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Haptic Wearable for Affective Mediated Touch

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Abstract

Social touch is an essential aspect of humans, as it allows people to communicate their emotions. Social touch has been seen to contribute to the health of the human psyche, allowing people to feel a sense of togetherness. However, social touch for couples in long-distance relationships is difficult because of the physical distance between the couple. This results in less affective touch, which results in a lack of emotional intimacy in the relationship. A haptic wearable for social, affective touch is a possible solution, as the wearable could mediate affective touch over a long distance.

Usually, couples would convey affective touch by giving a light touch like a gentle caress or a hug to their significant other. However, this is not possible if the couple is in a long-distance relationship. Therefore, a haptic wearable that simulates a gentle caress on the user's forearm is created. The haptic wearable goal is to make users communicate light, gentle caress to their significant other to support emotional intimacy. The first step for this wearable is to connect to an MQTT server. Second, a gentle caress is sensed by one of the users and sends the touch pattern to the MQTT server. Third, the other wearable worn by the other user will receive the touch pattern and reproduce the gentle caress onto the user's forearm.

This bachelor project will use the creative design process to make quick iterations of the prototype. The wearable also goes through an evaluation stage to evaluate the functional and systematic requirements. These requirements will be evaluated by the researcher and the participant from the user case study. Overall, the haptic wearable for social, affective touch showed positive results and met most of the established requirements.

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Chapter 1

Introduction

Social touch is an essential aspect of humans, as it allows people to communicate their emotions and is a solid contributor to a person's behavior [1]. Touch is essential for the human psyche, allowing people to feel a sense of togetherness. This sense of togetherness has positively affected people with cardiovascular disease and mental health issues [2]. The deprivation of touch leads to multiple consequences, especially with couples in long-distance relationships. Due to the lockdown and vigorous rules and regulation of the coronavirus pandemic, it has made it difficult for romantic couples to communicate their intimacy.

Intimacy is of utmost importance in the continuation of a romantic relationship. Intimacy has shown to be a disproportionate influence on couples' happiness and well-being [3]. Studies show that lack of intimacy leads to adverse outcomes, such as couples therapy or the end of the relationship [4]. A part of intimacy is emotional intimacy, which is the sense of closeness to a partner, the act of sharing personal information and trust. Emotional intimacy is the "glue" of a relationship and is an essential factor of relationship satisfaction [5] . To build emotional intimacy is by communicating emotions/feelings with each other, which is "affective" touch achieves.

Nevertheless, a solution needs to be designed to supports couples in long-distance relationships to communicate emotional intimacy since current communication forms do not give people the ability to express their emotions through affective touch [6]. The field of haptic technology brings a potential solution to the lack of social touch and affective touch. Haptic technology is a technology design to give touch cues instead of the traditional visual and auditory cues. Add internet technology with haptics allows people to communicate touch over long distances. As a result, this bachelor's prime focus is to investigate literature, design, and test a haptic wearable to support couples' emotional intimacy in long-distance relationships.

1.1 Research Questions

The starting point of the bachelor's project, main research question describe below:

How can we design a haptic wearable to support emotional intimacy for people in a long-distance relationship?

In addition to the main research question, the construction of sub-questions helps answer the main research question. The sub-questions aim to gain knowledge about specific areas of haptic wearables for affective mediated touch, such as how is emotional intimacy communicated, state of the art and hardware and software components:

SQ-1: What are the most effective type of haptic feedback for communicating affective touch over long-distance?

SQ-2: What is state of the art for haptic wearables and mediated emotional intimacy over long-distance?

SQ-3: How is affective touch communicated to support emotional intimacy ?

SQ-4: What components are needed to design a non-invasive haptic wearable for affective touch?

1.2 Report Structure

This bachelor thesis holds all the knowledge collected around haptic wearables for affective mediated touch. Firstly, what are “affective” touch and the benefits of affective touch discussed in chapter 2: State of the Art. The chapter also contains a literature review about current hardware components for communicating affective touch in the domain of haptic wearables. State of the art follows a literature review on existing products and research projects that provide wearable haptic methods to mediate affective touch in couples and the couples' experience. This chapter aims to answer the following sub-questions: What is the most effective type of haptic feedback for communicating affective touch over long-distance? What is state of the art for haptic wearables and mediated emotional intimacy over long-distance?

Secondly, chapter 3: Method & Technique is how the bachelor thesis will be conducted and detailed. Furthermore, the chapter will discuss the interview method and auto-ethnographic research approach, and the design process technique.

Third, chapter 4: Ideation. This is where the initial idea for the haptic wearable will be developed using a mind map. After the initial idea for a haptic wearable to mediated affective touch to support emotional intimacy in couples is created, it will go through user case scenarios. In this chapter, the sub-question: How is effective touch communicated to support emotional intimacy? Will be answered.

Fourth, chapter 5: Specification. In this chapter, requirements for the wearable are developed. After that, an initial design will be developed. After the initial design is developed, the components used to create the haptic wearable are discussed. Why each component is important for the haptic wearable, this will answer the third sub-question: What components are needed to design a non-invasive haptic wearable for affective touch?

Fifth, chapter 6: Realization. This chapter will cover the development of the prototype and each component involved in making the wearable. These components are communication, receiving haptic feedback and transmitting a haptic touch. After which, the components will be implemented together to make the prototype.

Sixth, chapter 7: Evaluation. The evaluation chapter is the testing part of this bachelor project. The goal of this chapter is to evaluate the requirements that were created in chapter 5: Specification. Both participants and researcher will evaluate the requirements.

Lastly, chapters 8 and 9: Discussion and Conclusion. These chapters aim to conclude the report by answering the research question and giving further recommendations about the continuation of the project.

Chapter 2

State of the art

When designing a haptic wearable to support couples' emotional intimacy, required research must be gathered to get information on the topic. This chapter focuses on the importance of affective touch and how a participant perceives this touch. Therefore, a literature review about the effective type of haptic feedback for communicating affective touch over long-distance is conducted to have insight into what method is best for communicating affective touch. Lastly, state of the art evaluates the currently existing methods, including understanding current means of communicating affective touch for couples. The chapter aims to answer the questions: What is the most effective type of haptic feedback for communicating affective touch over long-distance? What is state of the art for haptic wearables and mediated emotional intimacy over long-distance?

2.1 Literature Review

A literature review is conducted to provide an overview of effective haptic feedback methods for meditated affective touch. The study covers three critical parts: affective mediated touch, existing ways of communicating affective touch, and locations on the human body to communicate affective touch. Section 2.1.1 is focused on neurophysiology affective touch. Section 2.1.2 discusses meditated affective touch, currently effective communication methods. Section 2.1.3 talks about the most effective location on the human body to convey affective touch and the influence that relationship status has on the location of communicating affective touch. These results will guide designing haptic wearable to support couples' emotional intimacy in long-distance relationships.

2.1.1 Affective Touch

The neurophysiology of affective touch is important to understand when designing a wearable to meditate affective touch. Therefore, two parts are discussed: Defining affective touch, and sense of affective touch. These topic will help gather insight about the affective touch, and its influences on people.
To begin, affective touch described by Morrison [1], is the emotional aspect of social touch. These emotions are communicated through social events when a person touches another. According to Fernando Alonso-Martin [7], human feelings that can be communicated through affective touch is categorization as: "protective (hold, hug, cradle); comforting (stroke, rub, finger idle, and pat); restful (massage, scratch, and tickle); affectionate (tickle, scratch, massage, nuzzle, kiss, rock, hug, and hold); and playful (lift, swing, toss, squeeze, stroke, rub, pat, scratch, massage, and tickle)" (p. 2). These types of touches promote emotional comfort and positive effect for couples in long-distance relationships [8]. The positive effects show elicit emotional experiences, from the comfort feeling received from one's partner or the discomfort from a stranger's touch [9]. These studies show that affective touch is linked with the brain's emotion section, promoting comfort and supporting couples' emotional state. Moreover, there are many different types of touches like discriminative touch, but "affective" touch is the most preferred. As Apps describes, affective touch is the most preferred non-verbal communication method for expressing intimate emotions such as love and sympathy [10]. Confirmed by Debrot et al., romantic partners displayed that their emotional state was strengthened by touch [11]. These studies conclude that affective touch is an essential aspect of human relationships.

Sense Of Affective Touch

Sense of affective touch, described by H. Olausson [12], are receptors in mammals of hairy skin that activate and send signals to the neurons when the skin is touched lightly. Three components are discussed: where to produce "affective" touch, the neuroscience of "affective" touch, and the most effective method of conveying affective touch.
These receptors have fibers called CT afferent which detected these light touches. For example, a gentle stroke on the back activates these CT-afferent, focusing on the comforting caress-like interpersonal touch [13]. Humans have about 5 million follicles covering most humans besides palms, underfoot, genitalia, nipples, and lips [14]. Since "affective" touch is related to the CT-afferent fibers in the skin with hairs, the best way to communicate affective touch would be on hairy skin.
Moreover, when these CT-afferent fibers are activated, the brain processes these touches as pleasant. When a person receives an affective touch, the signals are

sent to the cortical sensory processing areas, such as this brain's insular part [12]. The function of the brain handles all sensory information and processes this information. This information tells the brain to produce oxytocin, a hormone known as the "love" hormone [15]. The hormone oxytocin is associated with humans' social and emotional processes and contributes to promoting social reward [16]. Social reward in this context is defined as the pleasant/rewarding experience from social interaction, which results in the person having a more pleasant state of mind and support the emotional connection with the other.
Lastly, affective touch is a form of touch that has specific parameters to achieve. Unlike other types of touches, such as discriminative touch, affective touch is achieved by the skin reacting to light, stroking touches, and the stroke's velocity. The ideal velocity of touch is between 1-10cm/sec [17]. Other factors that influence the perception of affective touch are force and temperature. The optimal temperature is about 32 degrees, and a focus ranging from 3 to 2.5mN [18]. These are the factors that are taken into account to ensure that the CT-afferent is activated. It shows that gentle strokes are the most effective method of activating the CT-afferent fiber and promote a pleasant feeling.

2.1.2 Meditated Affective Touch

As mentioned before, affective touch is essential for human relationships. Haans and Ijsselsteijn [9] explain that meditated social touch gives people the ability to touch each other over a distance by using haptic feedback technology. Haptic technology is a technology designed to give touch cues instead of the traditional visual and auditory cues. The addition of internet technology with haptics allows people to communicate touch over long distances. Nevertheless, current communication forms do not give people the ability to express their emotions through affective touch [6]. As a result, developing a new haptic wearable is a solution to help support "affective" touch.

Therefore an investigation into meditated affective touch is conducted. The question that is asked is: what haptic feedback methods exist to communicate affective touch? To begin, it is essential to define how haptic technology produces the sense of touch to participants and whether the haptic helped with mediated affective touch. Haptic touch can be split into two subsystems, cutaneous and kinesthetic. Cutaneous system uses the mechanoreceptors and thermoreceptors placed inside the skin to sense touch [19]. Whereas, kinesthetic system uses the mechanoreceptors in the muscle, tendons, and joints to sense touch [19]. Four central cutaneous haptic systems provide the sense of touch; pressure, temperature, electro-tactile, and vibrations [20]. Whereas kinesthetic provides the sense of touch by applying forces and motion to limbs, in which the receptors in the muscles, tendons, and joints are stimulated [21]. Both subsystems, cutaneous and kinesthetic, to be considered when answering the research question.

Cutaneous haptic feedback

Cutaneous systems are the most preferred form of haptic feedback, there is evidence to support this statement. To begin, cutaneous haptic feedback systems focus on stimulating the receptors in the skin. There are a lot of methods of producing a sense of touch. The most traditional used actuator is vibrotactile. Vibrotactile, stimulate the skin receptors by applying pressure to the skin. An example of a successfully designed vibrotactile prototype was done by Parks, where a device would communicate affective finger touch gestures using vibration [22] [23]. Vibration actuators have been proven to communicate affective touch, according to [9]. In addition, mediated affective touch using vibrotactile feedback has increased the individual's compliance [24]. Although vibrotactile is easy to use and the researchers did a lot of research in the field of vibrotactile technology. Vibrotactile is not perfect for stimulating the CT-afferents [25], which are the main "affective" touch component to convey emotional and pleasant sensations. Therefore, vibrotactile actuators alone lack accurate physical contact, as Haans, de Nood and IJsselsteijn [26] described, providing a means of mediated affective touch. It has to be taken into consideration when designing a haptic wearable for affective touch.

Another form of cutaneous haptic feedback to communicate affective touch is thermal actuators, which is a great method of stimulating CT-afferent but has its drawbacks. Thermal actuators focus on the thermoreceptors in the human skin, which allow the human to sense temperature changes. For example, the "Thermal Hug Belt" is a device that uses thermal feedback to communicate hugs over distance. The device would warm up using Peltier devices; when a person wants to convey a hug, they will use a controller to activate the partners' belt [27]. The belt demonstrated that there was a higher level of social presence. A study done by Olausson et al [28]. proves that thermal stimulated the nervous system and affective response of an individual. Thermal is excellent feedback for communicating affective touch, but it has some drawbacks. As thermal actuators are slow at producing heat, it would require a lot of energy to heat up quickly. It might have been more informative if the study measured the reaction time of the physiological responses between a human hugging another and the belt. Salminen et al., [29] did precisely this in their research and found that a rapid physiological reaction did not occur, which gave off an unrealistic feel to a real-life hug, suggesting that thermal actuators are not the best for mediated affective touch.

An alternative form of cutaneous haptic feedback to stimulate affective touch is pressure actuators. Pressure actuators work by squeezing the skin or applying a force onto the skin. For example, the “HaptiHug” used a pressure actuator to stimulate a hug. A user would put on a vest that had an actuator attached, and the actuator would tighten the vest giving the feeling of the participant receiving a hug from a human [30]. Tsetserukou’s [30] device demonstrated a sense of joy and relaxation among the participants, which proved that his device could successfully trigger emotions. Significant because it represents that pressure actuators are an excellent method of conveying emotions. Schirmer et al., [31] discovered that both actual human-to-human touch from a friend and a pneumatic squeeze armband gave the same haptic stimulus. Further, supporting the idea that pressure actuators are suitable actuators for representing a mediated affective touch.

Finally, electro-tactile haptic feedback has shown promise. Electro-tactile feedback affects the receptor as well as the nerve endings with electrical pulses. An example of this haptic feedback was a wristband attached to the participant’s wrist. The wristband would send an electrical pulse through the wristband while the user was drawing and receiving a mobile phone notification [32]. Although the result shows that the participant did recognize the feedback positively, there was no research into the participant’s emotional state. If they did more research into the participant’s emotional state, it would provide more information about the device’s user experience. Boldu et al., [33] did an investigation into the response of electro-tactile feedback by using magnetic fields. They discovered that electro-tactile feedback was possible to apply to the application of affective touch.

Kinesthetic haptic feedback

Kinesthetic haptic feedback systems focus on simulating the receptors in the muscle and joints. An example of using a kinesthetic haptic feedback system was Bailension et al., [34] where he used a force-feedback joystick to communicate several emotions. The joystick would perform pre-recorded movements of varies affective touch, for example a handshake. These movements would stimulate the receptors in the muscle and joints to simulate a touch. The study goal was to explore if participants could express and recognize affective touch through force-feedback. The force- Found strong evidence that participants interpreted the affective touch from another participant [34], this research opened up the possibility of communicating affective touch with haptics. As Huisman [35] describes, force feedback is an excellent enhancement in video-calling to support “affective” touch for participants in long-distance relationships. As a result, force-feedback is a good solution to convey affective, but force-feedback would be difficult to implement into a wearable since force-feedback requires more actuators to perform the movement.

2.1.3 Sensing Affective Touch

There are different types of sensors that are used to detect a person's touch. These sensors are called tactile sensors because they detect touch, force, or torsion as well some unknown sensors are being developed. The first method of sensing touch is capacitive sensing [36]. The sensor is similar to a capacitor found in electrical circuits, but a capacitive sensor works by detecting the electric field change. A commonplace of capacitive sensors are in the screens of smartphones. When a person touches the screen, the person changes the smartphone's capacitance, which the sensor detects and sends a signal. Capacitive sensors are ubiquitous in wearables, such as smartwatches, because of the sensor's simplicity and ease of adding them to small devices like wearables.

Furthermore, the most common sensor in the field of haptic technology is force sensors [37]. When the sensor receives an external force, the conductive layer warps and changes the sensor's resistance. This resistance is measured to translate the difference in resistance to force applied on the sensor. Force senses are ideal for wearables because they can be very thin.

Another sensor often applied in the field of haptic wearables is the flex sensors [38]. The sensor works when the strip is bent or twisted, which causes the resistance to change. This resistance is measured to give a reading of the torsion being applied onto the sensor. The flex sensor is thin and flexible, making it ideal for wearables.

Lastly, the traditional sensor there is also the GSR sensor [39]. GSR or galvanic skin response is a sensor that detects the electrical conductance of the skin. This sensor can pick up on strong emotion because the strong emotion activates the sympathetic nervous system, resulting in more sweat. GSR sensor is excellent for sensing strong emotion, and the sensor has been implemented into wearables before.

2.1.4 Location to meditated affective touch on the human body

The location is essential for producing an "affective" touch. As mentioned before, the human body is covered in hairy skin cells, where CT-afferent fibers convey affective touch can be anywhere. To be able to answer the question, where to communicate affective touch on the human body. It is vital to discuss existing guidelines that designers use to determine their design location and discuss participants' relationship status and its influence on where people like to be touched. Both aspects will be addressed.

Guidelines

Haptic wearables have been here for a long time and when designing wearables there are guidelines in place to help designers to achieve the best result. There has been research in wearables that describe the guidelines for determining the placement of a wearable. Gemperle [40], in his paper “Design For Wearability,” explains the following guidelines: proxemics, weight, accessibility, thermal tolerance, human movement, and sensory interaction as important when considering the placement of wearables on the human body. These guidelines help designers design a wearable for everyday humans, but Gemperle [40] created these guidelines twenty-three years ago. Technology has evolved since then, which means that a refresh of the guidelines is needed. Zeagler [41] did exactly so in his paper. He takes the guidelines created by Gemperle [40] and does an overview of each component of the guideline, and makes a body map to show the best placements for a wearable on the human body.

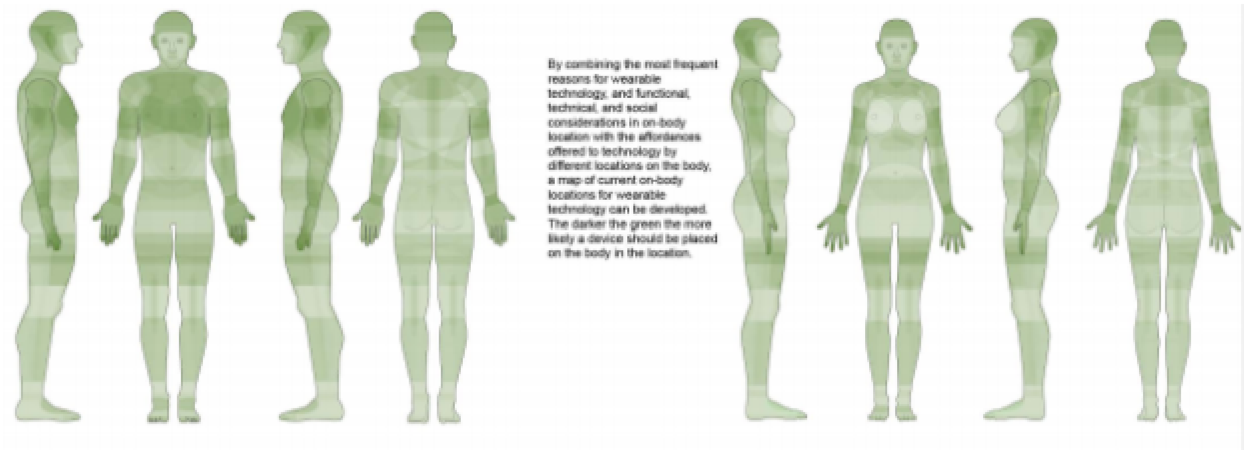

Figure 2.1: Most likely on-body locations for wearable technology if all consideration are weighted equally [41].

The brighter areas on the body map show areas where the human is least comfortable with a wearable placed, whereas the darker areas are more comfortable. As a result, the forearm/wrist is the preferred location for the placement of a wearable.

Relationship Status Influence

Relationship status has shown to influence the placement of wearables and when designing a wearable a designer must take into account the audience for the product. There has been very little research done in the field of affective touch [42]. The study discovered that producing affective touch is the most common location with the toucher's hand with the receiver forearm [43]. Hauser's et al., [43] experiment used a tracker to track the toucher's hand and receiver forearm and measured velocity, intensity, and position. The toucher would perform a task by touching the receiver, and the receiver would then describe the emotion she felt from the touch. However, the participants' used only the hand and forearm to communicate emotion. In most studies, such as Hertenstein et al,. [44] 300 plus students from both genders participated in his experiment. His experiment focused on communication via touch. The problem of this research is that the relationship status of the participant influences the findings. Suviletho explains that people are most comfortable with strangers touching their forearms or hands, as shown in figure 2.2 [45].

