Chair for Computer Science 10 (Media Computing and Human-Computer Interaction)

RWTH AACHEN UNIVERSITY

Avoiding Accidental Input: Evaluating Activation and Confirmation Techniques on Textile Sliders

Bachelor's Thesis
submitted to the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Nikita Huber

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Jürgen Steimle

Registration date: 17.12.2021
Submission date: 31.03.2022

Zentrales Prüfungsamt/Central Examination Office

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Huber, Nikita

Name, Vorname/Last Name, First Name

381082

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Abstract

Due to recent developments in the field of smart homes, daily objects for the home are more and more equipped with electronics in order to enhance their capabilities. Even the intensity of the lamp in our living room can be, by today's standards, regulated by a remote controller. Such controllers are however rigid and are often not directly integrated into the commonly used space. Therefore researchers in the field of Human-Computer Interaction (HCI) focused on the approach of seamless integrating sensing capabilities into textiles. The results are smart textiles that adopt the technical abilities of the traditional controllers while the visual and haptic expressiveness of the textiles is preserved. When such fabric controllers are integrated onto the surface of everyday objects in our home environment, the problem may arise that the user conducts an accidental input on the textile interface, as it is not always directly visible, and therefore unintended commands are triggered. As a result, interaction techniques need to be researched that provide a natural feeling and additionally feature a robustness against false activation. This work describes the manufacturing process of three textile prototypes. Moreover, eight unique interaction techniques are introduced that can be performed on these textile interfaces, whereby dissimilar activation and confirmation gestures are being utilized. Finally, we conduct a user study in order to evaluate the performance data and acceptability of each interaction.

Überblick

Aufgrund von jüngsten Entwicklungen im Bereich des intelligenten Wohnens werden alltägliche Objekte immer mehr und mehr mit elektronischen Komponenten ausgestattet, um deren Fähigkeiten zu erweitern. Selbst die Helligkeit der Lampe in unserem Wohnzimmer kann, nach heutigen Standards, durch eine Fernbedingung kontrolliert werden. Solche Bedienelemente sind aber steif und sind oft nicht direkt dort integriert, wo sie gebraucht werden, weshalb Forscher im Bereich der Mensch-Maschinen Interaktion (MMI) sich mit der Fragestellung beschäftigt haben, wie Sensoren in Textilien nahtlos integriert werden können. Als Resultat entstanden die intelligenten Textilien, die die technischen Fähigkeiten der klassischen Bedienelemente adaptiert haben, wobei die visuelle und haptische Ausdrucksfähigkeit der Textilien beibehalten wurde. Wenn solche textilen Regler auf Oberflächen von alltäglichen Objekten in unserem Wohnzimmer integriert werden, kann das Problem auftreten, dass Nutzer versehentlich Eingaben auf der textilen Schnittstelle tätigen, da diese nicht immer direkt zu sehen ist, und somit unabsichtliche Anweisungen ausgelöst werden. Aufgrund dessen, müssen Interaktionstechniken erforscht werden, die sich natürlich anfühlen und zusätzlich eine Robustheit gegenüber fälschlicher Aktivierung aufweisen. In dieser Arbeit wird der Herstellungsprozess von drei textilen Prototypen beschrieben. Weiterhin werden acht verschiedene Interaktionstechniken eingeführt, die auf den genannten textilen Schnittstellen ausgeführt werden können, wobei unterschiedliche Aktivierungs- und Bestätigungsgesten verwendet werden. Abschließend führen wir eine Studie durch, um Leistungsdaten und Akzeptanz jeder einzelnen Interaktion beurteilen zu können.

Acknowledgements

First of all, I would like to thank Prof. Dr. Borchers and Prof. Dr. Steimle for examining this thesis.

Secondly, I would like to thank my supervisors Oliver Nowak and René Schäfer for their helpful inputs.

Additionally, I want to thank my family for supporting me throughout the whole thesis. Moreover, I would like to thank Laura Drescher-Manaa and Esra Güney for their advice.

Lastly, I would like to thank everyone who participated in my study.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in American English. The first person is written in plural form and unidentified third persons are referred to in male form.

Chapter 1

Introduction

Electronics can be integrated into textiles in order to enhance their efficiency for applications in the area of smart homes.

For decades humanity has been using textiles in various applications so that textiles make up an essential and indispensable part of our daily lives [Parzer et al., 2018]. Additionally the advancements in the recent years in the field of microprocessors showed us that electronic devices can be easily integrated into our home environment and as a result vast developments in the area of the smart home were conducted [Zielonka et al., 2021]. However, most of these applications are being regulated by rigid controllers which have the disadvantage that they are often times not integrated into the commonly used space. For that reason researchers in the field of Human-Computer Interaction (HCI) focused on the approach of embedding sensing capabilities into textiles in order to create smart textiles which are a combination of digital electronics and ubiquitous textiles [Rus et al., 2017], [Brauner et al., 2017]. Mlakar and Haller [2020] state that these kind of textiles have the visual and haptic expressiveness of the fabric itself and can be used in various interactive application fields such as data storage, measurement of pressure distribution on the human body or using the fabrics as an input device. Sewing, weaving and embroidering are the most common manufacturing processes in order to create such smart textiles [Parzer et al., 2018].

Textile sliders are one possible implementation on how to use textiles as an input device and could have the ability

Smart textiles offer the possibility of replacing traditional, rigid controllers as they can be seamlessly integrated into the fabric directly at a commonly used area.

to replace traditional input controllers for simple applications such as volume control for a television. These textile interfaces could be directly embedded into a furniture such as the sofa and by that have an advantage over the traditional controllers that they are directly integrated into the commonly used place. Furthermore, a benefit of such textile controllers is that they can be designed in compliance with the principle of eyes-free interactions which describes the ability to precisely set values on a textile interface without actually looking at it. In order to achieve such capabilities, suitable haptic feedback needs to be carefully integrated into these interfaces. One major drawback of these textile controllers is however that any touch input, even when it is just unintentionally, can be recognized as actual user input. Because of these accidental touch inputs, the textile interfaces get falsely activated and as a result suddenly changing input values can be obtained. Therefore, suitable interaction techniques on textile sliders need to be researched that offer a certain robustness against false activation but on the other hand are still simple enough to be used for eyes-free interactions.

In the beginning of this thesis, we are going to manufacture three unique prototypes which feature in total eight dissimilar interaction techniques. As a consequence we are going to evaluate these interactions during a user study in order to obtain general performance data as well as user feedback. From there on we are able to derive first starting points on how these dissimilar interaction techniques perform on textile sliders and how they may be used in order to avoid false activation.

1.1 Outline

In the following Chapters of this thesis, we are going to present related work, discuss different interactions possible on textile sliders and the required prototypes as well as investigate during a user study the unique interaction techniques.

In Chapter 2, we introduce the related work that was already conducted in the area of smart textiles. Additionally, we give an inside view on already evaluated design principles for textile interfaces as well as how false activation can be avoided by utilizing single finger gestures.

We present the different interaction techniques and the corresponding prototypes of textile sliders in Chapter 3. Additionally, we show how the control software enables these unique interactions.

In a user study, that is presented in Chapter 4, we evaluate and discuss the various interaction techniques.

Conclusively in Chapter 5, a brief summary is given followed by an outline of possible future research that can be conducted in the area of interaction techniques on textile sliders.

Chapter 2

Related work

In this Chapter we are going to give an inside view on already conducted research in the area of smart textiles. By that we will gain additional information on how to embed electronic solutions into textiles interfaces. Moreover, we will have a look at various design principles that define how specific tactile feedback can be achieved in order to guide the user in an eyes-free environment while using textile controllers. Additionally, we will present an initial approach on how false activation can be avoided by utilizing specific finger movements.

2.1 Smart Textiles

Several sensing technologies have been utilized so touch input can be detected on a textile interface.

In the recent years several studies in the field of HCI were conducted that focused on possible sensing approaches for textile interfaces. As a result, resistive [Parzer et al., 2018], [Aigner et al., 2020], capacitive [Zhang et al., 2017], [Sato et al., 2012] or optomechanical [Bunge et al., 2020] sensors were manufactured. Resistive sensing approaches are based on fabric resistors that can be achieved by separating conductive materials by semi-conductive, compressible fabrics [Parzer et al., 2018]. When applying pressure on these sensors a changing voltage can be measured and by that a touch input can be derived. Fabric capacitors that are

constructed with conductive materials acting as electrode plates separated by a dielectric, form the foundation of capacitive sensing approaches [Parzer et al., 2018]. The electrical field between the electrode plates can be influenced by applying pressure onto these plates or by the simple presence of the human hand and by that a user interaction can be detected. The optomechanical sensing approaches rely on the fact that two optical fibers are aligned orthogonally to each other. One fiber is connected to light emitters acting as a light source and at the end of the other optical fiber, photo detectors are attached [Bunge et al., 2020]. When a force is applied onto the crossing, light can leak from one optical fiber to the other one and by that the photo detectors are stimulated which then can be interpreted as a touch input [Bunge et al., 2020].
When designing interactive textiles, the most suitable sensing approach for the application needs to be chosen as each sensing technology has its advantages and disadvantages [Parzer et al., 2018].

Through conductive yarns, electronics can be easily integrated into fabrics.

When enhancing textiles with sensing abilities, possible solutions that would allow an easy way of connecting soft textiles with rigid electronics needed to be discovered [Parzer et al., 2018]. In the Project Jacquard by Poupyrev et al. [2016] a highly conductive yarn was researched that would allow the unproblematic integration of electronics into textiles. A conductive yarn is essentially a yarn that can be sewn, woven or embroidered into fabrics but simultaneously acts as a conductor. Because of the possibility of directly integrating conductive yarns into the manufacturing process of smart textiles, the optics of the various textile applications are not being destroyed while making everyday objects interactive [Poupyrev et al., 2016].

By utilizing the pressure sensitive behavior of the researched, resistive yarn, Parzer et al. [2018] showed that pressure sensing capabilities can be easily embedded into textiles.

In a research conducted by Parzer et al. [2018], a resistive yarn-based textile pressure sensing technology is presented. Because of the conductive and restive properties of this yarn, the usage in various textile applications, such as pressure sensors, is possible. This resistive yarn can be sewn, woven or embroidered into fabrics because of its structural integrity and by that shows that it can be easily utilized in textile applications. As the yarn features a resistive coating, it is possible to solder it onto a printed circuit board which enables a smooth integration of electronics into textiles. During their research, Parzer et al. [2018] explored the pressure sensitive behavior of the yarn by applying certain pressure levels at yarn crossings. By that they confirmed that there is an proportionally coherence between the applied pressure and the resulting resistance of the yarn and by that proving pressure sensitivity of the yarn. Additionally, because of the conductive properties, Parzer et al. [2018] present various applications that utilize the assets of the researched yarn such as hand-sewn pressure sensors embedded onto a sofa which can be used to control RGB lights. Because the resistance of the yarn only changes when mechanical stress is applied onto it, a natural robustness against false activation is achieved [Parzer et al., 2018].

Aigner et al. [2020] present how various design parameters of a textile sensor influence its behavior.

Aigner et al. [2020] present a method for creating textile-based pressure sensors and by that achieve the possibility of enhancing arbitrary fabrics in their functionality. Such force sensitive resistor is created by applying resistive textiles and conductive yarns on top of a base fabric while using an off-the-shelf embroidery machine and materials. The sensing technique is based around the fact that when applying force on the sensor, the surface resistances of the conductive threads change and by measuring the subsequently changing voltage, a user touch input can be derived [Aigner et al., 2020]. Based on this fact, an activation of the sensor only happens when mechanical stress is registered, therefore a robustness against false activation is achieved in this sensing approach. These types of pressure sensors can be used in various applications such as textile sliders or seat covers in order to investigate the posture of a sitting person [Aigner et al., 2020].
By varying certain design parameters of the textile sensor such as electrode distance, electrode length, stitch length and electrode layering and trying out different space-filling patterns, Aigner et al. [2020] investigated the influence of these parameters on sensor properties such as dynamic range and signal-to-noise ratio. As a result Aigner et al. [2020] introduce design recommendations for creating pressure sensors with an embroidery machine where an optimal stitch length is presented, as it benefits the dynamic range of the sensor. Furthermore, Aigner et al. [2020]

provide a maximum trace distance that can be used when choosing an appropriate design pattern as such patterns can greatly influence the sensing behavior.

Unique textile interfaces were placed onto a motorized reclining armchair in order to evaluate dissimilar interaction techniques possible with such fabric controllers.

In a paper written by Brauner et al. [2017], three fabric-based controllers in the smart home environment were developed in order to investigated the usability and acceptance of textile interfaces in contrast to a standard remote controller. All fabric-based controllers where able to control a motorized reclining armchair in a living room environment and were constructed in terms of two dimensions: tactile design and interaction principle. Tactile design describes what kind of physical feedback is provided by the textile controller. A tangible fold or noticeable stitches were the two chosen tactile designs. The interaction principle represents how interactions may be performed on the surface of the textile interface. Brauner et al. [2017] designed the prototypes in such way so they can be either controlled by touching or by bending the fabric interface. *Touch the fold*, *bend the fold* and *touch the stitches* were the three resulting interaction techniques that were evaluated by utilizing the fabric-based controller prototypes. Resistive as well as capacitive sensing approaches were being used in order to achieve these unique interactions [Brauner et al., 2017].
Brauner et al. [2017] concluded that the participants enjoyed and valued the overall tactile feedback they received when touching the different textile interfaces. The most rated interaction technique was *bending the fold* because it supports a natural affordance and provides the user with a natural tactile guide which is especially important in eyes-free interactions [Brauner et al., 2017]. In conclusion, throughout there research, Brauner et al. [2017] successfully demonstrated the usage of conductive threads in textile interfaces.

2.2 Tactile Feedback

While developing textile interfaces for eyes-free applications, suitable haptic feedback needs to be discovered that would allow the user to orientate himself on the textile interface without looking at it.

Nowak et al. [2022] present various design recommendations for textile sliders, so that suitable haptic feedback can be achieved for eyes-free interactions.

Nowak et al. [2022] conducted two user studies in order to evaluate form factors and tick mark designs for textile sliders. During the first study, different slider properties were assessed such as guidance, end recognition and sliding support using various slider prototypes. As a result, Nowak et al. [2022] discovered that participants in their user study showed clear tendencies towards recessed, path sliders compared to where simply the outline of the slider was embroidered onto the textile. Sliders that are being created using this design rule offer much more support for the user in an eyes-free environment as much more orientation regarding the outline is provided. Additionally, during the first study, several shapes where evaluated regarding how good they are recognizable just by haptic feedback. Nowak et al. [2022] discovered that complex shapes used in an eyes-free interaction can lead to confusion.
In the second user study, conducted by Nowak et al. [2022], different tick mark designs were evaluated. Tick marks provide additional haptic feedback to the user so a more precise estimation regarding the position of the finger on the slider can be derived. The researches found out that the integration of three to four tick marks on the slider showed a significant higher accuracy in the selection and estimation task than competitors without tick marks and by that proved there importance for textiles interfaces, especially if they are intended to be used in an eyes-free environment [Nowak et al., 2022].

