WEARABLE INTERFACES IN VOICE PERFORMANCE

DESIGNING A MODULAR CONTROL SKIN FOR USE IN REAL-TIME SOUND AND MUSIC PERFORMANCE.

BY LUCAS DELFOS

CREATIVE TECHNOLOGY

SUPERVISED BY: DR. ANGELIKA MADER

MARCH 2024

UNIVERSITY OF TWENTE.

Contents

List of Figures

Part I

Abstract

This bachelor thesis presents the development and evaluation of a wearable control interface designed to enhance the performances of experimental artists in the musical domain while overcoming limitations typically associated with existing control interfaces. Several technologies, materials and development methods have been thoroughly examined. Where it was eventually found that Trill and MuCa technology could have great potential in creating a wearable interface. Using comfortable, wearable and conductive materials these technologies were made into prototypes which eventually led to a final prototype based on Trill capacitive sensing technology. While evaluation sessions with artists showed the wearable interface to have significant potential in innovatively modulating sounds, there are still improvements to be made and possibilities for future research.

Part II
Acknowledgement

I would like to thank Angelika Mader for being my supervisor during this research project. I would also like to thank Jonathan Chaim Reus for not only being my client but also guiding and helping me with every issue I faced. I would also like to thank all the wonderful people who helped my research with interviews, evaluations, or just plain skills and knowledge. It has been quite the experience to dive head-first into a subject I knew virtually nothing about but these people have made it such a pleasure to do so. Lastly, I would like to thank my family, friends and especially my girlfriend Rebecca. For listening to me, helping me and keeping my head up.

Thank you.

Part III

Introduction

Voice performance holds immense importance in the musical domain. It involves modulating various vocal aspects like pitch, tone, volume, rhythm, and timbre to create a specific vocal expression. To achieve this, artists mostly rely on their vocal cords and performative abilities. However, this limits artists to using only their skills when it comes to aspects like vocal control, precision, and modulation of vocal characteristics. To transform and even positively enhance the ability to convey emotions and engage with an audience, artists use technology. Usually in the form of large, external devices where vocals are processed and altered. Unfortunately, this means a separate team or person is in charge of the modulation of these aspects. This limits the control an artist has over altering his or her voice in real-time. This is where wearable technology can open up a world of possibilities. When wearing a controller, artists can interact with it using hand gestures, capacitive touching, finger tapping, etc. These interactions can control certain parameters, which, in turn, control the modulation of the artist's voice.

Some wearable controllers have already been developed with this goal in mind. However, most of these controllers are limited to the use of gloves, neglecting a plethora of other areas of the body an artist or vocal performer can interact with.

1 Challenge

The goal of this thesis will be to design a wearable control interface that uses the body to its full extent and lets artists alter musical aspects in their performances, thereby overcoming limitations that usually arise with existing control interfaces. However, designing a wearable device that allows performers to control their voices seamlessly can be complex. Firstly, the interface must be intuitive, user-friendly, and specifically built with artists in mind. Finding a balance between functionality, ease of use, and customization options is crucial. Secondly, because the wearable controller is going to be used during live performances, it is ideally wireless, or if using wires, the wires should be streamlined and durable enough for a performer to not get tangled in. Lastly, the whole interface should be durable enough to survive at least one performance, meaning the structure of the interface should be solid enough not to fail or break easily. To address all these challenges correctly, user testing and prototyping are needed.

2 Research Question

Based on the described challenge and situation this thesis aims to answer the following question:

RQ: How to design a wearable control interface that can be used in voice performance?

Answering this question requires multiple aspects to be thoroughly examined. To build a wearable interface that is specifically designed with artists in mind, it is necessary to know how artists would possibly use such a controller, what materials are needed to build it, and how it should react to interactions. Therefore, the following sub-questions arise.

SQ 1: How is the wearable control interface going to be used?

SQ 2: What materials are available to build a wearable controller?

SQ 3: How should a wearable controller process interactions?

Part IV
Background Research

3 Performance Arts

To answer the first sub-question: "How is a wearable interface going to be used?" research in certain topics is needed to understand the context. This includes an overview of the possible areas of voice performance where a wearable can be used. Afterwards, a general definition of digital musical interfaces is examined, as the wearable controller is, in essence, a digital music interface. Following this, the design process of a wearable by examining usable materials and technologies is discussed in depth. To answer the first research question, examining in what kinds of vocal practices a wearable control interface might be of use is crucial to understanding the use case of a wearable interface. In the following subsections, Solo singing, ensemble singing, and theatre will be discussed.

3.1 Solo Singing

Solo singing is an art practice where an individual artist, often a singer, performs without a group or other artists. Meaning the musical expression relies on one singer's voice to convey emotion, tell a story, and engage with the audience. Next to that, the artist does not have the musical elements of instruments to back his or her voice [15]. This places greater emphasis on the singer's ability to control their voice, making sure their voice is in key and provide the audience with a positive experience. Solo singing can be an especially emotional form of artistic expression, as it usually involves the singer opening up emotionally and expressing his or her inner self.

3.2 Ensemble Singing

Ensemble singing is a lot like solo singing, where the most notable aspect is the addition of multiple singers to a musical performance. This makes the performance less reliant on a single singer, but it also introduces the aspect of interplay between singers. Singers must not only have the ability to sing for themselves, but they should also be in tune with one another [15]. The ability to listen, respond, and adjust to other artists in real time promotes a tight musical connection that, when performed correctly, provides a positive experience to the audience. Maybe even more so than solo singing. Additionally, ensemble singing provides more possibilities for artistic exploration, allowing singers to experiment with a wide range of vocal techniques through collaboration with other singers.

3.3 Theatre

Theatre is an art form that combines several aspects. It revolves around artistic expressions and the ability to convey emotion through various art forms. Singing is an essential component of theatre, as it allows artists to convey emotions and inner thoughts. It can add a layer of emotion to storytelling that dialogue alone cannot. However, to correctly portray the emotions of a specific character, an actor must have a keen understanding of that specific character's personality. This is because the choice of musical style, tone, and vocal technique can be a crucial factor in defining and differentiating between characters within the context of the art piece which is portrayed [38]. Because of this, singing in theatre requires performers to not only be skilled vocalists but also proficient actors who can find a balance between music, emotion, and character development, contributing to an immersive experience for the audience.

4 Digital Music Interfaces

Digital music interfaces are technological systems that connect electronic devices and musical instruments to secondary systems. They convert analog audio signals into digital data which can then be used for processing and recording. In principle, digital music interfaces allow artists and musicians to turn sound or interactions into data, facilitating the connection between analog instruments and the digital world of computers [17]. A simplified diagram of digital music interfaces is shown in figure 1.

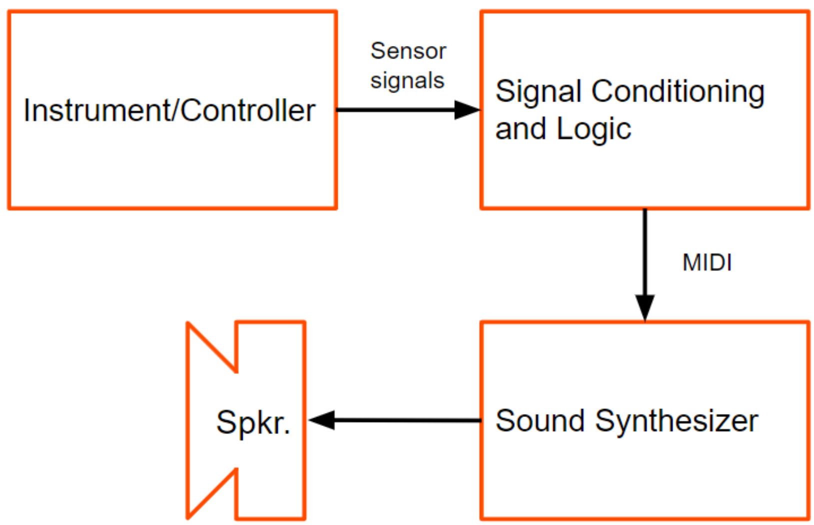

Figure 1: Simplified diagram of a Digital Music Interface

The elements in this figure make up the basic form of a digital music interface. The first element is the controller, which, in the case of this research, is the wearable. The controller sends signals into the system, like a microcontroller, where the signals are processed and cleaned up from noise, for example. The remaining signals can then be transferred via MIDI (or OSC) into a program or device that turns these signals into sounds. Lastly, the sound can be made audible. This can, for example, be done with the use of a speaker [10]. To categorize different types of digital music interfaces, they can be divided into 3 categories:

1. Virtual Instruments: Virtual instruments are often found in Digital Audio Workstations (DAWs). Virtual instruments can recreate the sounds of a musical instrument with a computer, emulating vintage synthesizers, keyboards, samplers, and instruments. Today, there are a multitude of virtual instruments, that can imitate almost all the musical instruments in the world. Virtual instruments allow artists to have a large collection of different sounds and textures at their disposal in a compact form factor such as a laptop.

2. Embedded Controllers: Embedded digital music interfaces refer to electronic devices that integrate digital audio processing capabilities into a compact and often portable form factor. They have a synthesizer built into them but often do not allow the user to customize every parameter of the sound to his or her liking. Embedded controllers often have a unique sound, which weighs up to

3. Physical Controllers: Physical controllers are interfaces that convert user interactions into MIDI or OSC signals, so they can be used in a computer. The wearable controller of this research is an example of a physical controller, next to the earlier mentioned MIMU gloves and MIDI keyboards.

5 State of the Art

To gain further knowledge about wearable controllers in voice performance, examining what projects have been realized considering this topic is of considerable importance. Additionally, examining how such projects are used by artists allows for a better understanding of how wearables are used. In the following section, a state-of-the-art will be conducted to provide an overview of the current stage of knowledge about this technology. Existing research and projects will be examined and discussed in the context of this thesis.

5.1 MI.MU Gloves

Starting with a brand that calls its project "the world's most advanced wearable musical instrument," which is quite a statement. The MI.MU gloves are wireless, wearable controllers and musical instruments. The gloves are fitted with sensors that track the movement of the hands and fingers of a user. This allows musicians to control their DAW (Digital Audio Workstation) or music software with a degree of complexity and expression not found in more traditional button and slider interfaces [34].

Figure 2: The MI.MO gloves.

The MI.MU gloves use data collected from embedded flex sensors in the fingers, together with accelerometers, magnetometers, and gyroscopes placed in the wrists. The raw measurements of these sensors are then processed through algorithms embedded into software called "Glover," which comes with the gloves. Using this software, users can map movements they make with the gloves to musical messages, like MIDI or OSC, which can then be understood by musical software or hardware.

5.2 Wave Ring

The Wave Ring [5] is a small device made by Genki Instruments that fits around the user's finger. It allows musicians to easily shape effects, send commands, and control sounds with simply the motion of their hands. It senses six different actions which can be used individually or combined. These actions are tilt, pan, roll, vibrato, tap, and click. The different motions allow artists to control any parameter in a new way. The ring can, for example, sense when any surface is tapped. This can, in turn, trigger notes or samples. Next to that, the buttons on the ring allow the user to cycle between presets, send commands, and simply pause Wave to move freely without changing anything [5]. Included with the ring is, like with the MI.MO gloves, a software package which allows users to unlock the full functionality of Wave. It enables controlling music with gestures, the customization of each button, and creating saved presets.

Figure 3: The Wave Ring by Genki Instruments

5.3 Showpiece

The next design is called "showpiece,". It incorporates numerous aforementioned aspects into its design, including the use of conductive fabrics, metal films, and textiles. The "showpiece" has a total of 52 handmade, pressure-sensitive sensors made out of conductive materials. These square textiles are embedded in the textile in an aesthetically pleasing way. When using the jacket as a MIDI controller, the sensors can emit an analog continuous signal when pressed by the user. These analog signals are then converted into MIDI or OSC signals, which are then read by a music program or DAW. The sensors can each be individually assigned to different loops, individual sounds, effects, or filters. This makes the jacket into an interactive MIDI controller while retaining the aspects of an actual jacket, like style, comfort, and warmth [4].

Figure 4: The "Showpiece" jacket

5.4 MIDI Jacket

The MIDI Jacket, designed by a company called Machina, allows a user to control different aspects of a performance, live act, or even music or visual production as any MIDI controller does. The only difference is that this interface is wearable and is mounted on a jacket. Additionally, a set of applications was designed that can be used with smartphones and tablets. In short, the jacket allows musicians to use a controller that is modular, portable, and with kinetic interaction [2].

Figure 5: The MIDI Jacket by Machina.

5.5 Sonalog gypsy

The "Gypsy" by Sonalog is unfortunately considerably out of date, therefore it cannot be defined as "state of the art" technology. However, the design is unique in this field and it has interesting aspects to offer. The designers of the gipsy specialize in building a variety of motion capture devices. With the gipsy, Technology that is usually used in areas like film, media and game industries now finds its way into the field of music production. The data communicated by the suit, without any additional software, merely encodes the positions of the arm sensors. Next to that, there are no configuration options on the unit itself. So, same as with the MI.MU gloves and the Waves Ring, the Gypsy needs the bundled software package "Exo" to function properly.

Figure 6: The Gypsy by Sonalog

5.6 Survey of artists

After analyzing what wearable technologies exist, existing wearable technology that can be used in voice performance can be examined. As well as how artists are currently using wearable devices. When examining the use of wearable technology in voice performance, the first artist that comes to mind is Imogen Heap. Heap is an electronica artist-producer as she incorporates technological extensions to sound-producing capabilities and kinetic expressions of the human body [37]. The reason Heap is such a revolutionary artist on the subject of wearables is because of her signature gesture-based controllers, which Heap helped design and develop [23]. The Mimu Gloves are a wearable device designed for musicians and performers. The gloves allow for gestural control and manipulation of sound and visuals. The MI.MU gloves will be discussed further in section 4. Heap uses these gloves to control various aspects of her voice through the movement of her hands, where each movement or gesture controls a different musical aspect. In her performance, Heap uses the gloves to add melodic elements like bells, synths and keyboards, which then become part of a song. Next to that, she uses her voice to create unique sounds which she then blends into the previously constructed soundscape. By moving the gloves and tapping her fingers she introduces effects like panning, reverb and delay. Additionally, she sets up the gloves in a way where moving around the podium changes the parameters of the gloves, allowing her to get an even wider range of effects and different soundscapes [24].

Figure 7: Imogen Heap performing with the MI.MU gloves

In addition to Imogen Heap, an artist that can be discussed is Franziska Baumann. Baumann is a musician and performer known for innovative and experimental vocal techniques. She is a vocal artist, composer, and researcher who explores vocal manipulation opportunities using interactive technology. Baumann focuses more on establishing patterns and links between sonic events through personal experience. Other than Heap, Baumann's work is characterized by its experimental and exploratory nature. Where she uses her wearable device to sculpt live and pre-recorded sounds in space.

Figure 8: Franziska Baumann performing with her glove controller.

6 Materials

After having analyzed where and how artists would potentially use a wearable voice controller and what projects have already been developed, the next sub-question can be answered, "What materials are available to build a wearable controller?". It is important to examine what kind of materials are available to successfully answer this question and get closer to realizing a modular wearable voice controller. In this section, three topics will be discussed. firstly, it is discussed how to facilitate wearable touch interfaces, afterwards moving on to materials that are suitable for the creation of a wearable voice controller and how these materials can be combined into sensor skin modules.

6.1 Wearable touch interfaces

To begin the research into wearable controllers, examining how to extract data from wearable materials and surfaces which artists can interact with is essential. This almost directly leads to sensor skins. The general definition of sensor skins is usually flexible materials embedded with a variety of sensors that are designed to monitor and collect data from their surroundings [9]. sensor skins can also act as sensors themselves. They can be highly useful in designing a wearable controller as they are usually able to stretch and bend, while still being able to collect data from interactions with users.

Sensor skins can be applied to specific surfaces or objects, which could then be integrated into, for example, wearable devices. Sensor skins can be used in a wide range of fields where sensing technology is combined with conforming to uneven surfaces. Sensor skins can, on the one hand, give machines or devices the ability to sense and interact with the physical world while on the other hand, gather data for analysis and feedback. Sensor skins are designed to provide real-time information and enhance the functionality of the systems they are used in. In this research, the broad definition of sensor skins can be summarized as comfortable and stretchable materials that make use of capacitive touch, resistance and conductivity for artists and performers to interact with them. In the following sections, Technologies will be examined which can be used to facilitate skin-like touch surfaces.

6.1.1 Trill Craft Boards

The Trill Craft is a 30-channel breakout board that can be used to make touch surfaces out of anything conductive. It can be used to create complex interfaces from conductive fabric, copper tape, metal, wire, and any other conductive material. The custom patterns created with conductive materials can then be used to design custom sliders, touch surfaces and capacitive sensors. These can then be embedded into other materials, creating a flexible, capacitive sensing material. When a user interacts with interfaces made with a Trill board, the conductive quality of skin changes the capacitance of each channel the user touches. Since the channels are usually arranged in grid-like patterns, this means that a single touch usually affects the capacity readings of several channels at once, to varying degrees. The Trill board is then able to sense the position of this touch by interpreting the shape of the readings of several adjacent capacitive channels. Using these readings, it can estimate the size of the touch by computing the overall amount of activation [3]. Trill uses the principle of self-capacitance to measure touch. Self-capacitance is a capacitive sensing measurement method in which a single electrode's capacitance with respect to earth ground is measured. A great example of how multiple electrodes can be combined as a capacitive touch sensor is the "Trill flex sensor". The Trill flex sensor consists of two parts: the base in which the Trill chip and a high-density connector are situated(1), and the flexible sensor which is made from elastomers combined with metallic films(2). The flexible sensor easily conforms to bends, corners and curves, allowing for endless possibilities to create projects with touch surfaces that are virtually any shape.

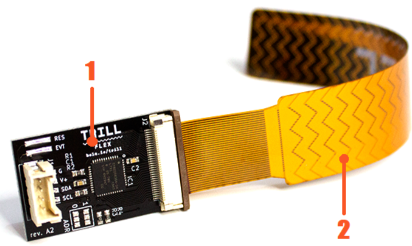

Figure 9: Trill Flex Sensor, where 1 is the base, and 2 is the flexible PCB.

6.1.2 MuCa Boards

MuCa Boards, created by Marc Teyssier, are a type of interactive, shape-changing user interface technology. These boards are designed to enhance the user's interaction with digital devices by providing tactile feedback and dynamic physical responses. MuCa boards can be used in the creation of skin-like touch surfaces since they allow for precise sensing on stretchable surfaces, mimicking the sensing capabilities of human skin. This sensing principle is based on so-called projected mutual capacitance. It identifies touch by measuring the local change in capacitance on a grid array of conductive traces [18]. Sensor skins using mutual capacitance usually consist of layers of conductive materials which can create an electric field on the surface of the skin. This material is usually a rubber-like flexible elastomer. When a user touches this surface or interacts with it, it disrupts the magnetic field created by the conductive traces. These disruptions can then be measured and processed to give precise information about where the sensor skin is pushed and how hard it is pushed. The Muco board allows users to connect multiple electrodes to it which can be embedded into a skin-like elastomer. These electrodes can be metallic wires, But also conductive polymers [29]. It then processes the before-mentioned inputs and transmits them as usable data via serial communication. In designing a wearable controller, the skin-like feel of the flexible elastomer can be considered unnecessary. However, the aspect of mutual capacitance can be useful.

Figure 10: Artificial skin created by Marc Teyssier, showing how the skin can sense pressure and position

6.2 Comparison of Technologies

The Trill craft board and MuCa board share similar aspects. They both use electrodes that can be placed in grid-like patterns to allow for capacitive sensing. They can both be used in the creation of sensor skins by embedding these electrodes into stretchable materials, creating a skin-like touch surface. However, the exact way in which they do this differs. This difference can be defined as the distinction between using the capacitance of a single conductor or the capacitance of the intersection between multiple conductors [12]. Some key differences include:

- Number of Conductors, Self Capacitance Involves a single conductor or an isolated conductive object whereas mutual capacitance involves two separate conductive objects or elements.
- Physical Arrangement, Self Capacitance focuses on the geometry and physical dimensions of a single conductor, while mutual capacitance goes more in-depth, Involving also the separation distance between two conductors.
- Applications, Self Capacitance is often relevant in the design of single capacitors and devices where the interaction is primarily with a single conductive element. Mutual Capacitance on the other hand is commonly used in technologies where the interaction involves multiple conductive elements. like touchscreens.

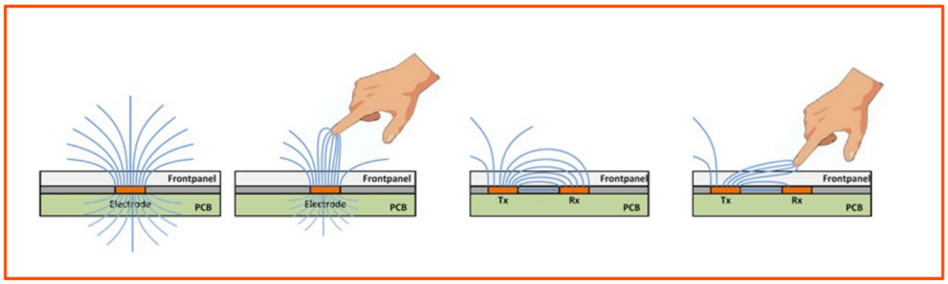

Figure 11: Self Capacitance(Left) and Mutual Capacitance(Right)

6.3 Creation of Modules

However, to be able to use these boards to their full potential, it is important to evaluate what materials can be used in the development of different types of conductive and capacitive surfaces. To provide users with a comfortable and enjoyable experience, it is essential to consider materials that are lightweight, durable, comfortable, and capable of housing the necessary electronic components. [18] Most capacitive sensing skins are generally composed of at least two types of materials: substrates and conductors [9]. These materials allow the sensor skins to stretch and give them the capacity to be easily integrated into projects, devices or wearables while retaining the aspect of conductivity [9]. In the following subsections, an overview is made of how sensor skins can be made by looking at the general materials that sensor skins consist of. First, substrates are examined. Afterwards, conductors are discussed in detail.

6.3.1 Substrates

A substrate is a term used in engineering to describe the base material on which processing is conducted. In sensor skins, the substrate is usually a thin, flexible, and often stretchable material, which allows the sensor skin to conform to the shape of the object, surface or body it is applied to [26]. This flexibility is important in the context of wearable technology, where the sensor skin needs to adapt to the contours of the body of a user. In the following subsections, two examples of substrates are discussed, Elastomers and Textiles.