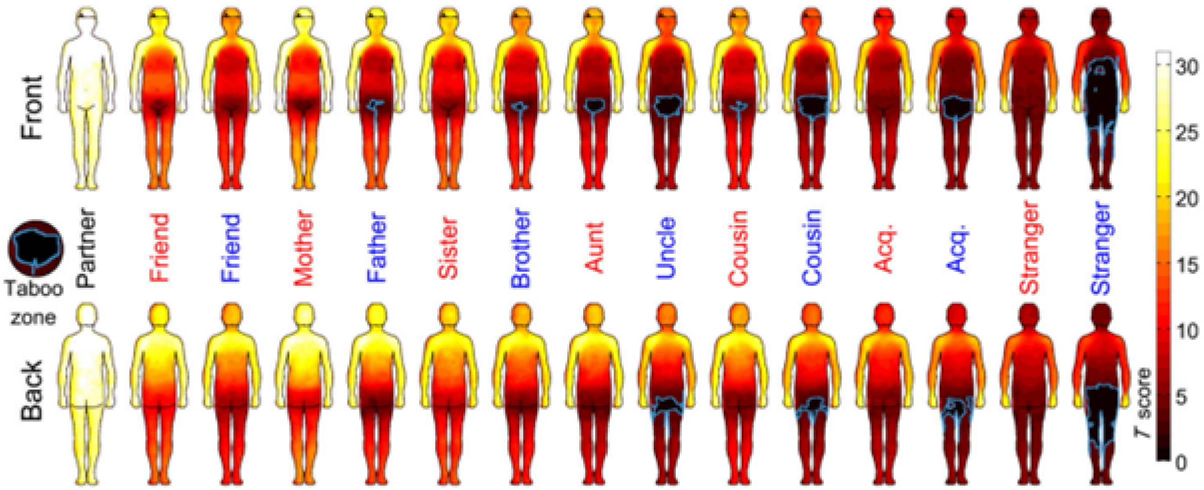

Figure 2.2: Heatmap of where people like to be touched based on relationship status of the person [45].

The darker the color represents the area that people do not want to be touched. As shown above, participants in a romantic status are open to their partner to touch them anywhere, which would be an excellent opportunity to explore more areas on the body to convey affective touch. This proves that relationship status between participants does have an influence on location of the wearable. When designing a haptic wearable it is important to take into account the customer. As a result, when designing a haptic wearable for couples in long-distance relationships the placement of the wearable is quite large. Although, the comfort of the participant also has to be taken into account as well.

2.2 State Of The Art

There are some existing haptic wearable products and research projects associated with meditated affective touch. State of the art is the section that will discuss some of these products and research projects—exploring the methods they used to meditate on affective touch. In the end, the question: What is state of the art for haptic wearables and mediated emotional intimacy over long-distance, will be answered.

2.2.1 TaSST (Tactile Sleeve for Social Touch): Affective Mediated Touch

The TaSST, in other words, the tactile sleeve for social touch, is a wearable designed to mediate affective touch [23]. The sleeve is designed to be worn on the forearm because it is sensitive to vibrotactile stimulation, according to [23]. Two users would wear the sleeve, the sender would touch the sleeve, and the receiver would perceive the touch on their forearm. Since the sleeve is both a transmitter and receiver, both users can communicate, touch, and feel a touch from each other. The TaSST can be seen in figure 2.3.

Figure 2.3: TaSST

The sleeve had two layers, input, and output. The input layer is wrapped around the output layer and has conductive wool pads. These conductive wool pads were weaved into Lyra pads [46]. The conductive wool is a wool that uses the principles of capacitive sensing and resistive sensing to detect touch. The benefit of conductive wool is it can be easily applied to existing clothing.

The output layer was in contact with the user's skin and had twelve vibration motors ordered in a four by three grid [46]. The vibration motor intensity is controlled by force applied from the other users' input layer. These vibration motors were forty millimeters apart and would result in more accurate single-point identification, stated by [46]. The sleeve allows the users to be distinguished and transmits different touching sensations, such as poking, hitting, pressing, squeezing, rubbing, and stroking. These touches are shown in figure 2.4.

Figure 2.4: TaSST different types of touch

A user study was conducted to test whether the tactile sleeve was capable of communicating affective touch. Before, the experimenters created pre-recordings of various simple, protracted, and dynamic touches using the input layer [46]. The participant then received these prerecorded touches through the output player and was asked to imitate the touch they received. The results that [46] found were the participants were most successful in imitating the touch.

Afterward, the user case was conducted by Huisman and Frederiks [47]. Participants were given the sleeve and were asked to express several emotions onto the input layer. These emotions would then be recorded by the sleeve and played back onto another participant. In conclusion, Huisman and Frederiks' [47] study provided evidence that emotion could be successfully expressed.

2.2.2 Kissenger

The Kissinger is a device that would meditate kisses over distance for romantic couples in long-distance relationships [48]. The goal of Kissinger was to help maintain a close connection by communicating intimacy through a kiss. The device can sense the lips' pressure and send the kiss's haptic sensation to the paired device. An image of Kissenger can be shown in figure 2.5.

Figure 2.5: Kissenger Product

The Kissinger consists of three main components; output, input, and control. The output component contains servomotors that flex the surface of the device's lip, giving the sensation of a kiss to the user. This helps the user evoke emotional responses and feelings to convey a kiss, according to Saadatian et al. [48].

Furthermore, the input component has force-sensitive resistors sensors placed around the lip. The sensor can detect varying levels of soft touches. These soft touches are mapped on a one-to-one basis, according to Saadatian et al. [48], which simplifies the device's interface for the user.

Next, the component is the controller, which has embedded circuits that act as the device's brain. Kissenger uses an Arduino Pro Mini as a controller to control the sensors and actuators. The controller provides wireless communication to communicate with another Kissenger device and will communicate if the pressure sensors detected a user's kiss. A figure of the control system of Kissenger is shown in figure 2.6.

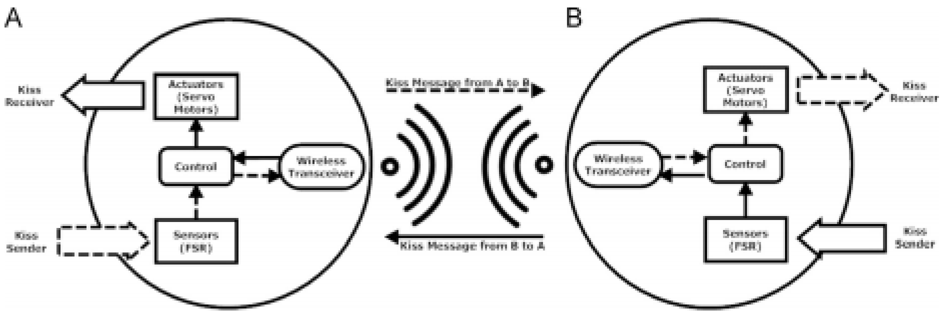

Figure 2.6: Kissenger flowchart

Lastly, Saadatian et al. [48] did a field study to evaluate the effectiveness of Kissenger. The field study was three weeks long, where participants would write in a diary about their experience and log when they used Kissenger. The dataset collected contained frequency of use and situation, and participants also had interviews once a week. The data raise many questions about the design and potential ethical issues that could arise. For example, during the field study, a couple felt guilty kissing a robot instead of their partner [48]. As well, a couple wanted to use the Kissenger at work but would feel embarrassed if their co-workers saw them kissing a device [48]. Although Kissenger provides questions about ethical concerns, there was much positive feedback that suggested that Kissenger did provide support for intimacy and help support the close connection in romantic relationships. As a result, Kissenger provided much insight into designing a device for supporting intimacy in romantic relationships.

2.2.3 Flex-N-Feel

Flex-N-Feel is a wearable device that allows couples in long-distance relationships to feel the sensation of their partner's hand through vibrotactile on their skin. The goal of the Flex-N-Feel is to design a tangible communication system for couples in long-distance relationships that would enable the couples to share physical touch [49]. The glove senses the flexing of the sending and receiving partner's fingers will feel the vibration on their hand. An image of the glove is shown in figure 2.7.

Figure 2.7: Flex-N-Feel Product

A glove design was adopted because flexing one's finger was a gentle, subtle, and caring way to touch a partner, according to Singhal et al. [49]. The glove has two main components, input and output. The glove consisted of flex sensors to measure the bend or flex in the user's fingers, as shown in figure 2.7. The sensors are placed on top of each finger, and the sensors will transmit the readings through a Wi-Fi module.

The output is split into two sections: the sensing and vibrotactile pattern. The sensing of the flexing in fingertip works by using linear coin-shaped on the back of each finger as shown in figure 2.7. When a user partner flexes their index finger, the three vibration actuators will vibrate. Furthermore, Singal et al. [49] designed the glove to simulate stroking or caressing patterns on the user's skin. Receiving a stroking pattern would generate a stronger emotional connection, according to Singal et al. [49].

Lastly, Singal et al. conducted an exploratory lab study to get insight into what characteristics are significant for facilitating a sense of touch for couples in long-distance relationships when using the Flex-N-Feel glove. In the lab study, eighteen participants participated, where they experienced the Flex-N-Feel glove and gave feedback during the interview and questionnaire afterward. Most of the participants enjoyed the Flex-N-Feel glove and facilitated a sense of touch between the couple. As a result, the study proved that vibrotactile sensation could simulate touch over distance and communicate important touches like intimacy.

2.2.4 Hey Bracelet

Hey, is a bracelet that notifies the user partner to feel a 'real' human touch over distance. For the company, it is vital to show that the user is thinking about their partner or a significant other. The Hey bracelet's goal is to use haptic technology to provide a touch by mimicking the feeling of human touch on the user's wrist [50]. An image of the Hey bracelet is shown in figure 2.8.

Figure 2.8: Hey Bracelet Product

The Hey bracelet works by using a sensor on the top surface to detect touch. The touch is sent to the Hey mobile app, where it is then sent to the chosen pair bracelet. These pair bracelets then use actuators to squeeze the armband on the bracket to simulate a human touch.

2.2.5 TactileWear: A comparison of Electrotactile and Vibrotactile Feedback on the Wrist and Ring Finger

TactileWear is a research project comparing electrotactile and vibrotactile feedback. The project developed two wearables, one for the wrist and another for the ring finger. The project's goal is to evaluate the suitability of electrotactile feedback as an alternative to traditional feedback methods, such as vibrotactile feedback [51]. An image of the wearables is shown in figure 2.9.

Figure 2.9: Tactile Wear Product

In total, there are four prototypes, two wrist bands, and two rings, each having a different type of output (vibrotactile and electrotactile). Two of the prototypes used vibrotactile feedback. One wristband and ring, which consisted of four vibration actuators when a touch is sensed, actuators will vibrate at a frequency depending on the applied touch. The other two prototypes used electrotactile feedback. One wristband and ring contains four electrodes and uses an LYBM toolkit with a pulse generator to create electrotactile feedback when a touch is sensed.

Furthermore, two studies were designed. One study was to investigate wearable types (wristband or rings), the feedback type (electrotactile or vibrotactile), and the combination of the two types of feedback and wearables. The study then continued into the user testing phase; participants were asked to draw where they felt the sensation on their arm/hand. As a result of study one, Stanke et al. [51] found that the wristband with electrotactile was most preferred as it was more localized and that the wristband was more convenient than the ring. Although electrotactile was most preferred, according to Stanke et al. [51], participants found the vibrotactile feedback more comfortable and less stressful. They were suggesting that vibrotactile is more subtle and gentle for the participant than electrotactile feedback. As a result, study one provides more information about electrotactile feedback compared to traditional feedback.

Lastly, study two was about the participant learning and recognizing the notification patterns [51]. The device would play a pattern with the two feedback technologies. For example, on the wrist, each motor would vibrate, going from right to left around the wrist. The participant would then need to recall the pattern. The patterns would become more complex. The data collected from this study showed that participants preferred vibrotactile wristband best for recognizing patterns compared to the other options, according to Stanke et al. [51]. The justification of this choice was that the wristband was more comfortable but less accurate than the electrotactile. As a result, of the two studies, it is clear that the participant's comfort with the wearable is more preferred than the task's accuracy.

2.2.6 Vibrotactile Array To Generate Pleasant Stroking Sensation

Vibrotactile Array is a research project investigating whether an array of vibrotactile actuators can produce a similar pleasant response as a gentle stroke [52]. The researchers focused on factors such as timing, body location, and social context to achieve this goal. These factors were derived from a study done by Matthew et al. [53], where the goal was to review core communicative function served by touch. These factors, the research project would design a wearable to simulate stroking. An image of the wearable is shown in figure 10.

Figure 2.10: Vibrotactile Array Product

Huisman uses these factors, a phenomenon called "apparent motion" and Tactile Brush Algorithm, to create a wearable [52]. The device uses cylindrical vibration motors placed at the participant's ventral side, three centimeters apart, starting from the wrist downward. Furthermore, with the knowledge of the number of actuators and the distance between the actuators, the Tactile Brush algorithm was implemented to generate a stroking stimulus. This algorithm at velocities below ten centimeters per sec has produced a sensation of stroking, according to Huisman [52].

Also, the motors' intensity level was set based on experts in the field, one set to fifty percent maximum, which peaked at two hundred hertz and the other set to thirty-five percent of the maximum, at the peak of hundred forty hertz [52]. These intensities will further provide the stroking stimuli for the user.

The next step was to conduct a user test. A participant would get the motors attached to their non-dominant arm. The participant was then given a test stimulus and asked to use a scale to log their response. The scale would record velocity, continuity, straightness, intensity, and pleasantness. The data collected sounds that vibrotactile stroking stimuli and pleasantness ratings from the users follow an inverted U-curve. Although Huisman [52] does mention in his findings that vibrotactile does not stimulate the CT-afferents, he does indicate that simple actuators can be used to produce stroking sensation. As a result, vibrotactile feedback for stroking is a viable method for mediated affective touch.

2.3 Conclusion

This section of the project is aimed to get insight into designing a haptic wearable for meditated affective touch for couples in long-distance relationships. The section consists of two parts: a literature review and state of the art. These parts help answer two research questions: What are the most effective types of haptic feedback for communicating affective touch over long-distance? What is state of the art for haptic wearables and mediated emotional intimacy over long-distance?

First, a subsection of chapter two is the literature review. This literature review aims to discover the effective type of haptic feedback for communicating affective touch. The research into the topic of existing haptic feedback to communicate affective touch shows that using a cutaneous system with a combination of actuators is most effective when communicating affective touch. Furthermore, it shows that when it comes to building a haptic system for communicating affective touch, it was essential to use the actuators to feel natural and comfortable to the participant. To be able to achieve this, the actuator should be subtle and not invasive.

Another factor was the location of communicating affective touch. Haptic feedback actuators can use these locations on the body to communicate effectively. Knowledge of the guidelines that designers use to build wearables, paired with how relationships influence the area they liked to be touched, shows that the forearm, the wrist is most desirable. Furthermore, when finding suitable locations, the design of the wearable itself influences placement. When designing a wearable, the audience's relationship status significantly affects a wearable device's possible placement.

Second, a subsection of chapter two is state of the art. State of the art focuses on existing research projects and products that meditated emotional intimacy over long-distance. The goal was to find standard design features and discover why the designers chose these features. For example, most of the wearables are designed for the arm of the participant. The reason is to do with comfort and convenience for the participant. As mentioned in section 2.2.5, the participant found that wearables on the wrist/arm found it more comfortable and convenient than other body locations.

In addition, vibrotactile feedback was the most preferred method of conveying affective touch. Vibrotactile feedback, according to many designers and researchers they found that participants found vibrotactile to be more stimulating than other types of feedback. For example, in the study of Flex-N-Feel, the researchers proved that intimate emotions could be communicated over long-distance. This is further proven in section 2.2.6, where they managed to produce a gentle stroke, which is an intimate emotion, with vibrotactile feedback. As a result, when designing a haptic wearable for couples in long-distance relationships, vibrotactile and wearable on the arm seem to give the best results for achieving this project goal.

Conclusively, vibration actuators placed along the forearm or wrist are an effective way of meditated affective touch. The actuator should feel as natural and not intrusive as it can be. Moreover, the actuators' placement should follow the guidelines to ensure the participant's satisfaction and comfort and the best result of communicating affective touch. Also, a gentle stroke on the arm has shown to be possible, and a gentle stroke is perceived as intimate and supports the emotional bond between partners. These recommendations will be used in designing wearable haptic feedback to support couples' affective touch in long-distance relationships.

Chapter 3

Method & Technique

3.1 Creative Technology Design Process

The creative technology design process will be used to develop a haptic wearable for affective mediated touch. The layout of the design process can be seen in figure 3.1. The design process has four components: Ideation, Specification, Realization and Evaluation.

Firstly, the ideation stage is focused on defining the project concept and the possible solution through brainstorming various possible design ideas. In this bachelor project, the goal is to create a haptic wearable to communicate affective touch for couples in long-distance relationships. After an initial idea is formed, the idea is then further explored through user case scenarios. This process will all be done in the ideation phase of this bachelor thesis in chapter 4: Ideation.

Secondly, the specification phase is about further explaining the initial idea created in the ideation phase. The specification phase also explains the possible components that can be used to create the haptic wearable. Furthermore, tests will be conducted based on each wearable component to check whether the components are performing at an acceptable level. These components will be evaluated based on functional and systemic requirements that are also developed during this phase. This phase of the design process will be discussed in chapter 5: Specification.

Thirdly, the realization phase is about the components discussed in the specification phase and combined into a final prototype. Each component mentioned will be integrated into the prototype, including workarounds that had to be implemented due to unforeseen complications. As a result of this phase, a final prototype for a wearable haptic device for affective meditated touch will be developed. The realization phase of this process will be mentioned in chapter 6: Realization.

Finally, the evaluation phase evaluates the prototype based on the requirements created in the specification phase. In addition, the evaluation phase will also bring up possible future recommendations on how to improve the haptic wearable. This stage of the process can be found in chapter 7: Evaluation.

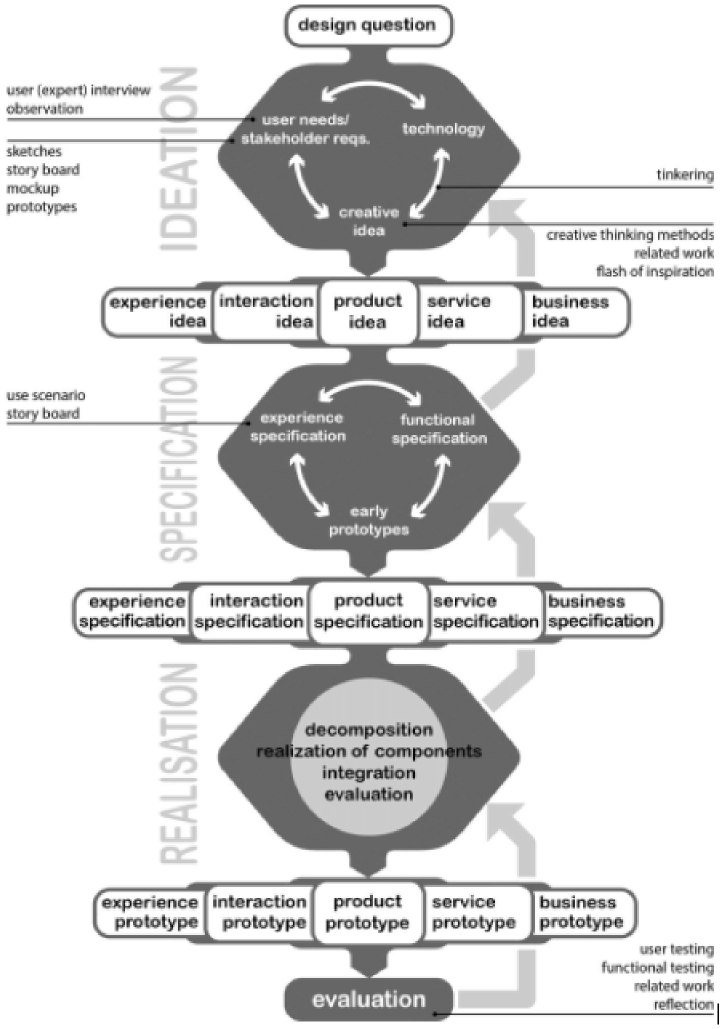

Figure 3.1: Creative Design Process [54]

Chapter 4

Ideation

This chapter explores several design possibilities. Furthermore, a mind map is created to formulate the preliminary design for this research project. Lastly, the design is then further explored through user case scenarios to gather insight into how potential users will interact and use the system. This chapter aims to have an initial design to communicate affective touch to support couples' emotional intimacy in a long-distance relationship.

4.1 Mind Map

To find a possible design for a haptic wearable to meditated affective touch. A mind map is created to brainstorm a viable solution for supporting emotional intimacy between couples. The mind map is shown in figure 4.1. The mind map explores the following questions: How to receive affective touch, what type of affective touch when to send affective touch, location to receive affective touch, how to detect affective touch, who will send and receive affective touch. These questions will help with brainstorming to come up with an initial idea for this research project.

