPin1, 200)
forward = !forward
Vibration state 2
VibrationDelay.repeat()
digitalWrite(motorPin2, ON)
Vibration state 3
VibrationDelay.repeat()
digitalWrite(motorPin3, ON)
Vibration state 4
VibrationDelay.repeat()
digitalWrite(motorPin4, ON)
Vibration state 5
VibrationDelay.repeat()
digitalWrite(motorPin5, ON)
forward = !forward
forward
!forward
vibrationOverlap.justFinished()
Overlap finished
vibrationOverlap.repeat()
digitalWrite(motorPin2, LOW)
Overlap finished
vibrationOverlap.repeat()
digitalWrite(motorPin1, LOW)
digitalWrite(motorPin3, LOW)
Overlap finished
vibrationOverlap.repeat()
digitalWrite(motorPin2, LOW)
digitalWrite(motorPin4, LOW)
Overlap finished
vibrationOverlap.repeat()
digitalWrite(motorPin3, LOW)
digitalWrite(motorPin5, LOW)
Overlap finished
vibrationOverlap.repeat()
digitalWrite(motorPin4, LOW)

Appendix D

Informational Brochure User Evaluation

This is the informational brochure that is given to the participants of the user test at the beginning of the user evaluation.

BACKGROUND

Social touch is an important part of human development and personal well-being. However, Social touch is also a close-proximity interaction between humans. Now, during the COVID-19 pandemic, social touch is minimized due to social distancing. Haptic technology allows for a sense of social touch, over a safe 1,5 meter distance. By creating a haptic wearable for social mediated touch, one person can touch another person over distance.

The research for this project is conducted by Esmarié Jonkergouw as part of her bachelor thesis for the Creative Technology course at the University of Twente. The goal of this bachelor thesis is to design a haptic wearable that can simulate a hugging sensation at 1,5 meter distance.

A haptic wearable is a clothing item that can simulate a touching sensation through technology. For this project, the wearable is a zipper vest which can easily be put on. The technolgoy used in the vest are inflatables and vibration motors. These components are used to simulate a hugging sensation. In this way, two people can hug each other while social distancing.

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INFORMATIONAL BROCHURE

PROJECT: HAPTIC WEARABLE FOR SOCIAL MEDIATED TOUCH

Contact information:
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06-19951687

This brochure contains information about the research project: haptic wearable for social mediated touch. The brochure can help you decide whether you would like to participate in this research.

RESEARCH INFORMATION

With the use of interviews and observations, information will be collected about the user experience using the haptic wearable for social mediated touch prototype.

In this brochure, information will be provided to explain what it would mean to partake in this research. You are free to decide whether you want to partake in this research. For any questions regarding the research you can contact Esmarié Jonkergouw. The contact information is provided on the front page of this brochure. The contact information of the supervisor is provided on the back of the brochure.

PARTICIPATION

Participation in this research is voluntary. You can discontinue your collaboration in this research at any moment, or refuse that your data is used for this research, without reason. Consent for participation only needs to be given once and will be valid until the end of the project duration.

RESEARCH INTERACTION

The goal of this research is to understand the user experience of participants using the haptic wearable for the social mediated touch prototype. This will be done by observation of the participants, while interaction with the wearable. During the research, you will be asked to perform some simple tasks to activate the mediated hug, as well as receive the hugging sensation. Afterwards, you will be asked the complete a questionnaire about your experience.

DATA COLLECTION

While performing the interaction tasks, observational notes will be taken and audio and video footage will be recorded. Furthermore, the answers of the questionnaire will be collected.

We will do everything in our power to protect your privacy as best as we can. No personal data will be extended to third parties. When processing your data for the research, this data will be anonymized.

In publication, anonymous data will be used. The forms and other documents that were used for this study, will be saved in a secure location at the University of Twente and on (encrypted) data carriers of the researchers. The collected data will be saved until April 2021. After this, the data will be deleted or anonymized, making it impossible to trace back to a person.

The collected data will, when necessary (for control of scientific integrity, for example), only be available in anonymous form, when extended outside the research group. The video footage from the research will be deleted after the end of this project, in Februari 2021.

DISCONTINUING OF PARTICIPATION

If you decide to discontinue your participation in the research, either during or after the research, all your data from the session will be deleted. When the research materials have been anonymized and can not be linked to you anymore, they can also no longer be deleted.

QUESTIONS ABOUT YOUR RIGHTS AS A RESEARCH PARTICIPANT?

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher, please contact the Secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) at the University of Twente.

ethics-comm-eemcs@utwente.nl

Appendix E

Questionnaire

Haptic Wearables for a Social Mediated Hug

Thank you in participating in this user test for the bachelor thesis about haptic wearables for social mediated touch! You just interacted with the haptic wearable and experienced a mediated hug. In this questionnaire, of about 10 minutes, some questions about your experience with the wearable are formulated. Please state your honest opinion.

The first section is about your greeting behaviour during the COVID-19 pandemic.

*Vereist

1. I experience less physical interaction during the COVID-19 pandemic *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

2. I follow the COVID-19 guidelines of the Dutch government *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

3. Greeting friends and family members while social distancing usually feels unnatural *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

4. How do you usually greet your friends and family members while social distancing? *

The Wearable

The goal of this section is to gather your opinion about the wearable itself.