6.3.1.1 Substrate: Elastomers

Elastomers are usually referred to as a type of flexible and stretchable material commonly used as the outer layer of the sensor skin. Elastomers are characterized by their ability to stretch and return to their original shape when force is applied to them [28]. This makes them ideal for multiple applications such as wearable technology, where flexibility and elasticity are essential factors. The elastomers used in wearable sensor skins are often made from silicone or other stretching, plastic-like materials. These materials allow the sensor skin to adapt to the shape of the body or object they are applied to, providing a comfortable and secure fit. Furthermore, elastomers enable the sensor skin to maintain its integrity and functionality when stretched or bent, making them suitable for various applications that need a certain amount of durability, usually because they include types of movements where bending and stretching of the materials is needed. Examples of elastomers include:

- Natural rubber: These are used in the automotive industry and in the manufacture of medical tubes, balloons, and adhesives.
- Polyurethanes: These are used in the textile industry for manufacturing elastic clothing like lycra.
- Polybutadiene: These are used for providing wear resistance in the wheels of vehicles.
- silicone: These are used in the manufacture of medical prostheses and lubricants as they have excellent chemical and thermal resistance.
- Neoprene: These are used in the manufacturing of wet suits and industrial belts. [7]

From these, silicone is chosen as a substrate for wearable control interfaces due to its flexibility, durability and most importantly, ease of use, since silicone is perfect for making flexible moulds.

6.3.1.2 Substrate: Textiles

Woven fabrics or textiles refer to materials that are created through the interlacing of two or more sets of fibres or threads, typically forming a grid-like structure. Using textiles in wearable technology has huge benefits. For example, textiles are soft and flexible so they can easily conform to the body's contours. This then ensures that the wearables made with them are comfortable for extended use. Their breathability also helps with regulating body temperature and preventing sweating, which further contributes to wearer comfort. Additionally, textiles offer a wide range of aesthetic possibilities, making it easier to create stylish and visually appealing wearables. lastly, textiles can be adaptable and suitable for embedding sensors and conductive elements. facilitating, for example, capacitative touch controls [31]. Common examples of textiles include:

- Cotton: Cotton is a natural fibre obtained from the seeds of the cotton plant. It is widely used in textile production due to its softness and breathability.
- Polyester: Polyester is a synthetic polymer fabric known for its durability, wrinkle resistance, and moisture-repelling properties.
- Nylon: Nylon is a synthetic polymer commonly used in textiles and other applications. It is known for its strength, durability, and resistance to wear.

6.3.2 Conductors

A conductor is a material or component that conducts electricity, allowing for current to flow through it. Conductors can transmit electrical signals between different parts of a sensor skin, like sensors, electronic components, and others. Enabling the detection and transmission of data. Examples include conductive threads, wires, or traces on flexible substrates [9]. In the following subsections, two types of conductors that can be used in a sensor skin are discussed. Namely, thin metal films, conductive polymers and conductive threads.

6.3.2.1 Conductor: Metal films

Conductive materials are, in most cases, rigid. However, when shaped as thin films, the metals become flexible [9]. When combining this thin layer of conductive metal with a flexible substrate, the result is a material that retains the attribute of conductivity, while gaining aspects like durability and, to some extent, stretchability [36]. Metal films are commonly used in wearables to create conductive traces or pathways for electrical signals. They can be patterned in specific ways to form connections between electronic components, like sensors, microcontrollers, and batteries. These conductive traces enable the flow of data and power throughout the wearable device. However, metal films can also be used in combination with substrates to form sensors themselves. Like the flexible pcb shown in figure 9.

6.3.2.2 Conductor: Conductive Polymer

Conductive polymers are types of plastic-like materials that can conduct electricity. They, like conductive metals, allow for the connection of electrical components and sensors since they are conductive while also having attributes like flexibility and stretchability. Conductive polymers can be easily processed and have excellent mechanical and electrical properties. making conductive polymer composites more useful than metals for manufacturing textile-based electronics [22]. next to that, conductive polymers can be used to build artificial skins [29], but this will be further explained in the section: Artificial skins. Three common examples of conducting polymers are listed below.

- Polyacetylene (PA): Although less commonly used, polyacetylene is known for its excellent electrical conductivity. It has been used in research for its potential in organic electronics.
- Polyaniline (PANI): Polyaniline is one of the most widely studied conductive polymers. It can be used in sensors, organic light-emitting diodes (OLEDs), and flexible electronics.
- Polypyrrole (PPy): Polypyrrole is another conductive polymer used in sensors, actuators, and organic electronics. It has good electrochemical properties [19].

6.3.2.3 Conductor: Conductive Threads

Conductive threads are specialized threads that can conduct electricity. The conductive aspect of these threads is usually achieved by incorporating conductive materials, such as metal fibres, into the thread structure [30]. These metal fibres then allow for the thread to become conductive, allowing electrical signals to flow through them. These threads are highly usable in wearable technology, as when they are integrated into fabrics, conductive threads can create electrical connections within garments, which allows for the incorporation of, for example, stretch sensors.

6.3.3 Implementations of Sensor Skins

To further get an image of the usability of sensor skins, examples where sensor skins have been implemented in other projects can be considered. To start, Earlier mentioned Marc Teyssier has used the artificial skin mentioned in section 6 To give a robot human-like sensing capabilities. The sensor skin detects multi-touch contact points with high tactile acuity, making it able to recognize expressive gestures such as tickling, stroking or pinching. They achieved a high resolution while keeping a human-like look and feel. Next to that, they built sensors with different shapes, curvatures or thicknesses, to conform with different shapes of robots [32].

Figure 12: A robot with different patches of sensor skin

Another example is a sensor skin that is based on integrating sensors into fabrics, allowing for a comfortable and wearable product with sensing capabilities. In this project, TU Delft developed a wearable garment with integrated knitted breathing and arm movement sensors. The arm sensor can detect small and large movements and has been tested from 10 - 40 per cent strain. The breathing sensor can detect a small increase in the chest circumference when the user is breathing. The final design is shown in figure 13.

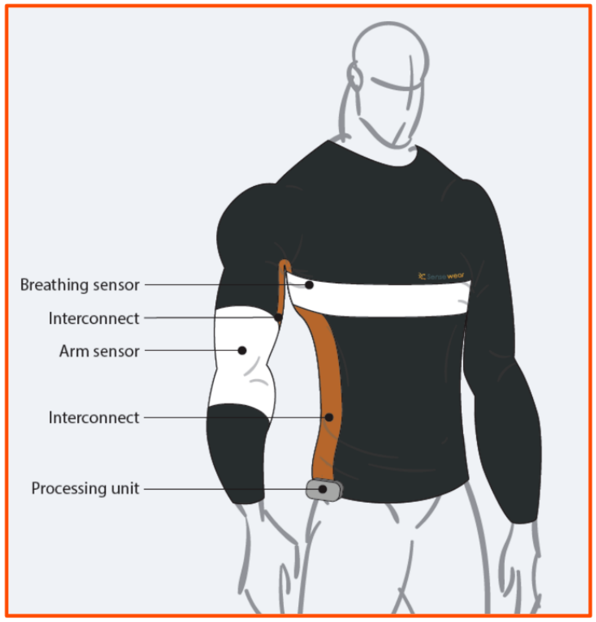

Figure 13: Final design of a sensing garment designed by the TU Delft

7 Technologies

After having analyzed the materials of which a wearable voice controller could consist of, the next sub-question can be addressed: ”How should a wearable controller process interactions?”. this question can be answered by examining what kind of technologies are available to successfully support the use of the earlier-mentioned materials. This is done by analyzing what is needed to link sensor modules together, connect them to a secondary system like a laptop and use incoming data for audio manipulation. This chapter will consist of comparative research into different ways of linking sensor modules, wireless communication protocols and audio manipulation tools.

7.1 Communicating Sensor Data to Software

To successfully communicate the data sent by sensor modules to the secondary system and make them work together in a wearable controller, the controller will need some sort of brain which combines and processes incoming data into usable information. Large and heavy controllers can immediately be left out since the wearable should be wireless and easy to carry. this leaves us with the topic of microcontrollers. A microcontroller is a compact integrated circuit designed for a specific operation within an embedded system. A typical microcontroller includes a processor, memory and input/output peripherals on a single board. Microcontrollers are found in robots, office machines, vehicles, etc. They are essentially simple miniature computers designed to control small features of a larger component, without a complex front-end operating system [20]. A microcontroller is an essential part of building a wearable voice controller. However, to choose the right microcontroller for this project, several requirements have to be considered.

- Connectivity. The microcontroller should be able to wirelessly connect to a secondary system. Meaning it should have an embedded chip which allows for wireless connectivity.
- Power consumption. The microcontroller will be battery powered and therefore it should use as little power as possible to ensure a long battery life.
- Processing power. The microcontroller should have enough processing power to collect and process incoming data at a high rate, making sure the wearable can work as fast as possible.

From these requirements, Size and processing power seem to be relatively uniform between multiple microcontrollers [11]. However, there are options available concerning the aspect of connectivity. As wireless protocols have different characteristics concerning latency, power consumption, range, etc. In the following subsection, Multiple wireless communication protocols will be considered that can be used to successfully transmit sensor data. These protocols are LoRa, Xbee, and ESP-now.

7.1.1 LoRa

LoRa, which stands for Long Range, is a wireless communication technology which can be used in Internet of Things applications. LoRa is especially known for its low power consumption and exceptional range, making it also suitable for multiple applications where battery life is of considerable importance [13]. LoRa technology has several use cases. for example, it is used in scenarios where cellular or Wi-Fi connectivity may be unavailable or too power-consuming. it offers a cost-effective solution for a wide range of applications that require wireless communication over large distances [8]. Considering these aspects, Lora sounds like a promising protocol to use for wearable devices. however, where Lora shines in devices or projects that need long-range communication with minimal power consumption, it falls short on aspects like low latency, real-time data transmission and high data rates [13]. This means that for this specific use case, LoRa will probably not be sufficient.

7.1.2 Xbee

XBee is a brand of wireless communication modules and devices created by Digi International. These modules(figure 14) are designed for short-range, low-power, and reliable wireless communication, making them suitable for various applications in the field of Internet of Things. Due to its Low-Power Operation and Reliable Communication [6] Xbee seems to be an adequate protocol for transmitting sensor data. however, it has some limitations. The Xbee radio is a standalone module. This means that for more complex data processing, a separate microcontroller is needed. This separate connection potentially increases overhead and thus, latency [14] [16]. Therefore it can be more beneficial to use a microcontroller which has a radio module built in.

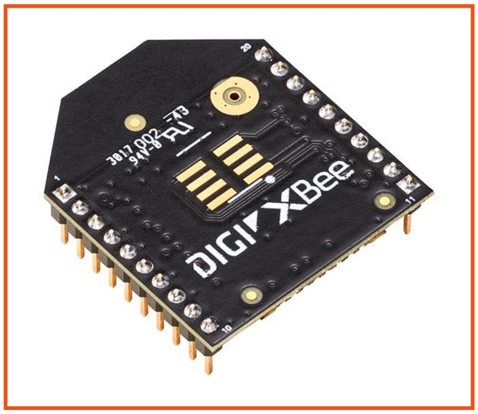

Figure 14: Xbee Module

7.1.3 ESP-now

This brings us to Esp-now. ESP-NOW is a wireless communication protocol developed by "Espressif Systems", the company behind the popular esp8266 and esp32 microcontroller platforms [33]. ESP-now is specifically designed for communication between ESP8266 and ESP32 devices. it boasts low latency and high performance while enabling direct communication between devices without the need for an access point or Wi-Fi router. This makes it suitable for peer-to-peer and point-to-point communication [25]. The low-latency communication aspect of esp-now makes it ideal for this use case. Next to that, there are multiple microcontrollers available with the esp32 module integrated into the board, minimizing overhead. considering these factors and previously mentioned protocols, Esp-now seems like the most suitable communication protocol for this specific use case.

7.2 Sound Control

When the sensor data has been received by the secondary system, It has to be converted into data which can actually be used to alter and trigger musical parameters. To do this successfully, the data can be converted to a protocol called MIDI or OSC. MIDI is short for Musical Instrument Digital Interface. It is a data transfer protocol that allows music systems and related equipment to exchange information and control signals. For example, in music production, MIDI messages can be used to control different parameters, such as playing notes, changing instrument sounds, adjusting volume, and more. The significance of midi is that it allows for different devices from different manufacturers to work together [27]. The OSC protocol on the other hand, can be summarized as a modernized version of MIDI, where MIDI supports a limited range of values, OSC is infinitely granular and bundled UDP messages occur simultaneously, continuously, and nonstop [1]. OSC allows for transferring multiple data types like floats and strings, while MIDI only transmits 1-byte integers. Lastly, OSC uses human-readable, URL-style addresses that can send data in the form of words and numbers.

7.3 Audio Manipulation

Audio manipulation is a subject of this research project which might not be mentioned enough in this research project, but it is an important one. To clarify, Audio manipulation refers to the process of altering or processing audio data to achieve specific desired effects, enhancements, or modifications. This can be done to add creative effects to audio signals or otherwise extract useful information from it. In the context of this research, audio manipulation refers to the altering and shaping of an artist's or performer's voice. This could for example include earlier-mentioned effects like volume and pitch automations. Since, for this research project, a controller will be designed that sends sensor data over a wireless connection to such a program, a program that can be used for real-time audio manipulation can be considered, SuperCollider.

7.3.1 SuperCollider

SuperCollider is a software environment for real-time audio synthesis and interactive control. It provides an interpreted object-oriented language which functions as a network client to a state-of-the-art, real-time sound synthesis server. It, other than max, manipulates sound through a textual interface. which means users have to implement objects like oscillators, effects and automation themselves rather than with pre-defined patches. The textual interface of SuperCollider can be seen in figure 15. The first version of SuperCollider was originally developed by James McCartney in 1996 solely for the Macintosh operating system. SuperCollider only became available to all types of operating systems when the third version of SuperCollider, which was initially developed specifically for the MacOS X operating system, became an open-source project that revolves around a community of contributing programmers [35]. SuperCollider can be used in all kinds of fields. For example, live improvisation, GUI design, dance-oriented music composition, electroacoustic music composition and sound spatialization. [35] SuperCollider is an open-source environment and programming language for real-time audio synthesis and algorithmic composition. However, with this precision comes complexity. So for new and inexperienced users, the interface might be overwhelming.

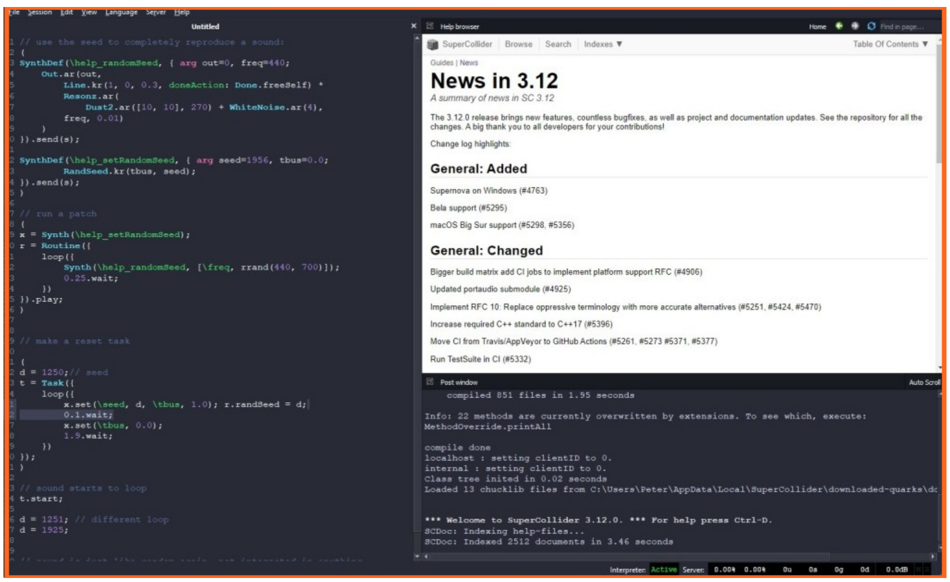

Figure 15: User interface of SuperCollider

8 Discussion and Conclusion

The subject of wearable technology can incorporate almost as many aspects as one wants, which can become overwhelming quite quickly. Therefore, certain subjects or specific materials have not been omitted from consideration examined thoroughly in the background research, either because they did not apply to a wearable controller intended for artists, were challenging to implement, or were too costly. For example, Ionic liquids and salt solutions can be utilized in sensor skin fabrication, but integrating them into elastomers can be a difficult and expensive process [9], thus falling outside the scope of this project. Therefore, it is essential to acknowledge that the technologies discussed in this thesis are those deemed feasible for implementation within this project's parameters and scope. It is also worth noting that the overview of potentially suitable technologies provided in the background research is not exhaustive, and only the most relevant and suitable options have been selected for consideration.

The background research can best be summarized by reflecting on the research sub-questions and to what extent they have been answered. Considering the first sub-question: "How is a wearable interface going to be used?" research was done in what areas of vocal practice a wearable control interface might be of use. Hereafter, the term "Digital Music Interface" was examined to find that a digital music interface usually consists of multiple elements which convert interactions into data. The combination of vocal practice, digital music interfaces and wearability was examined by assessing and discussing existing projects and how these projects are currently being used by innovative and experimental artists. In answering the second sub-question, "What materials are available to build a wearable controller?", Sensor skins were examined, how they fit into this research, how they are made, and what sensor skins are suitable to use. Hereby concluding that sensor skins need to be made out of flexible materials combined with conductive threads, films or electrodes to fit a wearable voice controller. Hereafter, suitable combinations of these materials and how they can be integrated into wearables were investigated, concluding Trill boards, conductive fabrics and MuCa boards can be used to make a wearable sensor skin in multiple ways while retaining comfort. And that combining their features into modules potentially leads to a wide range of functionality. To answer the last sub-question, "How should a wearable controller process interactions?", technologies were examined that are needed to convert interactions of target users into audio synthesis and manipulation. Multiple ways of communicating the data of sensors to software were examined, concluding that microcontrollers with embedded esp32 modules are going to be used, as well as the wireless communication protocol "ESP-now". Following this, a protocol that can be used to enable the sensor data to control musical parameters was assessed. This was done by comparing two protocols typically used in this field, MIDI and OSC. Lastly, a program that can be used for the actual manipulation of vocals was examined, SuperCollider.

The materials, technologies, and processes examined in the background research have provided significant insight into the production of a wearable control interface. This insight is essential in designing a wearable voice controller that properly addresses the problem it was designed for. By using the knowledge gained from the background research, a wearable interface can be developed which uses the appropriate materials and production techniques, thus ensuring a successful outcome.

Part V

Methodology

In this thesis, the main approach that is used for designing is the Creative Technology Design Process, which was established by Mader and Eggink [21] in 2014 and is shown in figure 16. The user-centred approach can be defined as an iterative design process where researchers focus specifically on the users and their needs during each phase of the design process. During this section, this definition is further explained in the context of this project.

9 Design Method

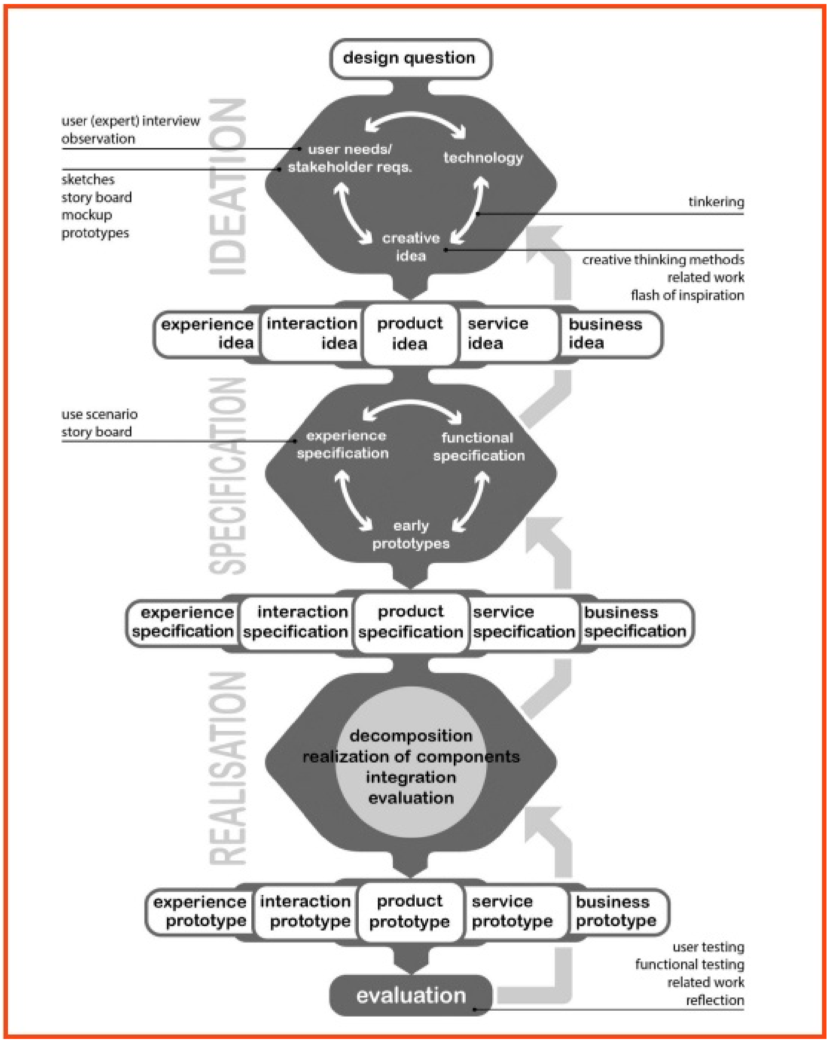

Figure 16: The Creative Technology Design Process

The creative technology design process focuses on turning a linear design process into an iterative one. This allows designers to continuously reflect on each phase of the process, improving it wherever possible. This makes the design process adaptive to new results and insights that may come to light during testing and evaluation. Additionally, it makes the design process highly flexible and have strict time complaints. The process consists of four phases. The ideation phase, the specification phase, the realisation phase and the evaluation phase.