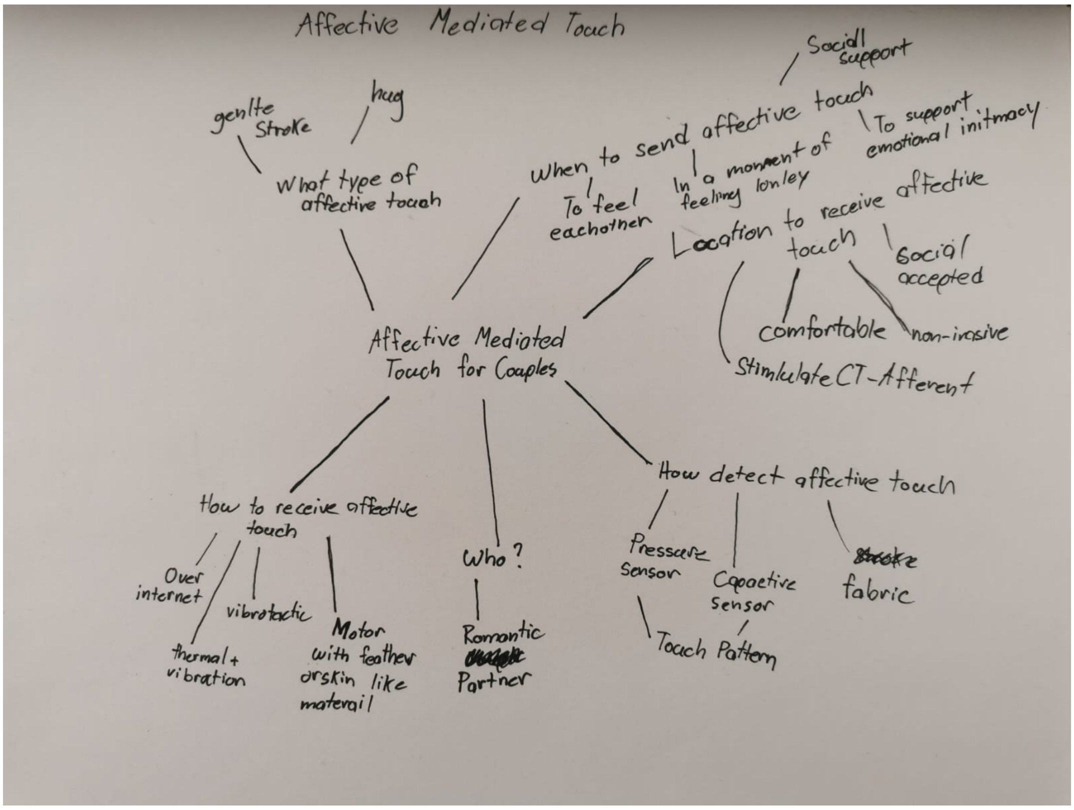

Figure 4.1: Mind Map, Affective Mediated Touch for Couples

First, how to receive affective touch; the wearable can receive touch by using a vibrotactile, motor that moves a skin-like material, or a combination of thermal and vibration. This could be a possible solution to receive affective touch. One component to be implemented is internet communication because it will allow the touch to be obtained from a long distance.

Second, detecting affective touch from the user can be answered using pressure or capacitive sensing, and these sensors can be implemented into fabrics. The sensor allows the design to detect the touch pattern that the user is transmitting. The wearable should detect the touch pattern the user is sending an accurate touch to receive a realistic touch.

Thirdly, location to receive affective touch is an essential aspect of the wearable. The wearable should stimulate affective touch and be non-invasive, comfortable, and socially acceptable for the user. The wearable should consider these components for designing.

Fourthly, when should the wearable send affective touch. This is for the user to decide when to send an affective touch. Although, the wearable should support the emotional intimacy and a feel of closeness for the users'. As the goal of the research project is to support emotional intimacy for couples.

Lastly, what type of affective touch should be sent to the user. There are two options to produce affective touch, which are hugging or a gentle stroke. This two-aspect stimulate the affective touch in the receptors and are the best methods for pleasantness. The design should be able to reproduce one of the types of affective to achieve affective touch. In conclusion, the mind map explores critical questions to help ensure a design that supports emotional intimacy for couples in a long-distance relationship.

4.2 Inital Idea

The results concluded in state of the art and mindmap showed in figure 4.1, a wearable placed on the forearm will be developed in which couples in long-distance relationships can communicate affective touches to their partner affective meditated touch. In addition to the literature, it was discovered that vibrotactile feedback was the best method for recreating affective touch on the human skin. Also, producing a gentle stroke on the arm proved to be the most effective method of affective touch. Therefore, the wearable output will use vibrotactile methods to create a gentle stroke on the users' forearm. Furthermore, in order for couples to provide a meaningful intimate touch, the partner's touch has to be tracked. For example, when a user strokes the wearable on the forearm, the wearable must communicate the touch pattern to the other wearable to ensure that the significant other receive the exact touch pattern that they would feel if they were together. In the end, the design must transmit and receive an affective touch from both parties of the relationship.

4.3 Video Calling

Couples that are in a long-distance relationship use video calling to help support their relationship. Users have indicated that video calling supports the partners to feel close to one another [55]. As a result, the study shows that video chatting is the most preferred method of communication because the technology is accurate mimics in-person communication compared to existing technologies.

Video calling has been a traditional means of communicating with love that can not meet in person. Although video calling is the most preferred method is does come with some drawbacks. One drawback is that it cannot communicate touch. As a result, the initial idea, in combination with video calling technology, will provide the ability for couples to have an in-person conversation and feel their partner's touch.

4.4 User Scenarios

User scenarios are generated to get more insight into the interaction between the user and the system. These scenarios create a real-world situation for users interacting with the system. In conclusion, user scenarios find potential barriers or issues that could arise during the interaction and tackle these problems to improve the design.

4.4.1 User Scenario 1

Alex is a student at the University of Twente. He lives on the university campus. Alex has been in a relationship with a girl named Abby for about one year. They meet in their hometown of Leeuwarden. Abby studies at the Technische University of Berlin, which is about a 6-hour drive away from Enschede. Since they are very far apart physically, they video-call each other to keep in touch every so often. Alex and Abby start to miss the feeling of their partner's touch. They used to cuddle and be together in person every day. So, Alex and Abby use the haptic sleeve system designed while they video chat with each other. Alex and Abby would put on the sleeve and connected it with their mobile phones. While they are video chatting, Alex can send a light touch on the sleeve to Abby, and she would feel the same light touch on her forearm. Once they finish with the video call, they can take off the sleeve. As a result, the system would allow them to touch each other when they already spend time together.

4.4.2 User Scenario 2

Erin is 25 years old and is an international student from Bulgaria. Erin has just finished her master's degree at the University of Toronto. During her time at the university, she got into a relationship with Daniel, who lives in Canada. Erin plans to continue to stay in Canada for work and Daniel. However, Erin must go back to Bulgaria because her student visa is about to expire and reapply for a work visa. The problem is for Erin and Daniel is that the time difference between them is quite significant. If Daniel is working, Erin has her free time and vis vera. So, they have no time to video call as often as a couple living in the same time zone.

Furthermore, they will not be able to see or touch each other physically because of the distance between them. Until Erin gets a work visa to work in Canada, they cannot support each other emotionally. So Daniel and Erin would use the haptic sleeve design to communicate their touches. They can feel each other because if Daniel is at work, he can send a gentle stroke on the sleeve to Erin while relaxing after work. The device would help support the emotional intimacy they had until Erin received her work visa.

4.4.3 User Scenario 3

Penny is a 28-year-old marketing executive. She lives alone in an apartment. Since the COVID-19 pandemic, Penny has been working from home. She recently had started seeing Lisa before the lockdown happened. Penny has been feeling lonely ever since the lockdown because she stays at home all day and goes outside for a walk from time to time. As a result, Penny wants to feel Lisa's touch again, not to feel lonely anymore. So, Penny and Lisa both use the device throughout the day. Whenever Penny or Lisa feel lonely, they can send a pleasant touch to each other. This allows Penny and Lisa to communicate their emotions more effectively than others means and support and grow their intimacy with each other.

4.4.4 User Scenario 4

Nathan just finished high school, is taking a gap year to travel around Asia. Nathan is in a relationship for three years with Charlotte. As Nathan is traveling Asia, he does not have must time to video chat with Charlotte, but he still wants to stay connected with her during his travels. So he uses the haptic sleeve to communicate gentle stroke to Charlotte during his trip. This would allow him to send meaningful touches during the day still and enjoy his travel in Asia. As a result, Charlotte does not have to worry about Nathan's lack of communication, and both partners feel close to each other.

4.5 Conclusion

The goal of this chapter was to make an initial design for affective mediated touch. By using the ideation process, an initial design was created. Since couples in long-distance relationships lack affective touch with their significant other due to the distance between them. Therefore, a lack of emotional intimacy between the couples. With the use of the mind map, methods were explored on a possible situation where a wearable can be introduced. The results from the mind map, a suitable interaction for affective mediated touch can be derived. The haptic wearable for affective mediated touch is an addition to the existing interaction of video calling. Video calling is one of the most popular methods of communicating with a significant other. However, video calling only gives visual and audio feedback and cannot provide the tactile feedback humans want. Therefore, tactile feedback is desirable for couples.

So, the addition of a haptic wearable that can give intimate, gentle stroke during a video call is a solution. Furthermore, user case scenarios are presented to elaborate more about the possible situation the wearable can be used. The scenarios all benefit from a haptic wearable for affective mediated touch, as it allows couples in a long-distance relationship to connect through touch over the internet.

To summarize, the ideation phase of this bachelor thesis presented an initial idea for the haptic wearable. The bachelor project will develop a haptic wearable that can communicate gentle stroke over the internet during a video call. This makes video calling a more pleasurable experience and will result in couples having a more intimate experience with each other. Next, the hardware and software elements are discussed in chapter 5: Specification to get insight into designing such a device.

Chapter 5

Specification

Based on the concept developed in the previous chapter, a list of requirements further explains the technologies used to design the prototype. The prototype specification is split into three subsections that cover wearable communication, receiving haptic feedback, and transmitting haptic feedback. As a result, chapter five will answer the fourth sub-question: What components are needed to design a non-invasive haptic wearable for affective touch?

5.1 Requirements

As mentioned in chapter four, the initial design was created, and a list of requirements for the prototype. The requirements are split into two distinct parts: systematic and functional requirements. The systematic requirements are a list of the prototype's technical requirements to perform the tasks. Furthermore, the functional requirement lists what the prototype should do from the end user's perspective. These requirements will be evaluated later in chapter seven.

System Requirements

The haptic wearable should be able:

- Be integrated into a wearable
- Be able to send a touch over the internet
- Be able to detect touch patterns
- Be able to receive information from the internet
- Be able to reproduce a gentle caress

Functional Requirements

The haptic wearable should be able:

- Support emotional intimacy between the partners
- Simulate a pleasant gentle stroke
- Be non-intrusive
- Be intuitive to use
- Make video calling a more pleasant experience.

5.2 Initial Design

The initial design is shown in figure 5.1. This drawing shows where the prototype will be placed on the users. The goal of the wearable shown in figure 5.1 is to allow a couple in a long-distance relationship to communicate touch over the internet while video calling. This means a wearable should sense the gentle stroke, communicate the touch over the internet, and reproduce the gentle stroke onto the user's fore-arm. The interaction between the wearable is further explained in the section: 5.3 Communication, 5.4 receiving haptic stimulation, and 5.5 transmitting a touch.

Figure 5.1: Wearable being used during video call [56]

5.3 Communication

Communication is one out of the three main components of the wearable. The communication component will handle the connection between both prototypes, allowing the user to send and receive touches from each, allowing others. Communication is split into microcontrollers and MQTT protocol. First, the microcontroller will discuss the microcontroller that will be used for the wearable prototype. Then, the MQTT protocol is the protocol that will be used to communicate the touch patterns over the internet from each device to the other.

5.3.1 Microcontroller

Microcontrollers are the brains of the prototype, as they will handle the process of data, send and receive data, and control the sensors and actuators. When selecting the best-suited microcontroller, a few key factors are considered. These key factors are size, environment tolerance, power consumption, and hardware interface [57]. The factors will be used to determine the best microcontroller for the wearable prototype.

Firstly, the size of the microcontroller plays an important role in designing a wearable device. Therefore, the microcontroller should be as small as possible to fit onto the wearable device. Furthermore, the microcontroller should also have all the necessary hardware components simultaneously, which increases the size. For example, an Arduino mega can integrate all needed hardware components, but it is quite large, making it challenging to fit the microcontroller into a wearable.

Secondly, temperature and water tolerance are considered for finding the best-suited microcontroller. The wearable will create a hot and moist environment due to the body heat and sweat gals. If the user is sweating during the video call due to the hot weather, the wearable will absorb the moisture, creating a hot damp environment for the microcontroller. The environment could damage or destroy the controller. As a result, the microcontroller should handle this environment without damaging or destroying the controller.

Thirdly, power consumption is an essential factor as it determines the controller's performance and how long the user can use the wearable device. The controller's performance is greatly affected based on the power the processor consumes. The higher the performance, the more power it consumes, so there is a tradeoff between performance and power consumption. Furthermore, most wearable devices are battery-powered, and unlike other mobile devices, they are required to stay on. For example, a smartwatch is always on to show the time to the user. For this project, the wearable does not need to be always on because it will only be used for video calling, and then it can be switched off. This means that the wearable only needs to stay on for the video call duration, which on average is about thirty minutes. As a result, the microcontroller can have more processing power.

Finally, the hardware interface of the microcontroller is crucial as it determines what hardware components can be integrated to complete the task. For example, the task that needs to be completed by this project is to connect to wifi and have enough input/output pins for the sensors and actuators. As a result, the microcon-

Microcontroller	Size	Tolerance	Power Consumption	Hardware Interface
Raspberry Pi Zero	3	3	5	5
Esp32	3	4	5	4
Arduino Uno	3	4	4	2

troller needs to have a Wi-Fi module integrated and have enough pins to connect all sensors and actuators for the wearable.

In conclusion, a chart to compare standard microcontrollers is shown 12. Using a rating system, five being perfect and one being imperfect. The chart uses the four key factors: size, tolerance, power consumption/processing power, and hardware interface. Each microcontroller is rated based on a scale from one to five. The chart shows that the raspberry pi is the best-suited microcontroller to perform the necessary tasks for this project. Although esp32 is also a well-suited microcontroller, the main difference between the two microcontrollers is processing power and software integration. The esp32 might not be able to handle the computation needed for the algorithm described in section 5.4.3. In addition, the raspberry pi zero is a small board that can be easily integrated into the wearable and has a wifi module integrated into the board. In addition, the raspberry pi has enough processing power to compute the input and output for the sensing and producing touch. As a result, the raspberry pi zero will be the microcontroller of choice for this project.

5.3.2 MQTT Protocol

MQTT protocol will be the protocol used for the wearable to communicate the data with the paired devices. This sub-section will discuss what the MQTT protocol is exactly, how the protocol works, and why this is the preferred protocol over other existing protocols. As a result, this will detail how the transfer and receiving of data will communicate touch over distance.

Why use MQTT?

MQTT will be the protocol used for communicating touch data between the two prototype wearables. MQTT has several advantages compared to other protocols for communicating data. Some of these advantages are lightweight, reliable, and bi-directional communication. The lightweight makes it so that data transmission is kept at a minimum, ensuring a minimum load on the network. Equally important, the MQTT lightweight protocol allows the prototype to be connected to unstable networks or networks with limited bandwidth and will still communicate with the other wearable device.

In addition, the MQTT protocol is reliable because it is an event-driven protocol. Notably, the MQTT protocol was used in 1999 by the gas companies to communicate data from their monitoring device located in the ocean to their headquarters on the mainland via satellite. This example explains that the MQTT is quite reliable for long-distance communication, which is perfect for this prototype as it has to communicate touch data over a long distance.

Furthermore, the MQTT protocol is bi-directional, meaning that both prototypes can send and receive touch data. To put it differently, bi-directional allows devices to be both transmitters and receivers, which makes this protocol an industry-standard in the internet of things application. Bi-directional capabilities are essential to have for this project because the device should receive and send touch data.

The MQTT protocol is perfect for this project because it is lightweight on the network, reliable, and has bi-directional capabilities. The lightweight will ensure that the load on the network is at a minimum and allows the prototype to still send and receive data on unstable networks. In addition, the reliability of the protocol ensures that data that is sent or received will arrive at its destination over long distances. Finally, the bi-directional capabilities of the protocol give the ability to make the prototype send and receive data. In conclusion, the MQTT protocol is the most preferred protocol to communicate touch data between the prototypes for this project.

What is MQTT?

To start, MQTT stands for Message Queuing Telemetry Transport. MQTT protocol is an extremely light messaging protocol that transfers messages between devices where the device is connected to unreliable networks or with limited bandwidth [58]. It is mainly used for machine-to-machine communication in IoT applications. In other words, the protocol is designed to communicate small messages to devices that are connected to a substandard network. In summary, the MQTT protocol is perfect for communicating small messages to devices connected to poor networks.

How does MQTT work?

The MQTT protocol works by using a publish-subscribe pattern [58]. This pattern is broken into three components, publisher, broker, and subscriber. Figure 5.2, a visualization of the interaction between the publisher, broker, and the subscriber, is shown. First, the publisher sends a message to the broker, not to a subscriber. Then, the broker receives this message and distributes the data to all the interested subscribers [58]. In order words, the broker mediates the communication between the devices and will forward messages from publishers to subscribers interested in the chosen topic.

In addition, this protocol is bi-directional, which allows the subscriber to become publishers and publisher to subscribers [58]. This is useful for this project because it will allow both users to send and receive a touch from each other. If one of the devices loses connection, all users that are subscribed to the topic of interest are alerted.

Equally crucial of the MQTT protocol is that it is an event-driven protocol [58]. Thus, the sending and receiving of messages are not periodic or ongoing data transmission [58]. This is what makes the protocol lightweight because transmission is kept at a minimum. Publishers only publish when they want to send data, and brokers only send out data to subscribers when new data has been published. In short, the MQTT protocol is ideal for the prototype for its lightweight, speed, and robustness.

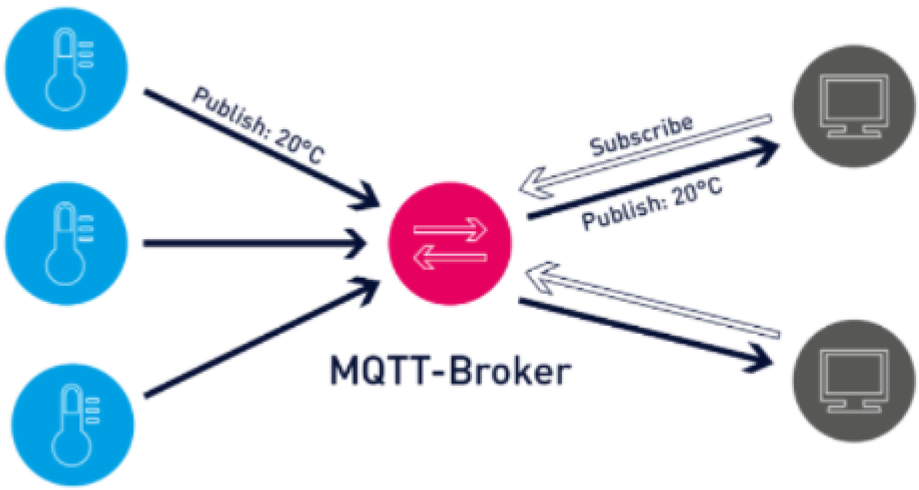

Figure 5.2: MQTT Architecture

5.3.3 I2C Protocol

I2C protocol is a serial communication protocol that allows electronics to communicate data on a single wire called the SDA line. This protocol will allow the raspberry pi or microcontroller to communicate with all twelve vibration motors drivers. Furthermore, the protocol is the best way to keep the number of wires used at a minimum. Without the protocol, the raspberry pi would have twenty-four connections that would have to send PWM signals. The raspberry pi is not capable of producing that many PWM signals in a short amount of time. As a result, the 12C protocol will allow the raspberry pi to communicate with the haptic motor drivers and keep the number of wires at a minimum.

5.4 Receiving Haptic Stimulation

Affective mediated touch can be achieved by a gentle stroke using vibration motors. Vibration motors are preferred because vibrotactile feedback is non-invasive, cost-effective, small, comfortable. Nevertheless, before vibrotactile feedback is integrated into the prototype wearable for this project, three topics need to be discussed and an experiment to determine the optimal force and velocity for receiving a stroke. The three topics include characteristics of a gentle stroke, interpret the stroke and the material:

- How to interpret the touch pattern from the other user
- What are the characteristics of a gentle stroke?
- How to control the vibration motor

5.4.1 Intepret Gentle Stroke

Users should feel their partner's unique touch pattern since gentle strokes can be produced in every direction at different lengths. For example, one pair could send a very short stroke towards the hand, whereas another couple would have a long stroke towards the elbow. In other words, every couple has their own unique way of caressing their partner on the arm. With this in mind, the prototype should produce these unique touch patterns without having the entire under forearm covered in a vibration motor. There are two components needed to achieve this desired effect: a haptic perceptual illusion from vibrotactile actuators and the tactile brush algorithm.

Illusion

The first component is the perceptual illusion from vibrotactile actuators. This illusion is a prominent feature of vibrotactile technology to produce a haptic perceptual illusion [51]. Using two vibration motors placed on the human body at a certain distance apart and when the motors are activated, they overlap, creating an illusion that makes the user feel a single vibration motor between the vibration motor. As a result, this can create a phenomenon called 'apparat motion', where two actuators feel like a continuous motion. [51].

In addition, the illusion was used before to create a pleasant stroking touch in a study done by Huisman [51], where he developed a wearable with multiple vibration motors to create pleasant stroking. His study showed that it was possible to create a pleasant stroking sensation with vibrotactile actuators. In summary, for this prototype, the illusion will help create virtual vibration motors to cover more of the forearm area with fewer vibration motors.

Tactile Brush Algorithm

The second component is the tactile brush algorithm which is an algorithm that can generate stroking stimuli [59]. The algorithm can create the apparent motion illusion mentioned in section 5.123 on a 2D grid of actuators. Although the algorithm does come with constraints:

- Single-point motion
- Straight-line motion
- The motion must be located on the grid formed by the actuators.

The prototype does fit the criteria for the algorithm. However, the only limitation of this algorithm is that a gentle stroke can only be straight and not curved. Although a minor limitation of the algorithm does give the desired effect producing gentle strokes in different directions and locations on the haptic wearable.