Contrasting functionalities of the textile interface can be indicated to the user, by varying certain design parameters of the interaction surface.

Mlakar and Haller [2020] conducted a research in order to present initial assumptions for designing interactive elements for non-wearable textile interfaces that provide the best recognition, perception and interaction. Five design recommendations for textile interfaces are presented, additionally several prototypes that demonstrate these recommendations in practice were created.
One of the stated design recommendation is that the easiest tactile contrast to recognize is height. Mlakar and Haller [2020] specify that other contrasts that may be used are shape and texture, whereby these contrasts are less recognizable. Furthermore, Mlakar and Haller [2020] provide a recommended shape size as bigger shapes are more easily recognizable which is especially important when different shapes indicate unique features. Additionally, Mlakar

and Haller [2020] emphasize that concave surfaces are perceived as interactive and a combination of convex and concave elements can be used in order to indicate opposite commands such as increasing the intensity of the light or decreasing it. Lastly, Mlakar and Haller [2020] recommend the usage of simple shapes as well know visual symbols and icons proved to be very difficult for tactile-only recognition.

At the end of their research, Mlakar and Haller [2020] challenged a group of nine designers and developers to implement several textile prototypes while using the recommended design principles. Unique prototypes were successfully created such as a speaker with concave shapes that can work as buttons. Others embroidered different sliders onto a textile in order to see how dissimilar shapes can affect the movement of a user.

2.3 False Activation

Sharma et al. [2021] present a novel approach on how to avoid false activation by utilizing the fact that single finger movements stand out from everyday hand motions during object interactions.

When designing textile interfaces for eyes-free applications, false activation can be prevented by choosing an appropriate sensing technology that provides a natural robustness against accidental inputs. An example for such an approach is resistive sensing as explained by Parzer et al. [2018]. Other methods utilize specific gestures in order to intercept accidental inputs.

Sharma et al. [2021] present a novel approach on how to avoid false activation on a gesture recognizer by utilizing single finger movements. The researches found out that for the hand motions during everyday object interactions, the fingers tend to be either static or multiple of them are moved concurrently. During a user study, Sharma et al. [2021] investigated the occurrence of trials with false activation during daily hand-object actions and found out that for 23 out of 36 actions, no false activation occurred. As a result, the researches recommend 7 types of single finger gestures that can be performed with the thumb, index or middle finger and by that avoid the approach of utilizing complicated-to-perform gestures that involve specific movement sequences in order to rule out accidental inputs. One benefit of these single finger gestures is that a compatibility with a wide range of grasps and everyday actions is ensured [Sharma et al., 2021].

Chapter 3

Interactions and Design

In this Chapter we present different interaction techniques on textile sliders and their corresponding prototypes. We explain in detail how these prototypes were manufactured as well as what there underlying sensing principle is. Additionally, we give an inside view on how the software enables the dissimilar interaction techniques.

3.1 Interaction Techniques

ABBREVIATIONS:
We will use the following abbreviations for the presented interaction techniques:

- **ARNM** - *Always Reactive* non-mechanical
- **ARM** - *Always Reactive* mechanical
- **CP** - *Confirmation* by pressure
- **CSO** - *Confirmation* by sliding out
- **AP** - *Activation* by pressure
- **ASI** - *Activation* by sliding in
- **ADP** - *Activation* by double pressure
- **SC** - *State Communication* by vibration feedback

We thought of eight unique interaction techniques that can be divided into four groups.

We aimed to derive at suitable and acceptable interaction techniques on textile sliders. For that we thought of dissimilar ways a user could interact with such a textile interface. When designing interaction techniques, especially for textile interfaces, a challenge is that they have to be as simple as possible in order to avoid reducing the usability of the interface while simultaneously the problem of unintentional user input has to be minimized. In the end we came up with eight possible interaction techniques, each offering a unique amount of robustness against false activation. Those interaction techniques can be divided into the following four groups: *Always Reactive*, *Confirmation*, *Activation* and *State Communication*.

Always Reactive interaction techniques feature no activation and no confirmation gesture and are therefore the simplest possible techniques.

Always Reactive interaction techniques represent the most basic way of interacting with a textile interface, whereby almost no protection against false activation is provided. During such interactions each touch input is directly recognized as actual user input so no confirmation or activation gesture has to be performed. As a result, we decided on two *Always Reactive* interaction techniques, one of which features a *non-mechanical* and the other one a *mechanical* approach. In the case of the *non-mechanical* method, the user has to simply slide his finger over the slider until he reaches the desired value. Releasing the finger from the textile interface, without performing any additional gestures, terminates the interaction and saves the desired value. The *mechanical* approach works almost in the same way, however the difference here is that the user has to move a mechanical object, in this case a sphere, in order to set the value. One benefit of this approach is that haptic feedback regarding the currently set value is provided to the user by the sphere. The interaction is terminated once the user reaches the desired value and lifts the finger from the textile interface.

While using the *Confirmation* interaction techniques, the user shall perform a confirmation gesture in order to save a new input value.

Interaction techniques that feature a *Confirmation* represent the second group of possible interactions on textile sliders. The user starts an interaction by simply touching the slider and moving his finger to a position that corresponds to the desired value he wants to set. If the finger is now simply lifted from the slider, the new value will not be saved but rather an abort is triggered with the consequence that the previously confirmed value is restored. In order to save a new value, the user has to perform a confirmation gesture. We decided that we will evaluate two possible confirmation gestures: *Confirmation* by pressure and *Confirmation* by sliding out of the slider. CP means that the user has to apply high pressure onto the slider for a short moment in order to signal to the slider that a new value is being confirmed. Until the finger is not lifted from the textile interface, the user is still able to perform corrections regarding the input value. The interaction is terminated when the finger is completely lifted from the slider. CSO means that a new value will be saved when the user slides his finger out of the slider at the position that corresponds to the desired value to be set. For that, a pressure sensitive area below the slider is needed in order to detect such a gesture. Also this interaction includes an abort feature which means if the user decides to simply lift the finger from the textile interface without performing a confirmation gesture, the slider will restore the previously confirmed value.

The next interaction techniques we thought of belong to the group of *Activation*, whereby each interaction in this cate-

Interaction techniques that belong to the group of *Activation*, feature an activation as well as a confirmation gesture. Here the textile interface is not directly reactive to user input.

gory also features a confirmation gesture. Here the slider is initially in an inactive state which means any touch input on it will be ignored. Consequently, the user has to perform some sort of activation gesture, so the user input can be detected. After the user reached his desired value, a confirmation gesture needs to be performed in order to save the new value. Simply lifting the finger from the textile interface will result in an cancellation, as with the *Confirmation* interaction techniques, hence the previously confirmed value would be restored. Initially we thought of the following two activation gestures: *Activation* by pressure and *Activation* by sliding into the slider. AP means that the user has to apply high pressure onto the slider for a short amount of time in order to activate the textile interface. Confirming a new value is performed in the same way as for the CP interaction technique. If the finger is completely lifted from the slider, the interaction is terminated.
Sliding into the slider is the other activation gesture we thought of and is a complement of the sliding out confirmation gesture. The whole process of this interaction technique is depicted in Figure 3.1.

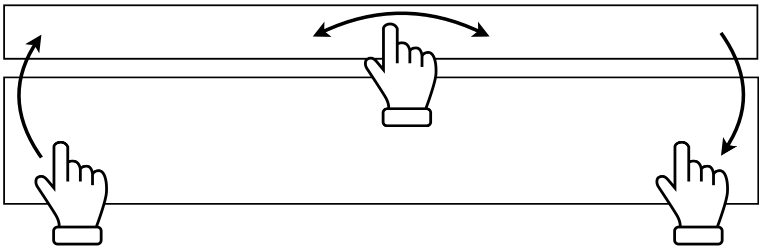

Figure 3.1: Overview of the ASI interaction technique. The narrow rectangle represents the slider and the pressure sensitive area is depicted by the wide rectangle. In order to activate the slider, the user has to slide into it from the pressure sensitive area. For confirming a value, the gesture has to be performed in the reversed way. The CSO interaction technique does not feature the activation gesture.

Here the user has to slide his finger from the pressure sensitive area (wide rectangle), that is located below the Slider (narrow rectangle), onto the slider in order to bring it in a reactive state. Confirming a new value is done by the the sliding out gesture, which is also used for the CSO interac-

tion.
Another interaction technique we thought of that holds properties of an *Activation* and is unique to the other presented techniques in this group, is the *Activation* by double pressure interaction. Here the user has to simultaneously touch the slider and the pressure sensitive area, located below the slider, in order to activate and to keep the slider in an active state. This process is depicted in Figure 3.2.

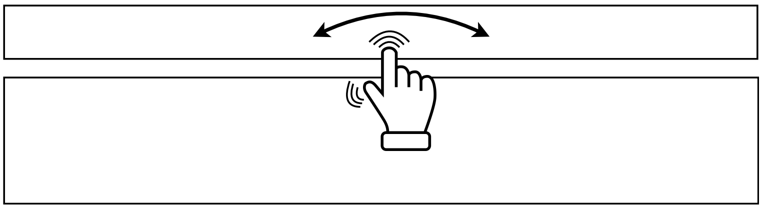

Figure 3.2: Overview of the ADP interaction technique. The narrow rectangle represents the slider and the pressure sensitive area is depicted by the wide rectangle. The slider is only reactive to touch input, when the user is simultaneously touching the slider and the pressure sensitive area.

As a result the user has to use two fingers in order to set a new value. One finger touches the slider (narrow rectangle) and by that is able to set a desired value, the other finger keeps touching the pressure sensitive area (wide rectangle) so the slider is reactive to user input. The interaction is terminated and the new value is saved if the user does not touch both interaction surfaces simultaneously anymore. Before activating the slider again, the user has to completely lift his fingers from the textile interface. Note, that with this kind of interaction technique, an indirect *Activation* and *Confirmation* is achieved by utilizing the fact that the user has to simultaneously apply pressure on two areas.

A *State Communication* interaction technique is a special case of an *Activation* interaction.

The last group of possible interaction techniques on textile sliders is the *State Communication* which can be seen as a special case of the *Activation* category. The main idea here is that the user has to slide his finger over the slider so he would reach the currently set value and by that activate the textile interface. Consequently some sort of feedback needs to be provided when the user reaches this value. Here we thought that suitable feedback could be achieved by a vibration mechanism. Also for the SC interaction a confirmation gesture has to be performed by the user, otherwise an abort will be triggered. For that we utilize again the confirmation by pressure gesture.

3.2 Electronics

We utilize a FSLP sensor in order to derive the position of a touch input on the textile slider.

In order to achieve different interaction techniques on textile sliders various electronic aspects need to be considered. One important purpose that needed to be achieved is the detection where on the slider a touch input is occurring. By moving the finger to a certain position, the user is able to set a specific value. The position of the touch input needs to be translated to a corresponding value between 0% and 100%. For this purpose, we decided to use a Force-Sensing Linear Potentiometer (FSLP) sensor from Interlink which is a linear position sensor that can be used for menu navigation and control. The FSLP sensor is an extension of the basic Force Sensing Resistor (FSR) as the lower membrane features two drive lines connected to either end of a printed fixed resistor and a sense line. When an external force is applied onto the sensor, the upper and lower membranes establish a connection, thus the sense line is shorted to a point along the fixed resistor. This allows us to determine the location of the touch point along the length of the fixed resistor as it is proportional to the resistance between either drive line and the touch point [Electronics, 2012]. In contrast to the FSR, the FSLP sensor is a three-terminal device as depicted in Figure 3.3.

In Figure 3.4 a schematic is shown on how the FSLP sensor needs to be connected to a microcontroller, which in our case is an Arduino Uno.

The arrow that points at the junction between R_1 and R_2 indicates the touch point. Consequently, R_1 represents the resistance from terminal $D1$ to the touch point and R_2 the resistance from the touch point to terminal $D2$. When the user touches the sensor exactly in the middle, the resistances R_1 and R_2 are equal otherwise depending on the

Figure 3.3: Overview of the three pins of the FSLP sensor. Each pin is connected to a microcontroller. For position sensing, the voltage of the sense line is taken. When measuring the applied pressure onto the sensor, the voltages of the sense line and the drive line 2 are relevant. Figure taken from [Corporation, 2012].

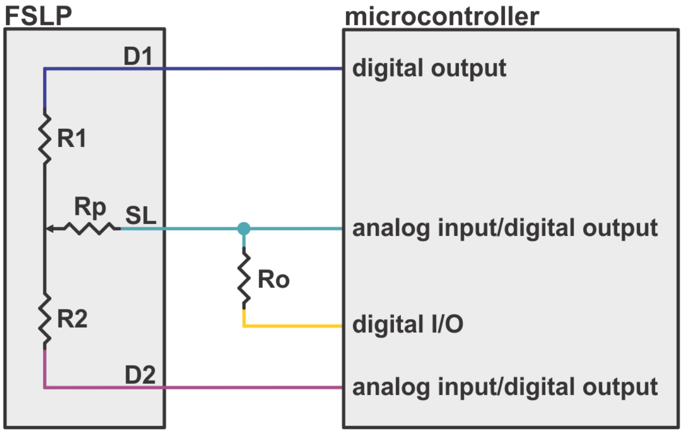

Figure 3.4: Circuit diagram of the FSLP sensor. As depicted, an external resistance R_0 needs to be integrated into the circuit in order to achieve position and pressure measurements. All four outputs are connected with a microcontroller. Figure taken from [Corporation, 2012].

position of the touch point, either R_1 or R_2 is bigger. In order to measure the position of the touch point, the pin that is connected to terminal $D1$ is driven high and the pin that is connected to terminal $D2$ is driven low. By further setting the pin that is connected to the bottom of R_0 to a high impedance input, which essentially disconnects R_0 from the circuit, the SL pin becomes the output of the linear potentiometer. Depending on the touch point, a voltage between $0\,\mathrm{V}$ and $5\,\mathrm{V}$ can be measured [Corporation, 2012].

We measure how much mechanical force is applied onto the surface of the FSLP sensor. This allows us to differentiate between various pressure levels.

Additionally the FSLP sensor is also able to measure pressure as the resistance of R_p changes depending on the magnitude of the applied pressure onto the sensor. By driving the pin that is connected to terminal $D1$ high and the pin that is connected to the bottom of the resistor R_0, we choose a value of $4.7\,\mathrm{k}\Omega$ for this resistor, low, the SL pin becomes an output of a voltage divider circuit which depends on R_1 and R_2. Towards an independence from R_1 and R_2, so an independence from the position measurement when measuring pressure, an additional voltage is measured at the pin that is connected to terminal $D2$, which provides us the voltage at the junction between R_1 and R_2. By using the measured voltage as the new reference voltage for the pressure voltage divider circuit, the desired independence is achieved. Note, that because now we are measuring a voltage at terminal $D2$, no current is flowing through the resistor R_2 [Electronics, 2012].