Ideation: The ideation phase consists of formulating a design question and subquestions. Afterwards, ideas emerge to try and answer these questions successfully. In the case of this research project, this phase is used to create sketches of possible wearable controller designs. To generate ideas or concepts, stakeholders have to be identified, the needs of the users have to be defined and previous research on the topic has to be considered. This can be done by, among other strategies, conducting interviews. For this research project, a set of sketches was generated that fit requirements and took into account additional aspects such as wearability, comfort and motion impedance.

Specification: During the specification phase, the generated ideas are refined to ensure a high-quality end product. In this phase, The ideas generated in the ideation phase are specified and improved upon. This is done by considering what materials were needed to possibly realise the ideas, and how these materials could come together to form a working prototype. With this information, a framework can be made that is used as a guide when building both the Trill and MuCa prototypes.

Realisation: After an idea has proven to be a valid solution to the given design question, the realisation phase begins. In the realisation phase, the idea is worked out to a prototype, and all aspects are implemented individually. This requires careful assessment of fabrication methods, requirements and design options. When a prototype is produced, it can be shortly evaluated, taken back to the drawing board and designed again. This allows for iterative improvements to be done, eventually leading to a fully working prototype which can be used to answer the design question.

Evaluation: Lastly, the prototype is evaluated. this is done to assess the usability of the prototype. The evaluation is executed by members of the targeted user group. during their interaction, they share their thoughts on the prototype to see if their user needs are met and at what level they are satisfied. New user needs can be discovered during these evaluations, which can be added to the project in the future.

Part VI
Ideation

In this chapter, the ideation for designing a wearable voice controller is explained. First, the stakeholders for this research are identified and shortly discussed. After which, a set of requirements is created. Lastly, preliminary design solutions are examined and discussed.

10 Stakeholder Identification

Four stakeholders have been identified for this project:

- Lucas Delfos (The researcher)
- Jonathan Reus(The client)
- Performing Artists
- The Audience

The stakeholders have been identified based on having an interest in this research. Of course, the researcher is among these, as this project is of considerable interest to him. Next to that is the client for this project, Jonathan Reus. Additionally, artists are a stakeholder, as they are the main target group of the wearable device and they will thus be using it the most. lastly, the audience is a stakeholder as the wearable controller aims to enhance the experience of vocal performance and thus, the experience of the audience.

11 Stakeholder Requirements

Based on the identified stakeholders, a list of requirements can be made. these requirements are:

1. It can be positioned in a versatile way on many places on the body of a performer: such as the face, arms, chest, legs, etc..
2. It can be composed of many individual control pieces that could be interconnected or placed in multiple locations to create a single control system.
3. It can be embedded into different kinds of wearable structures, such as sleeves or masks.
4. It can be low-latency.
5. it can be interchangeable between multiple systems
6. It is durable enough to survive a performance: the structure of the interface should be solid enough not to fail or break easily.
7. It can fit a wide range of artists' and performers' body sizes.
8. It can have an aesthetically pleasing design.
9. it can have features that are catered towards enhancing the visual experience of the audience, like LED's.
10. it can have a long battery life.

The requirements of these stakeholders can be summarized using the Moscow method. The Moscow method allows for the requirements to be sorted in order of importance. The researcher asks him or herself:

- What requirements are necessary for the successful completion of the project(must have),
- What requirements are important to project completion, but they are not necessary(should have),

- What requirements are not necessary for project completion but would be nice to have(could have)
- What requirements are not possible to incorporate in the scope of this research(will not have)

Based on this method, the requirements have been individually evaluated based on importance and functionality. afterwards, they were categorized like so:

Must Have: Requirement 1, 2, 3, 4 and 6

Should Have: Requirement 5 and 10

Could Have: Requirement 7 and 8

Wont Have: Requirement 9

12 Design Solutions

The earlier-mentioned requirements and their importance to this research project can then be used to create multiple designs that fit them and take them into account. The background research presented two technologies that can be used for the creation of these modules. The Trill craft and MuCa boards are mentioned in section 6.1. The different aspects of these boards can be summarized as follows: the MuCa boards allow for a 2-dimensional interface, supporting multiple touch and a wide range of values. The Trill boards support a 1-dimensional touch, allowing for the simple creation of buttons or sliders. To explore these aspects in different kinds of modules with different purposes, both Trill and MuCa technologies will be utilized for prototyping. Therefore, the ideation sketches are categorized into two sections, Trill and MuCa. Next to that, according to requirement 1, the design should be positioned in a versatile way on the body. However, this is only possible to a certain extent. This is because modules that are for example built specifically for the face, are difficult to design in such a way they fit the rest of the body as well. Therefore, another categorization is added to the ideation; Fixed or Modular. Fixed meaning a module is made specifically for a certain body part, and modular meaning it can be positioned on multiple places of the body. Lastly, there is a strap of fabric placed just below the chest in all designs, this is the place where the central microcontroller is placed. This is done intentionally, to allow for modules to be placed on different sections of the body.

12.1 MuCa: Fixed

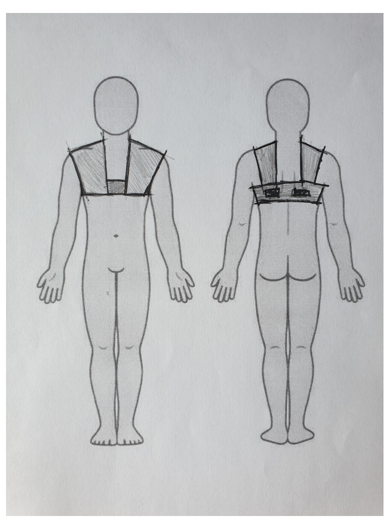

Figure 17: MuCa Fixed Design 1

The first design based on the MuCa board is a fixed layer of sensor skin, placed on the chest of the user. It allows for the user to have a big area of touch, where there is a wide range of values artist can map certain parameters to.

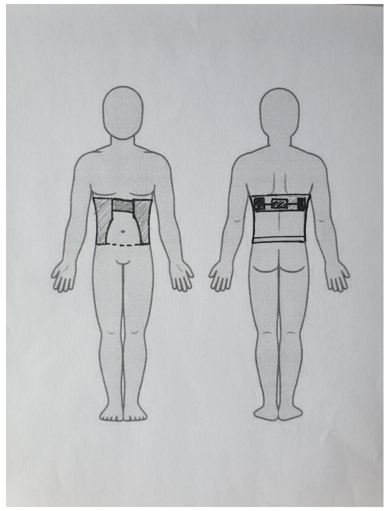

Figure 18: MuCa Fixed Design 2

The following design bears a resemblance to the first design. However, it is designed so that it fits the waist of an artist, rather than the chest.

12.2 MuCa: Modular

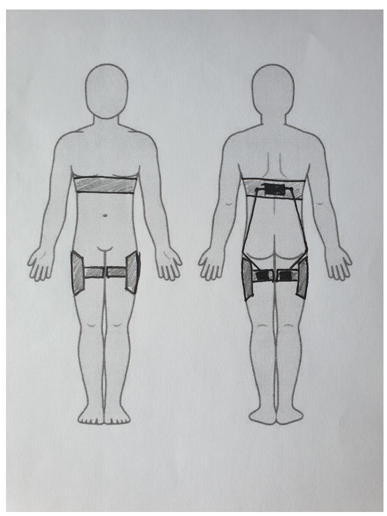

Figure 19: MuCa Modular design 1

The third design based on MuCa is focused on modularity. It includes patches of sensor skins strapped to the user's body. these patches can be placed on the upper legs, arms, waist and shoulders. the MuCa boards are placed on the straps that are fixed to the patches. connected to the central microcontroller on the back via wires.

12.3 Trill: Fixed

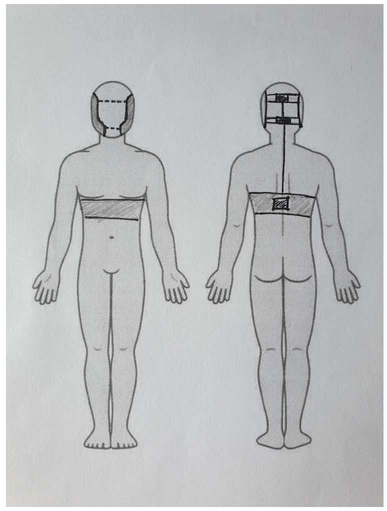

Figure 20: Trill Fixed Design 1

Moving on to designs based on Trill, this design allows for a sensor skin that can be placed on the sides of a user's face. This sensor skin can then be used for sliding or tapping interactions.

12.4 Trill: Modular

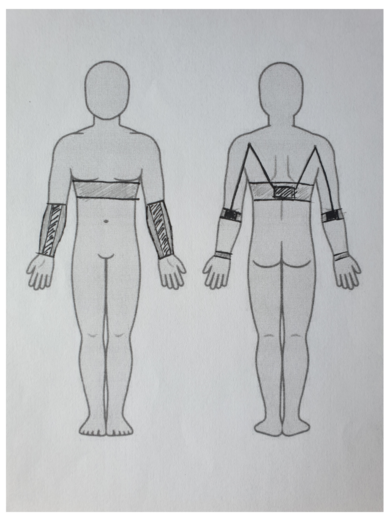

Figure 21: Trill Modular Design 1

This design focuses on a slider interface that is placed on the forearm, but can also be moved towards the upper arm or the upper leg. The sensor skin is embedded into a sleeve, which makes it suitable to be positioned on multiple body parts.

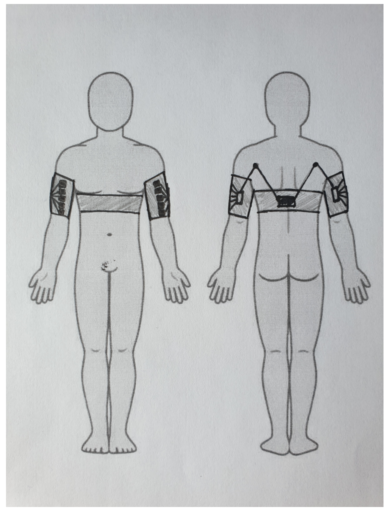

Figure 22: Trill Modular Design 2

The last design is similar to the previous one. However, this one incorporates a single-touch interface, having multiple capacitive buttons embedded into the sleeves. Artists can for example use these buttons to switch between modes or enable and disable effects.

13 Combination of Concepts

Ultimately, these designs will be combined to develop a modular interface that fits in multiple places on the body. This is done to incorporate as many body locations and user preferences as possible within the short timeframe of this research project. Two modules will be designed. One is based on the Trill board, and another is based on MuCa. The preliminary sketches have been shown to artists and costume designers to gather their recommendations, aiming to utilize these insights as a foundation for developing the best possible prototypes. The recommendations have been summarized below.

- **Trill:** During the showcasing of the trill prototypes, interviewees showed particular interest in the face design and lower arm sleeve design. However, it was suggested that, for the sake of modularity and simplicity, further development should focus on the sleeve. It was believed that this design could be adapted to fit multiple areas of the body while remaining relatively simple to fabricate.
- **MuCa:** With the MuCa designs, artists especially showed interest in the first fixed design which focused on the upper torso. As they were keen to see what interacting with that area would mean performance-wise. However, the costume designers pointed out that such a design would be hard to fabricate. Therefore the design was simplified to some extent, resulting in a rectangular design on the user's upper torso.

Part VII
Specification

In this section, the Preliminary requirements described in chapter V are converted into functional and non-functional requirements with the help of stakeholder interviews and a fictional scenario. Afterwards, the preferred prototypes of the ideation phase will be discussed in more detail. This concerns the physical design and the techniques used to develop the envisioned prototypes.

14 Functional and Non-Functional Requirements

To convert the preliminary requirements mentioned in section V to functional and non-functional requirements, interviews with stakeholders have been summarized. With this information, a persona can be established. Afterwards, an interaction scenario can be carefully analyzed and interpreted. This way it is possible to get an overview of what functional and non-functional requirements the system will need to provide the user with a satisfactory experience.

14.1 Stakeholder Interviews

To be able to successfully design a prototype with a specific target group in mind, stakeholder interviews can be of significant importance. Therefore, four interviews have been conducted with target users of the wearable voice controller. These are two artists in experimental music production and two performance costume designers. These interviews have provided insights into aspects like wearability, functionality, usability, etc. Next to that, stakeholders were asked to share their thoughts on early ideas and sketches, guiding this research project in the right direction. Overall, these interviews were of great importance in understanding the target audience and have been utilized extensively throughout the research. The setup of these interviews is described below. Thereafter, the results have been summarized in the form of key takeaways. The transcribed interviews can be read in appendix 27.

14.1.1 Stakeholder Interview setup

The participants were invited to take part in an online conversation about this research. When they agreed to participate, they were sent a short explanation of what was expected of them and they were asked to sign the consent form in appendix 26. The interviews themselves were set-up in a semi-structured way. Two different sets of questions were formulated, both catered towards the Participant's skillset and experience. These sets of questions are mentioned below.

- **Artist Questions**
  - What is your performance setup, interface, and what are you controlling?
  - Do you see advantages in using a wearable controller?
  - What aspects of your voice do you usually modulate or alter when using your system?
  - In what ways do you integrate your system into your performances?
  - Do you feel like your system allows you to achieve all of your artistic goals? if not, what would you like to explore further?
  - How does your system become part of your performance, musically and theatrically?
- **Costume Designer Questions**
  - Do you see the trill sensors integrated into a wearable voice controller? how?
  - How would you integrate e-textiles and sensors into a wearable?
  - Do you have recommendations for specific materials? (based on durability, availability, cost, etc)
  - What are things I will probably run into when designing a wearable?
  - What kind of methodology would you use to develop a wearable voice controllers

When these questions were answered sufficiently, participants were presented with the ideation sketches and asked to give their opinions on them.

14.1.2 Key takeaways

- **Artist Integrity:** A key point that emerged from the interviews was that the wearable should protect artist integrity. Especially in the sense that the wearable should not take over the artist's performance. It is important to consider that a performance should still revolve around the artist, rather than the wearable interface. While how artists use the interface has some influence on whether or not it dominates a performance, the wearable can still be designed in such a way that it gives artists full control of what they are doing. Visual aspects can also influence the effect a wearable interface has on a performance.

- **Simplicity:** A point that was raised mostly by costume designers was that the design should be simple. Complex designs would be more difficult to fabricate, which could cause problems within the time period of this project. Additionally, complex designs may pose challenges during fitting and interaction, further extending the time required to perfect each prototype. Moreover, a simplistic design is easier to integrate into costumes and performances, with simplified designs offering greater flexibility and ease of movement.

- **Feedback :** An important point brought up by the artists was that they felt like they would need feedback from the prototype. To clarify, artists need some sort of feedback to know if their interactions are registered or where they are in terms of parameters or settings. Without feedback, artists may be uncertain about the impact of their actions on the prototype, leading to potential frustration or flaws in real-time audio manipulation. This feedback could be given with the use of actuators or LEDs, informing the artists about their actions.

- **Placement :** Placement of the wearable was also made out to be an important point of consideration. While artists can wear the interface as they would want, some areas of the body might have more meaning or implications than others. For example, the upper torso might not be an area with implications for men but it can have intimate meaning for women. It should be thoroughly considered what touching a specific area of the body means. Not taking this into account can lead to an unnatural audience experience, while doing so might contribute to a more immersive audience experience.

- **Experience Design :** Lastly, it became clear through the interviews that, next to designing the wearable controller, the experience itself should also be kept in mind. In essence, this meant considering what an artist would want to do with the prototype in every step of the design and fabrication process. This ensures that the design and fabrication process is tailored to meet the specific requirements of artists, which promotes a positive user experience.

14.2 Persona

- Background: Luna Collins is a 28-year-old voice performer based in an urban arts community. She earned her Master's in Sonic Arts and has a background in classical vocal training. Luna is known for pushing the boundaries of traditional voice performance. She incorporates elements of electronic manipulation and unconventional vocal techniques into her work. She thrives on collaboration and often engages with artists from various disciplines to create immersive experiences in the musical performance domain.

- Personality Traits:

  1. Innovative: Luna is constantly exploring new ways of music-making and experimenting with unconventional vocal expressions. She is driven by a deep curiosity about the potential of the human voice as an instrument.
  2. Collaborative: Luna values collaboration and frequently partners up with artists, technologists, and performers to create interdisciplinary projects that challenge both herself and her collaborators to find something unique.
  3. Expressive: Her performances are not just about sound; they are emotional experiences. Luna uses her voice as a medium to try and convey a range of emotions to immerse her audience.
  4. Technical: Luna is comfortable with technology and uses digital music instruments and electronics to enhance and manipulate her vocal performances. She enjoys experimenting with sound processing equipment, always finding new ways to alter her voice.

- Goals and Challenges:

  1. Pushing Boundaries: Luna is dedicated to pushing the boundaries of experimental voice performance. Her goal is to explore to the fullest extent what is possible with the human voice.
  2. Recognition and Exposure: While known within a relatively large arts community, Luna aspires to gain recognition on a broader scale. She is open to participating in international festivals and collaborating with artists from different cultural backgrounds.
  3. Retaining a unique sound: Luna is mindful of maintaining her artistic integrity while also navigating the practical aspects of sustaining a career as an experimental voice performer. She wants to balance her ambition with having a unique sound that lets her stand out.

14.3 Interaction Scenario

In this subsection, an interaction scenario is given to describe the interactions that are possible when using the controller. The interactions that have been described are meant to answer the question; "How will Luna use the wearable voice controller?"

1. Luna is standing in the middle of her sound studio. Surrounding her are various musical instruments and equipment which she normally uses for her performances. She has recently been given a prototype of a wearable control interface. Which she was immediately excited about. Luna thinks the wearable interface could be a good addition to her collection of virtual instruments and controllers, as it could allow her to explore a new area of vocal expression.

2. Luna picks up the wearable controller, and she notices the controller is made out of flexible and comfortable materials. As she goes to try on the wearable controller she notices it is made in such a way that it fits on multiple areas of her body. This time, she decided to put the wearable on her left forearm. Next to that, she notices the sliding interface, instantly giving her ideas about what parameters she can control.

3. After turning on the microcontroller of the wearable, Luna plugs the USB receiver of the wearable into her computer. She notices the wearable sends data via the common protocol OSC. She is happy about this, as it makes connecting the wearable to her system a lot easier.

4. Luna links the wearable controller to multiple effects, including a delay effect. This effect makes her voice have an echo-like effect. With the wearable linked to this parameter, she can now control the amount of delay she wants to have on her voice in real-time.

5. As Luna sings into the microphone, she slides her fingers across the wearable interface and immediately notices the ease of how the parameter is controlled. the wearability and flexibility of the interface make it easy for her to move around and express herself through motion while the low latency of the wireless connection with her system makes the controller seamlessly alter her voice in real-time.

6. Out of curiosity, Luna tries to punt the controller on her upper leg instead of her forearm. She notices that this placement allows for a new range of motions, which she can link to different effects and parameters.

7. Luna is done using the wearable controller but she can not wait to use it again and explore what motions she can link to certain parameters. And what the effect of these motions will be on her performances.

14.4 System Requirements

Here, the requirements of the wearable interface are listed. The requirements have been composed based on the interviews described in section 14.1. In these interviews, artists and costume designers were asked about their preferences concerning a wearable touch interface. These preferences have been evaluated and summarized to get an overview of what requirements an ideal wearable controller should have. The requirements can be categorized into two different types: functional requirements and non-functional requirements. The functional requirements describe the functions and features the system has. Meaning what the system must be able to do. The non-functional requirements describe the general properties of the system. Meaning how the system will function and what quality constraints the system has.

Index	**Functional Requirement**
1.	The wearable must be able to control parameters and connect to the system via OSC.
2.	The wearable must be able to send data via a stable and extremely low-latency wireless connection. Which is picked up by a receiver plugged into the system
3.	The wearable must be able to accurately sense interactions from users using capacitive sensing.
4.	The wearable must be modular, meaning artists can place the interface on multiple areas of their bodies and combine multiple interfaces in a system
5.	The wearable must allow for a wide range of motions, meaning the interface should be flexible while still being able to accurately sense interactions
6.	The wearable should have an interaction surface that facilitates smooth touches and sliding motions so artists can easily interact with the controller
7.	The wearable should allow for multiple touches at once.
8.	The wearable should provide haptic feedback to the users with every interaction.
9.	The wearable should directly work on each system it has been plugged into, meaning no additional configuration is necessary
10.	The wearable should have a battery life that lasts at least one performance

Table 1: Functional Requirements

Index	**Non-Functional Requirement**
1.	The wearable must have a user-friendly interface, using comfortable materials.
2.	The wearable must have a durable build
3.	The wearable should be accessible to a wide range of artists with different body types

Table 2: Non-functional Requirements

15 Envisioned Prototypes

In this section, design choices are presented and explained to give an overview of what the prototypes will look like and what materials will be needed to fabricate them. The production process can be summarized into three parts, sensing, layering and fitting. The sensing describes how a touch is received by the system and how that data is communicated. The layering describes how the different materials come together to form a prototype. The fitting section describes how the prototype is then made to fit the body part it is intended for. In this section, these parts will be individually described concerning the Trill and MuCa prototypes.

15.1 Trill: Sensing

The Trill board works by measuring the capacitance of individual channels. The readings of these channels are then passed on from the Trill board towards a microcontroller. To embed these capacitive points into a wearable, they need to be extended from the Trill board to accommodate for sensing touch interaction. This can be done by connecting a conductive material with the touch points via a wire, thus measuring the capacitance of that conductive material, instead of the capacitive point on the Trill board. To clarify, the difference between the capacitive sensing directly on the Trill board and that of a point of conductive material connected to the Trill is shown. The left side shows the interaction between a user and the capacitive touch point while the right side shows their respective capacitance value reading.

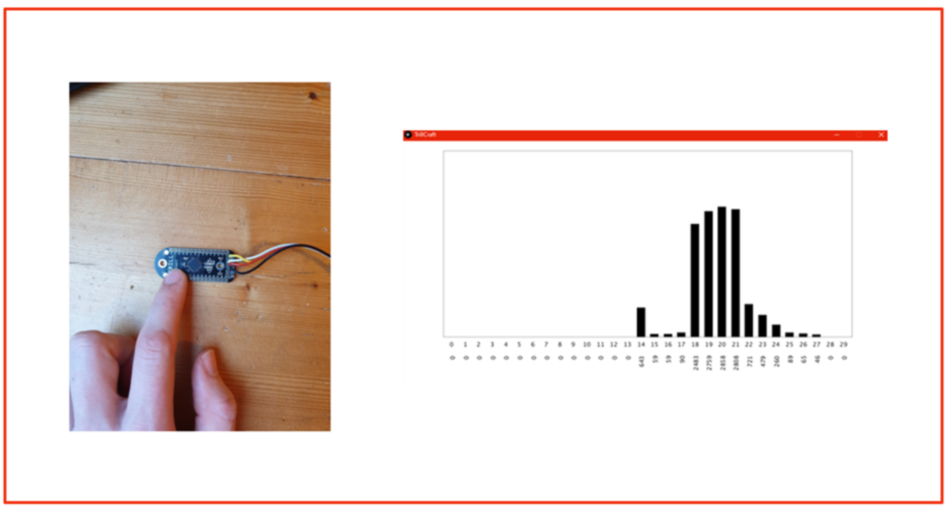

Figure 23: The capacitance reading when directly touching the Trill capacitive channels.