5. The wearable is easy to put on *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

6. The wearable is comfortable to wear *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

7. Why (not)?

8. The wearable has a pleasing look *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

9. The wearable is intuitive to use *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

10. The wearable is easy to turn on *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

11. It is easy to send a hug to another wearable *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

Hugging sensation

This section is about the experience you had with the wearable.

12. I enjoy the hugging sensation of the wearable *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

13. I felt pressure on the back *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

14. The pressure felt like two hands on the back *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

15. The pressure felt pleasant on the back *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

16. The vibration motors felt like stroking on the back *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

17. The vibration motors gave a pleasant experience *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

18. The hugging interaction feels similar to a real-life hug *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

19. The hugging sensation of the wearable gives feeling of closeness to the other person *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

20. I had a pleasant experience interacting with the wearable *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

21. How would you describe the hugging sensation you experienced? *

Concluding remarks

22. I would use the wearable in my day to day life to greet friends and family while social distancing *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

23. I would like to use the wearable again *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

24. I could think of a situation in which I would use the wearable *

Markeer slechts één ovaal.

	1	2	3	4	5	
Strongly Agree						Strongly Disagree

25. With whom would you use this wearable?

Vink alle toepasselijke opties aan.

- [ ] Close family members
- [ ] Other relatives
- [ ] Friends
- [ ] Collegues
- [ ] Acquaintances

Anders: [ ] ____________________

26. What do you like about the wearable? *

27. What don't you like about the wearable? *

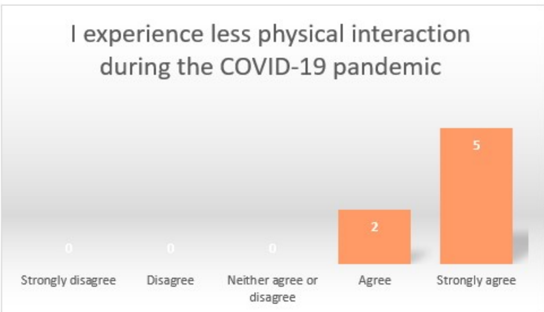
28. What would you change about the wearable? *

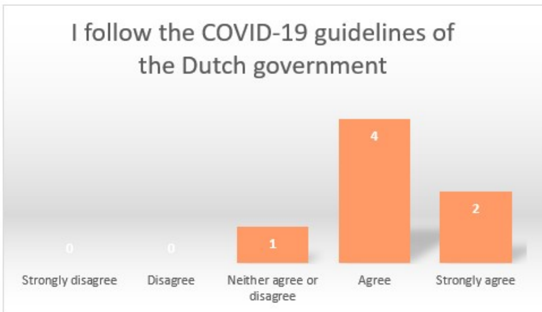
29. Do you have any other remarks about the wearable?

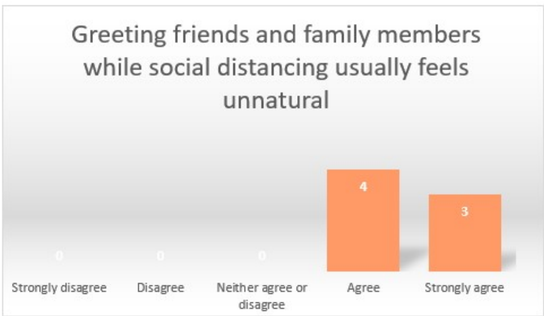
Appendix F

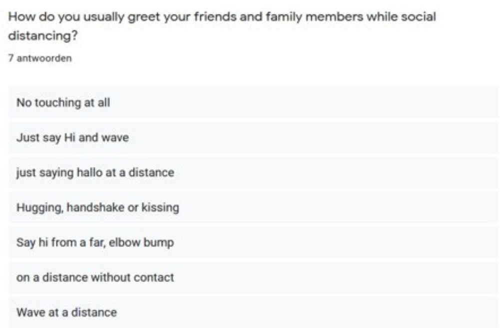
Results User Evaluation

F.1 COVID-19

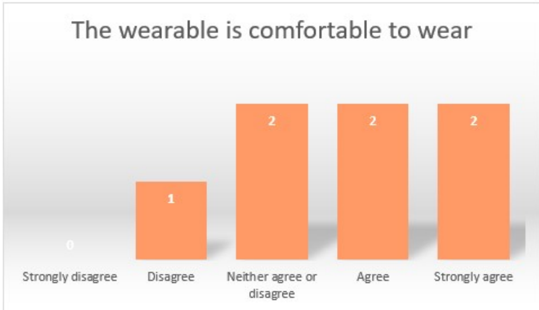








F.2 The Wearable



Why (not)?

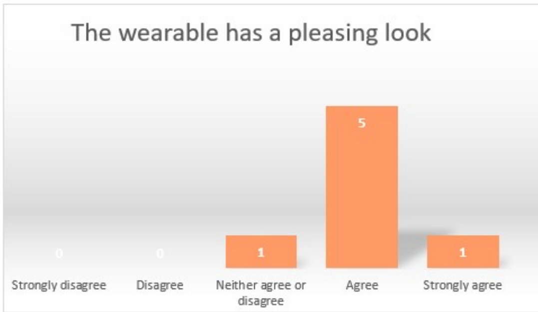
4 antwoorden

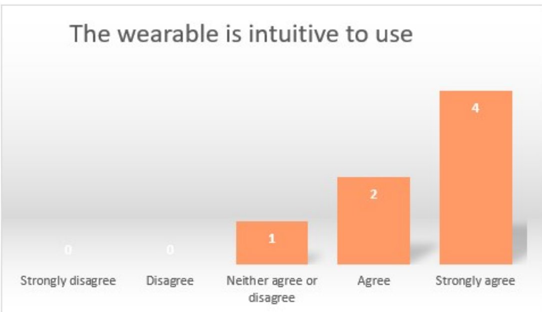
feels just a little more heavier than a normal vest