How it works

The Tactile Brush Algorithm goal is to compute several mathematical equations. These equations will create a continuous tactile stroke for the motors to recreate. The algorithm requires a tactile stroke as an input, shown in figure 5.3. This tactile stroke (H) is defined by:

- Starting and ending points P0 and P1
- Intensity I
- Frequency F
- T the time required to complete the stroke H:

$$H = \{P_0 = (x_0, y_0), P_1 = (x_1, y_1), I, F, T\}$$

Figure 5.3: Tactile Stroke Equation [59]

After receiving the tactile stroke, the next step is to process the data with the tactile brush algorithm. For example, figure 5.4 shows an indication of the algorithm. A 3x4 grid of vibration motors is set up, and the stroke received from the partner can be seen with the red dots that start at (1,3) and end at (4,1). The computation is split into four steps:

- Virtual Actuation Points
- Speed of the stroke and timestamp
- Duration and onset time for apparent motion illusion
- Mapping to physical actuators

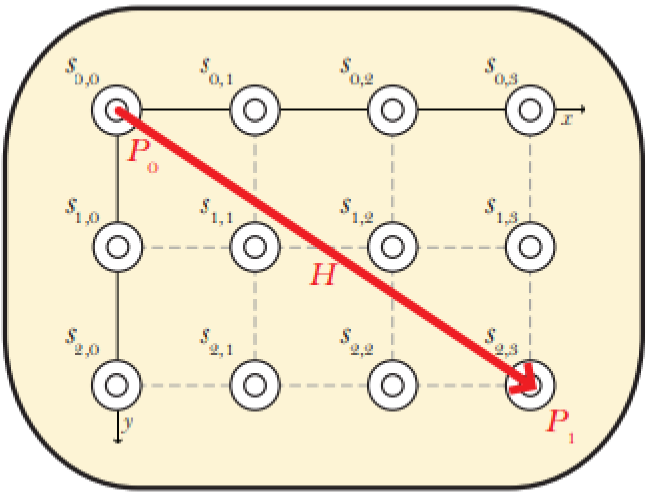

Figure 5.4: Example of stroke placed on the 3x4 grid of physical actuator [59]

The first step is to find the location of each potential virtual actuator (λi). Virtual actuator locations are determined by the intersection of the tactile stroke H and the actuator grid as shown in figure 5.5. In addition, it is important to note that the virtual actuator points defined by stroke H are independent of the tactile hardware. Meaning that some virtual actuators would overlap onto physical ones, but other virtual points would not. In the end, the virtual points locations are computed as seen in figure 5.5.

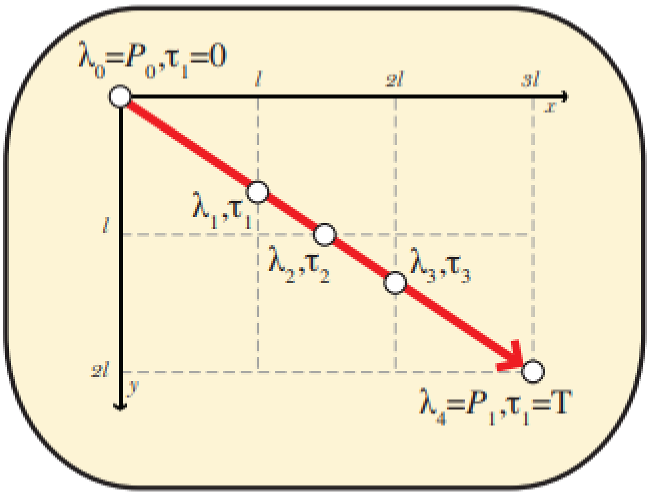

Figure 5.5: The intersection of the stroke and the grid lines [59]

The second step is to compute the velocity of the stroke and timestamps. Velocity can be calculated by dividing the length of stroke by the stroke duration (T). The following equation is figure 5.6:

$$v = \frac{\sqrt{P_1^2 - P_0^2}}{T}$$

Figure 5.6: Equation of velocity of the stroke [59]

V is the velocity of the tactile stroke H and P1, and P0 is the start and endpoints of the tactile stroke. Next is to compute for T the stroke duration. To compute the total duration requires the duration of stroke H and the time it takes for a virtual actuator to reach its maximum perceived intensity in milliseconds. To calculate the time it takes for the virtual actuator to reach its maximum intensity can be done with the equation shown in figure 5.7. As a result, the total duration of the stroke can be calculated

$$\tau_i = \frac{\sqrt{\lambda_i^2 - \lambda_0^2}}{v}$$

Figure 5.7: Equation of velocity of the stroke [59]

The third step is to find the duration and onset time for apparent motion illusion to produce a continuous tactile motion. However, instead of using the physical actuators, virtual actuators are computed by first computing the vibration durations di and SOAi for each virtual actuator. This is done with the following equation:

$$SOA_i = \frac{0{,}32 * \left(d_i' + \tau_{i+1} - \sum_{k=0}^{i-1} SOA_k\right) + 47.3}{1.32}$$

Figure 5.8: Equation to determine the stimulus onset asynchrony (SOA) for each virtual motor

The number thirty-two and forty-seven are the number that was derived from the experimental studies on apparent tactile motions [59]. In the end, the equation will return a SOA for each virtual actuator in the stroke. A visualization of mathematics can be seen in figure 5.9 based on the example shown in figure 5.4

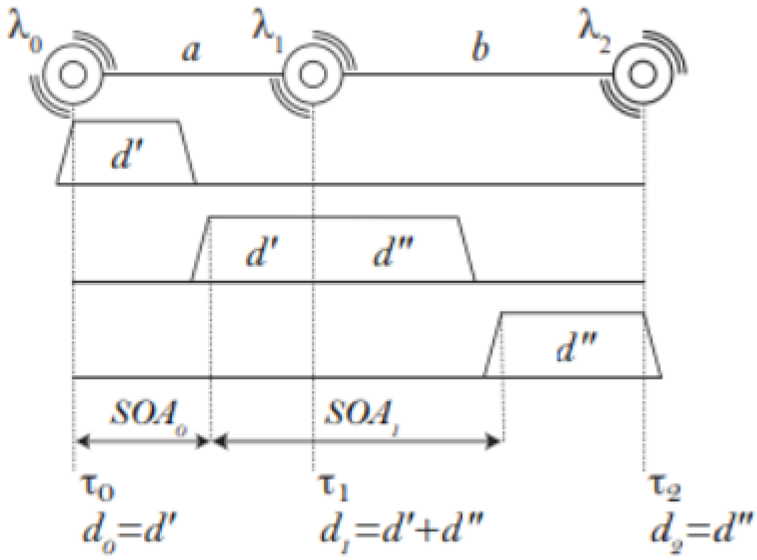

Figure 5.9: Visualization of the mathematics

Where tau is when it takes for the motor to reach its maximum intensity, Di prime and D double prime is the duration. SOA is the stimulus onset asynchrony, which is the amount of time between one stimulus and the start of another. In other words, this equation will solve the durations and SOAs for each virtual actuator that needs to be calculated.

The fourth step is mapping these virtual actuators (λi) to the physical actuators. When a virtual actuator overlaps a physical actuator, then they are equal. Otherwise, the two closest physical actuators that are can produce a virtual actuator at λi location. Finally, the intensity is calculated by using the following equation in figure 5.10:

$$A_1 = \sqrt{1-\beta} \cdot A_v,\ A_2 = \sqrt{\beta} \cdot A_v.$$

Figure 5.10: Equation to determine the intensity of each virtual actuator [59]

Where A1 and A2 are the two physical actuators, the virtual actuator (λi) at a certain intensity is represented by Av at the location represented by β. As a result of these four steps, it will be possible to create a stroke at a certain intensity, anywhere within the grid of physical actuators, which gives the user more freedom to create a unique stroke instead of a predetermined stroke. In other words, the algorithm makes it possible to reproduce touch patterns that the user's partner sends.

5.4.2 Haptic Motor Controller

The wearable should be able to control the intensity of the vibration actuators. In addition, the wearable will have to control each of the twelve vibration motor intensities separately. Thus, an electronic circuit or component has to tune the intensity of the vibration motor based on the output from the microcontroller and be able to use the I2C protocol. Such a device is called a haptic motor controller, as shown in figure 5.11.

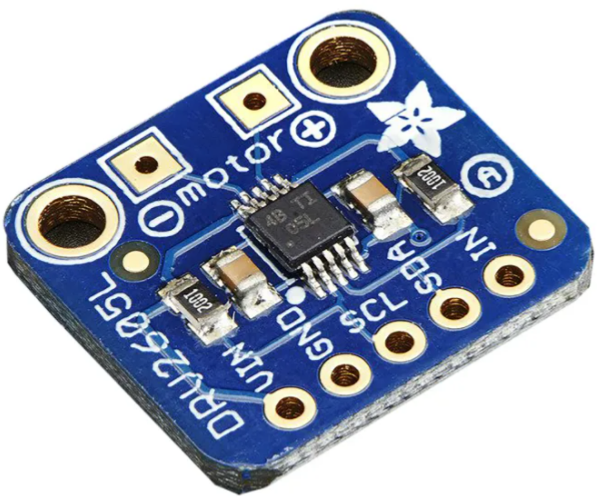

Figure 5.11: DRV2605L Haptic Motor Driver [60]

This haptic motor controller uses the DRV2605L chipset, which drives a little motor like the coin vibration motor used in this project. In addition, the driver works by sending the I2C protocol, which saves much time with wiring. Instead of wiring twelve vibration motors to the raspberry pi, only two wires from the raspberry pi are needed to be connected to the drives. These wires serve as a communication line for all the motors to the raspberry pi. As a result, this will be the chosen driver to control each vibration motor on the wearable because of its small size, I2C communication capacities, and motor driver capacities

5.4.3 Characteristic Gentle Stroke

Users should be able to receive a gentle stroke from their partner during their video call. A gentle stroke or a caress on the forearm has characteristics that have to be met to produce a pleasant gentle stroke on the arm. The main characteristics are force/intensity applied on the skin, velocity of the stroke, and heat of the touch. The wearable will simulate these three characteristics.

The first characteristic is the amount of intensity/force that needs to be applied to stimulate the CT-afferent nerve endings on the hairy skin of the body. As mentioned in section 2.1.1.1, the ideal force applied is from 3 to 2.5 millinewton, which is quite a bit of force applied to the skin. Thus, the wearable should be able to produce this force. This can be done by changing the intensity (the amplitude of the vibration) of the vibration motor to produce the required force to produce this force. Thus, Huisman experimented [59] to find the ideal intensity for stimulating the nerve endings, which was about 35

The second characteristic is the velocity of the stroke to ensure the stimulation of the CT-afferent nerve endings. As mentioned before in section 2.1.1.1, the ideal velocity of the stroke from a finger is between 1-10cm/sec. As a result, the velocity needs to be measured to ensure that the ideal velocity stimulates the nerve endings. Velocity can be measure using the equation:

$$V = D/T$$

Figure 5.12: Equation for velocity

Where V is the velocity, d is the distance between the vibration motor, t is the time it takes for the process to complete. With this formula, the velocity at which each motor turns on can be measured to get the ideal velocity. Thus, Huisman experimented [59] to find the ideal velocity for stimulating the nerve endings, which was about 6.35 cm/sec, which is within the range of 1-10 cm/sec mentioned in section 2.1.1.1. As a result, the wearable will ensure the speed of the stroke is in the range of 1-10 cm/sec and keep the speed as close to 6.35 cm/sec as possible.

The last characteristic is the heat of the stroke. The ideal heat to further stimulate the CT-afferent nerve endings is 32 degrees celsius, which is the temperature of interpersonal skin-to-skin touch. However, heat will not be the main focus for this wearable prototype since the heat actuator takes too long to warm up. The wearable itself could produce the ideal temperature depending on the material. For example, the material used for this project will be a fabric that is used in socks. This creates enough heat and airflow for the wearable not to get too hot for the user. As a result, the heat is determined by the material and the temperature of the wearable environment.

5.5 Transmitting Haptic Feedback

Everyone has a unique way of caressing their partner on their arm and it is important to capture this unique touch pattern. The unique touch pattern would make the user feel more intimate and comfortable with the wearable because the user would feel exactly what their partner is trying to convey instead of a pre-recorded stroke. Nevertheless, before this can be integrated into the prototype wearable for this project, two topics are important to discuss. In addition, an experiment will be conducted to see how accurate the wearable is on detecting the unique touch pattern using capacitive sensing and the multi-touch kit. The two topics include capacitive sensing, and multi-touch kit:

- How does capacitive sensing work, and why use this method?
- What is the multi-touch kit, how does it work

5.5.1 Capacitive Sensing

Capacitive sensing is a prevalent method of detecting touch in the field of haptics. As mentioned in section 2.1.2.3, capacitive sensors are ubiquitous in wearables because of the sensor's simplicity and ease of adding them to small devices like wearables. Nevertheless, capacitive sensing must be further explored to understand how this technology works and why this is the preferred method over other existing methods of sensing touch.

First, capacitive sensing works on the same principle as a capacitor in an electrical circuit. The sensor works by detecting the changes in the electric field around it, as mentioned in section 2.1.2.3. This change in the electric field can be measured to sense touch, force, pressure, et cetera. For example, touchscreens on the smartphone use capacitive sensing to detect users' finger touch when the finger touches the screen, the screen's capacitance changes, and the phone detects and translates it into a touch event. As a result, the capacitive sensor is intuitive and is pr

Second, capacitive sensors are pretty easy to be implemented into wearables because they are small in size, cost-effective, and easy to put together. In addition, the sensor can be placed on a curved surface like a forearm. Finally, unlike a force sensor that uses force to detect touch, a capacitive sensor can detect more detailed touch, perfect for detecting unique touch patterns. As a result, capacitive sensing will be the method that will be used to detect the unique touch.

5.5.2 Multi-Touch Kit

A Multi-Touch kit is the technology that will be used for detecting unique touch patterns from users. Before the technology can be implemented into the wearable there are points that are discussed to get a better understanding of the technology, as well as why this method is chosen for detecting unique touch patterns. As a result, this describes how the unique touch pattern will be detected on the wearable prototype.

Why ?

The Multi-Touch kit will be the technique used to detect the unique stroke pattern from the user's touch. The Multi-Touch kit has many advantages compared to other methods of detecting touch patterns of a user's finger. Some of these advantages include rapid prototyping capability, customization, and accuracy. These advantages are the main reason for implementing this technique into the prototype wearable.

The first point is the rapid prototyping capabilities of the technique are an important aspect of the technique. Rapid prototyping allows for fast prototyping and saves time. Compared to other methods where rapid prototyping is not so simple because it is only compilable with a certain microcontroller or that the fabrications of the technique take a lot of time. For example, using a multiple force sensor to detect touch will take a lot of time because each sensor needs to be calibrated correctly. Whereas, this technique is an array of copper lines.

Secondly, the customization aspect of the multi-touch kit allows for better coverage for the wearable. Customization gives the ability to make the detecting layer as big or small as needed depending on the size of the wearable. In addition, the material that is used to act at the conductive layer for capacitive sensing is versatile. For example, simple copper plating can be the conductive or conductive yarn stitched onto a textile. In other words, the technique can be customized which gives more flexibility to the design of the wearable.

Thirdly, the accuracy of the technique is important for this prototype. The importance of accuracy is the main goal for detecting the touch because the prototype should be able to detect the unique touch pattern from the user. Based on the multi-touch kit, the accuracy of the technique is very good as the technique was able to detect all the touches [61]. As a result, the multi-touch kit has shown to be accurate enough to detect the unique touch patterns for this project.

In summary, the multi-touch kit is perfect for this project. The rapid prototyping capability, customization, and accuracy of the technique make it possible to detect unique touch patterns in a simple way, as well as, customize the interface to fit the wearable. In conclusion, the multi-touch kit will be integrated into the wearable and will be the main method of detecting touch patterns.

How does it work?

The multi-touch kit works based on capacitive sensing technology and uses a range of frequencies to achieve actual readings of the touches from humans. Multi-touch uses frequencies from 100 kilohertz to 40 megahertz because the electric fields around the human body act like a quasi-static near field [61]. This allows for the multi-touch kit to use projected capacitive sensing with a transmit+receive mode. In other words, the transmitting signal sends a signal in the megahertz range. This creates a quasi-static electric field that allows strong capacitive sensing reading from the transmitting, human touch, and the receiving electrode. A visualization of the electrodes is shown in figure 5.14.

In addition, since the propagation of electrical signals in the defined frequency range is better for the human body than through other mediums like water, a touch from a human increases the amplitude of the receiving electrode. Pairing this with an SNR (signal-to-noise ratio), a microcontroller like an Arduino or esp32 can capture the reading [61]. In short, the multi-touch kit works using capacitive sensing technology and taking advantage of the quasi-static field of the human body when an electrical field is produced between the frequencies of 100 kilohertz to 40 megahertz. As a result, the multi-touch kit will be the technique used to capture the touch of the users and send over the unique touch pattern to the other wearable device.

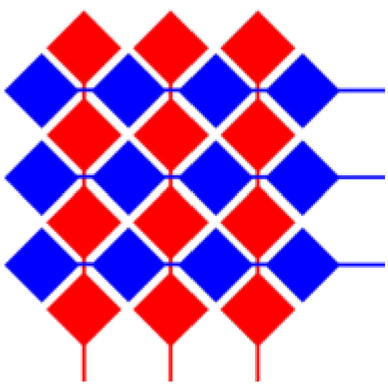

Figure 5.13: Blue is the transmitting electrode, red is the receiving electrode [61]

5.6 Wearable

In section 5.3 Communication, 5.4 receiving haptic stimulation, and 5.5 transmitting a touch have determined the components needed to detect, communicate and transmit touch; the final part is integrating these components into a wearable. The type of wearable chosen will be a series of velcro strips attached to a custom 3D printed cover.

Velcro strips are used as it allows the user to adjust the size of the wearable, so it fits the user's arm size. In addition, it allows the user to put on and take off the wearable with ease. Using velcro strips allows for easy use for the users and makes it comfortable for the user to wear.

In addition, a custom 3D printed cover is used to make sure that the vibration motors are precisely 4 cm apart and make them hidden to the user. As well, ensure that the motor is correctly touching the skin of the user. Furthermore, the custom print will allow the electronics to be hidden within the custom print. As a result, the custom-built cover will be used to ensure that all the electronics are integrated and hidden from the user.

5.7 Conclusion

In this chapter, the components needed to make the haptic wearable for affective mediated touch have been elaborated and discussed. Specifically, a haptic wearable that simulates a gentle stroke from a significant other over the internet supports emotional intimacy for couples. With this information gathered from this section, the fourth sub-question can be answered: What components are needed to design a non-invasive haptic wearable for affective touch?

Three components are needed to realise a haptic wearable to mediated affective touch: input, output, and communication are needed between the two wearables. Firstly, input, or the multi-touch kit, will be used to detect the unique touch pattern of the user. Once the user finishes his/her movement, it will process the data and send the stroke measurement to the other wearable. Secondly, the output, or the vibration motors, are implemented into the wearable to simulate the gentle stroke produced from the other wearable. This is done by using the tactile brush algorithm, haptic motor drivers, and vibration motors. The tactile brush algorithm will then process the data from the input and recreate the gentle stroke with the vibration motors. Thirdly, the two wearables have to be able to communicate through the internet. This is done by using an MQTT server that automatically connects the two wearables. Finally, these three components together can produce the wearable to communicate gentle stroke through the internet. With each of the component discovered, the haptic wearable for affective mediated touch prototype can be built. The realisation of this prototype is discussed in chapter 6: Realisation

Chapter 6

Realization

Based on the components discussed in the previous chapter, the haptic wearable for affective mediated gentle stroke can be constructed. The goal of this chapter is to explain how the components are implemented into the haptic wearables.

6.1 Setup of Multi-Touch Kit

The multi-touch kit component is going to be the component that detects and transmits the unique touch pattern. Two parts are required to build the component. These components are hardware configuration and software implementation. Once the software and hardware are correctly configured, this component will be completed, and in the next stage, communication can be constructed.

First, the hardware part of the component is constructed. Constructing the multi-touch kit required an Arduino, multiplexer (CD74HC40671) and six 100k ohm resistors. The hardware setup can be seen in figure 6.1. In addition, a series of copper strips is also created in a six by six grid. The final result of the hardware setup for this component can be seen in figure 6.2.

Second, the software part of the component was put together. There were two parts to the software that were being able to read the values and determine the user's stroke. A library was used to detect these touches provided by the authors of the multi-touch kit paper [61]. Once implemented and uploaded to the Arduino, the multi-touch kit system was working perfectly. The Arduino was able to pick up the touch of the user when touching the copper strips.

The next step was to determine the movement of the touch when the user was interacting with the conductive layer. The idea was to record the first spike and the last spike and map those values to a 3x4 grid. This spike happens when the user touches the conductive layer, and since a stroke can be calculated by a start and endpoint, all that was needed was to record the first and last spike. However, it became a challenge since the library would print to the serial and not store the values in an array. Thus, changing the library to output an array of strings was necessary. After the necessary changes were made with the library, other problems occurred. Problems with the sensitivity of the conductive layer and Arduino software language are limited to processing arrays of strings. The conductive layer would take 10 mins to calibrate, and finding a way to process the data coming from the readers was too slow or would crash the Arduino. Furthermore, time was an important factor in continuing with this method to detect unique touch patterns. As a result, another approach was taken to detect unique touch patterns from users, which will be mentioned in the following sub-section: Touch Screen detection.

In the end, the multi-touch kit hardware implementation worked. In addition, the software could read the incoming signals from the conductive layer with some degree of accuracy. However, since time was becoming an issue to fix the two major problems of detecting the start point and endpoint and the lack of accuracy, an alternative method was simple to this technology. As a result, the multi-touch kit was not used in the final prototype.