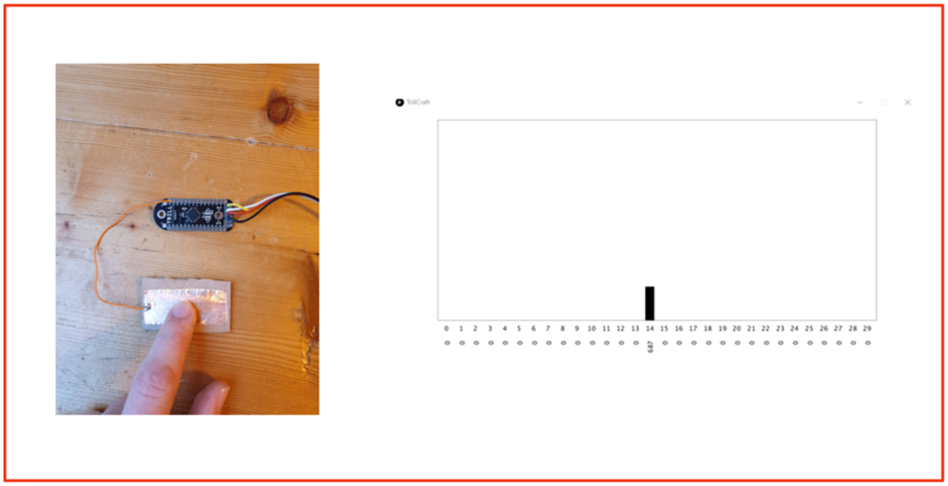

Figure 24: The capacitance reading when a conductive material is connected to a channel.

These figures show the values of the conductive material versus the direct capacitive points on the Trill. It should be noted that the loss in value is not directly due to the conductive material. Numerous aspects influence this value, like moisture and pressure. This explains the large difference in measured values.

To implement the sensing of touch into a wearable design, it is evident that these conductive materials need to be implemented and connected to the Trill board. These materials, along with the Trill, can be placed in a pattern like the one shown in figure 25. This is done to facilitate a slider-like interface as the design shown in chapter VI.

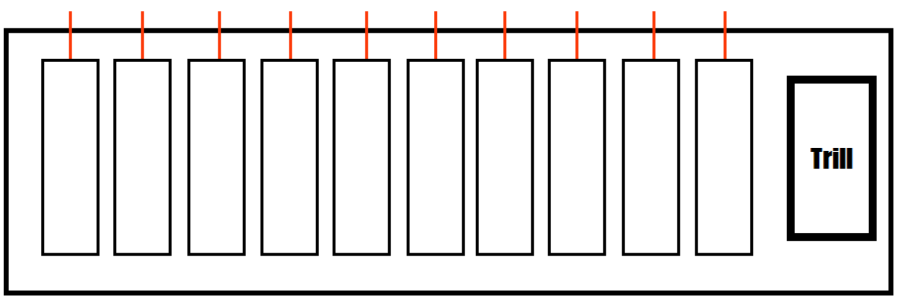

Figure 25: A pattern of electrodes in the Trill prototype

15.2 Trill: Layering

Having discussed how touches can be sensed using conductive materials, it can be considered how these materials can be layered with other elements to build a working and flexible prototype. The first layer is the layer that directly touches the skin of the user. Therefore this layer needs to be comfortable but also suitable for the placement of conductive materials. To satisfy these requirements, a piece of textile has been chosen, as it is flexible, comfortable and relatively easy to modify. On top of this layer, the conductive materials should be placed, this was chosen to be copper foil as it is somewhat flexible, highly conductive and easily attainable. Lastly, to protect the fragile copper film, a thin layer of silicone can be poured onto it. The reason silicone was chosen is because of its very suitable properties. It insulates the electrodes while retaining the aspect of flexibility. Additionally, it provides a smooth interaction for touches. These different layers and how they combine are shown in figure 26.

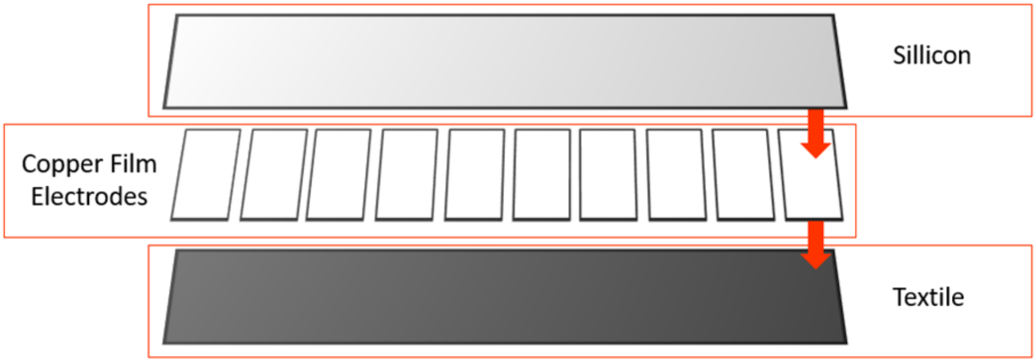

Figure 26: The different layers of the Trill prototype

Additionally, the electrodes will be connected to the Trill via wires. The Trill board and the wires are not shown in the diagram to keep it organized. The Trill board will be placed underneath the electrodes to allow for easy connectivity to the electrodes and to not be in the way of a user's movements.

15.3 Trill: Fitting

The Trill prototype is made to fit either a user's arms or legs. This means that the prototype should be able to curve around these body parts, be comfortable and should fit different arm or leg sizes. Therefore, designing a way to make the prototype close-fitting in every case can be a challenge. To accommodate for different body characteristics, the closing should be stretchable while still being tight. A possible option is lacing the prototype together on opposite sides. Shown in figure 27 is a possible example of how this can be done.

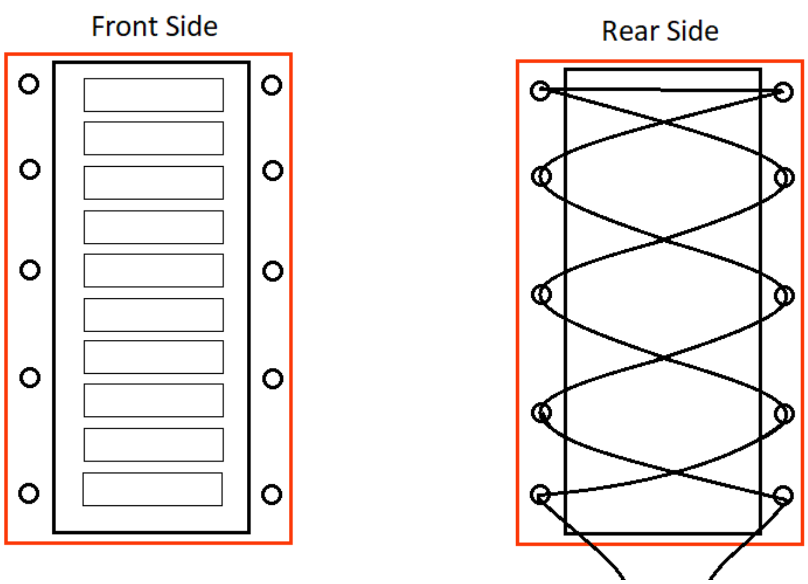

Figure 27: A closing option for the Trill Prototype: lacing

This closing is adjustable, thus allowing each user to adjust the lacing to fit the size of their arm. Next to that, if the rope used is elastic, the closing becomes more flexible as well. Making it an ideal option for the Trill prototype.

15.4 MuCa: Sensing

How the MuCa board senses touch is where it substantially differentiates from the Trill Board. Referring back to section 6.2, MuCa boards use mutual capacitance to sense interactions. While Trill boards use self-capacitance. This difference is reflected in the design process mainly by the different electrodes used for sensing. In a MuCa prototype, the sensing of interactions is done by measuring the capacitance between multiple electrodes, rather than measuring the capacitance of a single electrode. This adds complexity to the design, as the placement of electrodes becomes important. This is mainly because if there is a difference in the distance between the electrodes, for example, inaccuracies in data sensing can occur. To avoid this, electrodes have to be placed carefully while paying close attention to aspects like distance and placement. Since mutual capacitance is measured at the intersection of electrodes, electrodes can be placed in a grid pattern like the one shown in figure 28. Allowing for accurate sensing of interactions.

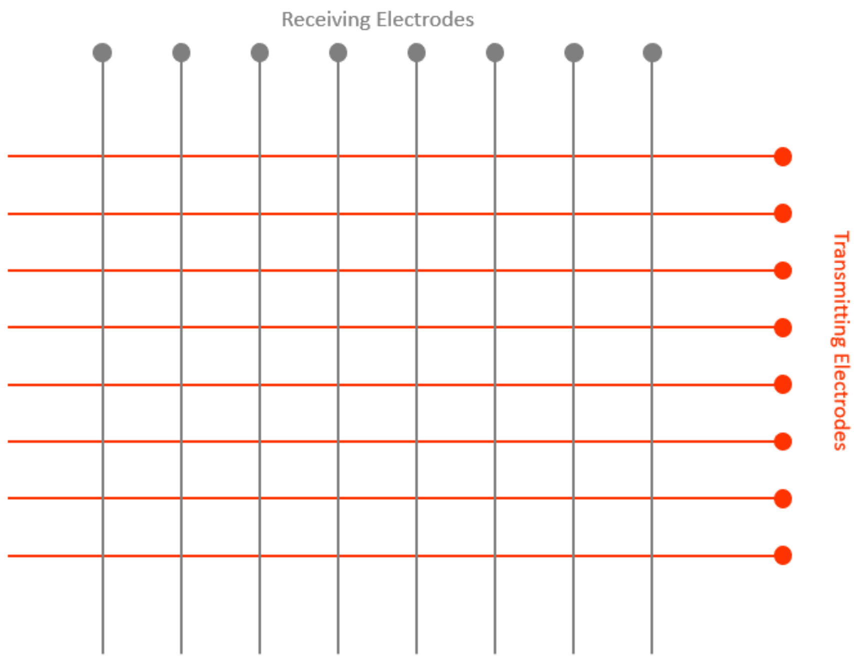

Figure 28: A grid pattern of electrodes to be used for mutual capacitance sensing

The electrodes are positioned in this way as the design process is based on research done by Marc Teyssier [32]. In this research, it was found that a grid pattern is easier to fabricate and requires fewer components. Next to that, using two orthogonal arrays of electrodes separated by a dielectric layer was found to be the most effective way of capacitive sensing in flexible interfaces.

15.5 MuCa: Layering

The layering process of the MuCa prototype will be reasonably similar to that of the Trill prototype. This is because the two prototypes consist of the same elements. Namely, a layer to place the electrodes on, the electrodes themselves and an insulating and protective layer of silicone. The electrodes can be made of the conductive threads mentioned in section 6.3.2 as they allow for sensing touches while having the aspect of stretchability. The layers of the MuCa prototype are shown in figure 29.

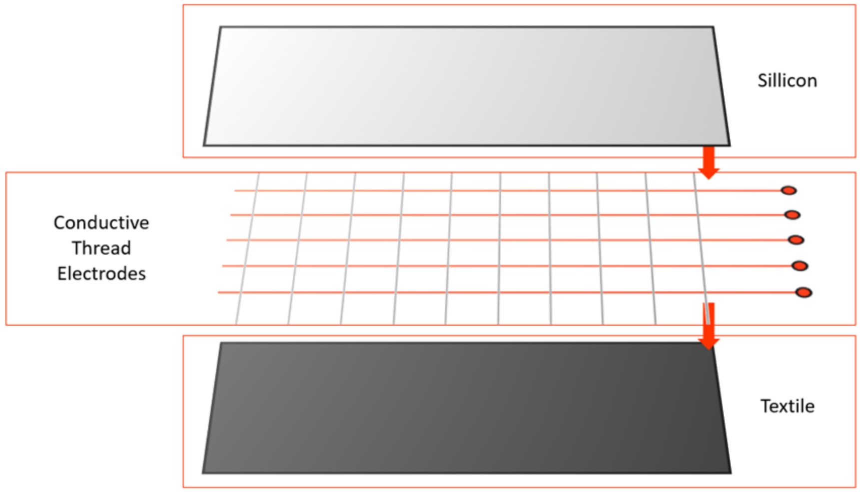

Figure 29: The different layers of the MuCa prototype

It should be noted here that, in the fabrication process, an extra layer or tool should be added to keep the electrodes spaced evenly and make sure they are held tight. This layer or tool should be rigid, to not break or bend under tension and interfere with the fabrication of the prototype.

15.6 MuCa: Fitting

The MuCa prototype is meant to be used in the chest area as well as on the abdomen. This placement results in the fact that a closing using lacing like with the Trill, becomes difficult to implement. Therefore, a closing has to be designed that can be used in relation to the prototype's intended placement while still being highly adjustable and comfortable. For this, simple straps can be used, like the one shown in figure 30.

Figure 30: Nylon strap with a plastic clasp

The MuCa prototype can be fitted to these straps. The straps can then be placed around the body of the user, allowing for a tight fit. Next to that, the straps are adjustable in sizing which makes them ideal for fitting a wide range of users.

15.7 System Connections

Lastly, it is necessary to specify how the prototypes are connected to a secondary system. The wearable senses interactions from users using electrodes connected to the Trill and MuCa boards. these boards send these interactions to the ESP-32 in the form of serial data. This serial data is then wirelessly communicated over the ESP-NOW protocol to another ESP that is connected to a secondary system like a laptop. The second ESP then communicates the incoming serial data to a Python script, which translates it into OSC. Lastly, the Python script sends the OSC data to Supercollider, which will be used to generate sounds and alter incoming vocals. To clarify, figure 31 visually summarises the system connections.

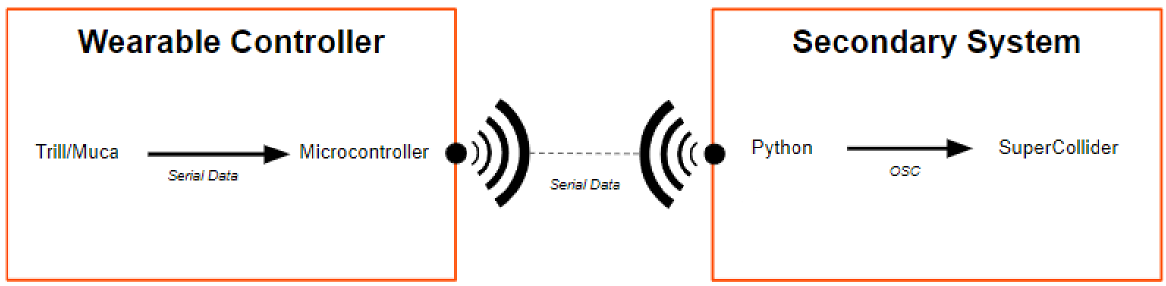

Figure 31: System Connections

Part VIII
Realisation and Iterative Prototyping

In this section, the realisation process of a wearable voice controller is explained. This is done by describing the process of rapid iterative prototyping. Iterative prototyping is a development approach that involves the creation of multiple prototypes. These prototypes are then evaluated and improved upon. This continues for multiple iterations, with each of these iterations incorporating feedback from the previous prototype. In this section, the developed prototypes, their flaws and the materials used in their development are described in detail. Thus describing the different aspects that need to be accounted for and how to eventually reach a satisfactory and functional prototype. First, Trill prototypes have been described. After which the MuCa design is discussed.

16 First Trill Prototype

16.1 Process

Before the first prototype could be realized, several steps had to be taken to ensure an optimal design process. For example, the first thing that had to be done was to acquire a piece of textile that would fit the prototype. Though this might sound like a simple task, there are several things in need of consideration when deciding on the right fabric. First, for the silicone to properly attach, the fabric needs to be quite porous. Next to that, the fabric will be in direct contact with the user's skin. Therefore it needs to be comfortable to touch. Taking these aspects into account, the following piece of fabric was chosen.

Figure 32: Textile for the first Trill prototype

Next, it was important to test the silicone that would be used in the fabrication process. This is because different types of silicone can greatly differ in aspects like viscosity, hardness and smoothness. The specific silicone that was used for the first prototype was the Smooth-on EcoFlex FAST. This type of silicone is characterized by its low viscosity and its soft, strong and stretchy end product. Testing this silicone first was essential in getting an image of what the end product would look and feel like. This test is shown in figure 33.

Figure 33: A test setup of the Ecoflex silicone

After this, a sketch was made to get an overview of electrode placement, the placement of the Trill board and the overall dimensions of the prototype. This sketch is shown in figure 34

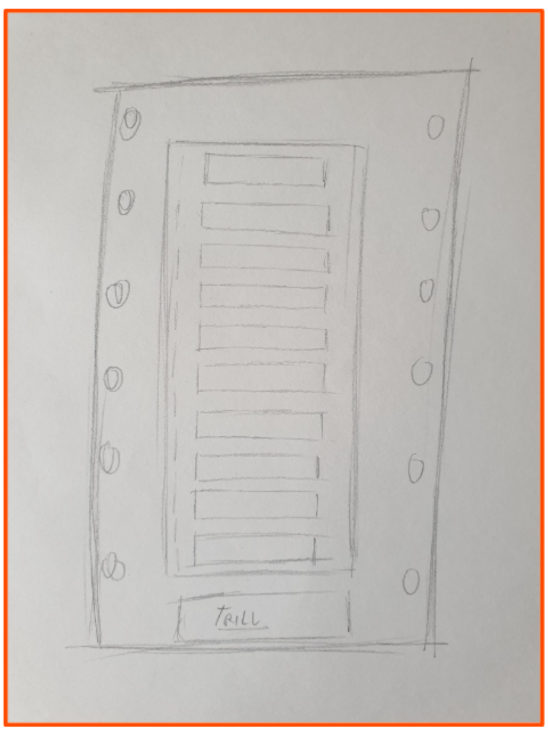

Figure 34: A sketch of the first Trill prototype

To clarify this sketch to some extent; all components are placed on a large piece of the textile. In the middle section, the electrodes would be placed. These electrodes could then be connected to the Trill craft which was placed underneath them via simple wiring. The electrodes could then be covered in a layer of silicone. On the left and right sides of the textile, holes could be made to pass a cord through to allow for a tight fit around a user's arm or leg.

The sketch in figure 34 was used as a guideline for the fabrication process. First, a piece of fabric was cut to size. Since this was the first prototype, the dimensions of this fabric were arbitrarily chosen to be 12cm by 20cm. Afterwards, the dimensions of the inner section of the electrodes were chosen to be 5cm by 18cm. These dimensions were drawn onto the piece of fabric. After which, the piece of fabric was put on a piece of cardboard and held in place by several needles. This is shown in figure 35.

Figure 35: The piece of fabric with the electrode section drawn.

After this, a mould was made out of thick cardboard which the silicone could be poured into later. First, the electrodes were cut out of a copper film. Each having a dimension of 1cm by 5cm. 11 of these copper film electrodes were then placed on top of the fabric. After which wires were soldered onto them so they could later be connected to the Trill craft. Thereafter the cardboard mould was placed on top of the fabric and firmly secured with several needles to make sure the mould was unable to move during the pouring of silicone. Lastly, the silicone was carefully weighed, prepared and poured onto the fabric. This is shown in figure 36.

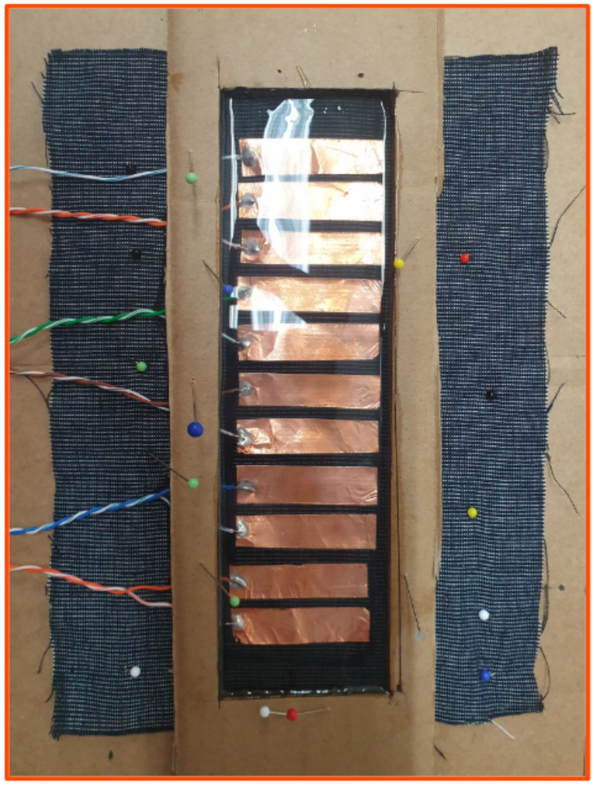

Figure 36: The first Trill prototype with the silicone poured

This setup was then left to cure overnight. When returning to the prototype and removing the mould the next day, several things could be noted. Namely, the cardboard mould was unable to keep all the silicone in the designated area and it had flown under the mould to some extent. This was most likely due to the soft properties of the cardboard and the low viscosity of the Ecoflex silicone. Next to this, the low viscosity of the silicone also allowed for it to flow through the fabric, leading to some of the silicone being on the underside of the prototype. However, the top layer of silicone had dried and the electrodes were protected to a satisfactory level.

After this, the Trill craft was positioned under the electrodes and secured to the fabric with a thin wire. The wires that were previously soldered to the electrodes could then be soldered to the capacitive touch points on the Trill, allowing for user interactions to be sensed by the Trill. Lastly, holes were made on either side of the fabric where a cord was passed through in such a way that it could be tightened and loosened to the user's liking. The finished first trill prototype is shown in figure 37, 38, and 39. It should be noted that, in these figures, the trill board is missing. This is because it was needed for further prototyping.