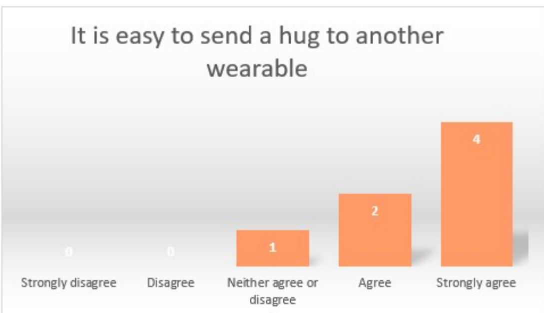
You can feel some of the parts quite well, does not feel like you are wearing normal clothes

You feel some of the wiring when you put it on, but that is fine

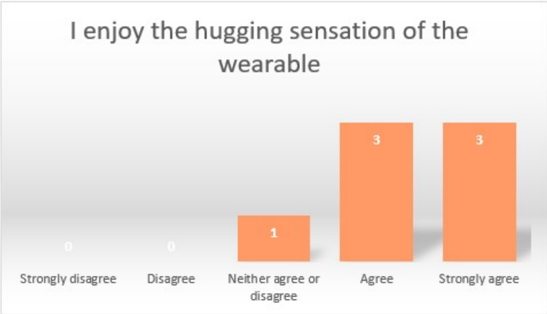
It is a little heavy

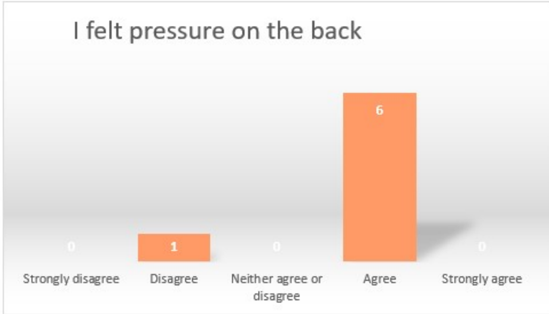


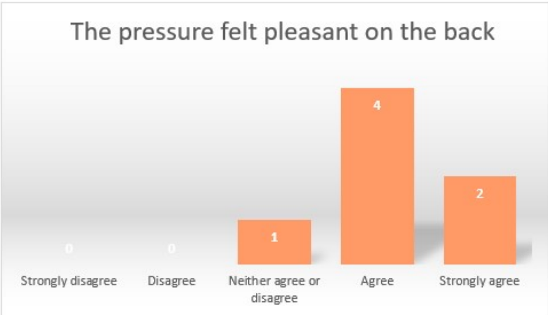


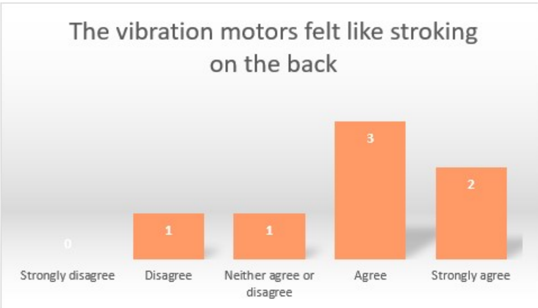


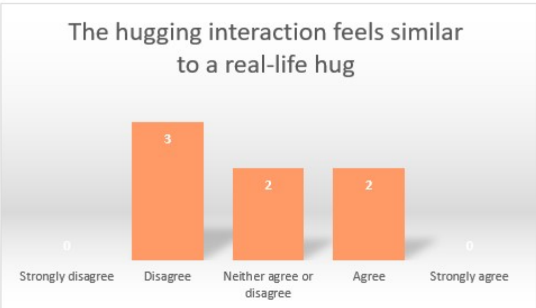
F.3 The Hugging Sensation



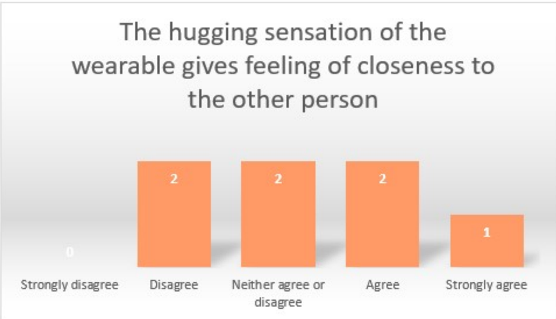


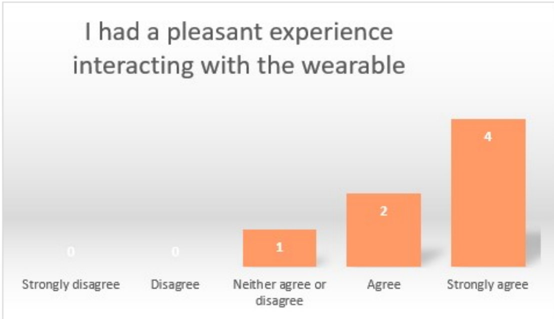






F.4 Overall Experience





How would you describe the hugging sensation you experienced?