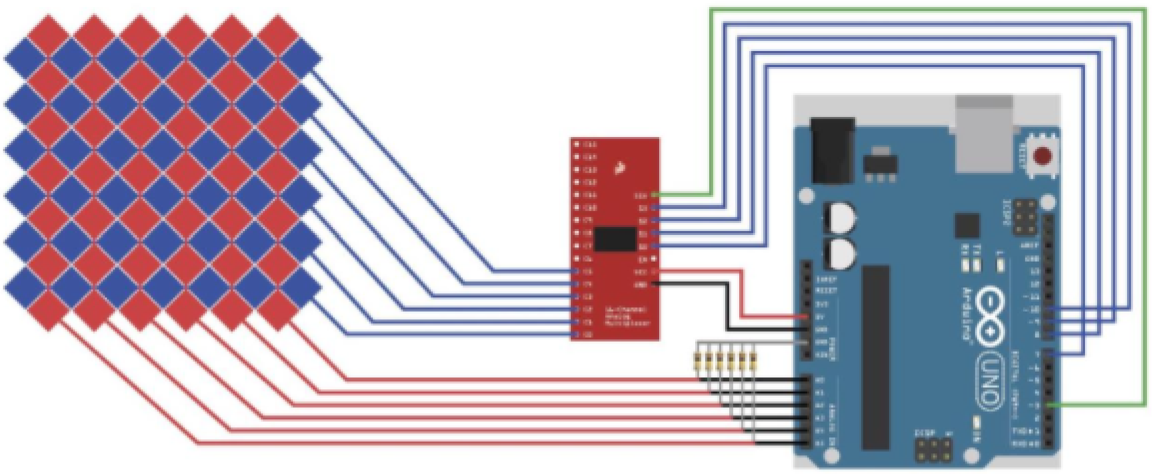

Figure 6.1: Hardware Setup for Multi-touch Kit [61]

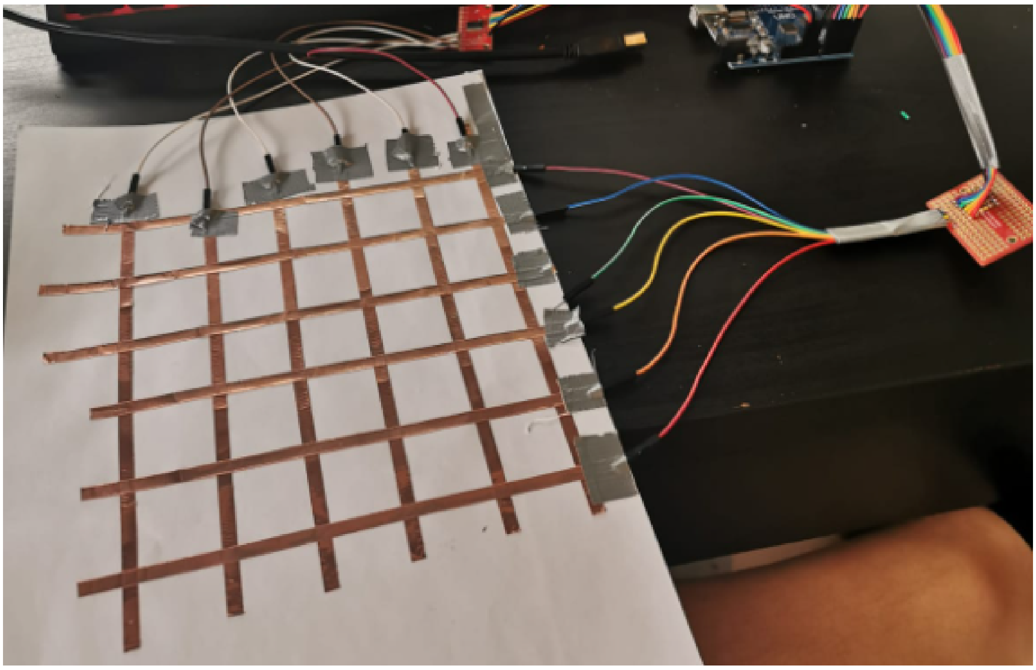

Figure 6.2: Hardware component for multi-touch kit

6.1.1 Alternative to Multi-touch kit

The alternative for the multi-touch kit was a smartphone with a touchscreen. There are several reasons why this was the best alternative for the multi-touch kit. These reasons are hardware implementation, software capabilities and efficiency implemented into a wearable device. Since a smartphone has internet capabilities implementing the MQTT service is possible. In addition, the smartphone has a touchscreen which is very accurate to detect human touches anywhere on the screen.

Second, a smartphone has the processing capabilities to read the touches from the touchscreen and process the data to find the start point and endpoint of the unique touch pattern the user is creating on the screen. Thus, a user-friendly application is created that allows the user to draw on the screen within a 3x4 grid. This application interface can be seen in figure 6.3. In addition to drawing the line, the software also reads the first point of touch and the last point of touch to produce a straight line from the startpoint to the endpoint based on the user input. As a result, this worked very well and accurately detected the user's unique touch pattern.

Lastly, a smartphone is easily implemented into a wearable device. Since smartphones are not that big and wearables exist globally for smartphones to be placed onto the forearm. This can be seen in figure 6.4. As a result, the smartphone was the best alternative to the multi-touch kit because of the implemented hardware, software capabilities, and the smartphone can be easily implemented into existing wearable devices.

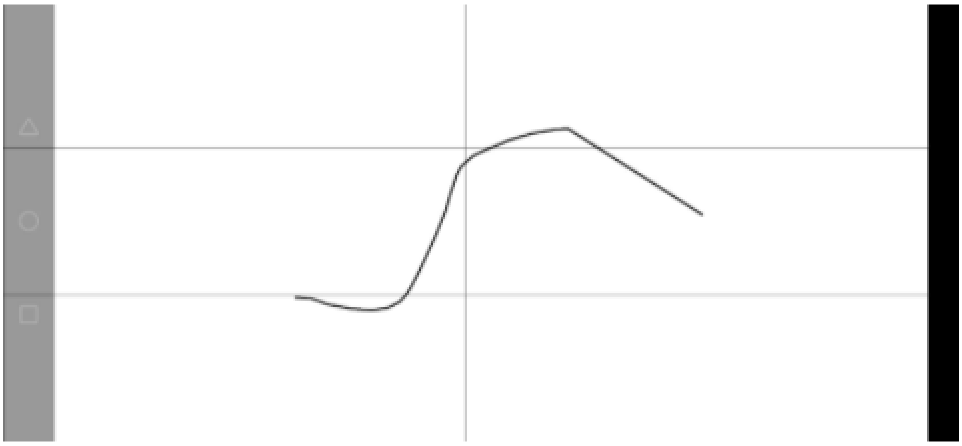

Figure 6.3: UI of the smartphone application

Figure 6.4: Wearable shelvee for smartphone

6.2 Setup Communication

The MQTT component will serve as the communication service between the wearables. The MQTT required three steps to set up correctly. The first step is to get a server that could be accessed through the internet. The second step was to set up the MQTT service on the server. The last step is to run an initial test to test whether the MQTT service was working correctly. Altogether, the communication would be set and ready to be used for commuting touch over the internet.

The first was to get a server that was accessible through the internet. The service used to get the server was a company named digital ocean [62]. This company gives the option for low-cost Linux servers that are used for web-hosting or storing data. Using software called MobaXterm, it was possible to remotely connect to the server and upload files, code and install tools [63]. With this server and the tools to interact with the server, the next step was to turn this empty server into an MQTT server.

The second step was to set up the MQTT service on the server. This was done by using mosquitto software. Mosquitto is popular software that allows users to set up MQTT service onto computers or a server. To set up the software, all that is needed to be done is installing the mosquito software and then installing it. After the installation was complete, the next step was to do an initial test.

The final step was to do an initial test of the MQTT. This was done with a laptop and the server. The laptop was connected to the home network with a python script that would subscribe to the “deviceOne/line” topic. Whereas the server would publish “1,3,4.5,1,1000” to the topic “deviceOne/line”. The publish message is an example of the message that would be sent between the wearable device. Where (1,3) is the start point, (4.5,1) is the endpoint, and 1000 is the stroke duration. This initial test can be seen in Figures 6.5 and 6.6. As a result, the communication component was working between two different device

```
root@haptic-MQTT:~# mosquitto_pub -h localhost -t "deviceOne/line" -m "1,3,4.5,1
,1000" -u "hoekje" -P "haptic"
root@haptic-MQTT:~#
```

Figure 6.5: Server Publishes Message

```
Connected with result code 0
b'1,3,4.5,1,1000'
1,3,4.5,1,1000
Connected with result code 0
```

Figure 6.6: Laptop Receives Message

6.3 Setup of Vibration Motor

The vibration motor component is the component that will produce the gentle stroke that it receives from the MQTT server. This component is split up into three parts, hardware, software, and 3D mounts. The hardware is about the physical components needed to control the twelve motors and each motor intensity at certain times. The software is about implementing the tactile brush and how to send commands to the motor drivers. Lastly, the 3D mount part is how each of the hardware components is placed on the user's skin. Each part is crucial for this component to produce a gentle stroke on the user's forearm.

6.3.1 Hardware

The hardware is about the physical components used to create tactile feedback for the users. The hardware components used are twelve drv2605L, twelve vibration motors, raspberry pi, a power source of 5V and 5 amperes and two tca9548a i2c multiplexers. The schematic for this component is shown in figure 6.7. Furthermore, the integration of each hardware component is discussed.

As mentioned in 5.4.5: Haptic Motor Controller, this driver (drv2605L) will control the vibration motor to control the intensity. In addition, the driver uses I2C protocols to communicate with the raspberry pi. However, during the construction of the hardware, a problem occurred. The problem was that drv2605L had a fixed address "0x05a".As mentioned in section 5.3.3: I2C protocols, each component must have an unique address to distinguish each drv2605L driver from the other. In other words, the raspberry pi did not know which drv2605L driver was which, and without this, there was no way to communicate which motor had to turn on.

However, the solution was to use a tca9548a i2c multiplexer, which would manage the I2C communication for the raspberry pi [62]. The tca9538a distinguishes each drv2506L driver making it possible to communicate to each vibration motor. In addition, since two multiplexers were used, each needed a different address labelled in figure 6.7. Changing the multiplexer address is simply supplying 5V to the A0 port, changing the address from 0x70 to 0x71.

Also, since there is quite a bit of electronics and motor in this wearable, a suitable power source is required. Every hardware component runs on 5 volts. A power source of 5V and 20amps is more than sufficient to run the entire wearable with this knowledge. Each electrical component needs to receive 5V power to ensure this everything is in a parallel configuration.

As a result, the hardware setup for this component is complete. The haptic motor drivers control the vibration motors' intensity, multiplexer allows the raspberry pi to distinguish between each motor driver, and finally, the power source to supply enough power to run the entire wearable. These hardware components will be used to produce tactile feedback from the MQTT server.

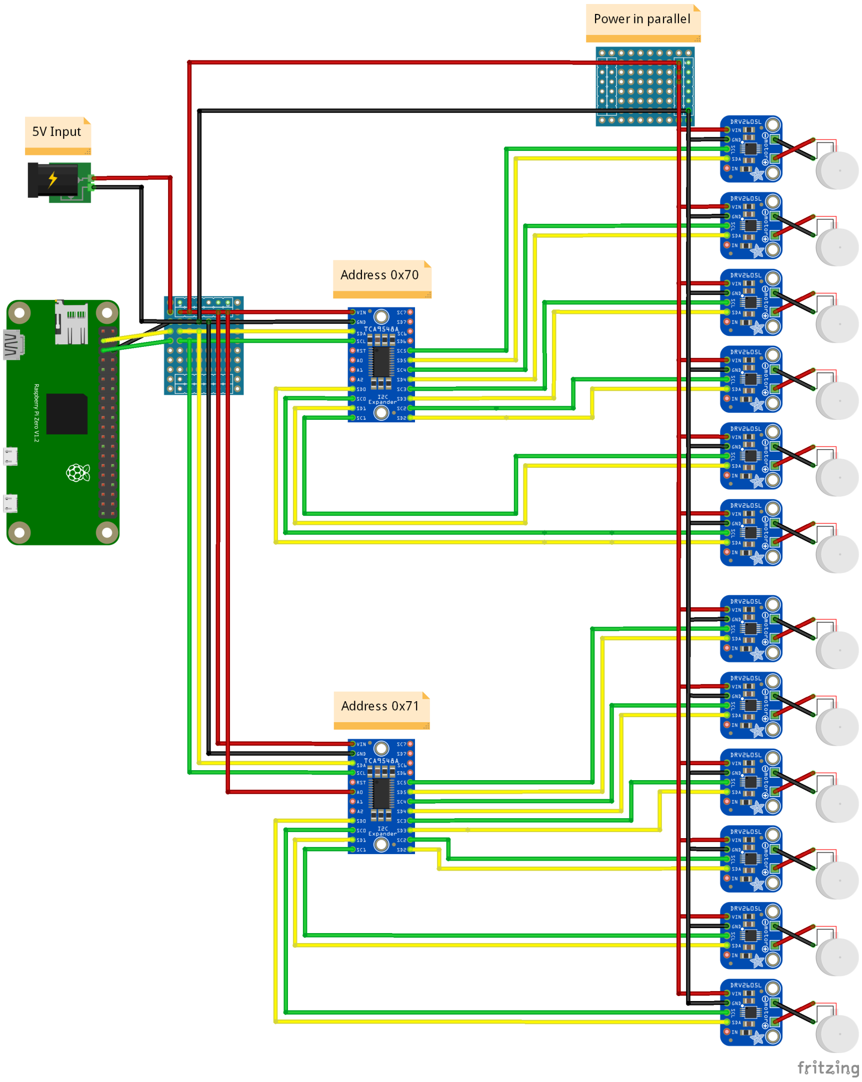

Figure 6.7: Schematic of vibration motor component to produce tactile feedback. Red: power, Black: Ground, Yellow: SDA, Green: SCL

6.3.2 Software

The software for the vibration motor component is the software to receive the data from the MQTT and produce tactile feedback. The software can be split into two sections, tactile brush algorithm and haptic motor driver control. These two parts are crucial for this component and both shared problems during the building process

Tactile Brush Algorithm

The tactile brush algorithm is formed using four classes: the stroke, tactile brush, actuator, and actuator step. The stroke and tactile brush classes handle the computations that are involved with the tactile brush algorithm. Actuator and actuator step class being the classes that represent the virtual and physical actuators of the prototype.

First, the incoming input from the MQTT server arrives. The input data from the server informs the software of the start point, endpoint, and the duration of the gentle caress that the user detected. This data is then sent to the stroke classes to compute the first three steps of the tactile brush algorithm.

Secondly, the stroke class computes the first three steps of the tactile brush algorithm. As mentioned in 5.4.4, the tactile brush algorithm has four steps involved: compute virtual points, compute stroke speed and time, calculate the duration of SOA for the apparent motion illusion, and finally map the physical actuators to the virtual ones. The first three steps of the algorithm are computed in the stroke class, which can be found in appendix B. After the computation, a list of the virtual actuator with each virtual point stores the location on the grid, intensity, start time, and duration.

Lastly, the final step of the tactile brush algorithm is computed in a separate class named the tactile brush class, found in appendix B. The final step is to map the list of virtual actuators with the list of physical actuators. After this step is complete, the final step will produce a list of physical actuators that need to be turned on to create a gentle caress on the user's skin. This list contains the start time in milliseconds, the intensity between 0-1, duration in milliseconds, and motor defined by a haptic motor class seen in appendix B. As a result, the output of the tactile brush algorithm is a list of actuator steps to create a gentle caress on the user's arm.

Haptic Motor Control

The haptic motor control is the part of the software that communicates and controls the haptic motor drivers, which those drivers control the vibration motors placed on the user skin. The two components involved in the haptic motor control are the multiplexer library and the haptic motor library. The multiplexer library was simple to implement and use. The library would return a list of connections with an address that was connected to the multiplexer. This list of connections would give the software the capability to distinguish each driver.

Furthermore, once the software could distinguish between the drivers connected to the raspberry pi, the next step is to control the vibration motor intensity and turn it on or off. To control the vibration motor required to set the haptic motor drivers into real-time mode. The real-time mode would allow the software to send an intensity to the haptic motor drivers using I2C protocols.

After, the modes were changed, and the haptic motor drivers were ready to receive data from the raspberry pi. This is done by sending an integer between -127 to 127 because the haptic motor driver changes the intensity and direction based on an amplitude of a sine wave. Values between 0 to -127 the motor will spin in the other direction than a value from 0 to 127. However, since the direction of spin of the motor is not important only values between 0 to 127 are used. As a result, when the list of physical actuators has an intensity of 0.5, the software will convert the value by multiplying 0.5 by 127 for the haptic motors.

6.3.3 3D Mount

The receiving gentle caress final components are the 3D mounts used to hold the haptic motor drivers and vibration motors. 3D mounts can be seen in figure 6.8, where the haptic motor is placed on top with a small hole for the wires of the vibration motor to go through. The vibration motor has very poor quality wires attached to the coils of the motor. Thus, a 3D mount that would hold the vibration motor in place would make sure that the motors wires would break. In addition, the 3D mount has two holes on the side for velcro strips to go through to make it easy to implement the mounts into a wearable device. As a result, the 3D mounts were created to ensure the electronic and motors wires would break and make the electronic easily placed on the user.

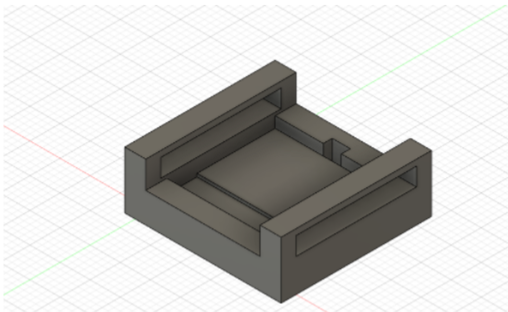

Figure 6.8: 3D mount for vibration motor and haptic motor driver.

6.4 Setup of Prototype

Each component has been developed, the sending and sensing, communication, and the vibration motor. The next step is to create a wearable for the sending and sensing and the vibration motor and use the communication protocol to communicate touch between the wearables. Two separate wearables are being made because of the user testing discussed in chapter 7: evaluation. After the components are put together, initial testing with the wearables can be done to check for any bugs or performance issues.

First, putting the components together, the communication link between the components has to be implemented. This was done using the MQTT libraries that are most common with the language that the component is using. For example, the sending and sensing component is made in processing so a library [63]. In addition, a library was used for the receiving component as well [64]. Once the communication component was implemented into both wearables, the next step was to make the two components into wearables.

Next, the two components had to be implemented into a wearable. The first component to implement into a wearable was the sending and sensing component. This wearable only required a running armband that could hold a smartphone, as shown in figure 6.9. In addition, the receiving component was also implemented into the wearable by using velcro strips, as shown in figure 6.9. Therefore, the prototype for this project was ready for initial testing.

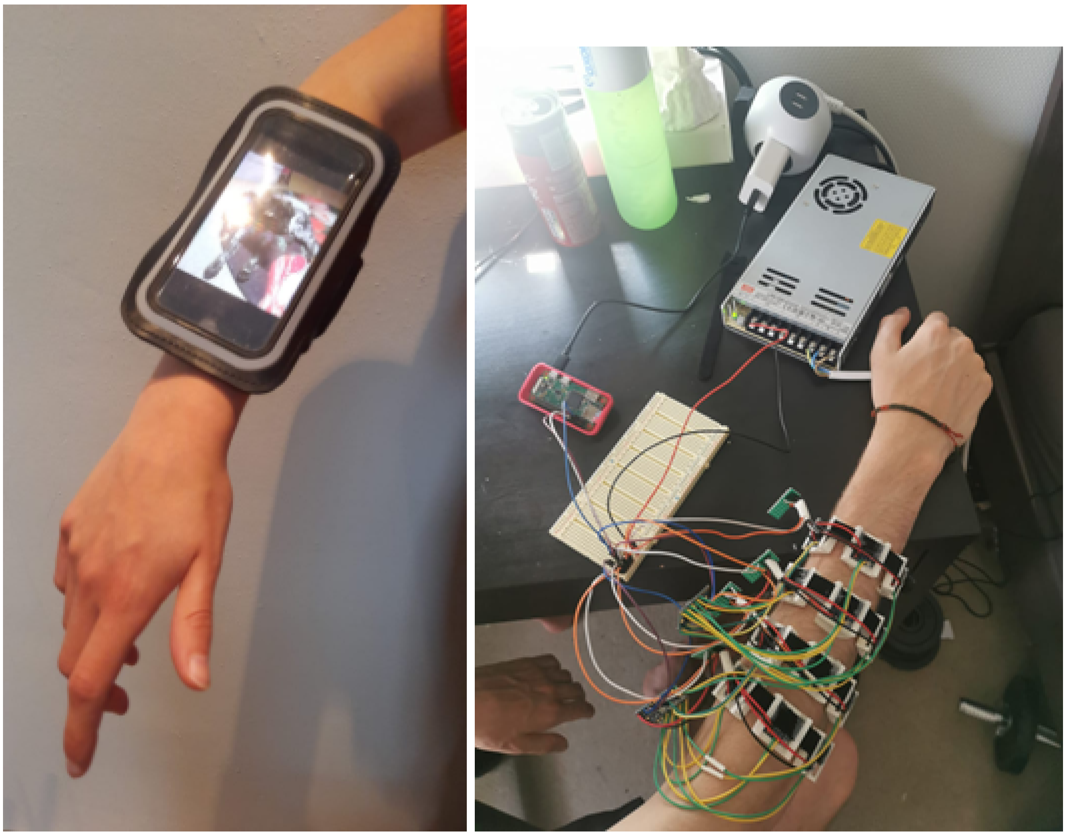

Figure 6.9: Prototypes for the project

6.5 Conclusion

The goal of this chapter is to explain how the components are implemented into the haptic wearables. In addition, how each component of the prototype was developed and implemented. The sending and sensing component uses a smartphone to detect the gentle caress and then sends it over the communication component. This communication uses the MQTT protocol to send and receive the start point, end-point, and duration of the gentle caress to the components. The other component being the receiving component. The receiving component receives the gentle caress and uses the tactile brush algorithm and haptic motor drivers to reproduce the gentle caress onto the user's arm.