We average the position measurements.

In order to reduce variations in the position data, we implemented an average filter, that averages over the last 50 position values. We found this value to be a good trade-off regarding the speed and accuracy of the filter. Additionally, during testing we found out that the sensor has the limitation that positions corresponding to the values 97% and above are almost impossible to detect. Because of that reason we map all values of 97% or above directly to 100%. The same applies to values below 4%. These are all directly mapped to 0%.

By measuring the applied pressure on the FSLP sensor, we can derive whether there is any touch applied on the sensor and additionally allows us to detect if a high pressure is applied onto the sensor which is relevant for certain interaction techniques as described in Section 3.1. During testing we found out that when a user touches the sensor in order to set a value, a pressure value of around $10 - 20$ can be measured. When applying high pressure onto the sensor, pressure values greater than 80 can be measured. The magnitude of these values are needed so the control software can differentiate between dissimilar pressure levels. Note that these pressure values are provided by the analog to digital converter (ADC) of the Arduino Uno.

As described in Section 3.1, a pressure sensitive area is needed that would allow us to detect, together with the

FSLP sensor, gestures such as sliding out of the slider. For that we could of course utilize multiple FSRs. However, these sensors are manufactured in a specific size which would restrict us in the ability to freely choose the dimensions of the pressure sensitive area. Thus, we decided to integrate our own textile sensor into the fabric, whereby the electronic principle is derived from the FSR. Figure 3.5 depicts the schematic view of the pressure sensitive area.

We decided to manufacture our own fabric sensor that would be used for the pressure sensitive area. The principle of this sensor is derived from the FSR.

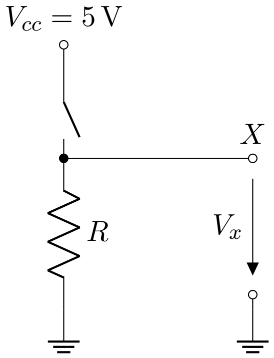

Figure 3.5: Schematic view of the pressure sensitive area. The resistor R represents the resistance of a resistive sheet. A conductive sheet is connected to a voltage source of $5\,\mathrm{V}$ and has practically no resistance, so acts like an ideal conductor. The switch is in an open position when the user is not touching the pressure sensitive area. When pressure is applied onto the sensor, the resistive and conductive sheets establish a connecting, hence a voltage $V_x > 0\,\mathrm{V}$ can be measured.

For such a fabric sensor three different materials are needed: a conductive sheet[1], a resistive sheet[2] and a mesh spacer[3]. As the name suggests, the conductive sheet is a highly conductive fabric with a resistance close to $0\,\Omega$. The resistive sheet is also a conductive fabric, however here the resistance is around $20\,\mathrm{k}\Omega$ per square centimeter which is indicated by the resistor R in Figure 3.5. The mesh spacer is needed in order to create a spacing between the conductive and resistive sheet when there are placed on top of each other and no external pressure is applied onto them. A volt-

When an external force is being applied onto the sensor, the conductive and resistive sheet establish a connection thus a voltage $V_x > 0$ can be measured which allows us to conclude that a touch input has occurred.

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[1] https://bit.ly/36hYDIL (*Accessed: March 30, 2022*)

[2] https://bit.ly/3s5jN5i (*Accessed: March 30, 2022*)

[3] https://bit.ly/3sOHM88 (*Accessed: March 30, 2022*)

age source of $5\,\mathrm{V}$ is connected to the conductive sheet, the resistive sheet is connected to ground as well as to an analog pin of an Arduino Uno in order to measure the voltage V_x. In theory when no pressure is applied, the measured voltage V_x is equal to $0\,\mathrm{V}$, so the switch is in an open position. When the user applies pressure onto the fabric sensor, the conductive and resistive material establish a connection, so the switch moves to the closed position, which consequently leads to the fact that a voltage $V_x > 0\,\mathrm{V}$ can be measured. By that we are able to detect that a user touch input has occurred. The exact value of V_x is not of interest for us as we only intend to use the sensor for detecting whether a touch has occurred or not. We cannot use this kind of sensor in order to distinguish between pressure levels. During testing we found out that due to the manufacturing process, a contact between the conductive and resistive sheet is achieved even when no pressure is applied onto the sensor which results in the fact that a voltage higher than $0\,\mathrm{V}$ can be measured in the no-touch phase. This behavior can be observed in Figure 3.6, where the measurements of the voltage V_x, by the ADC of the Arduino Uno, are displayed.

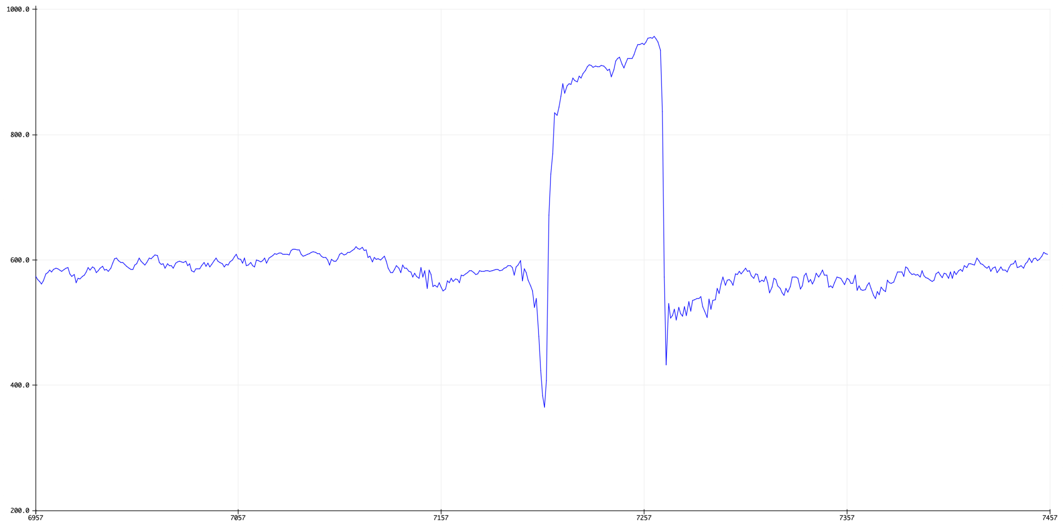

Figure 3.6: The voltage behavior of the pressure sensitive area during a no-touch and a touch event. The higher idle voltage level is clearly visible. During a touch event values of up to 900 can be achieved which allows us to derive whether a touch input has occurred.

The ADC of the Arduino Uno can return values between 0 and 1023. In a no-touch event, a value of around 600 can be observed which translates to $\frac{600}{1024} \cdot 5\,\mathrm{V} = 2.93\,\mathrm{V}$. When the user touches the pressure sensitive area, values of up to 900 or $4.39\,\mathrm{V}$ can be achieved. As a consequence we decided to adjust the threshold whether a voltage corresponds to a user touch input. Everything above 800 or $3.91\,\mathrm{V}$ is interpreted as a user input as it provides enough clearance from the expected values in the no-touch phase. We believe the reason for this behavior is that when a relative heavy textile is placed on top of the sensor, in order to hide the circuitry, the conductive sheet can be pushed down because of the weight applied on top which leads to the unwanted contact in the no-touch phase. In order to reduce variations in the pressure measurements, we implemented an average filter that averages over last 15 measurements. Here again, we found this value to be a good trade-off regarding the speed and accuracy of the filter.

We adjust the threshold of when a voltage V_x corresponds to a touch input.

We decided to use multiple vibrating Mini Motor Discs[4], so a vibration mechanism can be achieved which is needed for the *State Communication* interaction technique. By connecting one pin of the motor to ground and the other to a digital pin of an Arduino Uno, the motor can be controlled by setting the output of the digital pin to high. By that we are able to precisely control the duration of the vibration feedback as such feedback is only needed for a short amount of time when interacting with the textile interface. We found out that an on-duration of $500\,\mathrm{ms}$ for the motors is sufficient in order to provide suitable haptic feedback.

We use Mini Motor Discs for the vibration mechanism.

3.3 Fabrication Setup

All textile prototypes were designed with the usage of the Bernina Embroidery Software 8 DesignerPlus software[5] and consequently manufactured with the Bernina B880 embroidery machine. A needle size of 90 and a straight stitch needle plate were used in order to stitch the various proto-

For manufacturing the various textile slider prototypes, we utilize a Bernina B880 embroidery machine.

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[4] https://bit.ly/3H92rZw (*Accessed: March 30, 2022*)

[5] https://bit.ly/3AtkBnh (*Accessed: March 30, 2022*)

types. Additionally, the Bernina embroidery foot #26, a universal embroidery foot, was installed into the embroidery machine. For clamping textile fabrics in place we utilized the medium sized as well as the large sized oval clamping hook.

3.4 Textile Slider Prototypes

As described in Section 3.1, we intend to evaluate eight dissimilar interaction techniques on textile sliders. Because certain interactions represent a subclass of another interaction technique, for instance *Confirmation* by pressure is a subclass of *Activation* by pressure, we only need to manufacture three physically dissimilar prototypes and by just varying the control software, we can altogether achieve the desired eight interaction techniques. When designing and building the textile prototypes, we followed design guidelines for textile sliders introduced by Nowak et al. [2022] as a result of their research. Consequently all slider prototypes feature recessed paths with a three-tick-mark design which offers haptic feedback for possible eyes-free interactions.
Figure 3.7 shows the first prototype we manufactured which is used for the ARM interaction technique.

The first prototype features a sphere that is embedded into the textile, whereby the FSLP sensor detects its position.

This prototype features a sphere that is embedded into the textile so the user can move the sphere in order to set a value. The actual slider, that is the area the user can interact with, is represented by the inner, narrow rectangle with the three tick-marks. The cross section of this prototype is depicted in Figure 3.8.

Multiple layers of materials are needed in order to create this unique prototype. At the bottom we use a fabric ① where the FSLP sensor ② is adhered onto. In order to keep the sphere ④ in place, when a user interacts with the textile interface, we adhered at the border of the FSLP sensor 3D-printed edges ③. Throughout that we also achieve that the sphere is applying pressure onto the sensor at any given time. The haptic feedback of the slider consists of three lay-

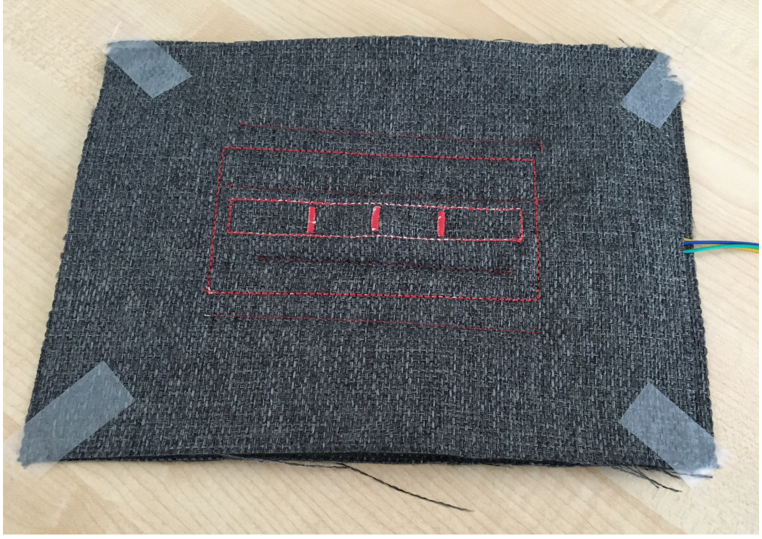

Figure 3.7: Figure of the first prototype. The inner, narrow rectangle with the three-tick-mark design is the slider. The bump in the middle is a result of the sphere that is embedded into the textile.

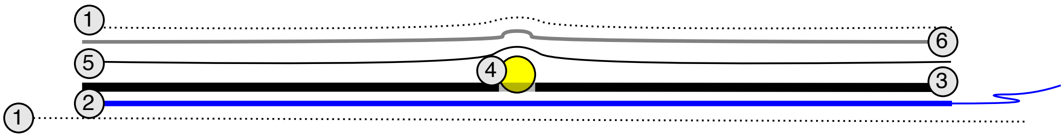

Figure 3.8: Figure of the cross section of the first prototype. Multiple layers that consist of different materials are used in order to achieve the requested features. ① - fabric, ② - FSLP sensor, ③ - 3D-printed edges, ④ - sphere, ⑤ - stabilizer, ⑥ - 3D-foam.

ers. First a stabilizer ⑤ is stitched together with a 3D-foam ⑥. Then a fabric ① is stitched on top. This package of three layers is then stitched together with the rest of the prototype.

The second prototype is shown in Figure 3.9 that we use for the CSO, ASI and ADP interaction techniques. Again, the slider is realized by the inner, narrow rectangle with the three-tick-mark design. Additionally below the slider

For the second prototype, we use our own fabric sensor in order to achieve the desired functionality of a pressure sensitive area.

a wider rectangle is visible. This area marks the borders of the pressure sensitive area.

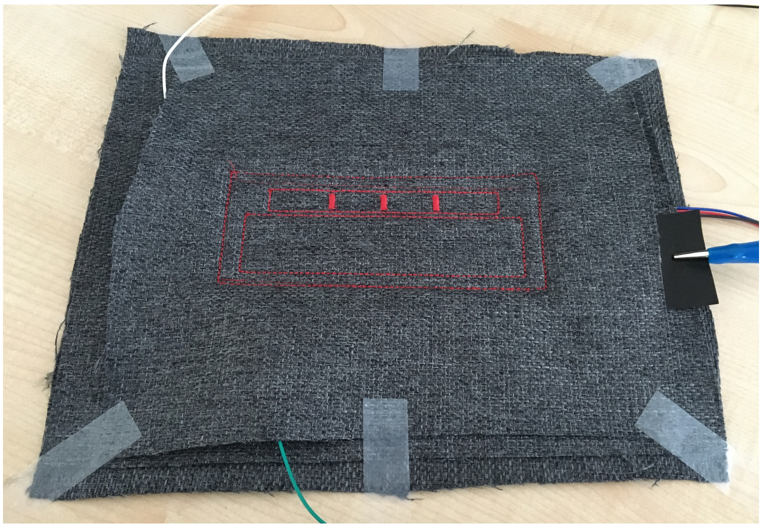

Figure 3.9: Figure of prototype 2. Here again, the slider is realized by the inner, narrow rectangle with the three-tick-mark design. Below the slider, a pressure sensitive area is located that is marked by the wider rectangle.

The resulting cross section from the slider's point of view is depicted in Figure 3.10.

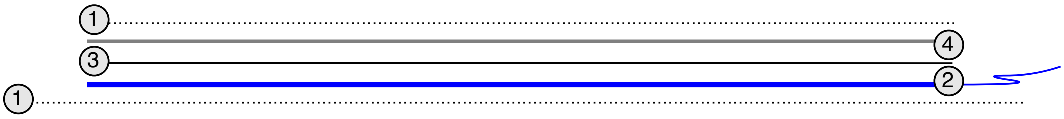

Figure 3.10: Figure of the cross section of the second prototype from the slider's point of view. Multiple layers are needed in order to achieve the desired functionality. ① - fabric, ② - FSLP sensor, ③ - stabilizer, ④ - 3D-foam.