7 antwoorden

Soft stroke of a hand

Comforting

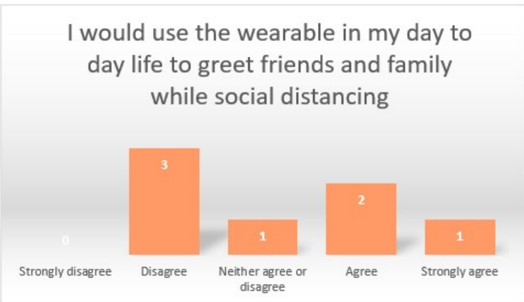
I felt the sensation of somebody stroking me on the back

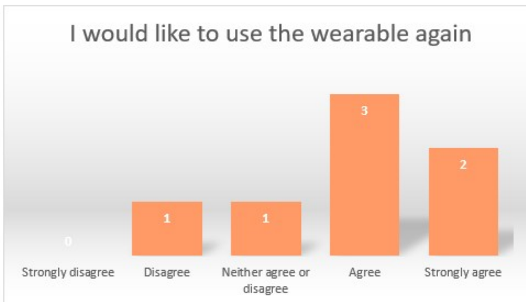
Feels more like a massaging device

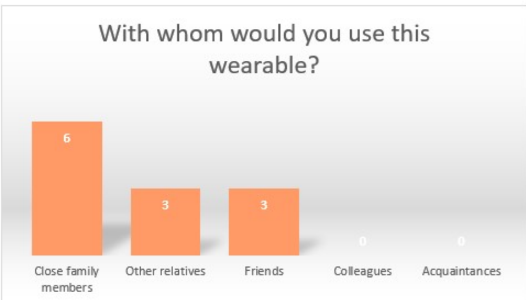
Felt nice as a replacement for the real thing but needs tweaking. Felt too robot-like

a light carassing of the back

It's a fun little interaction. Feels like a "tinteling" on the back







What do you like about the wearable?

7 antwoorden

Inovative

easy to use, comforting and would be great to use with elders whom we are now unable to hug

that you can clearly imagine that you are being hugged and feel closeness

Easy to send hugs, inflatable cushions

Its comfortable and easy to use

easy to put on and off

It's a fun experience!

What don't you like about the wearable?

7 antwoorden

- the preasure of the hand can be increased
- Nothing
- feels a bit heavier than normal thus will only wear for the special connection
- The vibration motors
- The way it simulates hugs is a bit robot-like, also makes a quite a lot of noise
- the feeling it gives could be better
- Could not really feel the pressure

What would you change about the wearable?

7 antwoorden

- design of the hand to make it firmer
- In the future different sizing so that the sensation is felt even more
- makes it a bit lighter
- The vibration motors don't really add anything, they need to be more precise
- I like hard/strong hugs so it could be a little harder in my opinion, but this is personal preference
- More pressure on the back
- Something to better feel the hands on the back

Do you have any other remarks about the wearable?

6 antwoorden

- None
- Include lining on th inside to hide wires.
- No
- great idea for feeling the connection with loved ones.
- I like the concept!

Appendix G

Ethical Reflection Report

G.1 Engaging the Design through Moral Values and Ethical Decision Making

G.1.1 Ethical cycle

The ethical cycle of van de Poel and Royakkers [49] will be used to discuss some key ethical dilemmas of this project. Each step of the ethical cycle will be explained. After which this step will be applied to this project. Several key moral principles, that are relevant to the project will be discussed. The moral principles that will be discussed are: beneficence, fidelity and justice.

G.1.2 Moral Problem Statement

The first step of the ethical cycle, is to formulate a moral question. This moral statement should meet three conditions: (1) clearly state the problem, (2) state for whom it is a problem, and (3) articulate the moral nature of the problem. The moral problem statement of this project is formulated as follows: To what extend can a haptic wearable for a social mediated hug contribute to the well being of an individual, while following the social distancing regulations?

G.1.3 Problem Analysis

During this step of the ethical cycle, relevant elements of the moral problems are described. These elements are: the stakeholders and their interests, moral values relevant to the situation and relevant facts. This phase gives an overview of the current situation. The stakeholders of this project are the designer, the users and the supervisors.

G.1.3.1 Stakeholders

The stakeholders of this project are the designer, the users and the supervisors. This section will discuss their interests.

G.1.3.2 Designer

A large stakeholder in this project is the designer. The designer will make most design choices and will ultimately develop the final prototype. The goal is to develop a prototype that meets their requirements, to show their design capabilities. The designer aims to finish this prototype in a certain time frame.

G.1.3.3 Users

Ultimately, the product is made for its users. These are people that want to be able to hug friends and family while practising the government's advised social distancing regulations. The user wants the product to be save to use. To get input from the users, a user test will be done with the prototype.

G.1.3.4 Supervisor

The goal of the supervisor is to provide the designer with certain requirements as to what the finished prototype should be. Furthermore, the supervisor also guides the designer in making their design choices.

G.1.4 Moral Values and Facts

There are several key moral principles to take into account during the design process of the haptic wearable for a socially mediated hug. The principles that will be discussed are beneficence, fidelity and justice. Some problems regarding haptic wearables for social mediated touch are addressed.

G.1.4.1 Beneficence

It is the responsibility of the designer to create a product that contributes to the welfare of the user. Currently, people are unable to hug others outside of their household, due to the COVID-19 pandemic. Touch is related to stress relief, feeling less lonely and social bonding [15], [16], [17]. This means these benefits are now often lost, especially for the more socially isolated individuals in society.