Furthermore, initial testing was conducted to indicate any bugs or performance issues that might come up. The initial testing was done by placing the wearable on the researcher's arm, and gentle caresses were sent from a smartphone with the sensing and sending component. As a result, the initial testing showed no problem in the system, only some minor changes in the intensity of the vibration motors to make it more comfortable to feel on the skin. In conclusion, the initial testing and all these components together form the prototype wearables used to support emotional intimacy for couples in long-distance relationships.

Chapter 7

Evaluation

This chapter's main focus is on evaluating the prototype's performance of the wearable by simulating a gentle caress on the forearm of the user during a video call. However, before the test can be conducted, ethical permission from the university ethical committee was required. After the university gave ethical approval for the user test, the requirements from chapter 5 are evaluated. The functional requirements are evaluated first with a user case study. After that, the system requirements are evaluated by the researcher and the user case study.

7.1 User Evaluation

The goal of the user evaluation is to evaluate the user experience with the wearable and whether it meets the intended purpose of the wearable. The evaluation is made up of several factors: The performance of the design and user satisfaction. The user evaluation goal is to evaluate the functional requirements mentioned in section 5.1.2 in chapter 5: Specifications. These requirements are:

- Make video calling more pleasant experience
- Simulate a pleasant caress
- Support emotional intimacy between the partners.
- Be intuitive to use
- Be non-intrusive

7.1.1 Participant

The user evaluation had a total of 4 people, or in other words, two couples. Only adults who were capable of giving consent were selected. As well, participants had to be in a long-distance relationship to take part in the study. Besides these requirements, participants had no other restrictions or requirements to participate in the user case study.

7.1.2 Data Collection

During the user case study, observational notes were taken from the video footage that was recorded. In addition, participants were asked to answer questionnaires at the end of the testing phase. This data will then be analyzed to evaluate the prototype performance.

7.1.3 Procedure

The user case study is in three phases. The first phase is the participant is informed about the wearable. The second phase is the participant starting a video call with their significant other and performing various actions on the wearable during the video call. The third phase is the participant being asked to fill in a questionnaire collected after the user case study is complete.

Phase 1

In the first phase, the participant is informed about the wearable, and the researcher will help one of the participants put on the receiving wearable because it is difficult to put it on by the participant. In addition, the participant will be asked to read the brochure that is provided, which explains the background, purpose of the study, and information about the study. The brochure can be seen in Appendix C.

After the participant has read the brochure, the participant is also asked to sign the consent form. Once the participant has given consent, the context of the haptic wearable is explained to the participant. This is done because the idea of how affective mediated touch is perceived would depend on how the participant uses the wearable. The context is as followed:

In a long-distance relationship, physically apart resulting in a lack of affective touch, touches like hugging or a gentle caress. Thus, a lack of emotional intimacy. This means that many affective touch interactions are not possible. For example, a gentle caress on the forearm. A gentle caress is a very pleasant touch that couples would often do to each other to show affection or closeness. However, this becomes a rarity in a long-distance relationship. For this reason, a haptic wearable was developed. The haptic wearable will simulate a gentle caress between the couple, allowing the participant to gently caress their significant other while still in a long-distance relationship.

Before the second phase, the participant is asked whether they have questions or objections regarding the user case study

Phase 2

In the second phase, the participant will be using the wearable during the video calling. During the user testing, a video will be recorded of the participant. This is done so that the research can focus on the user test and analyze the recorded data afterwards. The receiving wearable will be worn by the participant who is at the testing area, and the other participant will receive an android application through email. The participant can then download the sensing and sending the component onto his/her smartphone. Afterwards, the participant can send a gentle caress to the other.

First, the researcher will help the participant to put on the wearable device. When the participant has put the wearable on correctly, the participant is asked to video call his/her significant other using a video calling software and then asked to perform a series of tasks:

- Turn the wearable on
- Send a mediated gentle caress to the other wearable

Once the participant has completed the task, they can play around with the wearable for a maximum of 5 minutes. After these 5 minutes, the participant is asked to conclude the video call, and the researcher will help the participant take off the wearable device. Now that the participant has taken off the wearable phase, three begins.

Phase 3

During this phase, the participant is asked to answer a questionnaire about their experience with the two wearables. The questionnaire is split into four parts: intimacy, experience, transmitter, and receiving. In addition, some questions on the questionnaire will ask the participant to elaborate on their answers to understand the problem, performance and improvements of the prototype. The questionnaire that was used during the user case study can be found in Appendix D.

First, the intimacy part of the questionnaire aims to understand the dynamic of the relationship. For example, ”how often do you caress your significant other”. These questions help to understand whether a gentle caress is a preferable mediated affective touch. Furthermore, this section covers information about how close and connected they feel with their partner. For example, ”how close do you feel to your significant other?” This question would provide a baseline to help evaluate the wearable.

The second part of the questionnaire is the experience with the wearable. This part of the questionnaire goal is to evaluate whether the overall experience with the wearable was the desired experience intended for the wearable. These questions help gather information about the performance of the wearable and are the questions that will help evaluate whether the functional requirements were met.

The third part of the questionnaire was the transmitter wearable. Only participants that used the transmitter wearable were allowed to answer these questions. These questions would ask about the performance, ergonomics, and a comparison to performing to an actual gentle caress of the transmitter wearable.

The fourth part of the questionnaire was the receiving wearable. Only participants that used the receiving wearable were allowed to answer these questions. These questions would ask about the performance, ergonomics, and a comparison to producing an actual gentle caress of the receiving wearable. In conclusion, these four parts of the questionnaire will help answer the requirements mentioned in chapter 5: Specification.

7.2 Result

A complete list of the user evaluation result can be found in Appendix E. These results show the requirements mentioned in chapter 5: Specifications can be evaluated.

7.2.1 Intimacy

All participants answered that they use video calling as a method of communication between their significant others. In addition, all participants would caress their partner quite often, and all participants felt very connected with their partner. These results give a good baseline on how to compare the wearable effectiveness of supporting emotional intimacy. Furthermore, meditating a gentle caress during a video call was a good option because all participants used video calling methods and performed gentle caress quite often. In conclusion, a baseline has been set to compare the wearable experience during a video call and mediating a gentle caress was an excellent option.

7.2.2 Transmitting Wearable

This section evaluates the performance of the transmitting wearable. All participants that used the transmitting wearable found that the wearable was very comfortable. Furthermore, participants found that their unique touch pattern was being detected quite accurately and easy to use. However, most participants were disappointed that they could not make more complex touches like a heart shape or figures. Also, the wearable could have used a bit more user interface to help the participant understand the wearable abilities. Overall, participants did enjoy using the wearable.

7.2.3 Receiving Wearable

This section evaluates the performance of the receiving wearable. All participants that used the receiving wearable enjoy the sensation that was being created from the wearable. However, many participants agreed that the wearable did not feel like a real-life gentle caress on the skin. Furthermore, most of the participants were disappointed by the lack of movement they could do while wearing the wearable because of the number of wires. Overall, participants really did enjoy the experience with the wearable.

7.2.4 Overall Experience

Overall, the participants had an enjoyable experience interacting with the wearables. There were mixed results among the participants whether they would use the wearable again during a video call. Most of the participants explained that the wearable was enjoyable and it was nice to have this tactile feedback, but it did not feel like an actual gentle caress. Furthermore, most participants did not feel a significant change in their connectedness with their significant other. In addition, participants describe that they did like the experience of these touches with their significant other, but it did not feel intimate. However, participants did agree that the experience with the haptic wearable was enjoyable and would use the wearable again with some improvement.

7.3 Conclusion

The evaluation chapter aims to check whether all the requirements mentioned in chapter 5: Specification were met. Functional requirements are based on the results from user evaluation. The systematic requirements are based on the user evaluation as well as the researcher.

7.3.1 Functional requirements

The determination of the functional requirements is based on the findings done in the user evaluation. The following table is designed to evaluate to what extent each functional requirement was met.

- 4 - Requirement is fully met
- 3 - Requirement is most
- 2 - Requirement is partially met
- 1 - Requirement is not met

Haptic feedback wearable should be able....	Comment	Grade
Support emotional intimacy between the partners.	Most participant found the experience to be pleasant and enjoyable, but not all would use it again	2
Simulate a pleasant gentle caress	Participants did enjoy the sensation created by the vibration motor and detected by the smartphone. However, it did not feel like a real-life caress	3
Be non-intrusive	The wearable for the vibration motors wasn't easy to wearable because of the amount of wires. Also took a while to place onto the user arm.	2
Be intuitive to use	Almost all participant find it easy to use, but some participant found to difficult to start off	3
Make video calling a more pleasant experience	Most participant did enjoy the wearable during the video call, and some could see other placement for the wearable during a video call	3

Figure 7.1: Prototypes for the project

Overall, most of the functional requirements were met. The two requirements that were not met were the wearable being non-intrusive, and supporting emotional intimacy between the partners. Participants mentioned that the hold experience was enjoyable and had a fun time. However, all participants did mention at some point that it was not an intimate experience rather a more enjoyable experience. As a result, this requirement was not fully met.

In addition, the participant that wore the receiving wearable felt that the wearable was a bit uncomfortable at some stage during the user case study because of the lack of movement. This is due to the wearable having a lot of wires and that the connection between the wearable and the power supply was short. Also, the wearable tightly fit the user arm to ensure that the vibration motor had contact with the skin. As a result, this requirement was not fully satisfied.

Moreover, the three requirements that were met mostly were to simulate a pleasant gentle caress, be intuitive to use and make video calling a more pleasant experience. All these requirements were met to a degree, some participants mentioned some problems. For example, there were alot of mixed results with making video calling a pleasant experience. All participants agreed that it was an enjoyable experience and that it added a bit more sensation to the video calling experience. One participant mentioned that it distracted them because it was a new device and they were excited to test it out. However, most participants mentioned that they would not use the device every single time they would video call. This is due to the fact that it felt more like an activity for the participant than an addition to their normal video calling.

In addition, the requirement for simulating a pleasant gentle caress was also met to a certain degree. Most of the participants could feel the unique caress being sent by their significant other. However, it did not feel exactly like a caress the participants would receive from their significant other if they were together in the same room. This is due to the limitation of the technology, although it is quite close to a real caress, most participants would prefer a real caress from their partner. As a result, this requirement was met to a certain extent.

7.3.2 Systematic requirements

The systematic requirements are the requirements that the prototype should be able to perform. This is done with the results from the user evaluation, as well as the researcher. The systematic requirements are described in chapter 5: Specification.

The haptic wearable should..	Comment	Grade
Be integrated into a wearable	All components were in a wearable, however the power supply was not attached to the wearable	No
Be able to send touch over the internet	The wearable was able to send touch over the internet	Yes
Be able to detect touch patterns	The wearable was able to sense the touch being applied the user	Yes
Be able to receive information from the internet	Within a second the wearable was able to get data from the MQTT server	Yes
Be able to reproduce a gentle caress	The wearable was able to use the tactile brush algorithm to produce a gentle caress onto the user arm	Yes

Figure 7.2: Prototypes for the project

All systematic requirements of the haptic wearable were met, except for the one requirement. Being able to integrate the components into a wearable. Currently, most of the components are integrated into a wearable, but the power supply is not integrated. However, with a power bank this can be easily solved. Furthermore, the components could be implemented better into a wearable because the wearable is now covered in wires and exposed electronics. As a result, the only systematic requirement that was not met was being able to integrate everything into a wearable.

Chapter 8

Discussion and Recommendation

This chapter focuses on the recommendations for the continuation of the project. Some additions or changes to the prototype can be made to improve the performance and user experience further.

After completing the prototype for this bachelor project for affective mediated touch, some recommendations would help further improve the design of the prototype. The prototype has been user-tested. The results are used to create several recommendations for further versions of the prototype for affective mediated touch.

8.1 Unique Touch Drawings

Firstly, many participants found that a simple straight line as a gentle caress was not as fulfilling. Currently, the participant would draw a line, and the software would compute the start and endpoints to create a straight line for the algorithm to compute the gentle caress. However, participants recommend having the wearable produce these gentle caresses in weird shapes. For example, a participant wanted to make a heart so that their significant other could feel the heart drawing onto the skin. This would be an elegant improvement for the wearable as it gives the user the ability to send more complex touch patterns.

8.2 Wearable

Secondly, the two wearables should both have the ability to send and receive gentle caress. This is so that the users can communicate touch with each other instead of only being one-way. In addition, the components should be integrated better into a wearable. For example, the receiving wearable is covered in wires and looks aesthetically pleasing to the user. In addition, the wearable should be battery-powered instead of being powered by a power supply. These recommendations would improve the wearable performance and user experience.

8.3 Implement Multi-Touch Kit

Thirdly, implement the multi-touch kit that was mentioned in chapter 5: Specification. Although, it caused some problems initially because of the sensitivity of the capacitive sensing and processing. However, these problems can be resolved and make the wearable not depend on a smartphone to work. In addition, the drawing of the gentle caress would feel more real than drawing on a smartphone.

8.4 Further Testing

Lastly, since the testing of this prototype was only two couples. Further testing would be an excellent recommendation to get more data about the performance of the prototype. Since the result for only two couples cannot represent the target population for this project. Further testing would provide more detailed information about the performance of the wearable and its ability to support intimacy for couples in long-distance relationships.

Chapter 9

Conclusion

The aim of this bachelor project was to design a haptic wearable for affective mediated touch. In the introduction of this report, the main research question was formulated. The goal of this chapter is to answer the main research question.

How can we design a haptic wearable to support emotional intimacy for people in a long-distance relationship?

In addition to the main research question, a sub-question was made to help answer the main research question. The first sub-question.

SQ-1: What are the most effective type of haptic feedback for communicating affective touch over long-distance?

This sub-question was answered in chapter 2: State of the Art. A literature review was conducted to answer the sub-question about the most effective type of haptic feedback. The aim was to discover the effective type of haptic feedback for communicating affective touch. The research shows that using a cutaneous system with a combination of actuators is most effective when communicating affective touch. Furthermore, it shows that when designing a haptic system, it is important to use actuators that feel natural and comfortable for the participant. However, other factors influence the effectiveness of the feedback. For example, the feedback location would significantly affect the type of feedback that would be used. The location would be determined by the relationship between the participant and the guidelines that designers developed. As a result, the most effective type of feedback would be vibrotactile feedback on one of the users' forearm.

After the first sub-question is answered, the next sub-question can be answered.

SQ-2: What is the state of the art for haptic wearables and mediated emotional intimacy over long-distance?

This sub-question was answered in chapter 2: State of the Art. The goal was to find standard design features and discover why the designers chose these features. For example, most of the wearables are designed for the arm of the participant. The reason is to do with comfort and convenience for the participant. As mentioned in section 2.2.5, the participant found that wearables on the wrist/arm found it more comfortable and convenient than other body locations. In addition, vibrotactile feedback was the most preferred method of conveying affective touch. Vibrotactile feedback, according to many designers and researchers they found that participants found vibrotactile to be more stimulating than other types of feedback. For example, in the study of Flex-N-Feel, the researchers proved that intimate emotions could be communicated over long distances. This is further proven in section 2.2.6, where they produce a gentle stroke, an intimate emotion with vibrotactile feedback. As a result, when designing a haptic wearable for couples in long-distance relationships, vibrotactile and wearable on the arm seem to give the best results for achieving this project goal. As a result, the based on the exiting products that vibrotactile and placing on the user's forearm would give the best results.

After the second sub-question is answered, the next sub-question can be answered.

SQ-3:How is effective touch communicated to support emotional intimacy?

This sub-question was answered in both chapter 2: State of the Art and chapter 4: Ideation. The question requires two parts to answer: affective touch and when the user communicated affective touch. The first part is to understand the sense of affective touch mentioned in section 2.1.1.1, which describes affective touch as a pleasant feeling when the hairy skin on humans is lightly touched. In addition, these light touches have been researched and shown that light touches or non-sexual touches have shown to support emotional intimacy. Furthermore, in chapter 4: Ideation, a mind map was created with possible interaction users with affective touch. For example, hugging and a gentle caress are very common affective touches and typically described as intimate interaction. The mind map showed that a gentle caress would be the best method of producing an affective touch because it was the most common interaction for couples to convey non-sexual intimacy. As a result, to answer the sub-question, a gentle caress anywhere on the body is the most common non-verbal method of conveying emotional intimacy.

After the third sub-question is answered, the next sub-question can be answered.

SQ-4: What components are needed to design a non-invasive haptic wearable for affective touch?

This sub-question was answered in both chapter 5: Specification. The question requires three parts to answer: What components are needed to design a non-invasive haptic wearable for affective touch? These parts are communication, receiving haptic feedback, and transmitting a haptic touch. The first part is communication. A communication method was needed to communicate the touch from one wearable to the other wearable. The solution for this was to use an MQTT protocol because the protocol was easy to set up, and the protocol is designed for a small amount of data to be transferred quickly. The second part was how to receive haptic feedback. This was done with two major parts: the tactile brush algorithm and vibration motors. Those two parts were used because the tactile brush algorithm is an algorithm designed to recreate gentle caress using an array of vibration motors. This is also why vibration motors are used, but they are also used because of the findings from the literature review. Which found that vibration motors were the more preferred method of feedback for touch. The last part was transmitting a haptic touch. This was done using an android smartphone since the multi-touch kit did not work in the end. The smartphone provides an excellent way for users to communicate their touches because the user is able to draw on the touchscreen, and the smartphone can read the touch and process the touch to send it over to the other wearable. In the end, the components that were used to create this wearable was the MQTT protocol, vibration motors, tactile brush algorithm, and a smartphone.

With all sub-question is answered, the main question can be answered.

SQ-1: What are the most effective type of haptic feedback for communicating affective touch over long-distance?

With the Creative Technology Design Process, a haptic wearable for affective mediated touch has been developed. The wearable can simulate a gentle caress on the user's forearm to support the emotional intimacy for their significant other that lives a long-distance away. Once the wearable was developed, testing was done with participants to check whether it was a pleasurable experience. The evaluation showed that most participants found the experience with the wearable during a video call very enjoyable. However, with the limited testing and the wearable only being a prototype, some improvements and more testing should be made when working on the haptic wearable.