We use multiple layers in order to achieve the desired functionality of the slider. At the bottom we use a fabric ① where the FSLP sensor ② is adhered onto. Here again the haptic feedback of the slider is created by using three lay-

ers. A stabilizer ③ is stitched together with a 3D-foam ④. Then a fabric ① is stitched on top. This package is then stitched together with the rest of the prototype.
The cross section from the pressure sensitive area's point of view is shown in Figure 3.11.

Figure 3.11: Figure of the cross section of the second prototype from the pressure sensitive area's point of view. A resistive and a conductive sheet are needed in order to achieve the desired behavior of the pressure sensitive area. ① - fabric, ② - resistive sheet, ③ - mesh spacer, ④ - conductive sheet.

A resistive sheet ② is stitched onto a fabric ①. On top of that a mesh spacer ③ and a conductive sheet ④ is stitched. The mesh spacer allows us to separate the resistive sheet from the conductive sheet in a no-touch event. In an ideal case, the conductive and resistive sheets only establish a connection when the mesh spacer is dented due to an external force that is applied onto the textile interface by a user. A fabric ① is stitched onto the conductive sheet so the fabric sensor is hidden from the user.

Figure 3.12 shows the third prototype that we use for the ARNM, CP, AP and SC interaction techniques. The slider is again represented by the inner, narrow rectangle with the three-tick-mark design.

In the third prototype, Mini Motor Discs are placed below the FSLP sensor in order to achieve the vibration mechanism for the SC interaction technique.

The cross section of the third prototype is depicted in 3.13.

The motors ② that are used in order to create vibration feedback, are adhered onto a fabric ①. On top of that a thin wooden board ③ is placed as otherwise the FSLP sensor ④ would bend if placed directly on the motors because of the spaces between the motors. When the FSLP sensor is bent, the position as well as the pressure measurements be-

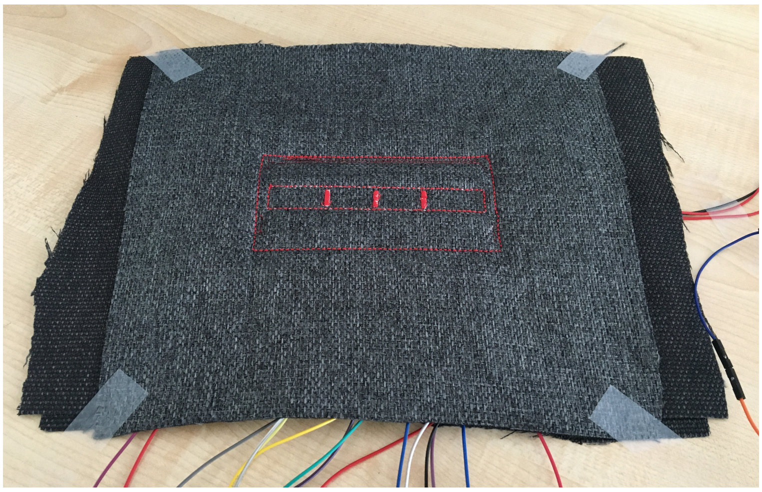

Figure 3.12: Figure of the third prototype. In the middle, the narrow rectangle with the three-tick-mark design is visible which represents the slider.

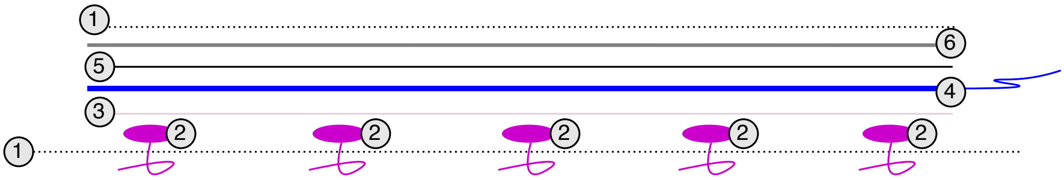

Figure 3.13: Figure of the cross section of the third prototype. Motors are located below the FSLP sensor so a vibration feedback can be provided which is needed for the *State Communication* interaction technique. ① - fabric, ② - vibrating motors, ③ - wooden board, ④ - FSLP sensor, ⑤ - stabilizer, ⑥ - 3D-foam

come unreliable. On top of the FSLP sensor, the haptic feedback of the slider is stitched onto that consists of a stabilizer ⑤, a 3D-foam ⑥ and a fabric ①.

For a detailed description of the manufacturing process for each prototype, refer to the following Git repository[6].

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[6] https://bit.ly/3L1LdzV (*Accessed: March 30, 2022*)

3.5 Control Software

In order to differentiate between the dissimilar states of each interaction, we decided to implement a state machine in the control software.

As mentioned in Section 3.2, various peripherals are connected to an Arduino Uno, which allow us to read and process sensor data so unique interaction techniques can be achieved. For writing the software, we utilize the Arduino IDE[7], so consequently all software is written in C++. In order to differentiate between the different phases of a interaction technique, we decided to implement a state machine in the control software. Depending on the interaction technique, different states are reachable. In the following we are going to explain the state machine for each interaction technique and thereby will simultaneously give an inside view on how the various interaction techniques are recognized. Initial states are indicated by a short incoming arrow.

The state machine of the ***Always Reactive*** **non-mechanical** interaction technique is shown in Figure 3.14.

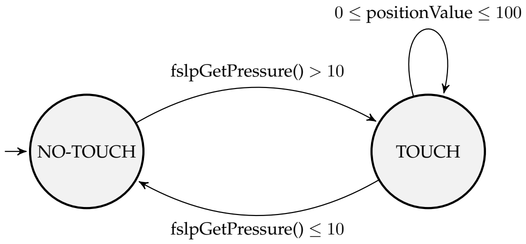

Figure 3.14: State machine of the *Always Reactive* non-mechanical interaction technique. Any light touch on the slider leads to the fact that the TOUCH state is reached and as a consequence the position value can be changed.

During this interaction two states are possible: NO-TOUCH and TOUCH. The TOUCH state is reached when a user touches the slider at an arbitrary point due to the fact that the FSLP sensor then detects a pressure level greater than 10. As a result, it is now possible for the user to manipulate the current position value. Once the user reached the desired value he wants to set, he can simply release his

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[7] https://bit.ly/3HnxAJ6 (*Accessed: March 30, 2022*)

finger from the slider which saves the position value and simultaneously by that the NO-TOUCH state is reached.

In Figure 3.15 the state machine of the ***Always Reactive* mechanical** interaction technique is depicted.

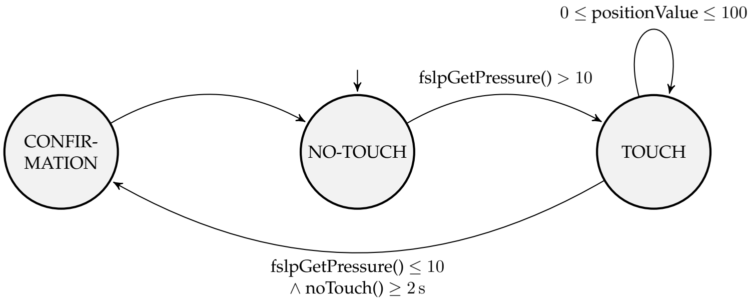

Figure 3.15: State machine of the *Always Reactive* mechanical interaction technique. When the user starts moving the sphere, the TOUCH state is entered and as a result the position value is changed depending on the sphere's location.

We implemented a timer of 2 s into the state machine of the ARM interaction.

The functionality of this state machine is very similar to the one of the non-mechanical interaction technique. However, here a sphere has to be moved by the user in order to set a desired value. As a consequence, the TOUCH state is reached when the user starts moving the sphere as then a pressure level greater than 10 is detected by the FSLP sensor. Once the desired position value is set and no changes regarding the position measurements are registered, for at least 2 s, the CONFIRMATION state is reached and subsequently the NO-TOUCH state is entered. We implemented the timer of 2 s so the user is able to resume the current interaction when the finger accidentally slips from the slider. This may occur as the sphere is very tightly embedded in the textile interface.

Figure 3.16 illustrates the state machine of the ***Confirmation* by pressure** interaction technique.

Interactions such as *Confirmation* by pressure, feature a confirmation gesture in order to save an input value. The user starts his interaction by simply touching the slider which leads to the fact that the FSLP sensor detects a pressure level

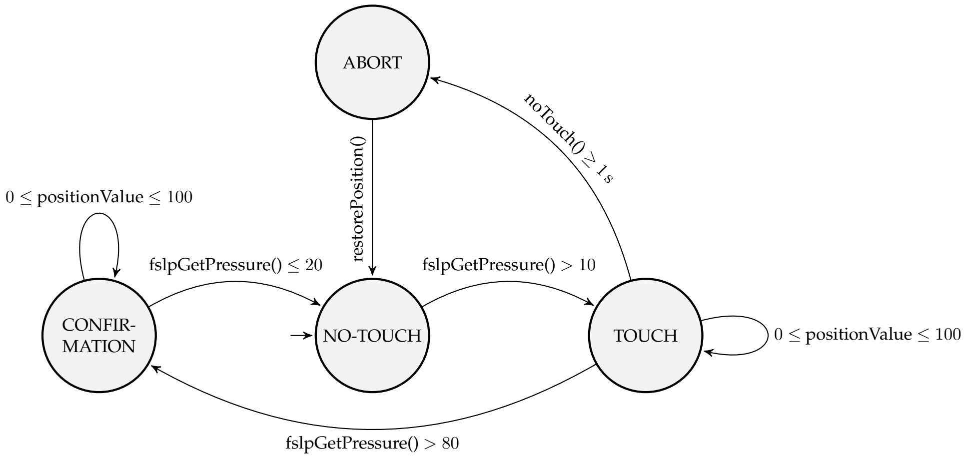

Figure 3.16: State machine of the *Confirmation* by pressure interaction technique. Here the slider is directly reactive to user input. However, a new value is only saved if the user applies high pressure for a short amount of time onto the slider at the end of his interaction.

The state machines of the *Confirmation* interaction techniques feature an ABORT state which is reached when the user does not perform the confirmation gesture in order to save a new input value.

greater than 10, as explained in Section 3.2. Consequently, the TOUCH state is reached where the position value can be manipulated. Once a desired value is reached by the user, high pressure for a short amount of time needs to be applied onto the slider. This will lead to the fact that a pressure level greater than 80 is measured by the FSLP sensor and subsequently the CONFIRMATION state is reached. Until the user does not release the textile interface, he can still apply changes to the position value. Only completely lifting the finger from the slider, will terminate the interaction finally. Note, that in the CONFIRMATION state the user does not have to apply high pressure onto the slider anymore. If the confirmation gesture is not being performed, the ABORT state is entered and as a result the previously confirmed value is restored.

The state machine of the ***Confirmation* by sliding out** interaction technique is depicted in Figure 3.17.

As with the CP interaction, a simple touch on the slider changes the current state to TOUCH. As a result the position value can be changed. In order to confirm a new value, the user has to slide out of the slider with his fin-

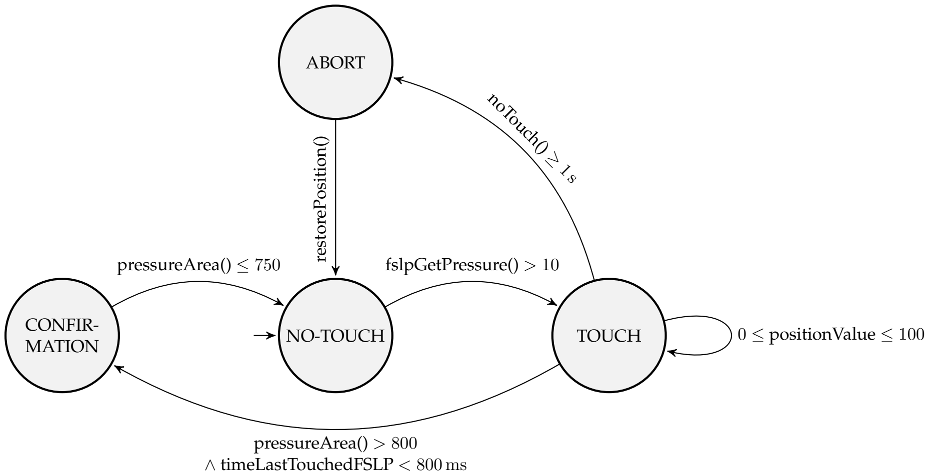

Figure 3.17: State machine of the *Confirmation* by sliding out interaction technique. The position value is directly manipulated once the user touches the slider. The desired position value is saved once the user slides his finger out of the slider.

ger and by that touch the pressure sensitive area located below the slider. For that, we measure the time difference between when the user last touched the slider and when for the first time the pressure sensitive area was touched. If this difference is within 800 ms, the gesture is interpreted as sliding out and subsequently the CONFIRMATION state is reached. If the user now completely lifts his finger from the textile interface, the interaction is finally terminated and the NO-TOUCH state is entered. Note that the functionality of the ABORT state is same as with the CP interaction technique.

All of the following interaction techniques need beside a confirmation also an activation gesture. The state machine of the ***Activation* by pressure** interaction technique is shown in Figure 3.18.

The functionality of this interaction is uniform to the counterpart that only involves a confirmation gesture, hence the state machines share a lot of similarities. The main difference here is that the slider is initially in an INACTIVE state and only reaches the ACTIVE state once the activation gesture is performed. For that, high pressure needs

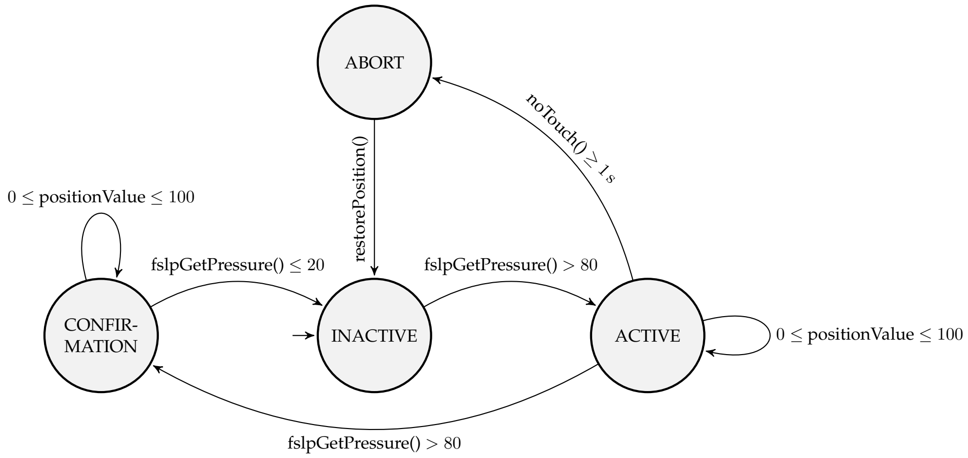

Figure 3.18: State machine of the *Activation* by pressure interaction technique. The slider will be activated by applying high pressure for a short moment. As a consequence, the slider is now reactive to touch input, so the position value can be changed. We utilize the confirmation gesture of the CP interaction technique in order to save a new input value.

to be applied onto the textile interface for a short moment, so a pressure level greater than 80 can be registered by the FSLP sensor. Consequently the position value can be manipulated, as the slider is now reactive to user input. The CONFIRMATION or ABORT states are reached under the same conditions as with the CP interaction technique.