Another aspect of beneficence is to prevent harm when possible. Therefore, it is essential to choose design options that do not cause harm to the users in any way. Not only does this mean that the design should not hurt the user, it should also be comfortable.

G.1.4.2 Justice

Furthermore, the finished product should be fair. Social touch can be interpreted differently depending on the culture, gender and of the user [15], [16], [20]. Not only does the amount of physical touch between closer relations differ between cultures, the meaning behind a physical touch can vary as well [16]. In some cultures, the need for physical contact is seen as dependency or weakness. Gender plays a role in social touch as well. Children are more likely to touch same-gendered individuals. Adults, on the other hand, are more likely to touch cross-gendered individuals [15].

Furthermore, perception of touch also depends on age. With age, the intensity of response to social touch increases [20], together with the perceived pleasantness of social touch [26]. The type of relationship between the interacting individuals, and location of the touch that is applied are important to consider as well [21]. Stress relief during social touch has been recorded to be higher amongst spouses, compared to physical contact with a stranger.

Lastly, perhaps a very specific ethical dilemma when it comes to social mediated touch technology is one of inclusion. According to [50], a more plump body type might not always be able to feel the vibrations of a vibrotactile stimulation. Perhaps, this is something that needs to be considered in the design process of the social mediated touch technology, and should definitely be tested.

G.1.4.3 Fidelity

Fidelity means honouring commitments. Haptic wearables for social mediated touch have some limitations when they are compared to actual real-life social touch [21]. Firstly, the interaction is not always mutual. In some cases there is only one sender and one receiver, without these roles being interchangeable. Secondly, the virtual touch does not feel similar to actual touch in terms of sensory richness. This is the case, because vibrotactile stimulation is used, which is not capable of stimulating real touch exactly. It is important to be honest towards the user about the capabilities and limitations of the intervention.

G.1.5 Options for Actions

In this phase, possible solutions for action are given. Solutions for problems stated in the problem analysis are formulated.

G.1.5.1 Beneficence

This wearable aims to simulate a hugging sensation between two individuals at a 1.5 meter distance. This means two people outside of the same household will be able to hug again during the COVID-19 pandemic. As touch is related to stress relief, feeling less lonely and social bonding [15], [16], [17]. These benefits might be present when using the haptic wearable, too.

Furthermore, it is important to avoid harm when possible. Therefore, it is important to pick design options that will not hurt users, and even be comfortable. Vibration motors will be integrated in the design. In essence these motors will not hurt the user, but some positions might be uncomfortable. Therefore, to make the best design decision, this is investigated. As the goal is to simulate a hug, only locations on the upper body are tested. Whether these locations are perceived as pleasant or unpleasant are notated. The result of this initial test of locations can be found in figure G.1. Pleasant locations are green, while unpleasant locations are red.

From this test, it can be concluded that mostly areas with bones close to the surface, such as the spine, are perceived as unpleasant locations for vibration. Whereas areas with deeper laying bones are perceived as pleasant. It is important to take these findings into account when choosing a location for the vibration motors. Overall, red locations should be avoided.

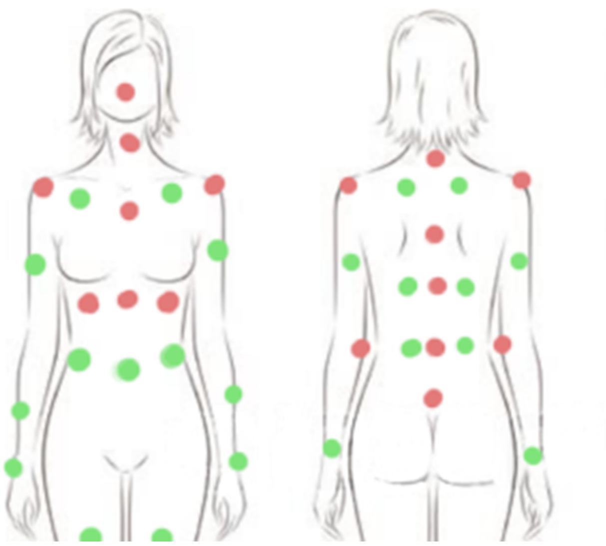


Figure G.1: Pleasantness of vibration motor locations. Red = unpleasant, green = pleasant

G.1.5.2 Justice

To ensure the haptic wearable for social mediated touch includes all body types. The vibrotactile simulation of different body types should be tested. One solution for this problem is to make the vibration strength variable. This way each person can choose their own vibration strength, and it can always be felt in the right amount. Adding this option does give an extra step in the interaction, making it less straight forward.
Fidelity

It is important to be honest towards the user about the capabilities and limitations of the intervention. It should be clear that the haptic wearable aims to simulate a hugging sensation, but does not claim to feel exactly like a real life hug.

G.1.6 Ethical Judgement

In this phase, how morally acceptable the possible options are, is judged. This is done on the basis of formal and informal moral frameworks.

G.1.6.1 Beneficence

Overall, making this wearable can contribute stress relief, feeling less lonely and interpersonal bonding [15], [16], [17], while social distancing. As the wearable allows for social touch, while real-life touch is currently not possible, it does contribute to the welfare of the user. Especially for the more isolated individuals in society. For example, those without any other household members.

The possible solution for making the design more comfortable by only placing vibration motors on pleasant locations is a simple one. This solution can easily be incorporated in the design and does not pose much problems.