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Appendix A

UML Flowchart

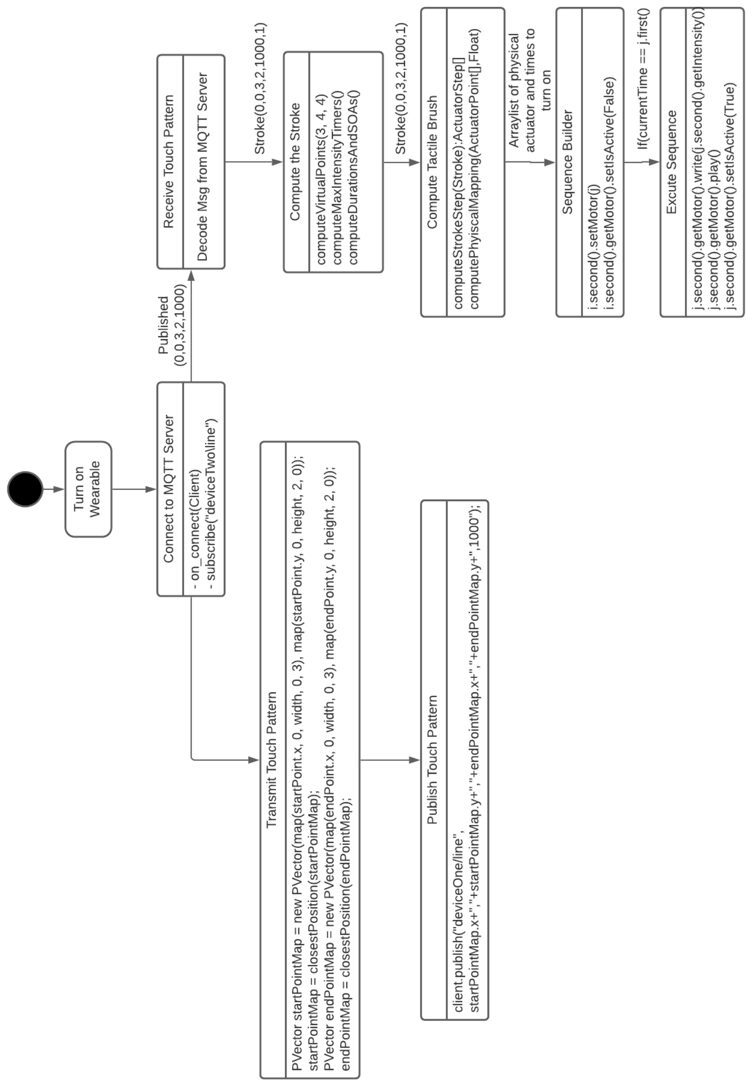


Figure A.1: UML Diagram to describe the interaction of the software

Appendix B

Code

```
import math
from ActuatorClass import ActuatorPoint, ActuatorStep
from Stroke import Stroke
from Pair import Pair

class TactileBrush:
    rows = 0
    columns = 0
    interDist = 0.0

    minCoord = ActuatorPoint()
    maxCoord = ActuatorPoint()

    actuatorTriggers = []
    computeStrokeSteps = []
    virtualPoints = []

    def __init__(self, rows, columns, distance):
        self.rows = rows
        self.columns = columns
        self.interDist = distance
        self.minCoord = ActuatorPoint(0,0)
        self.maxCoord = ActuatorPoint(self.columns * self.interDist,
            self.rows * self.interDist)


    def computeStrokeSteps(self,s):
        if(not(self.isPointWithinGrid(s.getStart()) and
            self.isPointWithinGrid(s.getEnd()))):
```

```
            print("Stroke start or end point out of grid range")
        self.virtualPoints = s.computeParameters(self.rows, self.columns,
            self.interDist)
        self.actuatorTriggers.clear()
        self.computePhyiscalMapping(self.virtualPoints, s.getIntensity())
        self.printArray()
        return self.actuatorTriggers

    def computePhyiscalMapping(self, virtualPoints, globalIntensity):
        for i in virtualPoints:
            if(math.fmod(i.getX(),self.interDist) < 0.001 and
                math.fmod(i.getY(), self.interDist)< 0.001):
                step = ActuatorStep(round(i.getX()/self.interDist),
                    (round(i.getY()/self.interDist)), globalIntensity,
                    i.getDuration(), i.getTimerMaxIntensity())
                self.insertActuatorStep(i.getStart(), step)
            # Virtual Actuator Phantom actuator
            else:
                l1 = 0
                c1 = 0
                l2 = 0
                c2 = 0
                if(math.fmod(i.getX(), self.interDist) < 0.001):
                    c1 = c2 = round(i.getX() / self.interDist)
                    l1 = math.floor(i.getY() / self.interDist)
                    l2 = math.ceil(i.getY() / self.interDist)
                elif(math.fmod(i.getY(), self.interDist) < 0.001):
                    l1 = l2 = round(i.getY() / self.interDist)
                    c1 = math.floor(i.getX() / self.interDist)
                    c2 = math.ceil(i.getX() / self.interDist)
                else:
                    print("Virtual Actuator at point:
                        "+str(i.getX())+","+str(i.getY())+ "is not on the
                        grid")

                #print(math.hypot(c1 - i.getX() / self.interDist, l1 -
                    i.getY() / self.interDist))
                #print(c1,c2,l1,l2)
                #print(math.hypot(c1-c2, l1 - l2))
                #print(math.fmod(i.getX(), self.interDist))
                #print(math.fmod(i.getY(), self.interDist))
```

```
            ratio = math.hypot(c1 - i.getX() / self.interDist, l1 -
                i.getY() / self.interDist) / math.hypot(c1-c2, l1 - l2)

            #float ratio = std::hypot(c1 - e.first / interDist, l1 -
                e.second / interDist) / std::hypot(c1 - c2, l1 - l2);
            phy1 = ActuatorStep(c1, l1, math.sqrt(1-ratio) *
                globalIntensity, i.getDuration(),
                i.getTimerMaxIntensity())
            phy2 = ActuatorStep(c2, l2, math.sqrt(ratio) *
                globalIntensity, i.getDuration(),
                i.getTimerMaxIntensity())
            self.insertActuatorStep(i.getStart(), phy1)
            self.insertActuatorStep(i.getStart(), phy2)


def isPointWithinGrid(self, point):
    if(point.getX() < self.minCoord.getX() or point.getX() >
        self.maxCoord.getX()):
        return False
    if(point.getY() < self.minCoord.getY() or point.getY() >
        self.maxCoord.getY()):
        return False
    return True

def printArray(self):
    for i in range(len(self.actuatorTriggers)):
        print("Time: "+str(self.actuatorTriggers[i].first())+", Physical
            actuator at column " +
            str(self.actuatorTriggers[i].second().getColumn())+
        " and row "+str(self.actuatorTriggers[i].second().getRow())+
        " triggered during
            "+str(self.actuatorTriggers[i].second().getDuration())+
        " with intensity
            "+str(self.actuatorTriggers[i].second().getIntensity()))


def insertActuatorStep(self, time, step):
    result = Pair(time,step)
    self.actuatorTriggers.append(result)
    if not result.second():
        result.first().append(step)
```

```
from ActuatorClass import ActuatorPoint
import math

class Stroke:
    startPoint = ActuatorPoint()
    endPoint = ActuatorPoint()
    startX = 0.0
    endX = 0.0
    startY = 0.0
    endY = 0.0
    duration = 0.0
    intensity = 0.0
    virtualActuators = []

    def __init__(self, startX, startY, endX, endY, duration, intensity):
        self.startX = startX
        self.startY = startY
        self.endX = endX
        self.endY = endY
        self.duration = duration
        self.intensity = intensity

    def getDuration(self):
        return self.duration

    def getIntensity(self):
        return self.intensity

    def getStart(self):
        return self.startPoint

    def getEnd(self):
        return self.endPoint

    def computeParameters(self, rows, columns, interDist):
        self.computeVirtualPoints(rows, columns, interDist)
        self.computeMaxIntensityTimers()
        self.computeDurationsAndSOAs()
        self.printArray()
        return self.virtualActuators
```

```
def printArray(self):
    for i in self.virtualActuators:
        print("Position: ("+str(i.getX())+","+str(i.getY())+"),
            triggered at: "+str(i.getStart())+" ms during
            "+str(i.getDuration())+" msec")
    print("----------------")


def printArrayTest(self, v):
    for i in v:
        print("Position: ("+str(i.getX())+","+str(i.getY())+")")
    print("----------------")
#   print("A Point: "+str(a.getX())+","+str(a.getY())+" Looking Point: "+
    str(b.getX())+","+str(b.getY())+" DiffX: "+str(diffX) + ", Cal:
    "+str(abs(diffX) < 0.001 and b.getY() - a.getY() > 0.001))
#   print("A Point: "+str(a.getX())+","+str(a.getY())+" Looking Point: "+
    str(b.getX())+","+str(b.getY()))
def cmp(self,a,v):
    checkList = []
    if(len(v) != 0):
        for b in v:
            diffX = b.getX() - a.getX()
            print("A Point: "+str(a.getX())+","+str(a.getY())+" Looking
                Point: "+ str(b.getX())+","+str(b.getY())+" DiffX:
                "+str(diffX))
            if(abs(diffX) > 0.001 and not diffX == 0):
                checkList.append(True)
            elif(abs(diffX) < 0.001 and b.getY() - a.getY() > 0.001):
               checkList.append(False)
            else:
                checkList.append(False)
        print(checkList)
        print("--------------------------------------------------------------")
        if(all(checkList)):
            checkList.clear()
            return True
        else:
            checkList.clear()
            return False
    return True

# Computation Functions
```

```
def computeVirtualPoints(self, rows, columns, interDist):
    self.startPoint = ActuatorPoint(self.startX * interDist, self.startY
        * interDist)
    self.endPoint = ActuatorPoint(self.endX * interDist, self.endY *
        interDist)

    v = []

    if(self.cmp(self.startPoint,v)):v.append(self.startPoint)
    self.printArrayTest(v)

    if(abs(self.endPoint.getX() - self.startPoint.getX()) < 0.001):
        for i in range (rows):
            c = ActuatorPoint(self.startPoint.getX(), i * interDist)
            if(self.isPointOnStroke(c) and self.cmp(c,v)):
                print(self.cmp(c,v))
                v.append(c)
                self.printArrayTest(v)
    else:
        coef = (self.endPoint.getY() - self.startPoint.getY()) /
            (self.endPoint.getX() - self.startPoint.getX())
        orig = self.startPoint.getY() - coef * self.startPoint.getX()
        if(coef == 0):
            coef += 0.000000001
        for i in range(rows):
            y = i * interDist
            ant = ActuatorPoint(round(((y - orig) / coef),5), y)
            if(self.isPointOnStroke(ant) and self.cmp(ant,v)):
                print(self.cmp(ant,v))
                v.append(ant)
                self.printArrayTest(v)

        for i in range(columns):
            x = i * interDist
            res = ActuatorPoint(x, round((coef * x + orig),5))
            if(self.isPointOnStroke(res) and self.cmp(res,v)):
                print(self.cmp(res,v))
                v.append(res)
                self.printArrayTest(v)


    if(self.cmp(self.endPoint,v)):v.append(self.endPoint)
```

```
        self.printArrayTest(v)

        self.virtualActuators = v

        self.virtualActuators.sort(key=lambda x: x.getX(), reverse=False)
        #self.printArray(v)


    def computeMaxIntensityTimers(self):
        speed = math.hypot(self.startPoint.getX() - self.endPoint.getX(),
            self.startPoint.getY() - self.endPoint.getY()) / self.duration
        #print(len(self.virtualActuators))
        begin = self.virtualActuators[0]

        for i in range(len(self.virtualActuators)):
            e = self.virtualActuators[i]
            self.virtualActuators[i].setTimerMaxIntensity((math.hypot(e.getX()
                - begin.getX(), e.getY() - begin.getY()))/speed)


    def computeDurationsAndSOAs(self):
        sumSOA = 0.0
        self.virtualActuators[0].setStart(0)

        self.virtualActuators[0].setDurationBeforeTimerMaxIntensity(0.0)

        for i in range(len(self.virtualActuators)-1):
            current = self.virtualActuators[i]
            next = self.virtualActuators[i + 1]

            sumSOA += ((0.32 * (current.getDurationBeforeTimerMaxIntensity()
                - sumSOA + next.getTimerMaxIntensity()) + 47.3 ) / 1.32)
            #print(sumSOA)
            next.setStart(sumSOA)
            current.setDurationAfterTimerMaxIntensity(next.getTimerMaxIntensity()
                - sumSOA)
            next.setDurationBeforeTimerMaxIntensity(next.getTimerMaxIntensity()
                - sumSOA)
            #print(str(current.getDurationAfterTimerMaxIntensity()))

        self.virtualActuators[len(self.virtualActuators) -
            1].setDurationBeforeTimerMaxIntensity(self.duration - sumSOA)
```

```
        self.virtualActuators[len(self.virtualActuators) -
            1].setDurationAfterTimerMaxIntensity(0)



    def isPointOnStroke(self, point):
        segDistance = math.hypot(self.startPoint.getX() -
            self.endPoint.getX(), self.startPoint.getX() -
            self.endPoint.getX())
        startToPointDistance = math.hypot(self.startPoint.getX() -
            point.getX(), self.startPoint.getY() - point.getY())
        pointToEndDistance = math.hypot(self.endPoint.getX() - point.getX(),
            self.endPoint.getY() - point.getY())
        return startToPointDistance + pointToEndDistance - segDistance <
            0.001

#testStroke = Stroke(3,(1/1.5),(1/1.5),2,1000,1)
#testStroke.computeParameters(3,4,1.5)
```

```
from ActuatorClass import ActuatorStep
class Pair:
    time = 0.0
    step = ActuatorStep

    def __init__(self, time, step):
        self.time = time
        self.step = step
    def first(self):
        return self.time
    def second(self):
        return self.step
```

```
from TactileBrush import TactileBrush
from HapticMotor import HapticMotor
from Stroke import Stroke
import paho.mqtt.client as mqtt
import board
import adafruit_tca9548a
import adafruit_drv2605
import time
```

```
#------------------------------------------------------------------------------------
#Declaration
tactileBrush = TactileBrush(3,4,1.5)
client = mqtt.Client("Wearable_One")
listOfActuator = []
listOfPhysialActuator = []
intervalList = []
# Create I2C bus as normal
i2c = board.I2C() # uses board.SCL and board.SDA
# Create the TCA9548A object and give it the I2C bus & Make list of
    phyiscal actuators
tca = adafruit_tca9548a.TCA9548A(i2c, 0x70)
tca1 = adafruit_tca9548a.TCA9548A(i2c, 0x71)
listOfPhysialActuator.append(HapticMotor(0,0,adafruit_drv2605.DRV2605(tca[3])))
listOfPhysialActuator.append(HapticMotor(0,1,adafruit_drv2605.DRV2605(tca[4])))
listOfPhysialActuator.append(HapticMotor(0,2,adafruit_drv2605.DRV2605(tca[5])))

listOfPhysialActuator.append(HapticMotor(1,0,adafruit_drv2605.DRV2605(tca[2])))
listOfPhysialActuator.append(HapticMotor(1,1,adafruit_drv2605.DRV2605(tca[1])))
listOfPhysialActuator.append(HapticMotor(1,2,adafruit_drv2605.DRV2605(tca[0])))

listOfPhysialActuator.append(HapticMotor(2,0,adafruit_drv2605.DRV2605(tca1[3])))
listOfPhysialActuator.append(HapticMotor(2,1,adafruit_drv2605.DRV2605(tca1[4])))
listOfPhysialActuator.append(HapticMotor(2,2,adafruit_drv2605.DRV2605(tca1[5])))

listOfPhysialActuator.append(HapticMotor(3,0,adafruit_drv2605.DRV2605(tca1[2])))
listOfPhysialActuator.append(HapticMotor(3,1,adafruit_drv2605.DRV2605(tca1[1])))
listOfPhysialActuator.append(HapticMotor(3,2,adafruit_drv2605.DRV2605(tca1[0])))
#------------------------------------------------------------------------------------
def excuteSequence(listOfActuators, startIntervalList, durationList):
  start = time.process_time()
  for j in listOfActuators:
    #print("Being Checked:
        "+str(j.second().getColumn())+","+str(j.second().getRow())+" Time:
        "+str(0 * 1000)+" Start Time: "+str(j.first()))
    if(j.first() == 0 and j.second().getMotor().getIsActive() == False):
      print("Being Played:
          "+str(j.second().getColumn())+","+str(j.second().getRow())+" at:
          "+str(0 * 1000))
      j.second().getMotor().write(j.second().getIntensity())
      j.second().getMotor().play()
      j.second().getMotor().setIsActive(True)
```

```
  ##------------------------------------
  seconds = 0.0
  for i in durationList:
    if(seconds < i):
      seconds = i
  seconds += 0.1
  start_time = time.time()
  print("Duration: "+str(seconds))
  while True:
    current_time = time.time()
    elapsed_time = current_time - start_time
    if(elapsed_time > (seconds/1000)):
      print("Total Time To Complete: "+str(time.process_time() - start))
      break
    for i in startIntervalList: #if one of the start interval is trigger
        activate motors
      if ((elapsed_time * 1000) >= i):
        for j in listOfActuators:
          #print("Being Checked:
              "+str(j.second().getColumn())+","+str(j.second().getRow())+"
              Time: "+str(elapsed_time * 1000)+" Start Time: "+str(j.first()))
          if(j.first() == i and j.second().getMotor().getIsActive() ==
              False):
            print("Being Played:
                "+str(j.second().getColumn())+","+str(j.second().getRow())+"
                at: "+str(elapsed_time * 1000))
            j.second().getMotor().write(j.second().getIntensity())
            j.second().getMotor().play()
            j.second().getMotor().setIsActive(True)
    for i in durationList:
      if ((elapsed_time * 1000) >= i):
        for j in listOfActuators:
          if((j.first() + j.second().getDuration()) == i and
              j.second().getMotor().getIsActive() == True):
            print("Being Stopped:
                "+str(j.second().getColumn())+","+str(j.second().getRow())+"
                at: "+str(elapsed_time * 1000))
            j.second().getMotor().stop()
            listOfActuators.remove(j)
##------------------------------------
# Build it based on the time
def sequenceBuilder(listOfActuator, duration):
```

```
  # Pair the listOfActuator with Actuator
  print(len(listOfActuator))
  for i in listOfActuator:
    #print(str(i.second().getColumn())+","+str(i.second().getRow()))
    for j in listOfPhysialActuator:
      #print("List Of Real: "+str(j.getColumn())+","+str(j.getRow()))
      if(i.second().getColumn() == j.getColumn() and i.second().getRow() ==
          j.getRow()):
        print("Mathced:
            "+str(i.second().getColumn())+","+str(i.second().getRow()))
        i.second().setMotor(j)
        i.second().getMotor().setIsActive(False)
  # Need to set
  startIntervalList = []
  durationList = []
  for i in listOfActuator:
    if i.first() not in startIntervalList:
      startIntervalList.append(i.first())
    if i.second().getDuration()+i.first() not in durationList:
      durationList.append(i.second().getDuration()+i.first())

  startIntervalList.pop(0)
  print(startIntervalList)
  print(durationList)
  excuteSequence(listOfActuator, startIntervalList,durationList)


#Produce Stroke
def produceStroke(msg):
  msgStr = msg.split(',')
  # (1,0.5,3,0.66,1000)
  startX = float(msgStr[0])
  startY = float(msgStr[1])
  endX = float(msgStr[2])
  endY = float(msgStr[3])
  duration = float(msgStr[4])
  intensity = 1;
  print(str(startX)+","+str(startY)+","+str(endX)+","+str(endY)+","+str(duration))
  receivedStroke = Stroke(startX,startY,endX,endY,duration,intensity)
  listOfActuator = tactileBrush.computeStrokeSteps(receivedStroke)
  # Produce the Phyiscal Stroke
  sequenceBuilder(listOfActuator, duration)
```

```
  #print(str(listOfPhysialActuator[0].getIntensity())+"Time start:
     "+str(listOfPhysialActuator[0].getStartTime())+" End Time:
     "+str(listOfPhysialActuator[0].getEndTime()))
  #print(str(listOfPhysialActuator[1].getIntensity())+"Time start:
     "+str(listOfPhysialActuator[1].getStartTime())+" End Time:
     "+str(listOfPhysialActuator[1].getEndTime()))

# This is the Subscriber for Vibration Motors
def on_connect(client, userdata, flags, rc):
  print("Connected with result code "+str(rc))
  client.subscribe("deviceTwo/line")

def on_message(client, userdata, msg): # Make sure to make this work lol
  client.disconnect() ### Once finishes the process of the stroke --
     Reconnect
  listOfPhysialActuator[0].play()
  time.sleep(10)
  produceStroke(msg.payload.decode())
  client.reconnect()

## Communication Setup
client.username_pw_set(username="hoekje", password="haptic")
client.connect("178.62.212.56")
client.on_connect = on_connect
client.on_message = on_message
client.loop_forever()
```

```
import board
import busio
import adafruit_drv2605
import math

class HapticMotor:
  columnPos = 0
  rowPos = 0
  intensity = 0
  startTime = 0.0
  endTime = 0.0
  isActive = False
  motor = None
```

```
def __init__(self, columnPos, rowPos, motor):
  self.motor = motor
  self.columnPos = columnPos
  self.rowPos = rowPos
  self.motor.mode = 0x06
  self.isActive = False

# Set Function
def setIsActive(self, isActive):
  self.isActive = isActive
def setStartTime(self, time):
  self.startTime = time

def setEndTime(self, time):
  self.endTime = time

def setMotor(self, motor):
  self.motor = motor

#Get Function
def getIsActive(self):
  return self.isActive

def getColumn(self):
  return self.columnPos

def getRow(self):
  return self.rowPos

def getStartTime(self):
  return self.startTime

def getEndTime(self):
  return self.endTime

def getIntensity(self):
  return self.intensity

def getMotor(self):
  return self.motor
```

```
  # Function
  def write(self, intensity):
    self.intensity = int(intensity * 255)
    self.motor._write_u8(0x5a, self.intensity)

  def pause(self, duration):
    self.motor.pause(duration)

  def play(self):
    self.motor.play()

  def stop(self):
    self.motor.stop()
```

```
class ActuatorPoint:
    # Attributes
    name = ""
    x = 0.0
    y = 0.0
    timerMaxIntensity = 0.0
    durationBeforeTimerMaxIntensity = 0.0
    durationAfterTimerMaxIntensity = 0.0
    start = 0.0

    def __init__(self, *args):
        if args is not None:
            if len(args) == 2:
                self.x = args[0]
                self.y = args[1]
        pass
    # Get Function
    def getX(self):
        return self.x

    def getY(self):
        return self.y

    def getTimerMaxIntensity(self):
        return self.timerMaxIntensity

    def getDurationBeforeTimerMaxIntensity(self):
```

```
        return self.durationBeforeTimerMaxIntensity

    def getDurationAfterTimerMaxIntensity(self):
        return self.durationAfterTimerMaxIntensity

    def getDuration(self):
        return self.getDurationBeforeTimerMaxIntensity() +
            self.getDurationAfterTimerMaxIntensity()

    def getStart(self):
        return self.start

    def getName(self):
        return self.name

    #Set function
    def setTimerMaxIntensity(self, timerMaxIntensity):
        self.timerMaxIntensity = timerMaxIntensity

    def setDurationBeforeTimerMaxIntensity(self,
        durationBeforeTimerMaxIntensity):
        self.durationBeforeTimerMaxIntensity =
            durationBeforeTimerMaxIntensity

    def setDurationAfterTimerMaxIntensity(self,
        durationAfterTimerMaxIntensity):
        self.durationAfterTimerMaxIntensity = durationAfterTimerMaxIntensity

    def setStart(self, start):
        self.start = start

    def setX(self, x):
        self.x = x

    def setY(self, y):
        self.y = y

    def setName(self, name):
        self.name = name

class ActuatorStep:
    column = 0
```

```
row = 0
intensity = 0.0
duration = 0.0
maxIntensity = 0.0
motor = None

def __init__(self, column, row, intensity, duration, maxIntensity):
    self.column = column
    self.row = row
    self.intensity = intensity
    self.duration = duration
    self.maxIntensity = maxIntensity

#Get Function
def getColumn(self):
    return self.column
def getRow(self):
    return self.row
def getIntensity(self):
    return self.intensity
def getDuration(self):
    return self.duration
def getMaxIntensity(self):
    return self.maxIntensity
def getMotor(self):
    return self.motor
#Set Function
def setColumn(self, column):
    self.column = column
def setRow(self, row):
    self.row = row
def setIntensity(self, intensity):
    self.intensity = intensity
def setDuration(self, duration):
    self.duration = duration
def setMaxIntensity(self, maxIntensity):
    self.maxIntensity = maxIntensity
def setMotor(self, motor):
    self.motor = motor
```

Appendix C

Informational Brochure User Evaluation

Information Brochure Dear reader, My name is Connor Adrianus Stork, and I am a third-year Creative technology bachelor student at the University of Twente. I want to invite you to participate in a user case study for the research I'm conducting for my bachelor thesis. Participation in the user case study is voluntary, which means you can withdraw at any time during or after the user case study if you choose to do so. Additionally, their data will be deleted. I want to inform you about the research that I am conducting. Feel free to ask any questions. I will be happy to explain anything in more detail. I am interested in the user experience of the wearable prototype that I have designed. I want to find evidence of whether couples can transfer a meaningful affective touch in a long-distance relationship to feel their partner's pleasant touch. A user case study will be performed online, followed by an evaluation to gather this evidence. The assessment is a semi-structured interview consisting of open questions that are completed online to limit the exposure of COVID-19. The user case study consists of a couple using the wearable prototype during a video call with their significant other. Before the user test starts, I will confirm that both participants have the wearable prototype on their forearm and ensure that both participants are comfortable. During the user test, the participant will be in their video call and perform the a of task sending a gentle stroke. When one of the participants strokes the wearable, the other receiver participant will feel the stroke on his forearm produced by the vibration motors. These vibration motors are similar to the motors that are used in smartphones. For the wearable, the motors are sewn in. At any moment, you can send an affective touch to the other participant. This can be done by touching the top of the wearable, where sensors will pick up the hand/finger movement. This gives the wearable the ability to send a unique vibration pattern. The sensor will not be placed directly on the skin. The user case study will take approximately 30 minutes of your time. The interview will be recorded in video and transcribed afterward for analysis purposes. The user test is not to be registered with video or audio. Before starting the user test, you will be asked to create a video call with your significant other. All information will be kept anonymous, which means that your name will not be included in the research, and data is pseudonymized. In my papers I write or any presentation that I create, I will make a name to represent you and will not reveal details nor exchange personal information with external parties. After the completion of the bachelor thesis, I will adhere to GDPR guidelines.