Hence the slider is not directly reactive to user input for *Activation* interaction techniques, the corresponding state machines therefore feature an INACTIVE state.

Figure 3.19 depicts the state machine of the ***Activation* by sliding in** interaction technique.

Also for this interaction an activation gesture is required, hence the ACTIVE state is reached once the user has touched the pressure sensitive area and from there slid his finger into the slider. This gesture is recognized by measuring the time difference between when the last time the pressure sensitive area and for the fist time the slider was touched. For a successful activation, the difference of these two timestamps has to be within 800 ms. The CONFIRMATION or ABORT states are reached under the same conditions as with the CSO interaction technique.

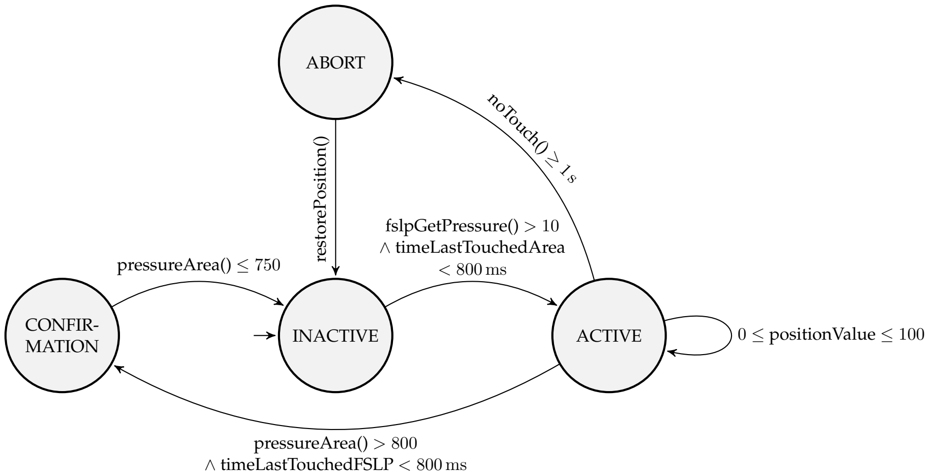

Figure 3.19: State machine of the *Activation* by sliding in interaction technique. Sliding into the slider activates it and as a result the position value can be manipulated. We use the confirmation gesture of the CSO interaction technique in order to save a new input value.

The following Figure 3.20 depicts the state machine of the ***Activation* by double pressure** interaction technique.

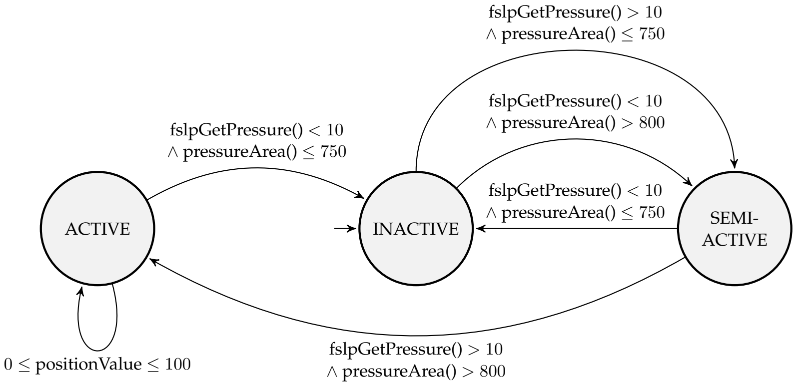

Figure 3.20: State machine of the *Activation* by double pressure interaction technique. The user has to simultaneously touch the slider and the pressure sensitive area in order to reach the ACTIVE state where the position value can be changed. If only one sensing surface is touched, the SEMI-ACTIVE state is entered.

As explained in Section 3.1, the ADP interaction utilizes the pressure sensitive area differently compared to the CSO and ASI techniques which leads to the fact that two fingers are required in order to set a new position value. The SEMI-ACTIVE state is entered from the INACTIVE state, once the user touches the slider but not the pressure sensitive area or vice versa. Only if both sensing surfaces are touched simultaneously, which means the FSLP sensor measures a pressure level greater than 10 and for the pressure area a value greater than 800 is detected, the ACTIVE state is reached where the position value can be changed by the user. The interaction is terminated and the input value is saved, once both fingers are released from the textile interface. Note that once one finger is released, the INACTIVE state is not directly entered as the second fingers has not been released yet. During this event however, the position value can no longer be manipulated.

The state machine of the ***State Communication*** **by vibration feedback** interaction technique is shown in Figure 3.21.

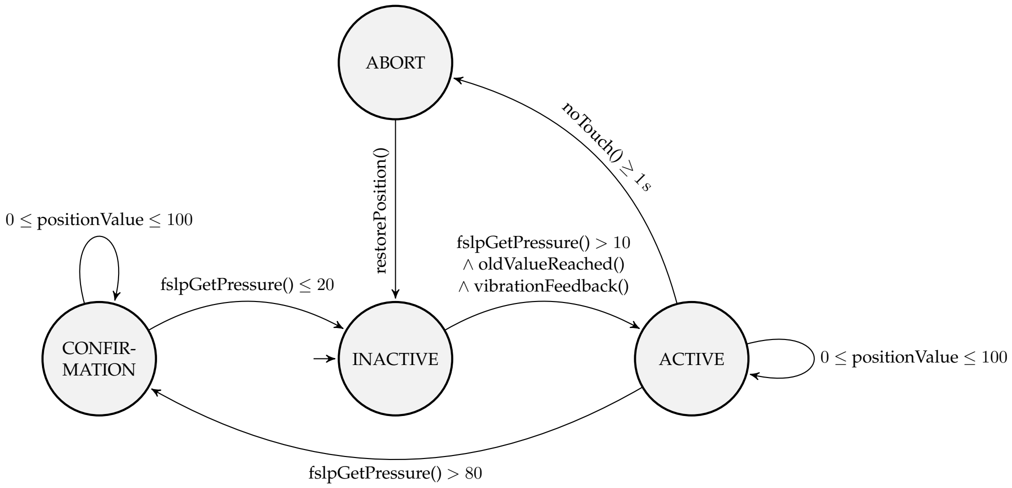

Figure 3.21: State machine of the *State Communication* by vibration feedback interaction technique. Here the user activates the textile interface by sliding over the slider until the currently set value is reached. Once this value is reached, a vibration feedback is provided and consequently the position value can be changed. We utilize the confirmation gesture of the CP interaction technique in order to save a new input value.

For this interaction, the user has to slide his finger over the slider until he reaches the currently set value. As a consequence a vibration feedback is provided and the ACTIVE state is entered where the position value can be manipulated. Because of this unique activation gesture, position measurements have to be performed even when the slider is currently in the INACTIVE state as constant comparisons need to be performed whether the user has reached the previously confirmed value. The CONFIRMATION or ABORT states are reached under the same conditions as with the CP interaction technique.

Chapter 4

Study

In this Chapter, we evaluate possible interaction techniques on textile sliders during a user study. For that, we utilize the three prototypes that were introduced in Chapter 3, together with their eight corresponding interactions. During the study, each participant performs all of the eight interaction techniques.

4.1 Aim

We investigate the performance of the dissimilar interaction techniques on textile sliders. Therefore, participants will be asked to interact with the various textile interfaces using the presented interactions. Our aim is to collect general performance data of each interaction technique and to gather the participant's feedback in order to get an inside view on how these interactions compare to each other and how they can be improved.

4.2 Participants

14 people participated in our study. Their age ranged from 22 to 30 ($M = 24.4$, $SD = 2.8$), whereby four participants were female and ten were male. One participant reported to be left-handed all other were right-handed. Most of the participants were enrolled in a technical study program.

4.3 Independent Variables

Two major independent variables can be identified.
One of them is TYPE. This variable features eight levels where each level corresponds to one of the eight interaction techniques to be evaluated.

The other variable is TARGET. One major part of the study is the target selection task which is explained in detail in Section 4.6. Here the participant has to set 21 target values for each interaction technique. Consequently the TARGET variable has 21 levels, whereby each level corresponds to one of the possible target values that are multiple of 5% in a range from 0% to 100%.

4.4 Dependent Variables

The dependent variables comprise of several properties that are important to measure when evaluating interaction techniques on textile sliders.

The variable ACCURACY [%] describes the deviation of the current input from the expected input.

One such variable is ACCURACY [%] which describes the deviation of the user input from the target value. This data is obtained by calculating the difference between the user input and the target value and subsequently taking the absolute value of the result in order to obtain positive numbers in all cases. The current input is compared to the expected input when the user terminates his interaction, so is no longer able to change the input value.

The duration of an interaction is expressed by the variable SPEED [ms].

The other dependent variable is SPEED [ms] which describes the amount of time that is needed in order to set a target value on the textile slider. The time measurement begins when the user starts to perform the activation gesture or in a case when the interaction technique features no activation gesture, the time of the first touch input is used as the starting time. An interaction is completely terminated when the user is no longer touching the textile interface, no matter if the interaction features a confirmation gesture or not, hence this event marks the end of the SPEED measurement.

4.5 Apparatus

Figure 4.1 shows the general setup of the study and the resulting apparatus.

Figure 4.1: General overview of the study setup. All three prototypes are fixed to the table. The laptop is used for visualizing the user input as well as data logging. Its position varies depending on which prototype is currently being evaluated.

All three prototypes are placed on a table in front of the participant. Each prototype is connected to a unique Arduino Uno that reads the various sensor values. The measured data points are then transferred via USB to a laptop which is responsible for firstly visualizing the input data to the participant and secondly saving all measured data points in a CSV file for further analysis.

4.6 Task and Visualization

The participants have to set 21 target values on a textile slider using each of the eight presented interaction techniques.

During the user study, the main task for a participant is to set given target values on the various textile interfaces using the present interaction techniques. We utilize Processing[1] in order to provide direct visual feedback to the user regarding the current input value as well as target value. Processing is a free integrated development environment (IDE) and graphical library, whereby among other things data from the Arduino Uno can be easily visualized. Processing utilizes the data that is being send from the Arduino Uno to the USB port. Figure 4.2 illustrates what the user is able to see when he is interacting with one of the slider prototypes.

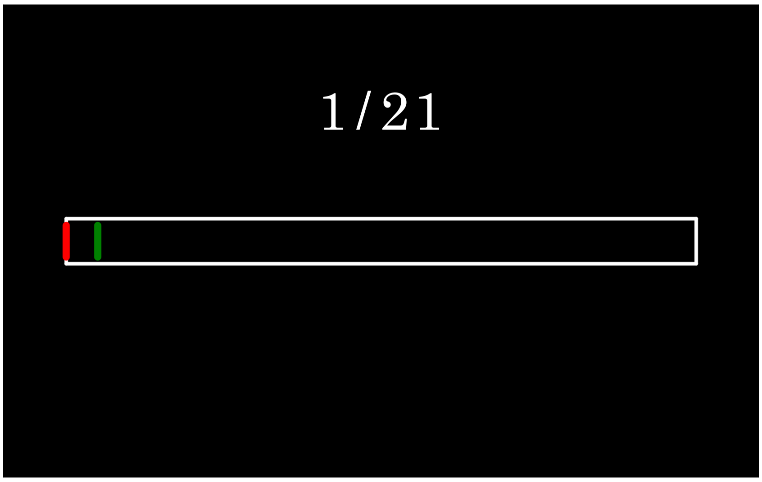

Figure 4.2: The visualization of the user input versus the expected input. The red line indicates the current user input and the green line corresponds to the target value that needs to be set. The counter above indicates how many of the 21 target values were already reached.

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[1] https://bit.ly/3s7XdZZ (*Accessed: March 30, 2022*)

The edges of the slider are denoted by the white rectangle. The vertical red line represents the value that is currently set on the textile interface. When the user moves his finger over the slider, the red lines moves consequently to the corresponding position, provided that the textile interface is reactive to touch input. The vertical green line is used to indicate a specific target value that needs to be set, so consequently the goal is to move the red line as close as possible to the green line in order to reach the given target value. The next target value is displayed once the user is no longer touching the textile interface. For certain interaction techniques it is necessary to confirm a new value by applying high pressure onto the slider. In order to provide visual feedback for this gesture, the color of the rectangle changes from white to green when enough pressure is being applied, until the slider is no longer being touched. Additionally, above the slider shape, a counter is located which indicates how many of the 21 target values where already set. In cases where an abort state is entered during a trial, the next target value is displayed once pressure is completely released from the textile interface. After that, the participant should focus on setting the next target value. Between each trial it is possible for the participant to take breaks.
During the target selection task, the focus should be on setting the given target values as fast and as precise as possible.

Throughout the target selection task, the participants are able to see a visualization of the current input value as well as target value.

4.7 Experimental Design

While the user has to compare dissimilar interaction techniques, we use a *within-subject* design. We counterbalance the different interaction techniques using *Latin Square* and randomize the order of the target values for each interaction technique. In total we record 8 TYPE × 21 TARGET = 168 trials per user.

4.8 Experimental Procedure

At the beginning of each user study process, the participant reads the informed consent form (Appendix A.1) which is additionally explained by the conductor. Afterwards, the conductor explains that the participant is allowed to take breaks between each target selection task but once the task is started for a specific interaction technique, it can not be interrupted anymore. Furthermore the participant is advised to use his dominating hand throughout the whole study and that after each interaction, the finger needs to be completely lifted from the textile interface as only then the next target value will be displayed.

Each interaction technique is explained in detail to the participant. Before the target selection task, the participant is able to familiarize himself with the presented interaction technique and additionally may ask questions about it.

The participant is informed that taking part in the study involves eight phases as eight interaction techniques need to be evaluated. At the start of each phase the present interaction technique is explained to the participant by the conductor. After that, the corresponding software is loaded to the Arduino Uno and the Processing script is started. Consequently, a test trial is conducted where the participant has the chance to familiarize himself with the present interaction technique. During that time the participant is also allowed to ask questions. Already during the test trial, target values are displayed to the participant by the Processing script. Data that is obtained during the test trial is not used for further analysis. Once the participant indicates to the conductor that he is now familiar with the present interaction technique, the conductor restarts the Processing script and enters the participant's ID. As a consequence the actual trial is started where the participant is required to set 21 target values that are multiple of 5% in the range from 0% to 100%. As explained in Section 4.6, the current user input as well as target value is displayed to the user throughout the whole phase.