G.1.6.2 Justice

By adding a the possibility to change the vibration strength, an additional step is added in the interaction sequence. This might be a minor inconvenience for some, but can be difficult for those that do not have natural affinity with technology. If choosing a utilitarian solution, one with the greatest good for the greatest number, this might lean towards not adding the possibility to change the vibration strength. This, because not many users will encounter the problem of not feeling the vibration. When choosing a virtue ethics solution, on the other hand, it is vital to be charitable to the user. Adding the option to change the vibration strength, in this case, would be most beneficial.

G.1.6.3 Fidelity

Lastly, honesty is discussed. The haptic wearable for a social mediated hug is not going to be able to exactly simulate a real life hug. Being honest about this limitation, might result in less people buying the product. This could mean two thing. First, the designer gains less money from the product. Second, less people might benefit from the beneficial properties of the product. However, by being dishonest this also means dishonouring the commitment to the user. Resulting in negative press, also leading to less people buying the product. Using virtue of ethics, it is important to be honest towards your user. This creates trust, showing your loyalty and honouring your commitment.

G.1.7 Reflection

The goal of this phase is to argue the choices made for the various options for actions. During the reflection, the outcomes of the ethical judgement phase are used.

G.1.7.1 Beneficence

Making the design does not harm any member of society, and might even benefit them in some ways. Therefore, it is ethically sound to make a haptic wearable for a social mediated hug, when looking at the overall welfare of the user.

Furthermore, it is easy to omit uncomfortable vibration motor locations. Therefore, it is no issue to do so. Only pleasant locations should be chosen when designing the haptic wearable for social mediated touch.

G.1.7.2 Justice

Here, there is something to say for each side. By adding a changeable vibration strength, the haptic wearable is more inclusive for all body types. However, doing this also adds a level of complexity to the overall design. For this first prototype, this feature will not be added. For the prototype, adding more features to the design is too time consuming. It is however, an important factor to keep in mind when further developing the haptic wearable for a social mediated hug.

G.1.7.3 Fidelity

Considering fidelity, it is important to stay open and honest towards the users. First, some user tests need to be done to see if the social mediated hug feels similar to an actual hug and if there are any benefits. Only then claims can be made about the usefulness of the product. This creates trust between the company and the user.

G.2 Ethical Analysis

G.2.1 Flow Chart

There are many possibilities available when it comes to social mediated touch. As previously discussed, the appropriate type of social touch partly depends on the type of relationship the sender and the receiver have, as well as cultural and intention aspects. To visualise what type of social mediated touch is appropriate a flow chart is created. This flow chart can be seen in figure G.2.

First, it is important to define the relationship between the sender and the receiver. If this relationship is romantic, and there is need for an interaction of sexual nature, stroking of the inner thigh, upper arm or breast would be appropriate [11]. If the interactions should not be of sexual nature, it resembles a relationship of a friend or close family relative. In that case the interaction could either be motivational, in which case a pat on the back would be appropriate, or to relieve stress, in which case a hug [34] or stroke of the lower arm [1] can be chosen. If there is another reason behind the interaction, more research should be done. If the interaction is between two stranger, an evaluation on whether touching is culturally appropriate should be done. If touching is not culturally appropriate between two strangers, no social mediated touch should take place. If it is appropriate however, a handshake or a pat on the back would be suitable interactions.

G.3 Toolkit

G.3.1 Ethical Risk Sweeping

To mitigate possible ethical risks, ethical risk sweeping can be a helpful exercise. By identifying possible risks and understanding these risks, foreseeable ethical problems can be avoided. With this first tool, some ethical risks of this project that might cause harm are explored.