After the user test, an interview is performed online. The interview will be video recorded. The purpose of the interview is to evaluate the experience of the user with the wearable. You will be asked a question about your experiences with the wearable and what could be improved or changed. Furthermore, you will be asked how you felt and felt closer to your significant other with the wearable during the video call. Lastly, asked whether you would use the wearable during your video calls with your significant other and any recommendation or improvements for the study.

The user case study is a great benefit that will help me get more insight into understanding the user experience of my wearable prototype. The study has low risk involved, the only risk is the drop off of the prototype. To ensure we limit the exposure of COVID-19, or spread of disease will we follow the RIVM checklist. In addition, before you participate in the user test, you can try out the wearable to get a feel for the wearable. You can withdraw at any time, if you find it uncomfortable and you wish not to continue, you have the right to withdraw from the study without giving a reason at any time. This is also applied during the user test or interview. The interview or user test will stop, and I will delete all data. If you decided that you do not want your information being used in the study and delete your data after the user test or interview, you could send an email to c.a.stork@student.utwente.nl with the request for deletion of your data. Your personal information and anonymous data will be carefully, securely, and separately stored in an encrypted server and USB drive. These documents will be deleted after the research is finished.

Furthermore, if you have any question regarding the user case study you can contact my supervisor at a.h.mader@utwente.nl or the ethic committee at the university of Twente which can reached by ethicscommittee-cis@utwente.nl

Informed Consent 'I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. Parts of the interview can be quoted where only your function will be mentioned. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time.

I agree to my interview being video-recorded. Furthermore, I agree that a transcription of the whole interview can be added as an appendix to the research. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Connor Stork.

- I agree to my interview being video-recorded. - I understand that taking part in the user case study involves I give permission for participating in the research and for collecting and using my data as described above. - I agree that my interview will be transcribed and can be added as an appendix to the research. - I have read and understood the information brochure, or it has been read to me. The objective of the research and produces are clear. I have been able to ask question about the research and my questions have been answered to my satisfaction

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

Signed in duplicate:

.... Name subject Signature

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

....

Appendix D

Questionnaire

What is your name ? *

Short answer text

What is your age ? *

Short answer text

How often do you see your signifcant other ?

	1	2	3	4	5	
Not Often	○	○	○	○	○	Very Often

What type of relationship do you have ? *

○ Long-distance

○ Close-distance

What methods do you use to stay in touch with your partner ? *

Short answer text

How often do you caress your significant other arm with a gentle stroke when you are together? *

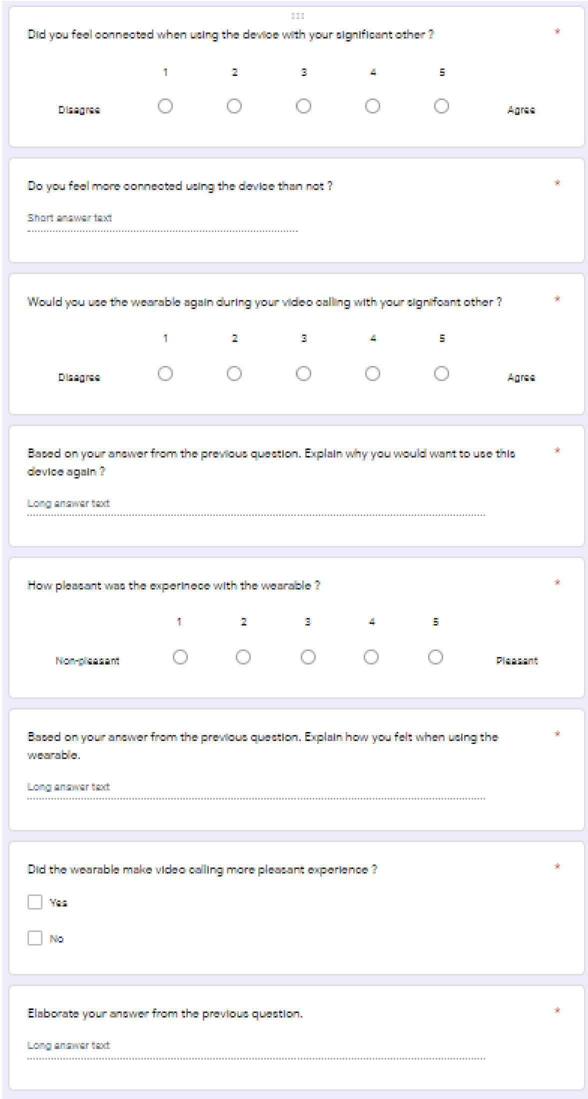
	1	2	3	4	5	
Not much	○	○	○	○	○	Very Much

How connected do you feel to him/her ? *

	1	2	3	4	5	
Not Much	○	○	○	○	○	Very Much

How important is it to you that he/she shows you affection ? *

	1	2	3	4	5	
Not Much	○	○	○	○	○	Very Much



Did you feel connected when using the device with your significant other ? *

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Do you feel more connected using the device than not ? *

Short answer text

Would you use the wearable again during your video calling with your signifcant other ? *

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Based on your answer from the previous question. Explain why you would want to use this device again ? *

Long answer text

How pleasant was the experinece with the wearable ? *

	1	2	3	4	5	
Non-pleasant	○	○	○	○	○	Pleasant

Based on your answer from the previous question. Explain how you felt when using the wearable. *

Long answer text

Did the wearable make video calling more pleasant experience ? *

☐ Yes

☐ No

Elaborate your answer from the previous question. *

Long answer text

Section 4 of 5

Transmitter Wearable

If you used the wearable that would transmit the genlte stroke, answer the follow questions. If you used the other wearable, answer questions on the next page.

Does producing the stroke on the wearable feel similar to producing a real-life stroke on the arm ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Was it easy to send a gentle stroke to another wearable ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Was the wearable comfortable to wear ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

What did you like about the wearable ?

Long answer text

What did you not like about the wearable ?

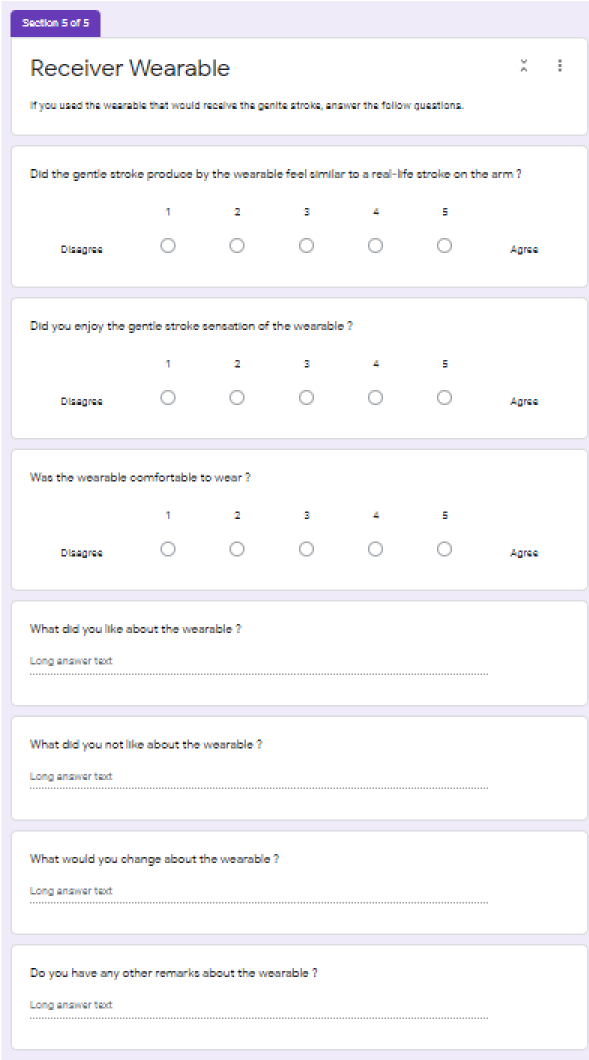
Long answer text

What would you change about the wearable ?

Long answer text

Do you have any other remarks about the wearable ?

Long answer text



Section 5 of 5

Receiver Wearable

If you used the wearable that would receive the genlte stroke, answer the follow questions.

Did the gentle stroke produce by the wearable feel similar to a real-life stroke on the arm ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Did you enjoy the gentle stroke sensation of the wearable ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Was the wearable comfortable to wear ?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

What did you like about the wearable ?

Long answer text

What did you not like about the wearable ?

Long answer text

What would you change about the wearable ?

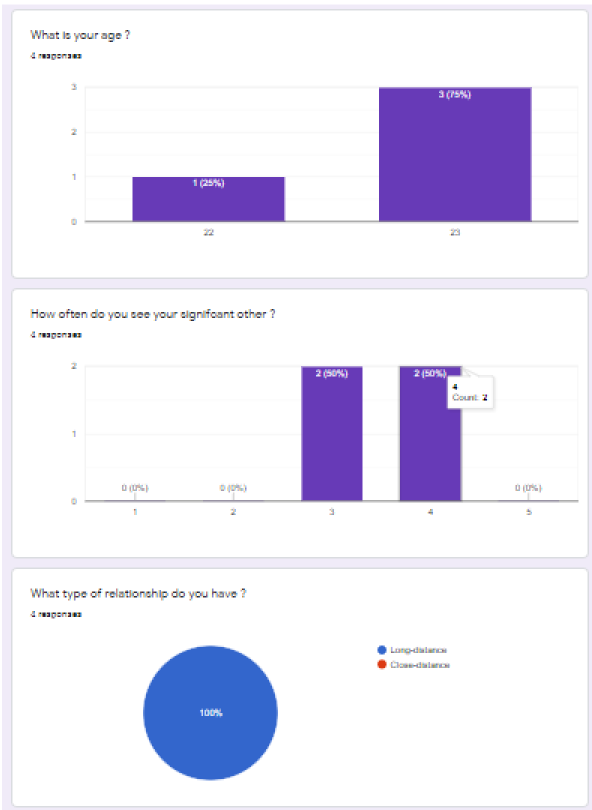
Long answer text

Do you have any other remarks about the wearable ?

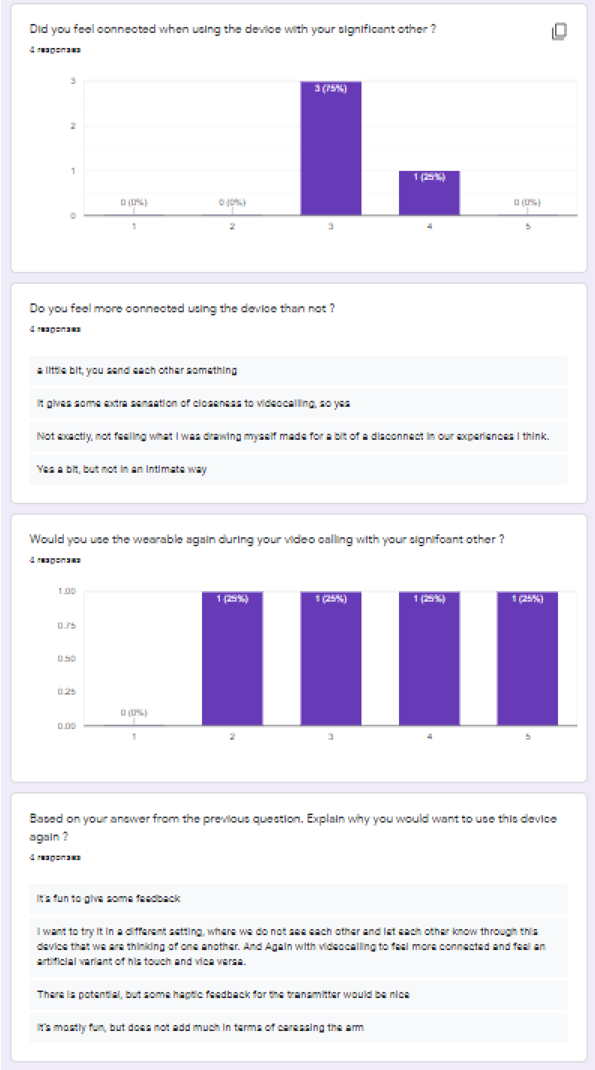
Long answer text

Appendix E

Results

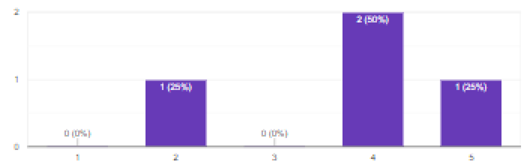



What methods do you use to stay in touch with your partner ?
4 responses
calling, apping, gaming
Video call, whatsapp messaging and online gaming
WhatsApp, FaceTime, Discord
WhatsApp, Snapchat, memes via Instagram, facetime & discord
How often do you caress your significant other arm with a gentle stroke when you are together?
4 responses
0 (0%)
0 (0%)
0 (0%)
1 (25%)
3 (75%)
1
2
3
4
5
How connected do you feel to him/her ?
4 responses
0 (0%)
0 (0%)
0 (0%)
0 (0%)
4 (100%)
1
2
3
4
5
How important is it to you that he/she shows you affection ?
4 responses
0 (0%)
0 (0%)
0 (0%)
3 (75%)
1 (25%)
1
2
3
4
5


Did you feel connected when using the device with your significant other ?
4 responses
3
2
1
0
0 (0%)
0 (0%)
3 (75%)
1 (25%)
0 (0%)
1
2
3
4
5
Do you feel more connected using the device than not ?
4 responses
a little bit, you send each other something
It gives some extra sensation of closeness to videocalling, so yes
Not exactly, not feeling what I was drawing myself made for a bit of a disconnect in our experiences I think.
Yes a bit, but not in an intimate way
Would you use the wearable again during your video calling with your signifoant other ?
4 responses
1.00
0.75
0.50
0.25
0.00
0 (0%)
1 (25%)
1 (25%)
1 (25%)
1 (25%)
1
2
3
4
5
Based on your answer from the previous question. Explain why you would want to use this device again ?
4 responses
It's fun to give some feedback
I want to try it in a different setting, where we do not see each other and let each other know through this device that we are thinking of one another. And Again with videocalling to feel more connected and feel an artificial variant of his touch and vice versa.
There is potential, but some haptic feedback for the transmitter would be nice
It's mostly fun, but does not add much in terms of caressing the arm

How pleasant was the experinece with the wearable ?

4 responses



Based on your answer from the previous question. Explain how you felt when using the wearable.

4 responses

It felt funny and a bit pleasant. but the wearable itself is not so comfortable to wear and the vibrations don't transition that smooth. A real stroke is just more pleasant.

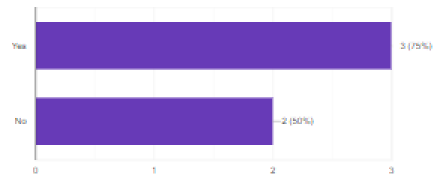
I felt excited to try something new and was suprised by how pleasantly the vibration stroke felt, although it does not feel like human touch of course.

It was fun to play around with, just like it is with any device or gadget that you are using for the first time.

Tingly and fun :)

Did the wearable make video calling more pleasant experience ?

4 responses



Elaborate your answer from the previous question.

4 responses

It was fun to do and experiment with but I would not do this every time

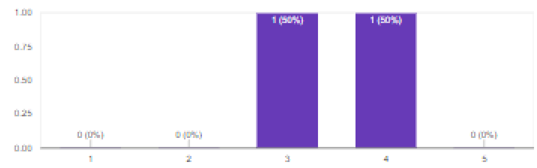
It added something extra, like I mentioned earlier. It is nice to try something new which is created to connect each other even more. Touch is important to me, so it is great to imitate that feeling of being near each other.

It did not necessarily add to the experience of the video call, it just changed the subjects we normally talk about in a video call as the device was new to us both.

Not necessarily pleasant, but certainly more fun

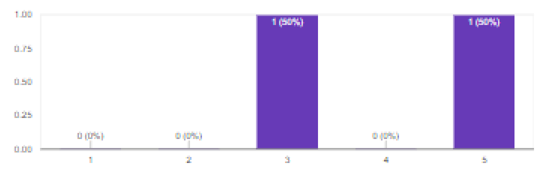
Does producing the stroke on the wearable feel similar to producing a real-life stroke on the arm ?

2 responses



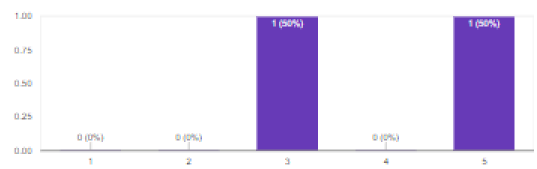
Was it easy to send a gentle stroke to another wearable ?

2 responses



Was the wearable comfortable to wear ?

2 responses



What did you like about the wearable ?

2 responses

There was no wearable yet, but the phone on your arm is easy to implement with a jogging phone bracelet.

It is intuitive to use.

What did you not like about the wearable ?

2 responses

There was no wearable yet

The display is too smooth to replicate the feeling of touching skin, as moving your finger along the display sometimes makes it stick due to its smoothness. Maybe adding a matte screen protector would improve the experience further, as it allows for gliding around your finger more easily.

What would you change about the wearable ?

2 responses

It would be even more ideal would be if you could send stroke figures, like zigzag movement or a circle

The display should be more matte and the GUI could be improved upon.

Do you have any other remarks about the wearable ?

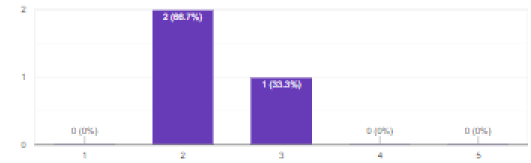
2 responses

Great project!

Interesting study!

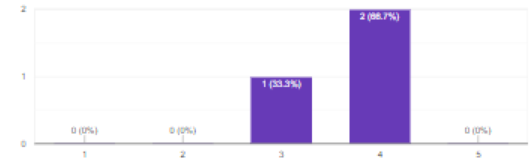
Did the gentle stroke produce by the wearable feel similar to a real-life stroke on the arm ?

3 responses



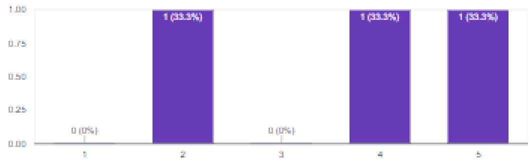
Did you enjoy the gentle stroke sensation of the wearable ?

3 responses



Was the wearable comfortable to wear ?

3 responses



What did you like about the wearable ?

3 responses

Vibration felt funny and it is cool that you send something to the other person

It fitted nicely around the arm and did not slide of or anything. It was quite easy to put on

various spots which vibrated, so not just one spot

What did you not like about the wearable ?

3 responses

A lot of wires

At this point of the project, the wires were quite vulnerable and one lost connection

Couldn't move freely

What would you change about the wearable ?

3 responses

Smoother stroke and that you can send shapes. And more comfy to wear.

Add a soft elastic material, so it becomes even easier and more comfortable to wear. And it would be nice if the tempo of the stroke was imitated

A slip on sleeve which you can move your arm freely in

Do you have any other remarks about the wearable ?

3 responses

nope

Great project

You could also use it on an other place :))))