Figure 37: First Trill prototype (1)

Figure 38: First Trill prototype (2)

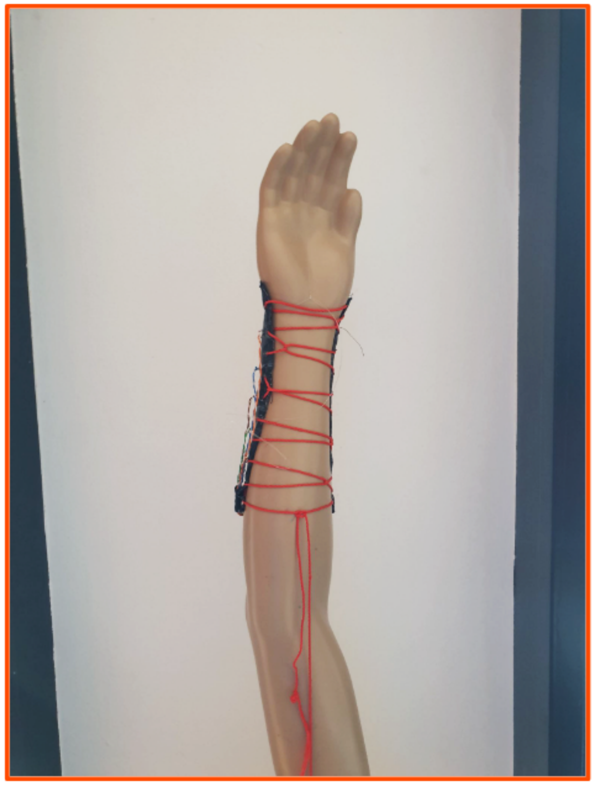

Figure 39: First Trill prototype (3)

16.2 Points of Improvement

During the testing of this first prototype, it became clear that several aspects were in need of improvement. To effectively take these aspects into account in the design process of the following prototype, an overview of the most important points of improvement can be made. This is shown below.

1. **silicone leaking:** A problem that needs addressing is the fact that when the silicone was poured into the mould and onto the fabric, it got under the mould as well as went through the fabric. This is a problem as it hinders the process of shaping the silicone in the right way and gets in places where it is not supposed to be.

2. **Wiring:** There were several things wrong with the wiring. Firstly, the wires that had been used were way too stiff and did not allow for much flexibility. This also made the prototype a lot more fragile. Next to that, The fact that these wires were soldered directly onto the Trill made it so the trill could be broken if one of the wires was pulled too hard in an explosive motion for example.

3. **Electrode placement:** As seen in this prototype, the electrode placement makes it so there are limited interactions possible other than individually interacting with electrodes and sliding across the interface. In the next iteration, electrodes can perhaps be placed in a way that allows for more and different types of interactions.

4. **Modularity:** As the Trill was secured directly to the fabric and the electrodes were directly soldered to them, this prototype did not allow for modularity. Making it impossible for the Trill to be interchanged between prototypes and different iterations for example.

5. **Closing:** There were several things wrong with the closing of this prototype as well, resulting in the prototype being difficult to put on and adjust. This was mostly due to there being friction between the cord and the fabric. Next to that, as the cord was not elastic, tedious adjustment was necessary every time the prototype was put on and took off. This in combination with the difficulty of adjusting means there is room for improvement.

6. **Microcontroller :** Lastly, in this prototype, the microcontroller that receives the data from the Trill was not accounted for. Therefore, in the next iteration, the microcontroller has to be incorporated into the design as well.

17 Second Trill Prototype

17.1 Process

The second Trill prototype was made in such a way that it incorporates the solutions to the problems stated in the previous section to the largest extent possible. To start, the fabric used in the previous prototype was probably too porous, making it easy for the silicone to flow through it. Therefore a new piece of fabric can be selected. The new fabric should be less porous than the first one, but some porosity is still needed for the silicone to properly attach. Taking this into account, the following piece of fabric was selected.

Figure 40: Textile for the second Trill prototype

To further reduce the leakage of silicone, a mould could be made out of stronger material to stop the silicone from flowing through or underneath it. Thus, the next mould was made from wood instead of cardboard. Moreover, it was found that the wires sticking out from the electrodes led to the mould not being able to sit flush with the fabric. This meant that, around the wires, the silicone could more easily flow underneath the mould. To combat this, grooves were made in the mould to ensure the wires would not be in the way of the mould touching the fabric. Lastly, the edges of the mould were rounded with sandpaper in an attempt to make the edges of the poured silicone smoother. The new mould is shown in figure 41.

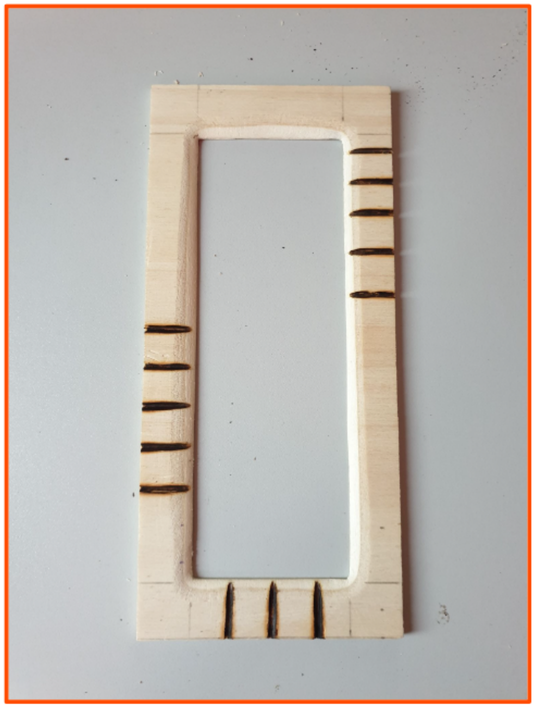

Figure 41: The mould for the second Trill prototype

Afterwards, a piece of fabric was cut to size and the electrodes were placed on top. This time, however, in an attempt to increase the functionality of the wearable interface, the electrodes were placed differently. With the electrodes placed this way, the first three electrodes could for example be used to select a mode of operation, while the others can still be used as a slider or individual touch points. The wires that have been soldered to the electrodes are also a lot less stiff, allowing for a lot more flexibility. The piece of fabric and the accompanying electrode placement are shown in figure 42.

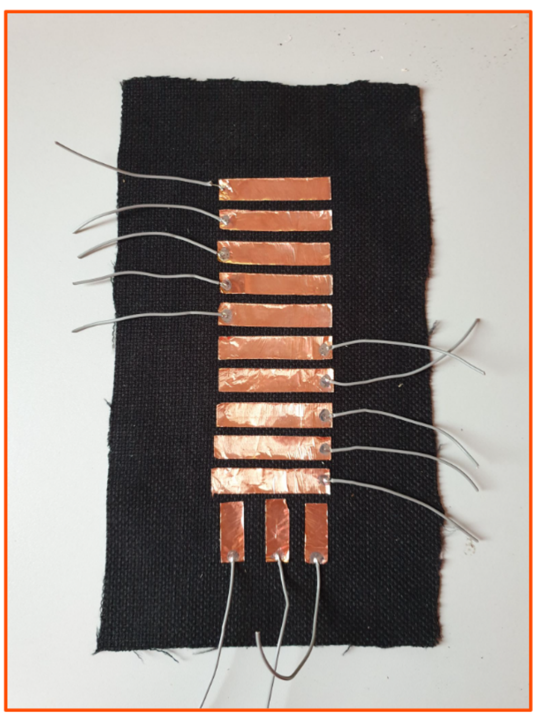

Figure 42: The piece of fabric with electrodes placed on top

The wires could then be lined up with the cut grooves in the mould, ensuring a tight fit with the fabric. Next to that, weights were placed on top of the mould. The setup was then left to cure overnight again. The result is shown in figure 43

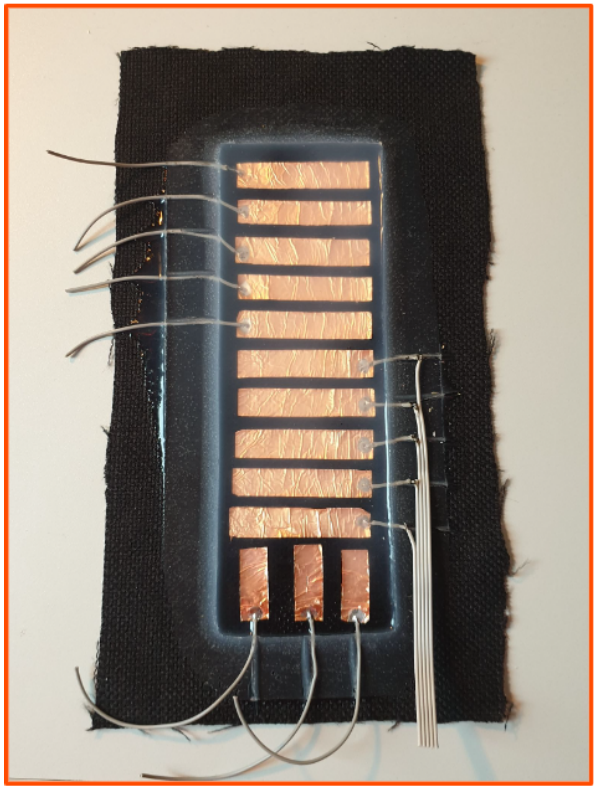

Figure 43: The second Trill prototype with cured silicone

Unfortunately, the silicone had again flown underneath the mould and even through the fabric. All be it to a lesser extent than with the previous prototype. This was probably due to the grooves not fully encapsulating the wires and thus making the mould not sit tight against the fabric. Hereafter, the wires could be soldered. A flat ribbon cable was used to allow for a nice-looking and compact solution for the wiring. These cables were placed on either side of the electrodes and soldered up to the electrodes themselves, which could then be connected to the Trill.

Here, the decision was made to design a connection interface, rather than soldering the electrodes directly to the Trill craft. This was done to make the design more modular. But also to make prototyping easier. The first iteration of this connection was made with 13 male header pins attached to the prototype, one for every electrode. The trill could then be positioned elsewhere with a custom cable of 13 female connectors connecting the Trill with the prototype. The male headers and female connectors used for this are shown in figure 44.

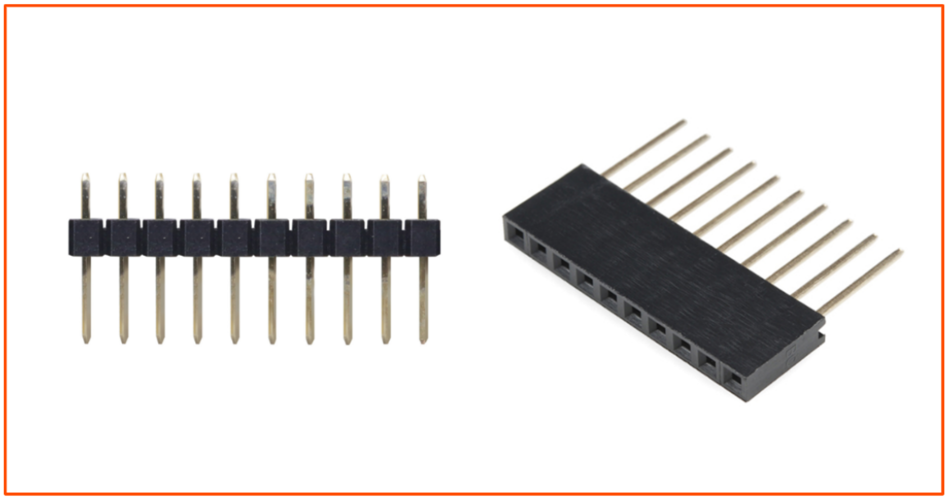

Figure 44: The header pins(left) and header connectors(right)

However, this connection turned out to be too fragile to be used reliably. Therefore, another connection was made using a 13-pin connector placed on the prototype. The Trill was then modified with male pins to facilitate a modular connection. The prototype with the second connection is shown in figure 45, and the modified Trill is shown in figure 46.

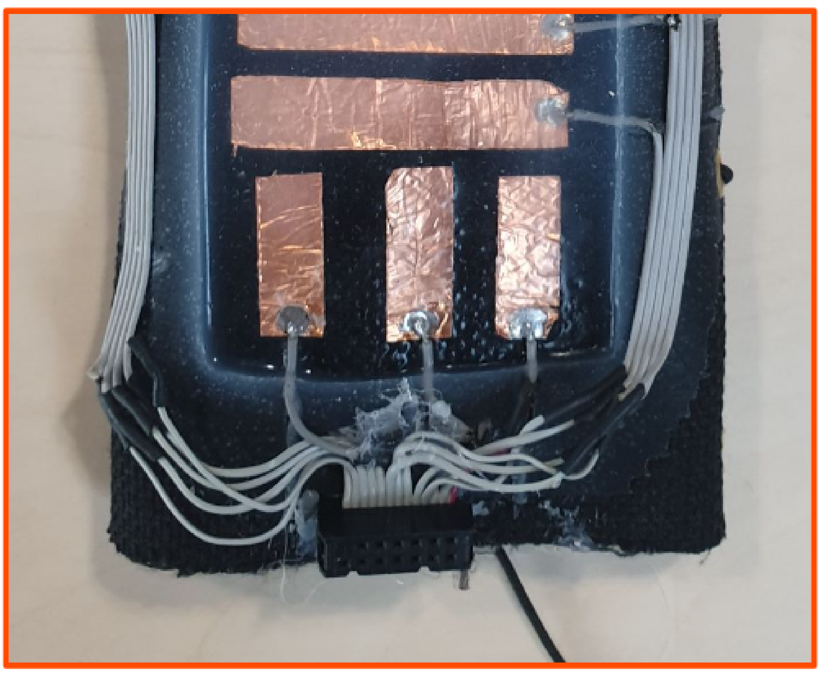

Figure 45: The second Trill prototype with an improved connector

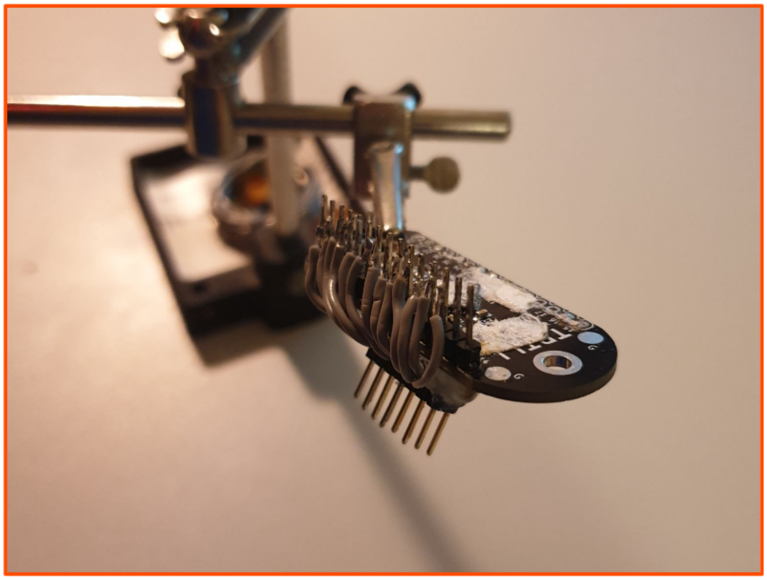

Figure 46: The modified Trill craft

This way, the Trill could easily be connected firmly to the prototype. Next to that, with this connection, there is no need to run 13 individual cables from the prototype to the Trill anymore. With this connection, only the wires from the Trill to the microcontroller need to be connected. Making the wiring more flexible.

With the connection from the electrodes to the Trill addressed, the connection from the Trill to the microcontroller can be attended to. As placing the microcontroller on the prototype would result in a package of electronics that could hinder the artist's performance, the microcontroller needs to be placed somewhere else and connected to the trill via wire. Therefore, a separate module was made to fit on the artist's upper arm. This module is shown in figure 47.

Figure 47: The module for the microcontroller

The last problem that needs to be dealt with in this prototype is the closing. To improve the ease of adjusting and fitting of the prototype several aspects need to be addressed. Firstly, the closing was hard to adjust due to the friction between the fabric and the wire. To minimize this friction, eyelets can be put into the fabric as shown in figure 48. These eyelets make it so the cord slides over a smooth metal surface rather than the fabric itself. Next, since the cord used in the first prototype was not elastic, it was hard to put on and take off without much adjustment. Therefore, an elastic cord can be used in the new version of the closing. Lastly, the way the cord was laced caused the cord to also rub against itself. Changing this lacing pattern should further minimize friction.

Figure 48: The eyelets used in the second Trill prototype

The interface of the second trill prototype can then be combined with the module of the microcontroller to allow the user to move without obstruction. The finished prototype can be seen in figure 49, 50 and 51. It should again be noted that the Trill board and the connection to the microcontroller are missing. This is again due to prototyping purposes.

Figure 49: Second Trill prototype (1)

Figure 50: Second Trill prototype (2)

Figure 51: Second Trill prototype (3)

17.2 Points of Improvement

The second prototype was a great improvement over the first, as it was an opportunity to address earlier shortcomings found in the first prototype. However, with this iteration, new shortcomings have been discovered through short testing sessions and careful examination of the end product. These imperfections are mentioned below to take them into account during the next iteration.

1. **silicone leaking:** With a different fabric used and attention paid to creating a strong mould that is flush with the fabric, the issue of silicone leakage persisted. Therefore a different mould needs to be used, or even a different, more viscous type of silicone.

2. **Fragility:** Due to to the overall design of the prototype(wiring, electrode placement, connector placement, silicone), it turned out quite fragile. this was also partly due to the silicone flowing through the fabric thus leaving less silicone to protect the electrodes.

3. **Sliding Interface:** The silicone that was used did not provide a smooth surface for users to slide their fingers over. To combat this, something has to be done about the silicone to make it smoother and easier to interact with.

4. **Wiring:** As stated earlier, the wiring contributed to the design being somewhat fragile. This was mostly because the wires from the electrodes were soldered to the flat ribbon cable at a right angle, rather than the ribbon cable being connected directly to the electrodes. This leads to points of weakness in the wiring.

18 Third Trill Prototype

18.1 Process

The third Trill prototype could build upon the steps taken to address earlier mentioned problems. These include fragility, wiring and interface issues. However, a persistent problem was the leakage of silicone through the fabric and underneath the mould. As previous attempts to address this issue have failed, a logical step was to examine the problem from another angle. Therefore, instead of addressing the mould and fabric, a different type of silicone was used that is more viscous and thus, leaks through the fabric less easily. As per the recommendation of the client of this research, for this prototype, Platsil gel 10 was used. This type of silicone is mostly used by special effect make-up artists to make skin-like prosthetics like the one shown in figure 52. It has a quick drying time and cures as a soft, flexible rubber.

Figure 52: A prosthetic made with Platsil Gel 10

The new silicone would expectantly successfully address the silicone leakage problem. Therefore it is necessary to focus on the issue of fragility. The wiring of the electrodes led to points of weakness. To have as few of these weak points, the wires were connected directly to the electrodes, leading to fewer solder points. Next to that, the wires were embroidered into the fabric to some extent. This was mainly to ensure the wires were unable to come loose while being integrated into the fabric neatly. To embroider the wires correctly, individual wires were used instead of a flat ribbon cable. Including these decisions in the design led to the fabric with electrodes and wiring in figure 53.

Figure 53: Piece of fabric with electrodes and embroidered wiring

Incorporating all the electrodes into the design and placing the connector at the underside of the prototype led to the design seen in figure 54

Figure 54: Piece of fabric with electrodes, embroidered wires and connector

Next, in an attempt to further increase the durability of the prototype, it was decided to cover all the electronics and wiring in a layer of silicone. Rather than just the electrodes. This means that the silicone can act as a flexible, shock-absorbing layer, and the electronics are more resistant to damage by outside factors. To facilitate this, a new mould had to be made that covered all the electronics. To do this in a precise and robust way, this mould was laser-cut in a piece of wood 8 mm thick. This mould could then be placed onto the fabric and held down firmly by wood clamps to ensure no silicone was able to leak underneath the mould. The setup of the prototype before the silicone is poured can be seen in figure 55.

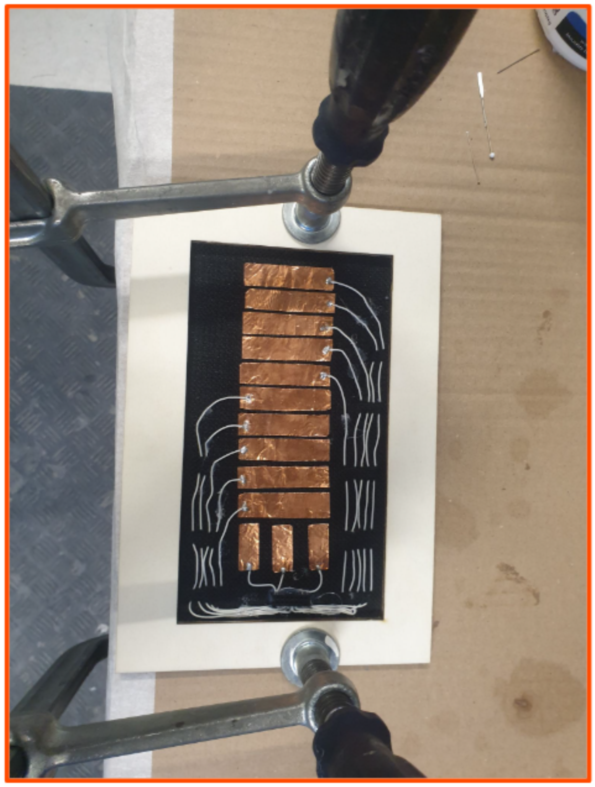

Figure 55: Setup of the third Trill prototype without silicone poured

Before the silicone could be poured, however, a solution needed to be found to make the silicone smoother to interact with. This can be done by examining additives. silicone additives refer to compounds that can be added to various silicone products, such as the ones used in this project. These additives can alter some properties of the silicone like increasing durability, improving heat resistance, and reducing friction. An example of an additive that reduces the friction between the silicone and a user's finger for example is Smooth-on SLIDE. SLIDE is an additive for platinum cure silicone rubber that creates a cured silicone piece with greatly reduced surface tension. This additive was added to the silicone in an attempt to create a smoother interaction surface. With the SLIDE added to the silicone, it could be poured into the setup. This can be seen in figure 56.