Once all 21 target values were set by the participant, a questionnaire (Appendix A.2) needs to be filled out. Depending on the present interaction technique, some questions are omitted. During that time, the conductor ensures that all data is saved correctly, uploads the software for the next interaction technique to the Arduino Uno and consequently

starts the corresponding Processing script.
Once all eight interaction techniques are evaluated once by the participant, the conductor asks the participant to fill out a final questionnaire (Appendix A.3).

4.9 Measurements and Feedback

We conduct this user study in order to compare dissimilar interaction techniques. As a result we need to obtain various data measurements as well as feedback from each participant.
Throughout the whole target selection task we measure the current time, target value, input value as well as present state of the textile interface, whereby the possible states dependent on the present interaction technique as introduced in Section 3.5. All measured data is saved in a CSV file and for each interaction technique a new CSV file is created. The measurements are taken approximately every $50\,\mathrm{ms}$. In total we obtain eight CSV files from each participant.

During the target selection task, we log data points approximately every $50\,\mathrm{ms}$.

Additionally to the logged data, we are also interested in the participant's perception regarding each interaction technique. For that reason a questionnaire, with a 5-point Likert scale, (Appendix A.2) has to be filled out after the target selection task was performed for one interaction technique. If the interaction features a confirmation or an activation gesture, additional questions are asked. Here the participant has also the chance to provide additional feedback on what he liked and did not like about the present interaction technique as well as how it could be improved.

We gather participant's feedback regarding each interaction technique by additional questionnaires.

At the end of each user study process the participant fills out a final questionnaire (Appendix A.3) where a ranking of all the eight interaction techniques has to be given.

4.10 Results

In the following, we will list the results we obtained from the target select task. Furthermore, we present the participant's feedback for each interaction technique. 38 trials were not further analyzed as during these trials an abort was accidentally triggered by the participant.

4.10.1 Performance Data

The means and standard deviations of the accuracy for each interaction technique during the target selection task, are depicted in Figure 4.3.

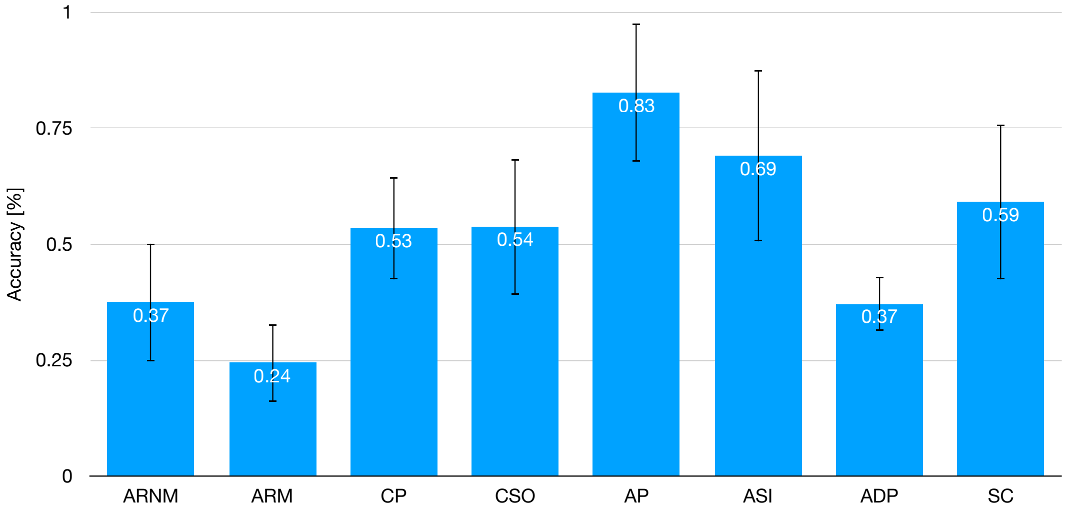


Figure 4.3: Means and standard deviations of the accuracy during the target selection task. The *Always Reactive* mechanical interaction technique achieved the highest accuracy, the *Activation* by pressure interaction the lowest.

The ARM interaction technique achieved the highest accuracy, followed by the ARNM and ADP interaction techniques. The AP interaction features the least accuracy.
In Figure 4.4 the means and standard deviations of the interaction speed are displayed. It must be observed that

the activation times of the AP and ASI interaction techniques could not be derived from the obtained data measurements because of software limitations, hence there are not included in the speed results for the mentioned interactions. The same applies to the confirmation time of the ADP interaction.

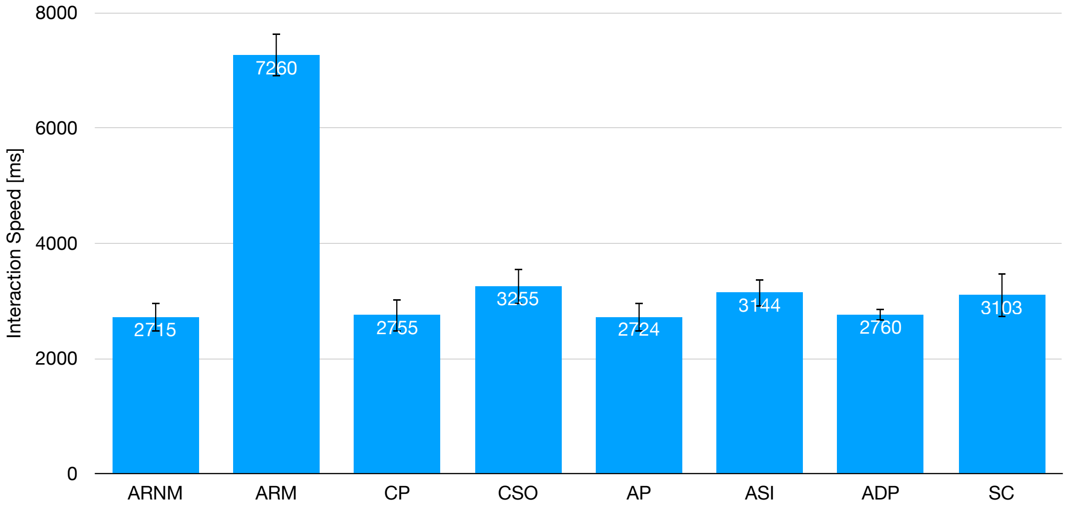


Figure 4.4: Means and standard deviations of the interaction speed during the target selection task. *Activation* by pressure features the fastest speed, *Always Reactive* mechanical the lowest. Activation times of the *Activation* by pressure and *Activation* by sliding in interaction techniques are not included. For the *Activation* by double pressure interaction, the confirmation time is not included.

Under these conditions, the AP interaction achieved the fastest speed during the target selection task. The ARM interaction technique features the slowest speed compared to all other interactions. However, here it needs to be considered that at the end of each interaction with the ARM technique, a timer is running that checks whether the sphere has not been moved for at least to 2 s. Only if this condition is satisfied, the NO-TOUCH state is entered which terminates the interaction.

The ARM interaction technique features the slowest interaction time.

In Figure 4.5 the means and the standard deviations of the activation time for the *Activation* by double pressure and *State Communication* by vibration feedback interaction techniques are depicted. As explained above, the activation times of the AP and ASI interaction techniques could not be derived from the obtained data measurements because of software limitations.

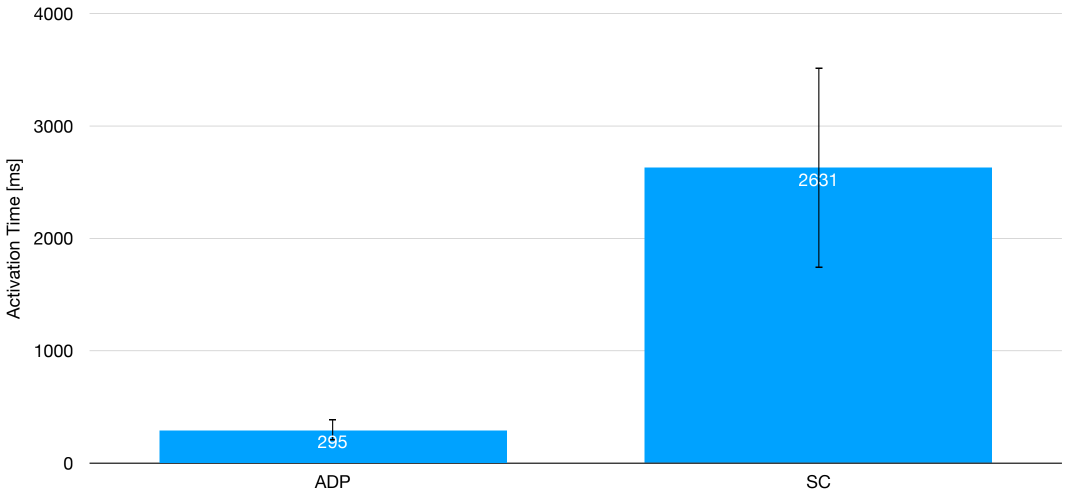


Figure 4.5: Means and standard deviations of the activation time. The activation times of the *Activation* by pressure and *Activation* by sliding in interaction techniques are not included. The *State Communication* interaction technique features a much higher activation time than the *Activation* by double pressure interaction.

It can be observed that the activation time for the SC interaction technique is much higher than compared to the activation time of the ADP interaction. The relative big standard deviation of the SC interaction indicates that there are a lot of variants in the activation time for this specific gesture.
The means and standard deviations of the confirmation time, for all interaction techniques that feature a confirmation gesture, are depicted in Figure 4.6. As explained above, the measured data does not allow to draw conclusion regarding the confirmation time of the *Activation* by double pressure interaction technique because of software limitations, hence it is not depicted.

The confirmation time of the CSO interaction technique is the shortest, followed closely by the ASI interaction. Interaction techniques where the input value needed to be con-

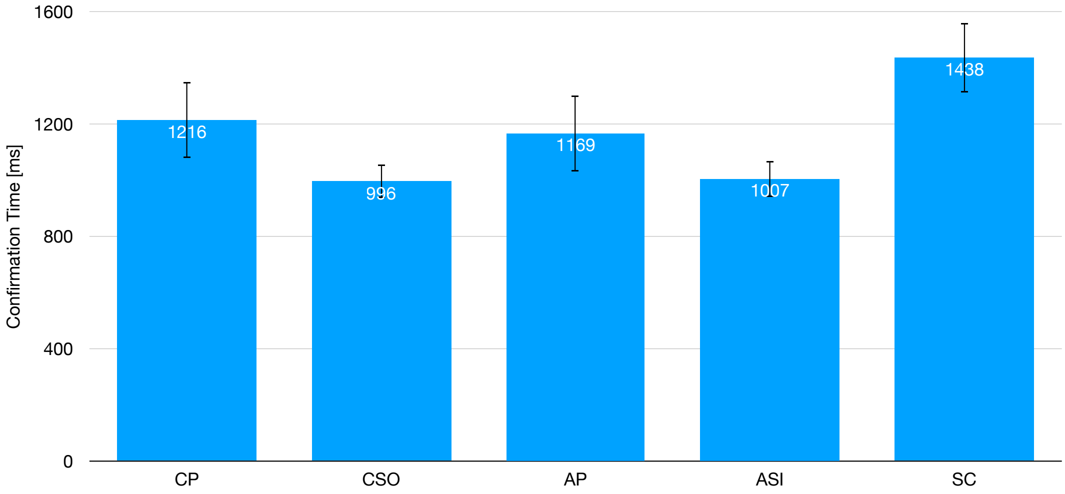


Figure 4.6: Means and standard deviations of the confirmation time. The *Confirmation* by sliding out interaction features the shortest confirmation time, whereas the *State Communication* by vibration feedback interaction technique has the highest confirmation time. The confirmation time of the *Activation* by double pressure interaction could not be derived from the measured data.

firmed by applying high pressure onto the slider, feature the highest confirmation time.

4.10.2 Questionnaires

The results of the questionnaires, that were filled out by the participants after each interaction technique, are shown in Table 4.1, 4.2 and 4.3. The questions were measured in a 5-point Likert scale for which 1 was the lowest and 5 the best score. Consequently, we calculated the resulting means and standard deviations.

4.10.3 Global Ranking

In Figure 4.7 a ranking of all interaction techniques is shown, whereby Rank 1 the highest and Rank 8 the lowest possible rank is.

Interaction Technique	*The Slider was comfortable to use*		*I could select the target values accurately*		*I was able to set the desired value quickly*	
	Mean	SD	Mean	SD	Mean	SD
ARNM	4.71	0.45	4.57	0.49	4.79	0.41
ARM	2.71	1.16	3.93	0.96	2.5	1.68
CP	4.43	0.62	4.29	0.59	4.64	0.61
CSO	3.93	1.16	3.93	0.88	4.21	0.77
AP	3.64	0.89	4.21	0.56	4.00	0.53
ASI	2.93	0.80	3.79	0.77	3.79	1.01
ADP	3.29	1.03	3.79	1.08	4.07	0.80
SC	3.36	0.81	3.93	0.59	3.36	1.11

Table 4.1: Participants overall perception regarding all possible interaction techniques. Each question was measured in a 5-point Likert scale for which 5 was the best score.

Interaction Technique	*The Confirmation gesture was physically comfortable to use*		*The Confirmation gesture was easy to understand*		*The Confirmation gesture was easy to perform*		*The system recognized the Confirmation gesture reliably*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CP	4.14	0.83	4.79	0.56	4.71	0.45	4.36	0.61
CSO	3.29	1.22	4.57	0.49	3.86	0.91	4.07	1.16
AP	4.14	0.74	4.50	0.50	4.14	0.74	4.14	0.74
ASI	2.71	0.88	4.21	1.08	3.43	0.90	3.79	1.15
ADP	4.29	0.96	4.57	0.62	4.43	0.73	4.07	1.03
SC	4.07	0.70	4.50	0.50	4.36	0.72	4.29	0.59

Table 4.2: Participants overall perception regarding all possible interaction techniques that feature a confirmation gesture. Each question was measured in a 5-point Likert scale for which 5 was the best score.

Confirmation interaction techniques were generally given higher ranks than interactions that belong to the group of *Activation*.

Most of the times the ARNM interaction technique was placed on one of the first three ranks. The ARM interaction was mostly placed on one of the lower ranks, however some participants placed this interaction technique also on a higher rank. CP was often given the first or second rank. The CSO is represented in almost all ranks, however most

Interaction Technique	*The Activation gesture was physically comfortable to use*		*The Activation gesture was easy to understand*		*The Activation gesture was easy to perform*		*The system recognized the Activation gesture reliably*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AP	3.79	0.67	4.36	0.48	3.79	0.67	3.93	0.70
ASI	2.43	0.98	4.43	0.62	3.29	1.10	3.64	1.04
ADP	3.29	1.03	4.29	0.80	4.21	0.86	3.86	1.19
SC	3.71	0.88	4.14	0.91	3.57	0.90	3.00	1.36

Table 4.3: Participants overall perception regarding all possible interaction techniques that feature an activation gesture. Each question was measured in a 5-point Likert scale for which 5 was the best score.