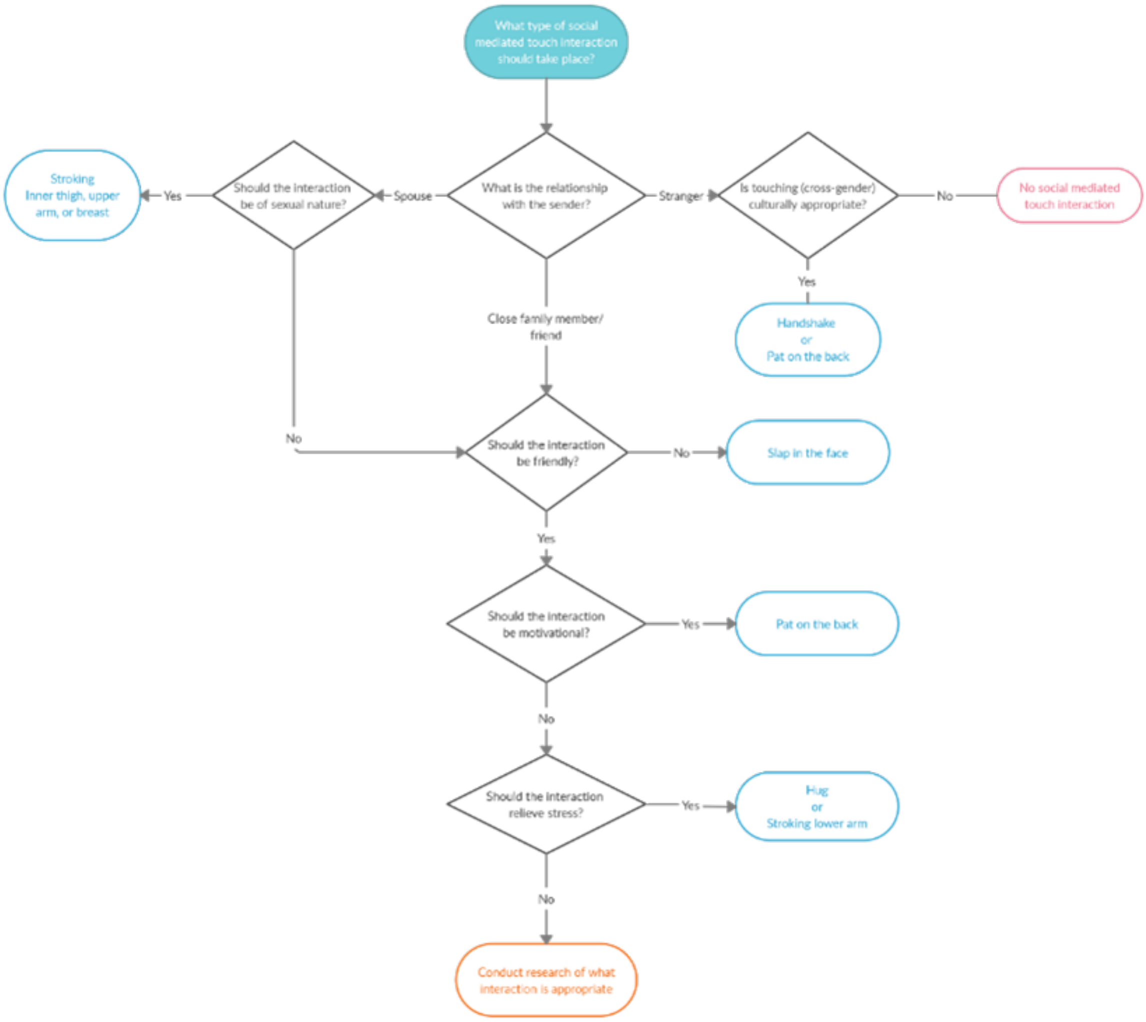


Figure G.2: Flowchart on the appropriate type of social mediated touch interaction.

G.3.1.1 Inclusion

There are multiple ways in which inclusion might pose as an ethical problem in this design. Firstly, the wearable takes form in a zipped sweater. The sweater should be rather tight in order for the silicone inflatables to perform enough pressure on the back to be felt. This means multiple sweater sizes are needed in order for the wearable to be used by a wide variety of users.

Also, as discussed earlier, a user with a more plump body type might not always be able to feel the vibration motors that are added in the wearable. Whether this is also the case within this project should be tested. To combat this problem, variable vibrations strengths could be added to the design.

Another aspect that should be looked at, is how touch can be perceived by different people. As previously discussed, touch can be perceived differently, depending on the age, gender and culture of the user. It is important to understand the user's needs and the context. Therefore, this can be an important factor to keep in mind when designing the product.

G.3.2 Ethical Pre-Mortem or Post-Mortems

This second tool focuses on avoiding systemic ethical problems. As the project is not finished, and has not undergone any user testing yet, only ethical pre-mortems are discussed.

G.3.2.1 Limitations of interaction

The haptic wearable for social mediated touch has some limitations when it comes to simulating a real life hug. It is not possible to perfectly simulate a hug using the technology available today. The prototype makes use of vibration motors and silicone inflatables to try and emulate a hug, but it will not feel like a real life hug. Technology options that are able to simulate the sensation of stroking (vibration motors) and pressure (inflatables) on the back are chosen to get as close as possible to the real thing. Whether the simulation is successful needs to be investigated by user tests. Furthermore, whether the prototype has any benefits that real life social touch has should also be tested.

G.3.3 Expanding the Ethical Circle

This project has mostly been executed by one person. Errors and ethical risks can be easily overseen when working alone. By looking at the stakeholders of this project and their interests , such oversights can be foreseen.

The main stakeholder of this project is the user. The user pool has a wide range, as anyone could use the product if they feel the need for a hug. To try and understand the user, four user case scenarios have been described.

Furthermore, once the product prototype is finished, user tests will be done to see if there are any problems with the system that might have been overseen. During these tests the users will be questioned about the product to see what their opinions are. These opinions will be evaluated and taken into account when further developing the system.

G.3.4 Case Based Analysis

With this project it is somewhat hard to find similar systems that have been brought onto the market, as haptic wearables for social touch is a relatively new use of the technology. There are some systems that have not yet been brought to market that can be analysed.

G.3.4.1 Huggy Pajama

The Huggy Pajama is an example of a similar system to this project. The Huggy Pajama is an interaction system for parents and children. With the Huggy Pajama, the user can send a hug to the pyjama through the internet. The goal of the system is to increase communication value between parents and their children.

An ethical consideration of the huggy pajama, is that children are the end user of the pyjama. In the case of this project, children specifically have not been considered to be the end user. However, children might actually use the system. First, it should be clear if children will be able to use the system. If they are, it should be made child proof. If they are not, this should be mentioned on the product.

G.3.5 Remembering the Ethical Benefit of Creative Work

It is also important to think about the positive outcomes of the project.