Figure 56: Setup of the third Trill prototype with silicone poured

Here it was discovered that the silicone used was indeed substantially more viscous than the silicone used in the first two prototypes. This led to the silicone not flowing over the entire piece of fabric properly and thus having a rough surface. Nonetheless, the setup was left to cure overnight. When the silicone had cured, it was discovered that the SLIDE additive had produced good results concerning the surface tension. This meant that interaction was a lot smoother. Afterwards, eyelets were applied to the fabric and a closing was made in the same way as with the previous prototype. The finished third prototype can be seen in figure 57, 58 and 59.

Figure 57: Third Trill prototype (1)

Figure 58: Third Trill prototype (2)

Figure 59: Third Trill prototype (3)

18.2 Points of Improvement

1. **Surface Roughness:** Due to not testing the silicone properly before pouring it into the mould, it was discovered too late that the viscosity of the Platsil silicone was substantially higher than expected. This resulted in the silicone being too viscous to properly flow over the prototype. While the use of a different silicone did fix the problem of leakage, it introduced a new problem of silicone not forming a smooth surface for interaction.

2. **Wiring:** Embroidering the wires into the fabric itself seemed to have worked. However, it was thought that there were no significant advantages to placing the wires on top of the fabric and pouring silicone over them. Next to that, embroidering the wires caused them to touch the skin, leading to the trill board reading capacitance values of the skin it was placed upon rather than a user's hand.

3. **Microcontroller and Trill placement:** In the third Trill prototype the microcontroller was placed on the upper arm of the user, while the trill was placed on the prototype itself. Unfortunately, both seemed to be causing some obstruction in movement. This means that, in the following prototype, both boards need to be positioned differently or mounted differently.

19 Fourth Trill Prototype

19.1 Process

The fourth Trill prototype could address the final problems that have been identified in previous prototypes. To address the surface roughness of the previously used Platsil, a different type of silicone could be used for the final Trill prototype. As per the recommendation of the client of this research project and of Dr. ing. G. Englebienne, an expert in wearable robotics, Dragon Skin FX-Pro was chosen. Dragon Skin FX-Pro is a soft, stable, high-quality platinum silicone rubber specifically designed for creating silicone makeup devices and skin effects.

Figure 60: The Dragon Skin FX-Pro

As this was platinum silicone, the SLIDE additive could again be used to improve the surface tension of the silicone and make it easier to interact with. However, it was also decided to use another additive called silicone thinner. silicone thinner is an additive that reduces the viscosity of platinum silicones. This could be used to make sure the silicone would flow evenly over the prototype and create a smooth surface. The silicone thinner additive is shown in figure 61.

Figure 61: The silicone thinner

Before testing the dragon skin silicone, the copper film electrodes could again be placed on a cut-out piece of fabric. This time, the wiring was again done with a flat ribbon cable which was not embroidered into the fabric. The final piece of fabric can be seen in figure 62.

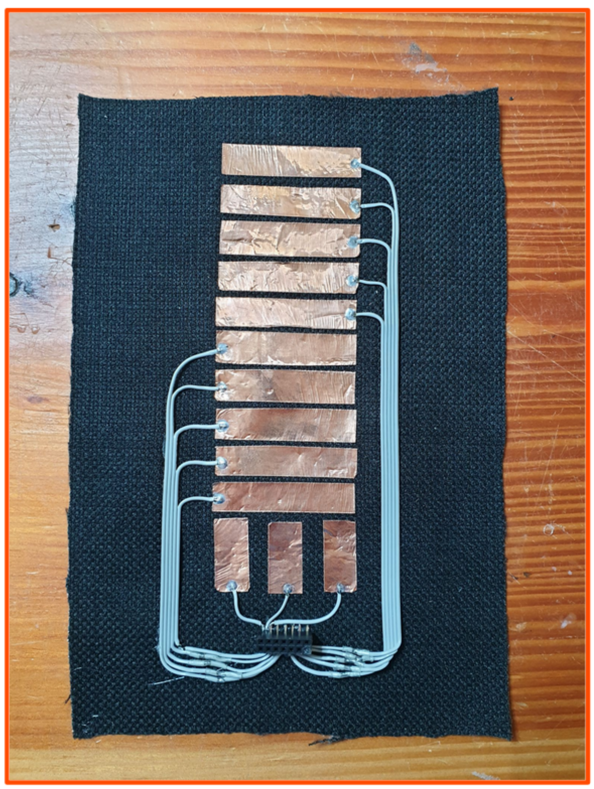

Figure 62: Final piece of fabric of the fourth Trill prototype

To test the attributes of the Dragon skin in relation to the additives that were going to be used, a small test setup was made with differing values of the additives. It should be noted here that 10 percent thinner and one percent SLIDE(mentioned in the figure as Smooth-on) are the maximum values to be added to silicones. The dragon skin silicone was placed in a cardboard mould with different levels of additives as seen in figure 63.

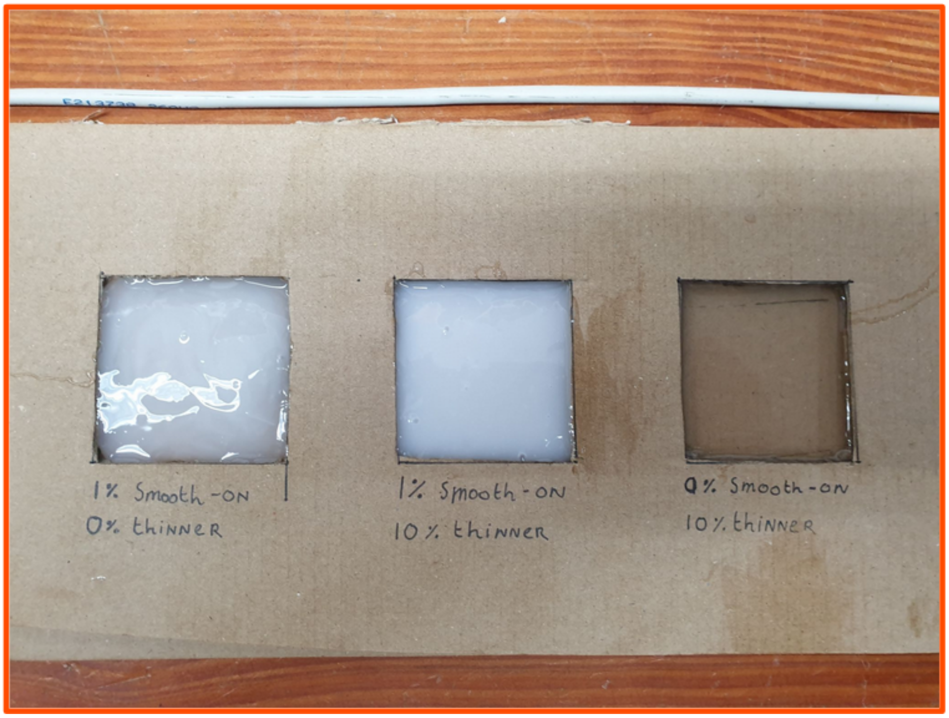

Figure 63: Dragon skin silicone with different levels of additives

Unfortunately, while the test did show the silicone thinner to have a noticeable effect on the viscosity of the dragon skin, there was no difference in surface tension between the batches that used the SLIDE additive and the ones that did not. This seemed like a strange result, as the SLIDE additive did work on the previous prototype. Due to this, it was assumed that the SLIDE only demonstrated its surface-tensioning effect in larger quantities of silicone. Next to that, The SLIDE additive gives the silicone a white colour, which was not perceived in the previous prototype as the Platsil silicone has a white colour itself. This whitening effect is subjectively not a large issue, as users will probably not need to see the electrodes to interact with the prototype.

Next, a setup was made to be able to pour the silicone over the electronics. This setup is shown in figure 64. In this figure, the fourth Trill prototype is positioned on the left. On the right side of the figure, the MuCa prototype is placed. This prototype is described in section 20.

Figure 64: The final setup with the Trill prototype(left) and the MuCa prototype(right) without silicone

Next, a solution of dragon skin silicone with 10 percent thinner and 1 percent SLIDE additives was carefully measured and poured over the silicone, which can be seen in figure 65.

Figure 65: The final setup with the fourth Trill prototype(left) and the MuCa prototype(right)

This setup was left to cure overnight. Afterwards, eyelets were placed in the fabric in the same way as with previous prototypes.

To finalize the trill prototype, several improvements were made to the Trill and microcontroller module and the connection between them. To start, a set of 3D-printed parts was made to house the Trill module and the microcontroller. These housings consist of a box for the microcontroller, a lid for this box, and a small plate to hold the Trill and connector. The 3D model can be seen in figure 66. Figure 67 and 68 it is shown how the electronics fit into these housings.

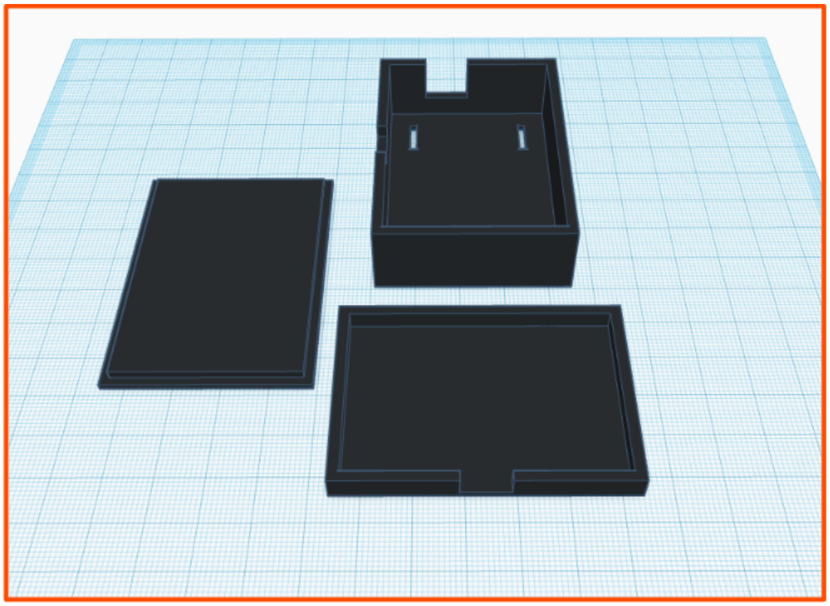

Figure 66: 3D model of Trill and microcontroller housing

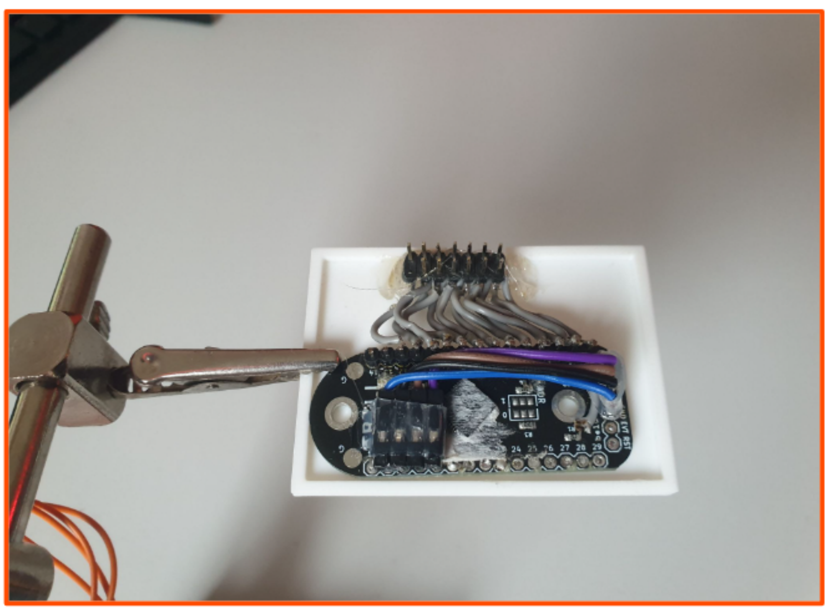

Figure 67: The Trill housing

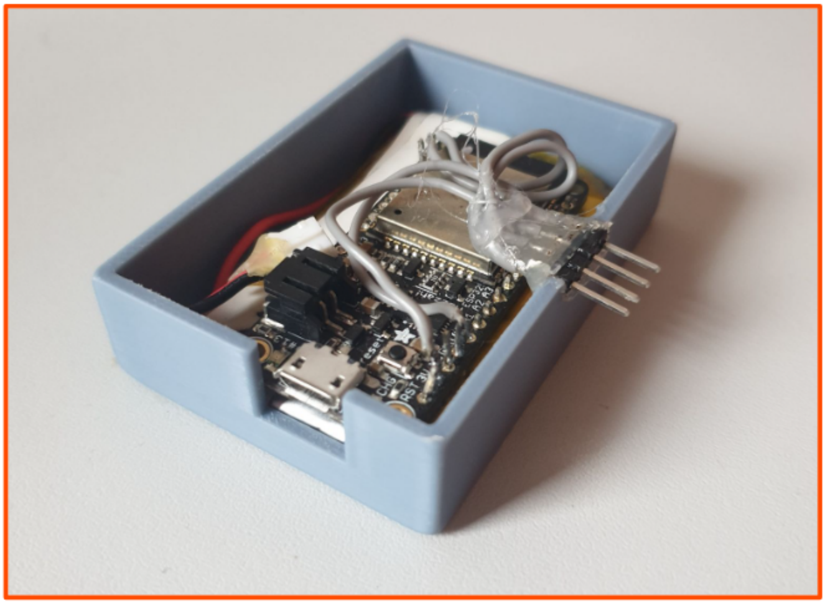

Figure 68: The microcontroller housing

The housing for the microcontroller was made in such a way that it could be positioned in multiple ways. For example, holes are made in the bottom to pass elastic ribbons through. These can be used to place the housing on a user's arm or torso. Next to that, the housing was sanded and corners were rounded so that it could easily slide into a user's pocket. This gives a user multiple possibilities of positioning this housing, making it easier to incorporate in, for example, costumes.

Lastly, a cable was made to connect the microcontroller to the Trill. the cable was made to fit simple header and pin connections placed on the Trill and microcontroller. The cable is shown in figure 69.

Figure 69: A cable for connecting the Trill and microcontroller

After putting all components together, the fourth Trill prototype can be seen in figure 70, 71 and 72.

Figure 70: The fourth Trill prototype(1)

Figure 71: The fourth Trill prototype(2)

Figure 72: The fourth Trill prototype(3)

19.2 Points of Improvement

The fourth prototype is the last version of the Trill wearable voice controller. Despite this, there are still some issues which could be fixed in a new iteration. Unfortunately, due to time constraints, these issues will go unresolved for now. This does not mean that this prototype is unusable, however, as regardless of these issues it is more than suitable for user interaction.

1. **Surface:** For an unknown reason, the additives used for this prototype did not work as expected. While the SLIDE surface tensioner worked well with smoothening the surface of the third prototype, the additive did not function properly with the fourth. This is most likely due to the usage of a different silicone. However, as dragon skin is a platinum core silicone, the additive should have worked the same. The thinner additive did have some effect on the viscosity of the dragonskin, but it was not enough to enable the silicone to flow in such a way that it covered the prototype smoothly. This resulted in an uneven and bumpy surface.

2. **Cable connection:** The connection between the microcontroller and the Trill board is formed by a cable with connections made out of header connections. This results in the cable being able to come loose easily and disconnect with, for example, impulsive movements.

20 First MuCa Prototype

20.1 Process

As seen in chapter VII, the fabrication process of a MuCa prototype can, in many ways, be similar to that of a Trill prototype. Therefore a starting point can be to select a piece of fabric to place electrodes on. These electrodes can then be embedded in silicone and wired up to the actual MuCa board. Much like the Trill, this piece of fabric should be comfortable, flexible and porous to some extent. The electrodes differ greatly from those of the Trill, however, as the electrodes used for this prototype are conductive threads placed in a grid-like pattern. The conductive thread used in this prototype is the "shieldex 117/17 x2 hcb tpu" as it is highly conductive and has an additional transparent plastic coating, which protects the thread from accidental shorts. This conductive thread can be seen in figure 73.

Figure 73: The conductive thread

This thread can then be placed into a grid-like pattern to be able to sense interactions via mutual capacitance. The electrodes should be evenly spaced to allow for accurate sensing. To make sure the distance between electrodes is kept uniform, holes can first be measured and drilled in a substrate of styrofoam or cardboard. passing wires through these holes places them in a grid-like pattern. Next to that, the wires can be tightened by glueing them to the substrate, ensuring the threads remain straight. The setup of the electrodes being placed in a grid on a styrofoam substrate can be seen in figure 74.

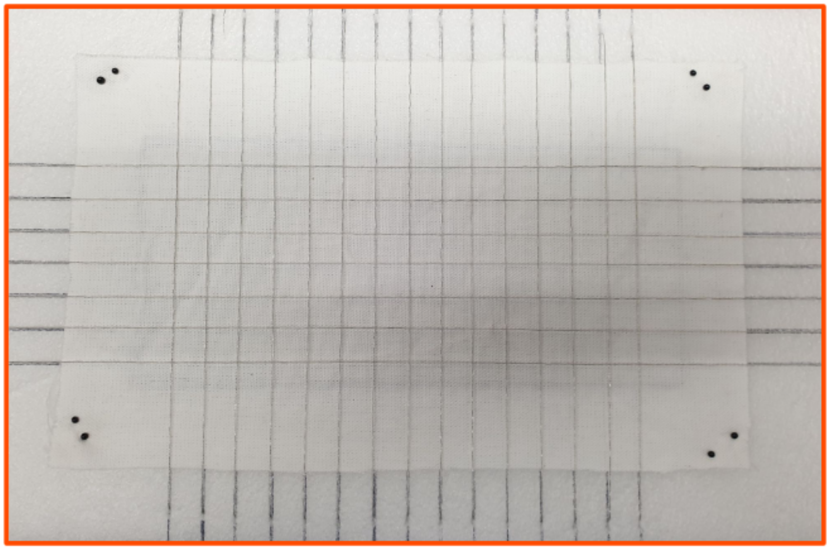

Figure 74: Conductive thread electrodes placed in a grid pattern

The threads are placed in a pattern of 7 by 15 electrodes. These numbers were chosen to accommodate as many electrodes as possible in the given size of the prototype while retaining even spacing between them.

Afterwards, a mould could be placed on top of the fabric and electrodes. This mould was made based on the design sketches in section VI and the dimensions are chosen in such a way that the prototype would fit a user's chest or torso. The mould placed on top of the fabric and electrodes can be seen in figure 75.

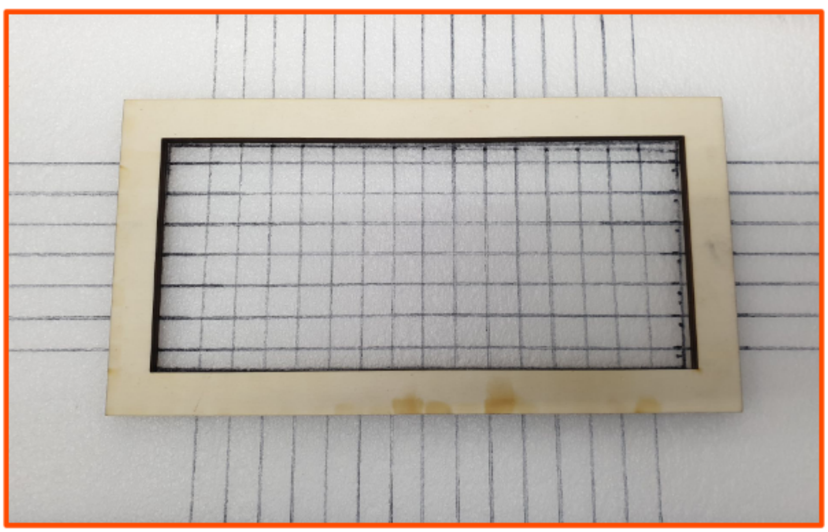

Figure 75: The mould placed on electrodes in a grid pattern

The mould, substrate, fabric and electrodes were then firmly clamped down to ensure no silicone would flow under the mould. The silicone that was used has the same composition as that used in the last Trill prototype. The setup can be seen in figure 64 and 65. After the silicone had fully cured, the electrodes were embedded into the silicone. The piece of fabric with electrodes and cured silicone is shown in figure 76.

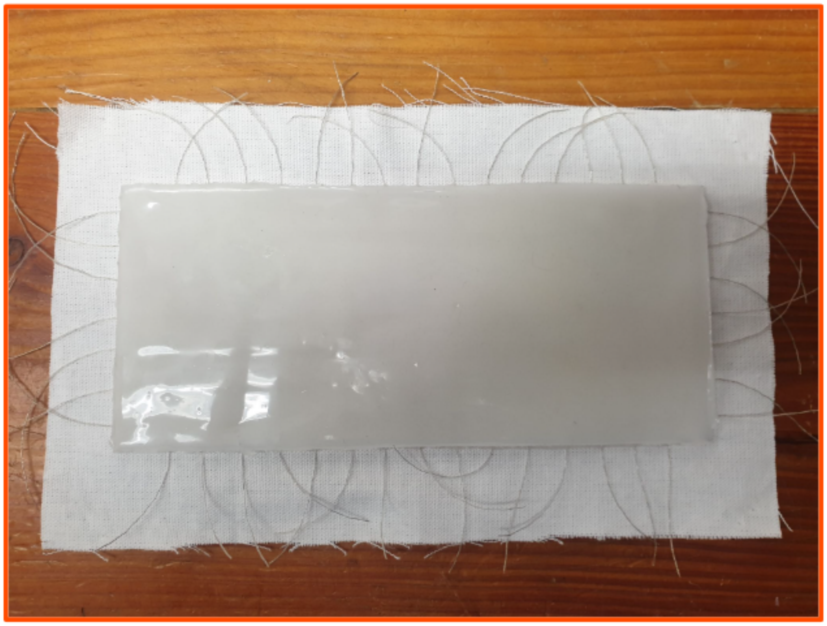

Figure 76: The piece of fabric with conductive thread electrodes and cured silicone

After the sensing electrodes were integrated into the silicone, they needed to be connected to the MuCa board in some way. It was decided to, as with the trill, develop a modular connection to allow for the MuCa board to be connected and disconnected from the silicone module. To successfully do this, the conductive threads needed to be extended and connected to a header connector. This turned out to be a challenge, however. This was because conductive threads burn up when attempting to solder them. To extend these threads and eventually connect them to a header connector, the conductive threads were each thoroughly intertwined with a normal electrical wire and glued so they would be unable to come loose. The silicone module where the conductive threads have been extended can be seen in figure 77.