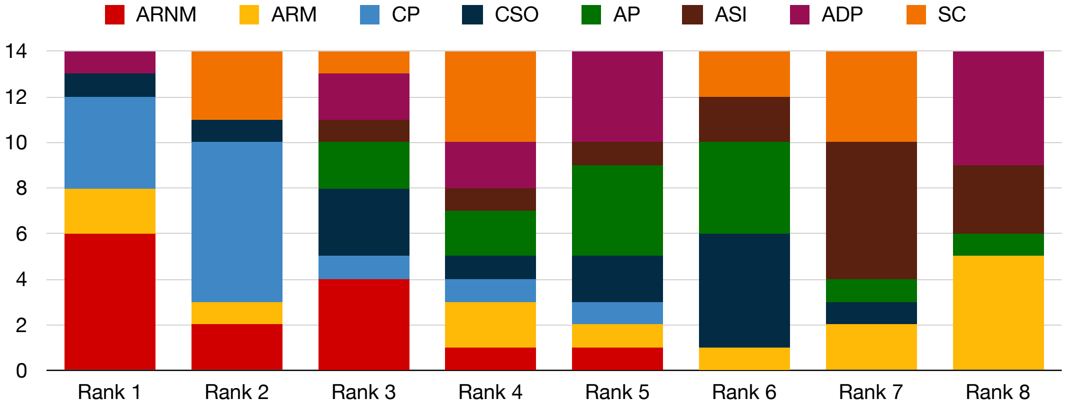


Figure 4.7: Rank distribution of all eight interaction techniques. Rank 1 is the highest and Rank 8 the lowest possible rank.

often it was placed on the sixth rank. Interaction techniques that feature an activation gesture were distributed among all possible ranks, whereby the ASI interaction was mostly placed on the second to last or last rank.

4.10.4 Comments

In the following we summarize the most common remarks of the participants for each interaction technique.

Always Reactive **non-mechanical**

A lot of participants (8x) liked the simplicity of the interaction and the fact that the textile interface was directly reactive to user input. It was reported that without any confirmation gesture a user might tend to quickly slide over the slider in order to set a value which may introduce additional uncertainties (3x).

Always Reactive **mechanical**

It was positive perceived that the sphere directly provided feedback regarding the currently set value (2x) and it was possible to set the desired value very accurately (8x). However it was very uncomfortable to move the sphere (9x) and the three tick-marks interrupted the movement of the sphere (2x).

Confirmation **by pressure**

The confirmation gesture was declared as very intuitive (9x) and the possibility of making adjustments regarding the input value, even after the confirmation gesture was performed, was perceived as very useful (3x). Additionally, it was reported that the distances between the different pressure levels were big enough (4x). The fact that the slider is directly reactive to user input, was also perceived as very positive (2x). However, sometimes it was stated that when confirming a value by pressure, more inaccuracy to the input value was introduced because the input value may change depending on how the finger was lifted from the textile interface (3x).

Confirmation **by sliding out**

It was stated that the confirmation gesture feels natural (2x). Moreover, it was emphasized that it was good that the slider was directly reactive to user input and no activation gesture needed to be performed (2x). However, for some participants the sliding out gesture was uncomfortable to perform because of the bump located between the slider and the pressure sensitive area (2x). Moreover, it was sometimes negatively perceived that it was necessary to slide out vertically as otherwise the input value could be accidentally manipulated during this gesture (3x).

Activation by pressure

Participants liked the ability to make adjustments regarding the input value even after the confirmation gesture was performed (2x). Additionally, it was perceived positive that the activation gesture could be performed close to the target value (3x). Sometimes it was hard for the participant to verify whether the activation gesture was successfully performed as no visual feedback for this part of the interaction was provided (4x). It was stated that it was difficult to get a feeling on how much pressure needed to be released after the activation gesture without accidentally removing to much pressure so an unwanted abort would be triggered (3x).

Activation by sliding in

One participant (1x) liked the fact that the activation gesture could be performed diagonally which allows to directly reach the target value after the activation gesture. The sliding out gesture was perceived as uncomfortable because of the bump located between the Slider and the pressure sensitive area (3x) and in general the sliding in gesture was perceived as more uncomfortable than the sliding out gesture (2x). Additionally, the participants did not like that the finger had to be moved around a lot in order to set a desired value (2x).

Activation by double pressure

Participants stated that they were able to set the target values quickly and precisely because they were able to distribute the needed pressure among two fingers (4x). However, some participants did not like the fact that two fingers were required for the interaction (2x).

***State Communication* by vibration feedback**

Some participants perceived the vibration feedback as helpful (6x). Moreover, it was reported that it was difficult to find the currently set value in order to activate the slider (5x). Two (2x) participants reported that a vibration mechanism may also be suitable in order to signal that the confirmation gesture was successfully performed.

Because of implementation limitations, all participants reported that the needed pressure for each interaction technique was perceived as too high.

Overall all participants (14x) reported that the needed pressure for each interaction technique was sometimes too high, especially at the left and right edge of the slider, whereby for some participants it was more problematic than for others. Additionally, some participants stated that the height of the tick marks could be reduced as it influences the accuracy when setting a desired value which is located directly at a tick-mark position. This was especially perceived negatively when the interaction technique featured a confirmation by pressure gesture (2x).

4.11 Discussion

The ARNM interaction technique received very positive feedback because of its simplicity.

It was no surprise for us that the *Always Reactive* non-mechanical interaction technique was given most of the time one of the better scores, which can be seen in Figure 4.7. This shows the general acceptance of such an interaction. Data from the target selection task proves that this interaction features the second best accuracy, see Figure 4.3, and the lowest interaction time, see Figure 4.4, compared to all other interactions. From the feedback that we obtained through the questionnaires and discussions, it became clear that a lot of participants enjoyed the easy usability and simplicity of this interaction technique. However, sometimes it was reported that because the ARNM interaction does not feature any confirmation gesture, a user might tend to just quickly slide over the textile interface which could add additional uncertainties when setting a new input value. This statement shows that there is a tendency towards interaction techniques that feature some sort of confirmation ges-

ture as such a gesture can provide the needed feedback to the user that a new value has been actually set.
Some participants liked the fact that they were able to precisely set a desired value using the *Always Reactive* mechanical interaction technique. This claim is supported by the performance data, shown in Figure 4.3, as this interaction features the best accuracy. However, some participants criticized that the sphere was not easily movable which lead to the fact that setting a target value took much longer than with any other interaction technique which can be observed in Figure 4.4. As a consequence, this interaction got the lowest rating regarding the question, whether the Slider was comfortable to use which is depicted in Table 4.1. Although this is mostly a problem of how the sphere was embedded into the textile and could be addressed in future implementations. Additionally, it can be concluded that tick-marks for the mechanical interaction technique are not needed as the sphere already provides enough haptic feedback to the user. This statement is supported by the fact that participants reported that they were not able to feel the tick-marks during the whole interaction. Because of the implementation limitations, the ARM interaction technique got placed a lot of times on one of the lower ranks however other participants in accepted the general idea of this interaction as shown in Figure 4.7.

The best accuracy was achieved with the ARM interaction technique, however it received negative feedback because participants reported that it was uncomfortable to move the sphere.

The *Confirmation* by pressure interaction technique was generally perceived as more comfortable to use compared to the *Confirmation* by sliding out interaction. This sensation can be observed in Table 4.2 and as a result the CP was often placed on the best or second best rank, compared to the CSO interaction which was frequently placed on one of the lower ranks. We believe the reason for the negative perception towards the CSO interaction technique is because of the way how the corresponding prototype was manufactured. As explained in Section 3.4, the slider and pressure sensitive area are separated from each other and as a result a bump between these two sensing areas is perceptible. Sliding over this bump was often times perceived as uncomfortable, hence the negative feedback towards the CSO interaction technique. As a consequence, we recommend if this kind of interaction technique is to be further evaluated in future researches, the sensing area and the slider should

For *Confirmation* interaction techniques, the CP was mostly preferred over the CSO interaction.

be brought as close as possible together or in the best case should be combined in one fabric sensor. In Figure 4.3 a very similar accuracy of the CP and CSO interaction techniques can be noted. Some participants had the feeling that the confirmation gesture of the CP interaction introduces more inaccuracy because depending on how the finger was lifted from the slider, the input value could be changed unintentionally at the last moment of the interaction as here touch input was recognized until the finger is completely released form the textile interface. Through further discussions, it became clear that these perceived uncertainties were enhanced by the given height of the tick-marks as participants reported when applying high pressure onto a tick-mark in order to confirm a target value, the finger could be unintentionally tilted at these positions. Other participants highlighted the fact that when they did not vertically slide out of the slider during the CSO interaction, the input value could be changed unintentionally at the last moment of the gesture. As depicted in Figure 4.6, the CP features a higher confirmation time then the CSO interaction. We believe that this is due to the fact, that the CP allows changes to the position value even after the confirmation gesture was performed and by that the participant was probably motivated to make further adjustments regarding his input value. The overall interaction speed of the CP however is lower than of the CSO interaction as shown in Figure 4.4.

The CP interaction technique has a higher confirmation time than the CSO interaction.

In general, interaction techniques that feature an activation gesture were less accepted by the participants compared to all other interactions as they were often perceived as unnecessary complex. Especially the *Activation* by sliding in interaction was placed a lot of times on one of the lower ranks as depicted in Figure 4.7. Some participants stated about this interaction technique that the sliding in gesture is physically even more uncomfortable to perform compared to the sliding out gesture. Additionally, it can be observed that the ASI has the second worst accuracy of all interaction techniques which is depicted in Figure 4.3. The AP features the lowest accuracy and the fastest interaction time compared to all other *Activation* interactions as shown in Figure 4.3 and 4.4. However, why the accuracy of the AP is significantly lower than compared to the SC interaction, even though they both feature the same confirmation ges-

Interaction techniques that feature an activation gesture were generally perceived as unnecessary complex by the participants.

ture, should be further investigated in future research. Additionally, the AP has a higher confirmation time compared to the ASI interaction as illustrated in Figure 4.6. Again, we believe this is due to the fact, that the AP offers the possibility of changing the input value even after the confirmation gesture was performed. It was often stated that it is sometimes challenging to differentiate between the various pressure levels needed for the AP interaction technique. That often lead to the fact, that participants accidentally entered the CONFIRMATION state to early and by that the conformation time was unintentionally extended for this specific interaction technique. Reducing the needed pressure, when the slider is in the ACTIVE state, might address this problem. The *Activation* by double pressure interaction features the second best accuracy of all possible interactions as depicted in Figure 4.3. Participants who placed this interaction on one of the higher ranks, stated that they could accurately set the desired target value because the needed pressure for the interaction could be distributed among two fingers. As shown in Figure 4.7, the *Activation* by double pressure interaction was also placed on the last rank as some participants did not like the fact that they had to use two fingers for the whole interaction. Additionally, participants reported that the needed pressure for the ADP interaction was perceived as too high. This however is more a problem of the implementation as the fabric sensor for the pressure sensitive area is not reliable enough in order to detect light touch inputs. As a consequence, we recommend to use fabric sensors that do not require a lot of pressure, preferably capacitive sensors, so the perception regarding the interaction technique does not get influenced by the sensor limitations.

Participants stated that by using two fingers for the ADP interaction technique, they were able to precisely set the given target values.

The SC interaction technique was distributed among almost all possible ranks which is shown in Figure 4.7. This interaction features the longest activation time, see Figure 4.5, as some participants often tapped the slider in order to find the currently set value which extended the activation time significantly. Because of that, the SC interaction got the second lowest rating in the participant's perceptions regarding how quickly they were able to set the desired value. As depicted in Figure 4.3, the SC features the second best accuracy of all *Activation* interactions. Addi-

The SC interaction technique has the longest activation time as for some participants it was difficult to find the currently set value.

tionally, it can be observed in Figure 4.6 that the SC features a significantly higher confirmation than the AP interaction although both interaction techniques feature the same confirmation gesture. This result is surprising to us and needs to further investigated during future research.

All participants reported that during the target selection task, they were mainly looking at the visualization of the input and target values rather than down at the textile interfaces. This was stated for each interaction technique and proves to be a first indication that all presented interactions are suitable for applications in an eyes-free environment.

Confirmation interaction techniques should be further investigated because of their general good performance data and positive perception. Additionally, these kind of interactions feature a certain amount of robustness against accidental inputs for eyes-free applications.

In conclusion it can be observed that the ARNM interaction technique is very suitable for applications where only very simple interactions are required. If the sphere of the ARM interaction is easier movable, it could represent a very promising alternative as it features a much higher accuracy than the ARNM interaction. However, it needs to be considered that these two interaction techniques offer no protection against false activation and therefore any touch input, even when it was just accidental, will be detected.
Interaction techniques that feature a confirmation gesture are more robust again false activation. As a result, these kind of interactions should be preferred if the interaction is supposed to be used in an eyes-free environment. The CP interaction should be the primarily choice as it received much more positive feedback than the CSO interaction. Nevertheless, if the technical difficulties of the CSO will be addressed in the future, so the sliding out gesture is perceived as more comfortable by the user, this interaction could be a very suitable alternative as it offers a very similar accuracy and even a shorter interaction time compared to the CP interaction.
If a robustness against false activation is desired to be achieved by using an interaction that requires more than one finger, the ADP is a good alternative as it features the second best accuracy and a relatively low interaction time. For such an interaction however, fabric sensors should be used that require almost no pressure for touch detection as otherwise the interaction is perceived as very uncomfortable by the user. Because of the mixed feedback regarding this interaction, we recommend to further investigate this

technique in future research. All other interactions that feature an activation gesture, especially the ASI, should be the least preferred choice as these interactions were often referred to as unnecessary complex and sometimes not easy to use.

Chapter 5

Summary and future work

5.1 Summary and contributions

We manufactured prototypes in order to research suitable interaction techniques on textile sliders for possible eyes-free applications.

In this thesis we focused on evaluating eight dissimilar interaction techniques on textile sliders. For that, we created three unique textile prototypes. In order to achieve the ability to detect touch input on a textile interface, we used a FSLP sensor and additionally to that manufactured our own fabric sensor. Both sensors utilize properties of resistive sensing approaches. The different interaction techniques could feature a confirmation as well as an activation gestures and were therefore categorized into one of the following groups: *Always Reactive*, *Confirmation*, *Activation* or *State Communication*. We implemented for each interaction technique a state machine so we could distinguish between the different steps of the interaction.

During a user study eight dissimilar interaction techniques were evaluated.

In our user study we compared each interaction technique to each other. For that, we recorded the performance data of each participant during a target selection task. Additionally, we also obtained the participant's perception of each interaction by additional questionnaires. From this data, we could derive that the ARNM and the CP were the most preferred interaction techniques because of their simplicity.

Other interactions were given lower ratings even though some of them feature better performance data as well as a higher robustness against accidental inputs.

5.2 Future work

The ARNM and CP interaction techniques received very positive feedback. However, interactions with an activation gesture were less preferred.