In 2020, social touch between individuals is minimized due to the COVID-19 pandemic. This means, society is currently missing out on the benefits of social touch. Social touch has been related to social bonding, level of loneliness, stress relief and communication. Bonding between humans is partly based on physical interaction. According to Morrison [17] and Cascio, Moore and McGlone [14], social relations have been linked to the release of oxytocin in the bloodstream. Oxytocin is a hormone that plays a role in social bonding and aids in forming lasting relationships [15]. Furthermore, Huisman [21] states that higher amounts of this hormone have been found in individuals portraying frequent physical social contact with their partner. Therefore, social touch could be an indicator of the quality of the relationship between individuals [16].

Secondly, physical social touch could also aid in decreasing in social loneliness. According to a study by Tejada, Dunbar and Montero [16] participants that were exposed to a small amount of physical contact felt less neglected by their close relationships, compared to participants that received no physical contact. Amongst single participants, who generally received little physical contact in their daily lives, this neglect score was particularly low after receiving the physical touch. This suggests that there is a higher decrease in loneliness for single people, when receiving social touch. This study also reported a lower heart rate in the participants that received the physical touch, suggesting a positive effect on physiological well being.

Not only does social touch help against social loneliness, it can also help against stress. According to Morrison [17], social touch can act as a stress buffer, as it promotes the regulation of responses to acute stressors and other short term challenges. A study by Gallace and Spence [15], concurs with this statement. Their study showed that after receiving affectionate physical contact from a romantic partner, individuals had a decreased overall blood pressure and heart rate during a stressful event, when compared to individuals that received no physical touch.

Lastly, social touch also seems to play a role is communication. According to Hertenstein, Holmes, McCullough and Keltner [23], social touch enables the communication of positive and negative emotions and can intensify the display of emotion from the face and voice. Hertenstein et al. [23], conducted a study with 248 participants to see which emotions could be communicated through social touch of the forearm. [23] concluded that this study provides evidence that social touch can communicate several emotions. At least eight emotions could be distinguished: happiness, love, gratitude, sympathy, sadness, disgust, anger and fear.

These finding are further substantiated by a study by Kirsch et al. [24]. Their study also showed that multiple emotions could be communicated through social touch. While the study by [23] focused mainly on social touch of the forearm, this study allowed social touch of the whole body. With the whole body available for social touch, especially communications of sensual emotion , such as arousal desire and lust were easily distinguishable.

By creating a haptic wearable for social mediated touch, this might benefit the stress levels, level of loneliness and interpersonal bonding experiences again. Even after the pandemic, the haptic wearables for social touch can be used for in long distance relationships for these purposes.

G.3.6 Think About the Terrible People

Some people might want to use the project inappropriately. As the system is using a Bluetooth connection between two devices. At this moment, anyone can connect to any device nearby. Also, this means the system is hackable. Terrible people might connect to or hack a device and control the vibration motors and silicone inflatables as they want to. Therefore, it is important to make sure the system can be turned on and off quickly when desired, without being overwritten by a hacker. Furthermore, a feature can be added where the user first has to accept the other user before they can send hugs to each other.

G.3.7 Closing the Loop: Ethical Feedback and Iteration

It is important to know that the ethical cycle is never finished. During the further development of the project, it is important to always check back on the ethical considerations. When continuously looking for ethical problems, they can be resolved quickly and effectively.

G.4 Impact Statement, Limitations and Concluding Remarks

The biggest way haptic wearables for social mediated touch serves as a driver for change is that is allows for touching between two individuals over a distance. Now, touch is still a very proximal interaction, but this can change with the use of haptic technology. With social mediated touch, two people have a new sensory way to communicate, even when they are not able to touch each other.

As touch is related to stress relief, feeling less lonely and social bonding, haptic wearables for social mediated touch might result in a higher social well being for more socially isolated individuals. Now, in the year 2020, during the COVID-19 pandemic, people are advised to stay at home and practice social distancing. This means they are not able to touch anyone outside of their household. During this time a social mediated touch intervention could help people feel more connected. Especially for those living alone, haptic wearables for social mediated touch can give them the sensation of hugging a friend or family member. For this project the technology will be used to simulate a hug. In the future, however, haptic wearables will be able to do much more than that. Enabling the feeling of real life interactions for long distance relationships. Overall, this technology still needs a lot of development to feel like a real life touch, but eventually it will get there.

Appendix H

HC-05 AT_MODE_SKETCH_01

```
// Basic Bluetooth sketch HC-05_AT_MODE_01
// Connect the HC-05 module and communicate using the serial monitor
//
// The HC-05 defaults to commincation mode when first powered on you will need to manually enter AT mode
// The default baud rate for AT mode is 38400
// See www.martyncurrey.com for details
//


#include <SoftwareSerial.h>
SoftwareSerial BTserial(2, 3); // RX | TX
// Connect the HC-05 TX to Arduino pin 2 RX.
// Connect the HC-05 RX to Arduino pin 3 TX through a voltage divider.
//

char c = ' ';

void setup()
{
    Serial.begin(9600);
    Serial.println("Arduino is ready");
    Serial.println("Remember to select Both NL & CR in the serial monitor");

    // HC-05 default serial speed for AT mode is 38400
    BTserial.begin(38400);
}

void loop()
{

    // Keep reading from HC-05 and send to Arduino Serial Monitor
    if (BTserial.available())
    {
        c = BTserial.read();
        Serial.write(c);
    }

    // Keep reading from Arduino Serial Monitor and send to HC-05
    if (Serial.available())
    {
        c =  Serial.read();
        BTserial.write(c);
    }

}
```

Figure H.1: HC-05 AT_MODE_SKETCH_01