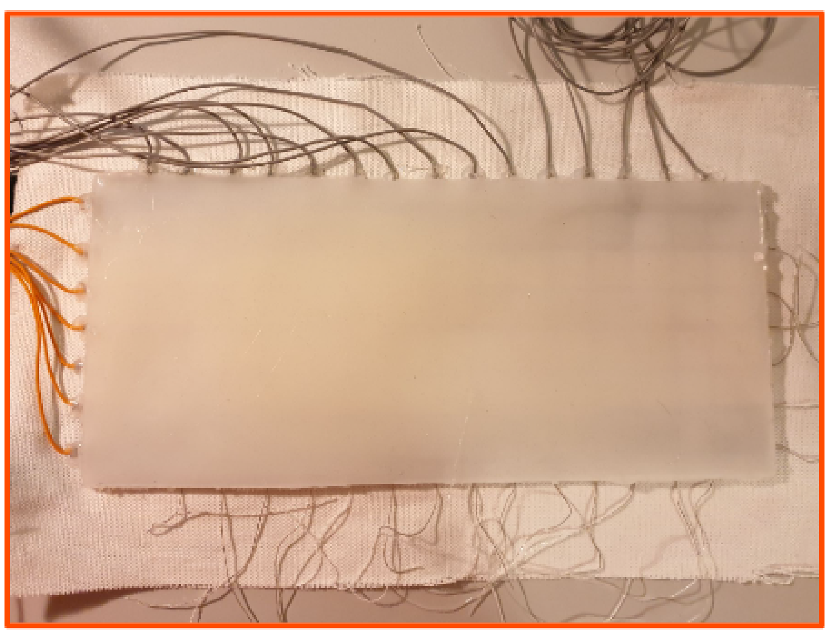

Figure 77: silicone MuCa module with extended conductive threads

To fit the silicone module to the body of a user, nylon straps discussed in section 15.6 were glued to the rear side of the prototype.

Figure 78: silicone MuCa module with nylon straps

20.2 Points of Improvement

1. **Straps:** In this prototype, the nylon straps used to fit the prototype to a user's body were glued to the piece of fabric. And while the straps seem to be secured to the fabric properly, it does not feel like a durable solution. Therefore, these straps can be stitched to the fabric instead of glued. This should be done before the pouring of the silicone.

2. **Smoothness:** As with the fourth trill prototype, the SLIDE additive did not significantly affect surface tension. This is especially problematic in the MuCa prototype as the intention is to let users interact with it in the same way as with a touch screen. Due to the low surface tension, users are unable to properly slide their fingers across the prototype.

3. **Complexity:** It was deemed extremely difficult and time-consuming to solder, wire and connect each electrode to a connector to facilitate a modular connection. This was because the electrodes themselves are fragile, and burn up when exposed to the high heat produced by, for example, a soldering iron. Next to that, the large quantity of wires makes it difficult to implement them into the design in an aesthetically pleasing way.

20.3 Discontinuation

At this point in the production of MuCa prototypes, it was decided to not continue with the iterative prototyping process. This was done for several reasons. Firstly, due to time constraints. Developing a functional prototype not only necessitated hours of prototyping but also required a substantial amount of time to design software capable of facilitating data communication and utilizing that data for audio manipulation. Next to that, during this research project, a new technique for developing prototypes utilizing mutual capacitance sensing was explored at the University of Twente. This technique uses flexible PCBs instead of a grid-like array of electrodes for sensing interactions, rendering it more accurate in identifying touches, more durable, and significantly easier to produce prototypes. Consequently, continuing to use the fabrication method employed previously would result in a prototype inferior to one utilizing a flexible PCB. Lastly, Switching to this new fabrication method would entail a significant setback in prototyping knowledge, ultimately leading to a prolonged overall process. Consequently, the time and cost invested would increase substantially. For these reasons, the continuation of MuCa prototyping in this research is unfortunately not feasible.

Part IX
Evaluation

To determine how the wearable prototype can be used by artists and how it meets requirements, evaluations have to be carried out. In this section, the structure of evaluations is explained. This includes the supporting code that was needed for the wearable interface to produce sound, the setup and how the evaluations were carried out and the results. Lastly, it is examined to what extent the requirements listed in section VII have been met.

21 Structure of Evaluations

21.1 SuperCollider

Connecting and mapping the prototype to each artist's system is a complex and time-consuming process. Therefore, to efficiently evaluate the prototype, a system was made which uses the prototype to give artists an accurate representation of what is possible to achieve. This system was made in SuperCollider, mentioned in section 7.3.1. It takes the OSC data sent by the prototype and uses it to synthesize sounds based on the artist's interaction. In this system, there are two sections of code called patches. These patches can be executed individually, both having different interactions and accompanying audio modulations. Shown in figure 79 is the layout of the Trill prototype. This will clarify what areas of the prototype are used in the different patches.

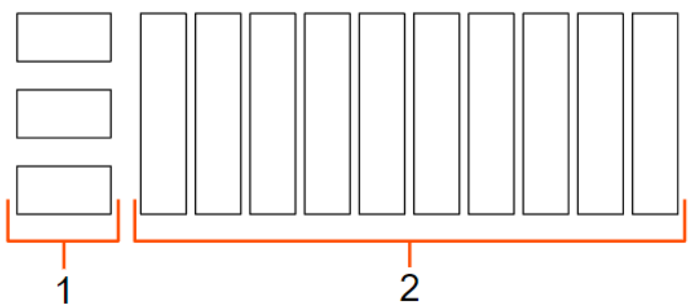

Figure 79: Areas of the Trill prototype

21.1.1 Vocoder Patch

The first patch can best be described as a vocoder. It uses the artist's voice as an audio input and duplicates it in different pitches based on how the user interacts with the prototype. Each electrode in area 2 on the prototype corresponds to a note of the major scale. When artists sing into a microphone connected to the system and press a certain electrode, their voices are played back at a certain pitch. The goal of this patch is to determine how the prototype can be used as a wearable keyboard where each electrode has a distinct function, separate from the other. In this patch, the electrodes in area 1 are not used.

21.1.2 Reverb Patch

The second patch is meant to determine how the prototype can be used when the electrodes have a function relative to the other. In this patch, the electrodes in area 2 can be used as a slider, where the lowest electrode corresponds to the lowest intensity value of a certain effect and the highest electrode to the highest intensity value. Using the electrodes in this way means that area 2 of the prototype can be used as a slider to increase or decrease the intensity of a certain effect. In this patch, this effect is a reverb where the slider controls the room size and decay time. When artists sing into a microphone connected to this system, sliding their finger towards the upper electrode corresponds to a more audible reverb effect. The electrodes in area 1 each correspond to a different level of an effect called distortion. This alters the waveform of incoming audio. It can be noted here that these electrodes originally controlled the selection of different effects, which could then have their intensity controlled by the electrodes in area 2. However, this turned out to be too ambitious to implement within the period of evaluations.

21.2 Setup

The evaluation was held in the artist's home studio. The researcher made sure that there was enough space for the user to move around with the prototype and be able to interact with it how they wanted to. Next to that, the researcher sat next to the participant to observe how the participants interacted with the wearable. The evaluation is set up in a semi-structured way, where a framework of questions is prepared beforehand, as a guideline during the evaluation. Artists are invited and encouraged to explain their answers and expand on them thoroughly. Overall, the evaluations took an average of 30 minutes and led to the artists sharing their honest opinions about the prototype.

21.3 Steps Of Procedure

1. The participant was invited to participate in the evaluation process via email. When a date and time were agreed on, the information brochure and the ethical consent form were presented. The user was asked to read the brochure and sign the consent form. The brochure and consent form are shown in appendix 26.
2. The researcher meets the participant in their studio. Everything that is needed for the evaluation is brought to this location. The purpose of the research and prototype are thoroughly explained to make sure the participant is aware of the context and importance of the evaluations.
3. The participant is given the prototype and asked to put it on in a way that they see fit. It is explained how the wearable itself works and what is expected of the participant.
4. The participant is then presented with the first patch and given some time to explore its attributes. If aspects are unclear they are explained. When the participant is finished using the first patch, the second patch is presented and explained.
5. tem While participants are using the wearable and its patches, their interactions are observed to get an idea of how participants use the wearable. Next to that, they are asked questions about the prototype concerning usability and comfortability.
6. If the participant indicates to be finished, the wearable is taken off again. afterwards, they are asked if there are any general remarks or suggestions for improvements.
7. Lastly, the participant is thanked for their contribution to this research.

21.4 Questions

An overview of the semi-structured interview questions is shown below. The interview is audio recorded to capture the artist's answers in real-time, giving an accurate representation of their reaction to the prototype. These audio recordings are deleted at the end of this research project to safeguard the participant's privacy.

1. Usage - How will the prototype be used? (Both Patches)
    - Do you think controlling the prototype is intuitive? (Both patches)
    - Do you feel like the prototype limits you in any way(physical and functional)?
    - For what applications would you use this prototype?
    - Do you feel like this prototype could add to your performance? In what way?
    - How would you describe the touch interactions of the prototype?

- Do you think the prototype is accurate in perceiving your interactions?
- Can you imagine controlling other things using this prototype? ref

2. Wearability - How comfortable is the prototype during usage?

   - How does the prototype feel? Are the materials comfortable?
   - Do you feel like the prototype fits on the areas of the body it is intended to?
   - What do you think of the aesthetics of the prototype? Is there something you would like to change?
   - would you wear it on stage?
   - would you wear it as an instrument? how do you feel about it?
   - Where else on your body can you imagine having this control of sound?
   - How durable do you think the prototype is, considering the physical movements and demands of your live performances?

3. General questions

   - How would artists describe their overall experience using the voice controller in a live performance setting?
   - Are there any overall suggestions for improvements?

22 Results

To assess to what extent the wearable could be used by artists, The reactions to the questions mentioned above, together with their overall reaction to interacting with the prototype, have been summarized below based on the categorization of the aforementioned questions.

1. **Usage** :

   - **Intuitivity:** The prototype was considered to be very intuitive to use, artists found that the integration of the different patches was in line with their expectations and allowed for a quick and natural workflow. Artists only needed a short explanation of how the different patches operate to be able to comfortably interact with the wearable interface for a longer period of time. Next to that, the sounds produced by the wearable coherently corresponded to user interaction, adding to an intuitive experience.
   - **Pressure sensitivity:** Artists were the electrodes to be pressure-sensitive. Meaning that they were expecting the amount of pressure applied to the electrodes to influence, for example, volume. This was especially apparent in the vocoder patch, where some artists expected that applying more pressure to a certain electrode, would make the corresponding pitch louder. It became clear that adding pressure sensitivity could expand the prototype's functionality. And while the prototype supports pressure sensitivity, it was not included in the patches.
   - **Size:** It was mentioned that artists would prefer the prototype to be smaller. This was mainly because a smaller wearable would be easier to integrate into costumes and would draw less visual attention from the audience. Next to that, because the wearable incorporates the wiring of electrodes into the large silicone patch as well, there is an area of silicone that does not sense interactions while appearing the same as the area that does. For some artists, this was confusing at first. However, after interacting with the prototype, it turned out to not be a persistent problem.
   - **Electrode Presence:** Adding to the confusion about electrode placement is the fact that the silicone used in this prototype is not see-through. Not seeing or feeling where the electrodes were placed led to artists having difficulty replicating actions or specific voice manipulations. It was suggested to add tactile feedback to the prototype, allowing artists to feel where the electrodes are without needing to see them. This together with a see-through silicone would greatly increase accuracy.
   - **Limited Movement:** Users also mentioned their movement to be somewhat limited when using the prototype. This was mainly apparent with the vocoder patch, however, as it requires the user to constantly touch the prototype to make sound. Positioning the prototype on the upper arm while using this patch caused both arms of the user to be occupied, thus limiting their movement. In the reverb patch, this was less of an issue. This patch does not require continuous interaction with the prototype to produce sound.
   - **Functionality:** Artists were particularly enthusiastic about the prototype's versatility, noting that the prototype offers a wide range of functionality. This became especially apparent when users were presented with the patches, as they offered multiple ways of using the wearable. Moreover, artists pointed out features of the prototype that could be used for other purposes than was currently done in the patches. The versatility of the prototype showcased the adaptability of the wearable but also emphasized its potential to inspire artists to experiment.
   - **Accuracy:** A point that stood out during evaluations was the accuracy of the prototype. While the wearable was accurate enough to provide users with an enjoyable experience, it was difficult for artists to replicate a certain action or find a specific electrode. However, users found that the unpredictability in electrode identification and the challenge of replicating specific actions added an element of spontaneity to their artistic expressions, which can be beneficial in experimental voice performance.

2. **Wearability** :

   - **Comfort:** Artists found the wearable to generally be very comfortable. The materials were said to be soft and did not cause discomfort when in contact with skin. The wearable was even noted to have a "Skin-like" feel. However, while the closing of the prototype around a user's arm was easy to use and adjust, it could have thicker wires. This was because the wires that were used were said to be too thin and could therefore cause discomfort when wearing the prototype for extended periods of time.
   - **Positioning:** The prototype was initially placed on the participant's forearm. Although this was said to be a good position for the wearable to be in, users also experimented with placing the prototype on different areas of the body. For example, the upper arms and legs. This offered new possibilities for interaction and experimentation with patches. However, the forearm and upper arm were considered to be a more comfortable position for the wearable as it would be easier to reach and interact with during a performance.
   - **Durability:** The wearable interface itself was considered to be very durable, as participants noted that it felt like the wearable could be bent, stretched and pulled without deforming or breaking. However, the wiring of the interface to the microcontroller and battery was considered to be fragile and somewhat in the way of a user's movements. This was also underlined by the wiring connection breaking during one of the evaluations.
   - **Placement Opportunities:** Next to the areas of the body this prototype was intended for, participants were opportunistic in identifying areas where they could imagine having that same control over their voice. Some noting the face could be an engaging area to interact with, envisioning an interplay between their voice and facial movements. While others were more interested in the shoulder and neck area. Users also mentioned that thinking about possible placements of the prototype also brought up the question of what touching a specific area means to an audience, and how it can enhance the connection artists have with their audience.
   - **Aesthetics:** The aesthetics of the prototype can be an important area of improvement, as participants mentioned that the prototype appeared "flashy" and "quite noticeable" when worn, suggesting the need for a potential shift towards a more discreet design. Considering the challenging perception of electrodes, incorporating a see-through silicone material might offer a solution. Since it not only aligns with a sleeker aesthetic but also facilitates a more user-friendly appearance.

3. **General :**

   - **Suggestions and Experience :** Overall, the prototype was considered to be versatile, intuitive, comfortable and fun to use. Artists were generally opportunistic about the potential the wearable could have in their performances or as a new way to manipulate their voices. However, there are areas in which the prototype can improve. Such as durability, aesthetics, accuracy and size.

23 Met Requirements

Index	Functional Requirement	Implemented
1.	The wearable must be able to control parameters and connect to the system via OSC.	Yes
2.	The wearable must be able to send data via a stable and extremely low-latency wireless connection. Which is picked up by a receiver plugged into the system	Yes
3.	The wearable must be able to accurately sense interactions from users using capacitive sensing.	Yes
4.	The wearable must be modular, meaning artists can place the interface on multiple areas of their bodies and combine multiple interfaces in a system	Partially
5.	The wearable must allow for a wide range of motions, meaning the interface should be flexible while still being able to accurately sense interactions	Yes
6.	The wearable should have an interaction surface that facilitates smooth touches and sliding motions so artists can easily interact with the controller	Yes
7.	The wearable should allow for multiple touches at once.	Yes
8.	The wearable should provide haptic feedback to the users with every interaction.	No
9.	The wearable should directly work on each system it has been plugged into, meaning no additional configuration is necessary	No
10.	The wearable should have a battery life that lasts at least one performance	Yes

Table 3: Implemented functional Requirements

Index	Non-Functional Requirement	Implemented
1.	The wearable must have a user-friendly interface, using comfortable materials.	Yes
2.	The wearable must have a durable build	Partially
3.	The wearable should be accessible to a wide range of artists with different body types	Yes

Table 4: Implemented non-functional Requirements

Part X
Discussion and Conclusion

24 Discussion

The results from the evaluations indicate that the wearable interface prototype has the potential to enhance artists' performances. However, there are several limiting factors which potentially affected the outcome of this research. For example, the evaluations were carried out with a small number of participants. This was due to time constraints and the targeted user group being small, as experimental technology is relatively uncommon in vocal performances. This made it especially difficult to find users that fit the target group. While this small sample size was enough for a detailed evaluation process, the evaluation sessions will need to be carried out with a larger number of participants in the future. A larger sample size will not only lead to an increase in the quantity and accuracy of the results but also ensure that the prototype's usability and effectiveness cater to a more representative user base. Thus facilitating a more reliable foundation for refining and optimizing the design based on real-world user feedback.

Other limitations can also be seen in the wearable itself. While users found the prototype to be innovative and fun to use, the evaluations presented several shortcomings of the wearable as well. There were several factors which impacted the accuracy of the wearable, making it hard for artists to replicate actions and locate specific electrodes. This could be improved upon by using a different silicone and implementing haptic feedback to give users more control over which actions they want to perform. Next to that, the wearability of the prototype can be improved. Specifically regarding the need for more comfortable, durable, and aesthetically pleasing materials. This feedback prompts a focus on less fragile wired connections and the use of materials that cause less discomfort over longer periods.

Another limitation of this research is in the aspect of modularity. The prototype was made modular in that a single module could be placed on multiple areas of the body. This was achieved to a certain degree, but artists noted the prototype to be significantly more usable and comfortable on the lower and upper arms than the upper legs. To further extend the modularity of the wearable, research can be done on different module shapes, different body areas for which a wearable can be made, and different types of interaction corresponding to a certain area of the body. By addressing these modularity challenges, future iterations of the wearable could achieve greater versatility and user satisfaction.

Next to that, it should be noted that the specific SuperCollider system used for testing the prototype did not enable artists to fully explore the potential of the wearable. Throughout evaluation sessions, participants encountered limitations in functionality due to the constraints imposed by the patches. These instances highlighted that, while the hardware theoretically supported certain functions, they were not implemented in the software. As a result, the complete capability of the wearable has yet to be evaluated. Enhancing the functionality of these patches would significantly enhance the versatility of the wearable, enabling artists to fully assess its potential.

Lastly, wearable technology is an innovative and rapidly evolving field. Given its dynamic nature, researchers must closely monitor the latest advancements in, for example, fabrication methods to avoid inadvertently incorporating outdated technologies into their work. This has been proven difficult in this thesis, as the fabrication process for a wearable that uses a MuCa board has seen significant improvements over a short period. This had a significant role in the discontinuation of MuCa prototyping, as easier-to-build and more accurate technologies had become available. Researchers doing innovative research in wearable technology should therefore make sure they remain adaptable to emerging trends and methodologies.

25 Conclusion

This thesis set out to find an innovative solution to give artists more control over manipulating their voice while overcoming limitations typically associated with existing control interfaces. Extensive background research in materials, technologies, and artist requirements was necessary to develop a prototype capable of effectively addressing the question: 'How can a wearable control interface be designed for use in voice performance?' Through this exploration, it was determined that a wearable control interface utilizing Trill technology holds promise for integrating sensor skins into voice performance. This approach offers opportunities for innovative design, versatile interactions, and a wide range of functionalities. Furthermore, the practical application of such a prototype was thoroughly investigated through interviews and collaboration with artists, ensuring that the prototype effectively serves its intended purpose. The examination of these areas demonstrates a user-centred design process for creating wearable interfaces. While there are improvements to be made, this research can be seen as a glimpse into the potential wearable technology has to become a much larger area of research in the musical domain, where wearable technology can not only enhance artists' performances but allow them to reach a level of vocal performances not seen before.

Part XI
Future work

During research on this subject, the scope of this thesis expanded significantly, leading to numerous potential areas for further examination. Future research has the potential to delve deeper into these areas, thereby expanding the influence this research has within the musical domain. Below are several key points that, upon further examination, could enhance the comprehensiveness of this research.

1. **Further Prototyping:** While the fourth trill prototype marked the final iteration of this research project, there are still opportunities for further improvement. Future research could focus on examining the limitations of the latest prototype and subsequently designing a version that addresses these shortcomings. Iteratively refining the wearable's design could contribute significantly to its overall usability and effectiveness in real-world scenarios.

2. **Advanced Evaluations:** Improvements can also be made in the evaluation process of prototypes. Since current evaluations possibly did not allow artists to explore the wearable to its full potential. Future work could enhance this process by conducting evaluations with a larger number of participants and designing software that supports the wearable to a higher standard. Thus allowing researchers to discover results that have possibly not been addressed in this thesis.

3. **Area-specific Modules:** To enhance the modularity of prototypes, researchers can conduct extensive research into designing wearable control interfaces tailored for different areas of an artist's body. This involves focusing on understanding the nuances of interacting with specific body regions and crafting modules accordingly. Furthermore, additional testing and research with potential users are essential to design prototypes capable of enhancing performances in new and innovative ways.

4. **Continuation of MuCa Prototyping:** While this research did not expand on mutual capacitance sensing using a MuCa board, it can still have potential in the musical domain. When researchers focus on state-of-the-art production methods, prototypes using mutual capacitance can have significant implications. Mutual capacitance can offer greater versatility, enhancing musical interfaces and offering musicians new possibilities for expression and interaction.

5. **Connections to Artists' Systems:** In this research, prototypes were developed to communicate data via OSC, enabling interaction with various music production software, virtual instruments, and audio manipulation systems. However, the task of creating a universally usable wearable proved more challenging than anticipated. Experimental artists typically utilize systems that do not integrate devices that communicate over OSC. Therefore, future research could focus on exploring options for designing a more universally adaptable prototype or developing accompanying software to facilitate seamless connectivity with a wide variety of systems.

6. **Other Contexts:** Lastly, this research provided insight into how innovative wearable technology could transform vocal performances, offering new possibilities for artistic expression. Future research could focus on additional domains where wearable technology might offer innovative solutions, such as in medical diagnostics, biotechnological advancements, or theatrical experiences. Expanding research into these areas could explore new angles wearable technology presents to existing problems, and push the boundaries of innovation across multiple domains.

References

[1] Britelite Immersive — The Remote Control of the Future: OSC — briteliteimmersive.com. `http://briteliteimmersive.com/blog/remote-control-future-open-sound-control-osc`. [Accessed 28-11-2023].