In our user study we found out that interaction techniques that are classified as *Always Reactive*, were perceived positively by the participants. Therefore, future research should focus on how these interactions perform in an eyes-free environment with additional focus on how accidental input influences the performance of such techniques. Especially the ARM might be a promising solutions for such applications. Furthermore, the performance of the *Confirmation* interaction techniques should be evaluated in an eyes-free environment as they also received very positive feedback and feature a very good performance, especially the CP. Based on that, *Activation* interactions should also be further investigated. During our study we found out that such interactions were often distinguished as unnecessary complex but on the other hand offer the most protection against accidental input. Maybe other interaction techniques can be found that are similar robust whereby the corresponding gestures are perceived as more natural. The ADP interaction technique might be a good starting point.

Capacitive sensing in textile sliders should be further investigated.

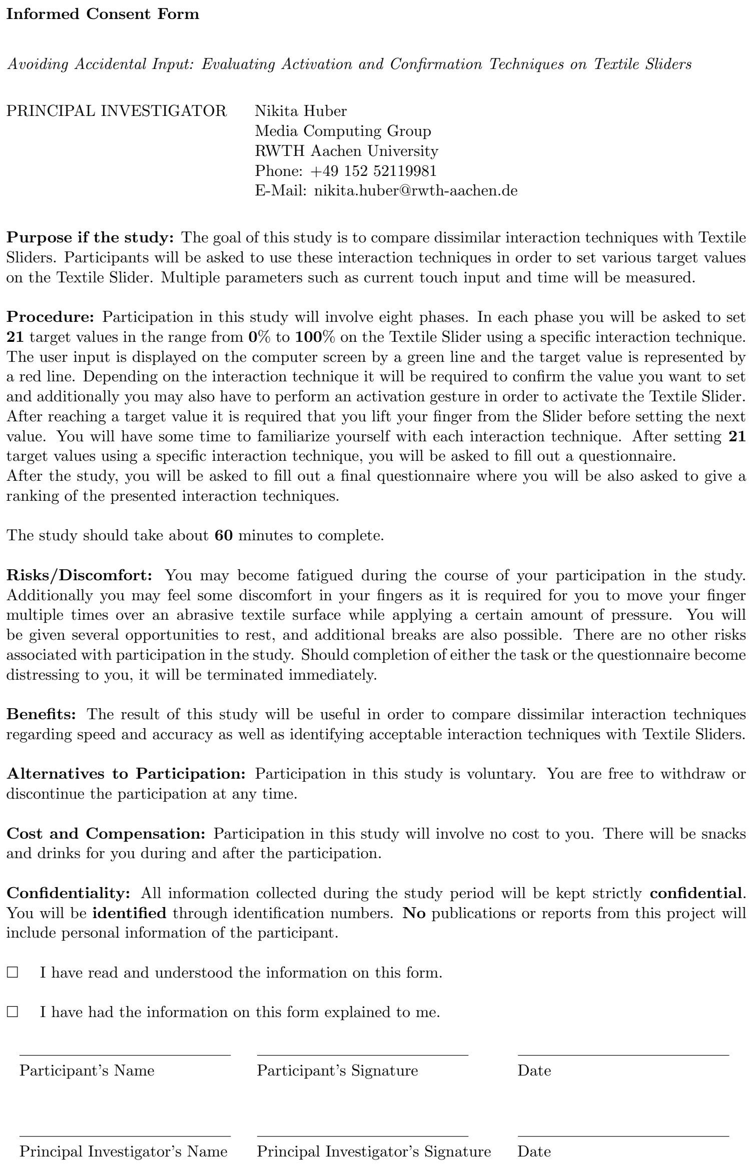
On the other hand, alternative solutions should be found on how to achieve sensing capabilities in textile sliders that require almost no pressure for touch recognition. For that, capacitive sensing approaches could be further investigated. This could address the participant's aversion towards pressure and by that during future studies the participant's perception can mainly focus on the given interaction technique. However, it needs to be considered that pressure sensitive approaches offer a natural robustness against false activation as these kind of sensors are only responsive when mechanical stress is applied onto them.

Appendix A

User Study Material

In the following the materials, that were used during the user study, can be found.

A.1 Informed Consent Form



Informed Consent Form

Avoiding Accidental Input: Evaluating Activation and Confirmation Techniques on Textile Sliders

PRINCIPAL INVESTIGATOR
Nikita Huber
Media Computing Group
RWTH Aachen University
Phone: +49 152 52119981
E-Mail: nikita.huber@rwth-aachen.de

Purpose if the study: The goal of this study is to compare dissimilar interaction techniques with Textile Sliders. Participants will be asked to use these interaction techniques in order to set various target values on the Textile Slider. Multiple parameters such as current touch input and time will be measured.

Procedure: Participation in this study will involve eight phases. In each phase you will be asked to set **21** target values in the range from **0**% to **100**% on the Textile Slider using a specific interaction technique. The user input is displayed on the computer screen by a green line and the target value is represented by a red line. Depending on the interaction technique it will be required to confirm the value you want to set and additionally you may also have to perform an activation gesture in order to activate the Textile Slider. After reaching a target value it is required that you lift your finger from the Slider before setting the next value. You will have some time to familiarize yourself with each interaction technique. After setting **21** target values using a specific interaction technique, you will be asked to fill out a questionnaire.
After the study, you will be asked to fill out a final questionnaire where you will be also asked to give a ranking of the presented interaction techniques.

The study should take about **60** minutes to complete.

Risks/Discomfort: You may become fatigued during the course of your participation in the study. Additionally you may feel some discomfort in your fingers as it is required for you to move your finger multiple times over an abrasive textile surface while applying a certain amount of pressure. You will be given several opportunities to rest, and additional breaks are also possible. There are no other risks associated with participation in the study. Should completion of either the task or the questionnaire become distressing to you, it will be terminated immediately.

Benefits: The result of this study will be useful in order to compare dissimilar interaction techniques regarding speed and accuracy as well as identifying acceptable interaction techniques with Textile Sliders.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation at any time.

Cost and Compensation: Participation in this study will involve no cost to you. There will be snacks and drinks for you during and after the participation.

Confidentiality: All information collected during the study period will be kept strictly **confidential**. You will be **identified** through identification numbers. **No** publications or reports from this project will include personal information of the participant.

☐ I have read and understood the information on this form.

☐ I have had the information on this form explained to me.

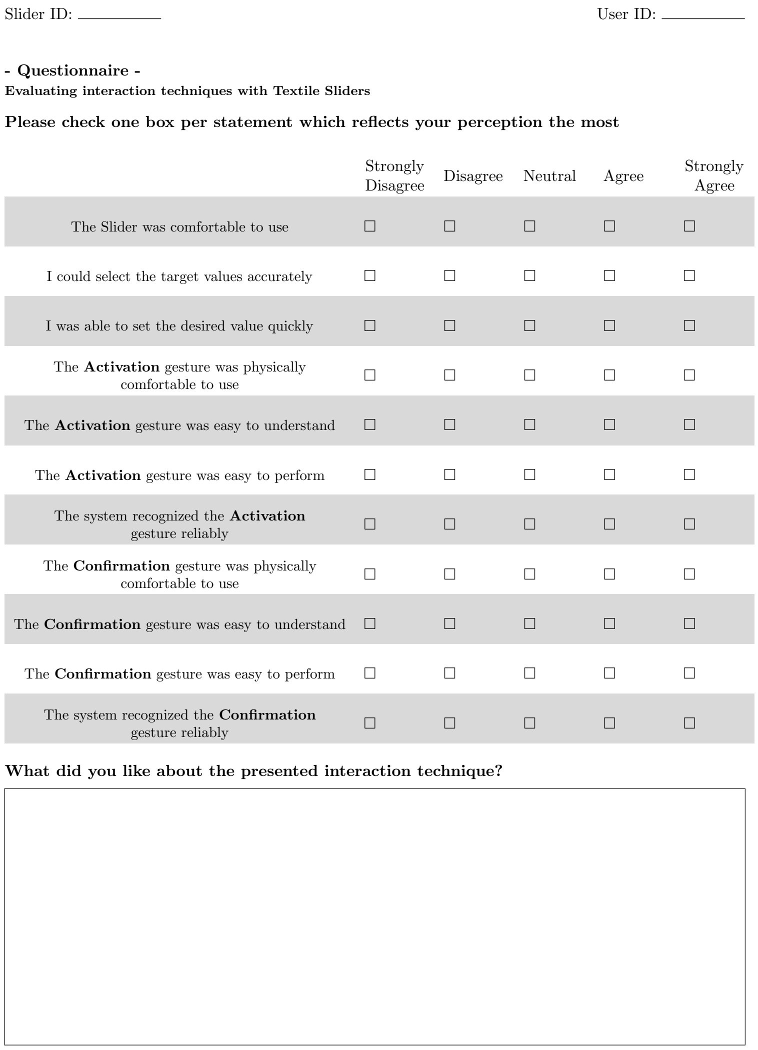
Participant's Name
Participant's Signature
Date

Principal Investigator's Name
Principal Investigator's Signature
Date

Figure A.1: Informed Consent Form which was handed to the participant at the beginning of the user study.

A.2 Questionnaire for Interaction Technique

Depending on the current interaction technique some questions were omitted as not all techniques feature an activation or confirmation gesture.



Slider ID: ________

User ID: ________

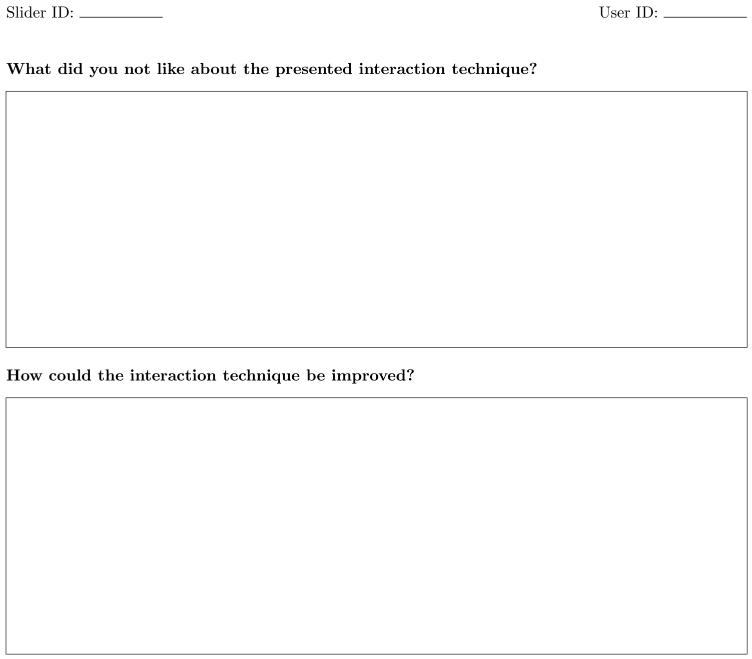
- Questionnaire -

Evaluating interaction techniques with Textile Sliders

Please check one box per statement which reflects your perception the most

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The Slider was comfortable to use	☐	☐	☐	☐	☐
I could select the target values accurately	☐	☐	☐	☐	☐
I was able to set the desired value quickly	☐	☐	☐	☐	☐
The **Activation** gesture was physically comfortable to use	☐	☐	☐	☐	☐
The **Activation** gesture was easy to understand	☐	☐	☐	☐	☐
The **Activation** gesture was easy to perform	☐	☐	☐	☐	☐
The system recognized the **Activation** gesture reliably	☐	☐	☐	☐	☐
The **Confirmation** gesture was physically comfortable to use	☐	☐	☐	☐	☐
The **Confirmation** gesture was easy to understand	☐	☐	☐	☐	☐
The **Confirmation** gesture was easy to perform	☐	☐	☐	☐	☐
The system recognized the **Confirmation** gesture reliably	☐	☐	☐	☐	☐

What did you like about the presented interaction technique?



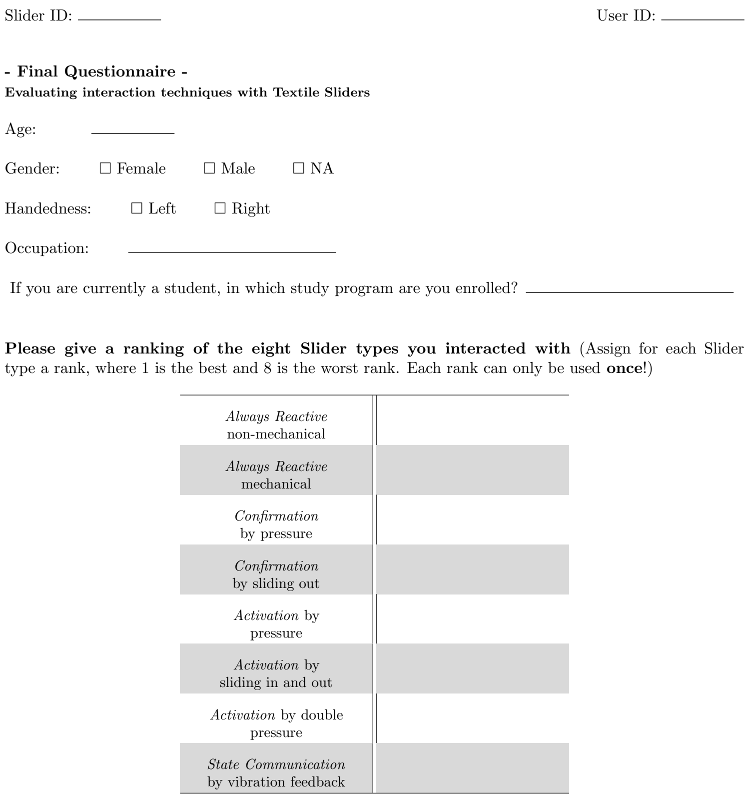
Slider ID: _________ User ID: _________

What did you not like about the presented interaction technique?

How could the interaction technique be improved?

Figure A.2: The Questionnaire for each interaction technique which was filled out after the target selection task.

A.3 Final Questionnaire



Slider ID: ________ User ID: ________

- Final Questionnaire -
Evaluating interaction techniques with Textile Sliders

Age: ________

Gender: ☐ Female ☐ Male ☐ NA

Handedness: ☐ Left ☐ Right

Occupation: ____________________

If you are currently a student, in which study program are you enrolled? ____________________

Please give a ranking of the eight Slider types you interacted with (Assign for each Slider type a rank, where 1 is the best and 8 is the worst rank. Each rank can only be used **once**!)

Always Reactive non-mechanical	
Always Reactive mechanical	
Confirmation by pressure	
Confirmation by sliding out	
Activation by pressure	
Activation by sliding in and out	
Activation by double pressure	
State Communication by vibration feedback	

Figure A.3: Final Questionnaire which was handed out to the participant after all interaction techniques were evaluated once.

Appendix B

Software Files

In the following Git repository all Arduino, Processing as well as Bernina files can be found.

https://bit.ly/3txCe3D (*Accessed: March 30, 2022*)

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Typeset March 30, 2022