[2] The MIDI Controller Jacket Research & Development journey. — machina.cc. `https://www.machina.cc/blogs/news/midi-controller-jacket`. [Accessed 28-11-2023].

[3] Trill Touch Sensors - Bela.io — bela.io. `https://bela.io/products/trill/`. [Accessed 16-11-2023].

[4] Soundable Fashion by designer Ylenia Gortana — Berlin Fashion Week — fashionweek.berlin. `https://fashionweek.berlin/en/blog/single-news/soundable-fashion-by-designer-ylenia-gortana.html`, 2019. [Accessed 28-10-2023].

[5] Wave — genkiinstruments.com. `https://genkiinstruments.com/products/wave`, 2023. [Accessed 28-10-2023].

[6] Puput Dani Prasetyo Adi, Volvo Sihombing, Victor Marudut Mulia Siregar, Gomal Juni Yanris, Fricles Ariwisanto Sianturi, Windania Purba, Saut Parsaoran Tamba, Julianto Simatupang, Rahman Arifuddin, Subairi, and Dwi Arman Prasetya. A performance evaluation of zigbee mesh communication on the internet of things (iot). In *2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT)*, pages 7–13, 2021.

[7] Admin. Elastomers: Definition, examples, properties, types, applications, Aug 2022.

[8] Aloÿs Augustin, Jiazi Yi, Thomas Clausen, and William Townsley. A study of lora: Long range amp; low power networks for the internet of things. *Sensors*, 16(9):1466, Sep 2016.

[9] Jennifer Case, Michelle Yuen, Mohammed Mohammed, and Rebecca Kramer. Sensor skins: An overview. *Stretchable Bioelectronics for Medical Devices and Systems*, page 173–191, Apr 2016.

[10] Perry R. Cook. Remutualizing the musical instrument: Co-design of synthesis algorithms and controllers. *Journal of New Music Research*, 33(3):315–320, September 2004.

[11] Vani Dasu and Swapna Raghunath. Network technologies and microcontrollers in internet of things (iot)-a review. *i-Manager's Journal on Communication Engineering and Systems*, 10(1):1, 2021.

[12] Stephane de Barros, Eros Vanzella, Laura Pentericci, Adriano Fontana, Andrea Grazian, and Marco Castellano. Galaxies at iz/i ˜ 6: physical properties at the edge of the cosmic reionization. *Proceedings of the International Astronomical Union*, 11(S319):7–9, August 2015.

[13] Shilpa Devalal and A. Karthikeyan. Lora technology - an overview. In *2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, pages 284–290, 2018.

[14] R. K. Dhammi, K. M. Soni, S. Selvam, and Prabhdayal Singh. Realtime wireless data collection, analysis and processing using xbee radios and java. In *2017 2nd International Conference on Telecommunication and Networks (TEL-NET)*, pages 1–6, 2017.

[15] Martha Elliott. *Singing in style: a guide to vocal performance practices.* Yale University Press, 2006.

[16] Robert Faludi. *Building wireless sensor networks: with ZigBee, XBee, arduino, and processing.* " O'Reilly Media, Inc.", 2010.

[17] Michael Gurevich, Bill Verplank, and Scott Wilson. Physical interaction design for music. In *International Conference on Mathematics and Computing*, 2003.

[18] Ezgi Ismar, Senem Kurşun Bahadir, Fatma Kalaoglu, and Vladan Koncar. Futuristic clothes: Electronic textiles and wearable technologies. *Global Challenges*, 4(7), March 2020.

[19] Namsheer K and Chandra Sekhar Rout. Conducting polymers: a comprehensive review on recent advances in synthesis, properties and applications. *RSC Advances*, 11(10):5659–5697, 2021.

[20] Ben Lutkevich. What is a microcontroller and how does it work?, Nov 2019.

[21] Angelika Mader and Wouter Eggink. A design process for creative technology. 09 2014.

[22] Daimei Miura and Ryutaro Asano. Biosensors: Immunosensors. In *Encyclopedia of Sensors and Biosensors*, pages 298–314. Elsevier, 2023.

[23] Ben Murphy. *An Artistic Framework for Adapting Existing Works of Electronic Music to Live Performance*. Music and Entertainment Industry Educators Association, 2022.

[24] Condé Nast. Watch Imogen Heap's full Wired 2012 glove demo and performance — wired.co.uk. `https://www.wired.co.uk/article/imogen-heap`. [Accessed 04-11-2023].

[25] Roberto Pasic, Ivo Kuzmanov, and Kokan Atanasovski. Esp-now communication protocol with esp32. *Journal of Universal Excellence*, 6(1):53–60, 2021.

[26] Peter Roberts, Mason Zadan, and Carmel Majidi. Soft tactile sensing skins for robotics. *Current Robotics Reports*, 2(3):343–354, 2021.

[27] Joseph Rothstein. *MIDI: A comprehensive introduction*, volume 7. AR Editions, Inc., 1995.

[28] Robert Shanks and Ing Kong. *General Purpose Elastomers: Structure, Chemistry, Physics and Performance*, pages 11–46. 03 2013.

[29] Douglas E. Snyder and Erik D. Sapper. See me, feel me, touch me, heal me: A contextual overview of conductive polymer composites as synthetic human skin. *Journal of Composites Science*, 6(5):141, May 2022.

[30] Matteo Stoppa and Alessandro Chiolerio. Wearable electronics and smart textiles: A critical review. *Sensors*, 14(7):11957–11992, 2014.

[31] Seiichi Takamatsu, Takahiro Yamashita, Takahiko Imai, and Toshihiro Itoh. Fabric touch sensors using projected self-capacitive touch technique. *Sensors and Materials*, 25:627–634, 01 2013.

[32] Marc Teyssier, Brice Parilusyan, Anne Roudaut, and Jürgen Steimle. Human-like artificial skin sensor for physical human-robot interaction. In *2021 IEEE International Conference on Robotics and Automation (ICRA)*, pages 3626–3633, 2021.

[33] Dnislam Urazayev, Aida Eduard, Muhammad Ahsan, and Dimitrios Zorbas. Indoor performance evaluation of esp-now. In *2023 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, pages 1–6. IEEE, 2023.

[34] Guest User. MI.MU GLOVES — Science Gallery Dublin — dublin.sciencegallery.com. `https://dublin.sciencegallery.com/sound-check-exhibits/mimu-gloves`. [Accessed 28-10-2023].

[35] Andrea Valle. *Introduction to Supercollider*. Logos Verlag Berlin, Berlin, Germany, June 2016.

[36] Jiangxin Wang, Meng-Fang Lin, Sangbaek Park, and Pooi See Lee. Deformable conductors for human–machine interface. *Materials Today*, 21(5):508–526, June 2018.

[37] Alexa Woloshyn. Imogen heap as musical cyborg: Renegotiations of power, gender, and sound. *Journal on the Art of Record Production*, 4, 2009.

[38] WB Worthen. Acting, singing, dancing, and so forth: Theatre (research) in the university. *Theatre Survey*, 45(2):263–269, 2004.

Part XII

Appendix

26 Information Brochure and Consent Form

Information brochure

Dear reader,

You have been asked to participate in a study concerning the development of a wearable controller in voice performance. This brochure will provide you with the necessary information about the topic and what is asked of you. please read it carefully.

The purpose of the research

Voice performance holds immense importance in the musical domain. It involves the modulation of various vocal aspects like pitch, tone, volume, rhythm, and timbre to create a specific vocal expression or convey a particular message. However, voice performance can still be improved in areas related to vocal control, precision, and real-time modulation of vocal characteristics. This research project seeks to explore these areas and find ways to integrate wearable technology into voice performance. In order to design and evaluate a wearable control interface, collaboration with artists is necessary to develop a wearable interface that is specifically aimed at artists and performers.

What will happen during the session

For this research, several prototypes have been developed. These prototypes are made of textile and silicon and can sense touches made by users. They are wearable interfaces which can be used as a controller within the musical domain. During the session, participants are asked to test these prototypes. Next to that you will be asked to state your opinion on several aspects of the interface. For example, comfort and usability. The goal of this session is twofold. Firstly, the evaluation of prototypes. Meaning assessing what can be improved, what you like about the interface and if you have any notable feedback for the interfaces. And second, studying how you would use the prototypes and how they add to your performance.

Risks of participating.

A potential risk of this study is that, since the prototypes use silicon, some people might have an allergic reaction to the silicon. Users with known allergies should communicate their sensitivities to the evaluators to ensure appropriate precautions are taken.

Procedures for withdrawal from the study

If a participant decides to withdraw from the study, they should communicate their decision to the study coordinator or contact person. Participants may do this verbally, in writing, or through any agreed-upon communication method. If such a withdrawal is received, the participant is allowed to leave immediately. Participants are allowed to withdraw from the study until the moment of anonymization, which will happen a week after the evaluation session takes place.

Personal information

During the session, some personal information of the participant will be collected. This includes name, contact information and some background information regarding the experience the participant has in the field of vocal performance. Next to that, notes will be taken during the session, these will consist mostly of feedback, notable interactions and points of interest. The participant has the right to request access to and rectification or erasure of all personal data at all times.

Data usage

All the information collected will strictly be used for this research project only. Access to all data will be controlled, limiting it to authorized personnel only. The notations of the session may be archived and stored for future use. If this is the case this process will prioritize the preservation of participant confidentiality. Audio recordings and notations will be transcribed and anonymized after the evaluation session. Afterwards, the recordings are deleted and identifiable personal data is removed before publication. When disseminating research findings, responsible practices are vital. The results will be shared in a manner that respects privacy, offering aggregated and anonymized data whenever possible.

Contact details

If there are any questions about the research feel free to contact us at any time.

Researcher: Lucas Delfos
Email: l.delfos@student.utwente.nl

Project Supervisor: Angelika Mader
Email: a.h.mader@utwente.nl

Ethics Committee Computer and Information Science
Email: ethicscommittee-cis@utwente.nl

Consent Form for The Development of a Wearable Control Interface in Voice Performance

	Yes	No
Please tick the appropriate boxes		
Taking part in the study		
1. I have read and understood the study information dated 10-1-2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I have read the risks associated with participating in this study and believe I am not at risk of harm.	☐	☐
Use of the information in the study		
1. I understand that the information I provide will be used for a report on the development of a wearable voice controller.	☐	☐
2. I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
Future use and reuse of the information by others		
1. I give permission for the notes that are taken during the session to be archived in the University of Twente archive for a maximum of 10 years. So it can be used for future research and learning.	☐	☐
2. I agree that my information may be shared with other researchers for future research studies that are similar to this study. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.	☐	☐

Signatures

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Participant name:

Participant Signature:

Date:

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name: **Lucas Delfos**

Researcher Signature: 

Date: **12-12-2023**

Study contact details for further information: [*Name, email address*]

Name: Lucas Delfos
Email: L.delfos@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

27 Artist Interview Transcriptions

27.1 Interview 1

(Speaker 1): apologize for my, sorry. Yes. I apologize for my limited English.

(Speaker 2): So no, it's totally okay. My English isn't, isn't that good either. So we'll, we'll just manage. We will manage, of course. Okay. So I guess let me first start by introducing myself a little bit. So my name is Lucas. I'm turning one years old, study creative technology at the uni over here. So that's the University of Twente. And for my bachelor thesis, I'm designing a wearable controller, which is, which can be used in voice performance. it's designed for artists, so they can control and modify certain parameters or alter their voice in any way. And that's why I kind of want to interview you, of course, because because of your experience in vocal performances, and of course, your experience with with wearables as well. with your glove, I'd say. Yeah, so that's kind of my, who am I and why am I doing this? Would you like me to tell, would you like to tell something about yourself too?

(Speaker 1): Yes, of course. Yeah, first of all, very nice to meet you, because I think it's a very important question and issue about wearable controllers in vocal performance. I'm looking, yeah, I'm looking around, I've been looking around for a long time, also for new collaborative approaches in that way, in that sense, because I started at Stein, Amsterdam studio for electro instrumental music in 2001. So I'm a, I'm a singer, composer, performer, improviser, researcher, educator. So, and I'm a lot in improvised music, but also interdisciplinary multimedia projects, staged vocal performances, etc. I do solo performances, I do collaborative projects. Sometimes I'm even, I was singers in music theater, so where I collaborated with other composers.

(Speaker 2): Okay.

(Speaker 1): And yeah, when I, when I started singing and doing field recording, recording my own voice and starting to compose with those recordings, I wanted to use them on stage as well. And I started to play with all sorts of machines and tapes and synthesizers and samplers. And then I was looking for a way to perform without being tied to knobs and faders where I really could perform. So I knocked at Stein in 2001, and I got there an artist residency. And they had the sensor lab that just is analog to MIDI interface. And I could design my instrument and could choose the sensors I wanted to have to control. And for me, it was clear that I wanted to build those sensors in a body close approach. And as a singer, I'm anyway a lot playing with gestures, if I sing for example. And therefore I aimed to develop sensors connected to this MIDI application that then I could build in a glove. Okay.

(Speaker 1): And this application was, the first application was had to be programmed, the whole mapping had to be programmed with C++.

(Speaker 2): Okay.

(Speaker 1): And I'm not a programmer, but luckily my partner is a software developer. So he, yeah, that was really lucky. So I just could tell him what to do. And then he was programming for me. And then later on, Frank Baldé, he developed a new mapping program called Junction. And that's a graphic surface and not programming code. So I learned that program. And that was great because it allowed me then directly to compose the interaction myself. So I was not dependent on my partner anymore. So I just could just on the flow, just map new stuff. And that allowed me also to just approach even a more sensitive way of interaction with, yeah, with sensors and sound and sound processing. And later on, I then had residencies at the ECST in Zurich and they work with MPSonic. So my aim was to connect gesture with specialized process sound or with the disembodied mediated voices. And I was exploring how can I compose for body and specialized sound. So I did a couple of solo performances for MPSonic and voice. And yeah, and then it's really a different difference for me whether I'm playing solo concerts where I much more designed this interaction design or if I'm in improvisational contexts in bands or groups where I have to be really reactive and interactive. And then of course, the gesture is sometimes secondary because it's first of all, it's about the music and how it sounds and how it comes together. And I also work together with media artists like video scenographers. So we design also like big projects for video and specialized sound and images and so on. And I teach at the University of Bern. It's a fantastic master of composition and creative practice, where students develop their own projects. So it's a very individualized master. And we just help them during two years to go really a huge step further with their own approach as artists, as media artists, as singers, as instrumentalists, as composers. Yes. And beside, I do tours and projects and work on my own stuff. I wrote the book. Maybe you heard this one. Yeah. That was my COVID project. Just write a book, I guess.

(Speaker 2): So you're obviously involved in a very wide range of all sorts of things. All sorts of things, music and voice related.

(Speaker 1): Yes.

(Speaker 2): But because you said you wanted to alter your voice use technology while live, so in real time, right? In performing. But why would you then go towards wearable technology and not towards some sort of sampler, or a MIDI keyboard? Because you could also integrate that into your performance, right?

(Speaker 1): Yes, I have, of course, I have all these controllers, also because my students, they work with those controllers, this innovation and da da da da. But for me, it's... How can I say? I think we perform also with our bodies. So our body is also a communicative tool. So why not to use this communicative tool to make even the performance stronger or to communicate also this whole abstract world of sound and sound processes in a way that it's perceivable also on a direct energetic level. And because I think we... Our body is also an interface, it's our first interface to perceive the world, to understand the world. And then to re-embody this technology or re-embody the computer, to have this human computer interaction. This embodied human computer interaction is also based on the thinking that I think the machine is not just an object. The machine is something that we interact with and has its own agencies and it has its own also the softwares and the machines that have their own agencies. It's not just it. It's something we interact with. And I'm very interested in embodying the machines in the way that we also perceive the machines not just as an it or that we do not perceive the loudspeakers just as an it. So that we just have this more equal thing of human and machine.

(Speaker 2): Okay. And do you feel like wearable technology kind of explores that field a little bit more than a regular MIDI controller would do?

(Speaker 1): Yes. Yeah, it depends. I mean, that's a huge range of perception. If you have just a normal MIDI controller, like the Novation controllers, like this tap controller or faders on knobs. And it's a very, how can I say it's also a male approach in a way, because we know these controllers, we have been knowing these controllers for for a lot of time. So we understand controllers, but we don't understand if there's somebody sitting at the controller if he's playing music or if he's writing emails, because you can press a button and you can, everything can happen. And if with, for example, with a glove, I just make a statement also, I make a statement of how to I interact with the machine. And if you talk about wearables, of course, we also have to consider the wearable itself as a perception tool. If I have a glove, it may reference like a requisite on, yeah, you see the cables, you see something like a cyber glove, it creates kind of expectations, or how does that make sound, it might be very, I don't know what technological and so on. But you can also think of wearables like costumes and play with them, make statements for identities or non identities in a very wide range. If you think of stage music, of staged music with technology, and but to embody them could be even go to a theatrical level of meaning, or just an embodied meaning with making some performance statements with the variables. So you have to think about how it looks like, what are the expectations of the variables, or if I have a ball in my hand, or if I yeah, and then connected together, connected to to the gestures, it creates variations of meanings. Yeah. And I define meanings with the with the variable and the gesture. So if I if I have a glove, and I design a gesture connected to specific sound process, I also compose a kind of organology. So it's not like with a violin, but it's another organ of organology. So we have all freedom to just connect any gesture to any sound process or to any sound. Yeah. And that defines for me also organologies. So we are, of course, it's a lot of work. And sometimes we have crashes, and so on. But it gives a tremendous freedom to you to design your own mapped composed world.

(Speaker 2): it's very nice statement. Yeah, okay. And in in using wearable technology, you feel like the wearable allows you to to further into to your voice, or to to sounds in general. But do you feel like wearable technology allows you to achieve your artistic goals? In that sense?

(Speaker 1): Yeah, yes. In in a way, in, of course, there are always limitations that are that come together with the technology itself. If I have sensors, for example, each sensor has its own agency. If it's just benders or distance measuring, or if I have the gyroscope, I have to map those possibilities that are given with the sensors. If I would work with a camera, it would have other limitations in the sense that I would have to be always in the same position so that the camera can detect my movements within a range or if I have a tracking system with sensors on my body. I haven't worked with that yet. I must stay probably also they would just create their own limits and their own possibilities.

(Speaker 2): Okay, so it depends on the kind of wearable or technology you're using.

(Speaker 1): Yes. But you were asking if I could can achieve my artistic goals?

(Speaker 2):Yes.

(Speaker 1): So yeah, basically, I'm a singer and I have an embodied voice. So my body has to is the carrier of my voice. I sound through my body. So it's the embodied voice. And then there is this mediated voice, whether it's processed or pre composed. So there's the mediated or even disembodied voice that has no bodies, but maybe that can evoke imaginary bodies when someone is listening to voices. So if we wouldn't see each other, I would imagine a body from you, you know, so your voice says, Okay, it's a young man. He's middle European. He's this kind of thing. There are persona references, the references about the person. And if I if I work even with abstract voices that are mediated, that may not just be text or, or, or melodies or something recognizable, but have a kind of emotional ambience or abstract, multi layered vocalities. They, they may like trigger imaginary bodies in the perception of the listener.

(Speaker 2):Yeah.

(Speaker 1): You understand what I want to say?

Yeah, yeah. And then we have the this is like, yeah, me the embodied voice and these disembodied voices. And then the third thing is this part in between. So this I embodied voice, and this it the disembodied voice, and this interaction, it's like the IU communication. It's like a second person that defines also the perception. So we have like three main, three main artistic, how would you say? Persons or embodiments?

(Speaker 1): Yeah, or topics that define the artistic result, the embodied voice, the disembodied or mediated voice, and this the way I communicate in this in between, between me and the disembodied voice, with what kind of gestures with what kind of wearables, how it looks like how it sounds like what how are the gesture connected to the disembodied voice? You understand what I want to say?

(Speaker 2): I kind of I kind of do, I think. So maybe would it be okay to say? So there are three topics? Would it be me? Would it be you, me, and what's in between?

(Speaker 1): Not you, but I'm talking about my artistic work. So me, the embodied voice, and then the voices that come out of the speakers, either clips, samples or processed voice. And then the communication in between. So they're like, like, co players that create an artistic meaning. We were that we were talking like the how it looks like the sensor, glove, the wearable, the way the interaction is composed, the way the gesture is connected to sound processes. Yeah, so this is this in between I'm talking about, yeah. And this in between, I define with several co players, again, this is like the subtitle then. So the co players are then how it looks like the gesture connected to sound, then the gesture itself, etc, etc.

(Speaker 2): Yeah, okay, so kind of an explanation of about what the disembodied voice is, or what your voice performances actually are, in essence, right?

(Speaker 1): Yeah, yes.

(Speaker 2): Okay. That's good to know. Okay, then in in that having that that that disembodied voice, then what aspects of your voice would do you usually modulate or alter or modify when when in a performance? So how do you modify your disembodied voice?

(Speaker 1): If you're talking about live processing, then it's like granulation. I like shuffling and fragmentation, together with variations of delay and feedback. Yeah, I like freezings, buffers, loops, variations of reverberation, pitch shifting. Okay. Is there any particular reason for for that? Is it does it make a specific kind of sound? Those effects? Um, I think the I'm always interested in, of course, also new processes. But then it's a question of what which processes make sense for me to use. So for example, I was working also with distortion, but I found it very difficult in the context of what I'm doing. And I immediately got kind of, yeah, I should do probably should do it together with a limiter or so.

(Speaker 2): Yeah. Or what is it called? Compressor?

(Speaker 1): The harmonizer.

(Speaker 2): Oh, okay. Sorry.

(Speaker 1): But then they just create this one sound and you have this. Yeah, sometimes it's nice to use it. So, so I changed the applications from composition performance to performance to composition. So it's not just I have not just a fixed instrument. I really am. There are some I really like because I know, I like maybe one, one aspect I like is if I cannot control it, absolutely. So for example, I like to play with three parameters, where, for example, the X axis of a gyroscope changes the fragmentation, and the horizontal axis changes the delay. And with the ultrasonic distance, I can change the feedback. And then I really have to to search with a gesture. So it's a very, I cannot absolutely because it's always different. If you have three parameters, working in one time or, or also if the if the sensors are not able to control it really precisely, for example, if I take two benders, I freeze part of recorded vocals. And then with two benders, I just change the the part. Yeah. And then yeah, it's just Google is a lot around and I have them to play with what's there.

(Speaker 2): okay. So it's also an aspect of randomization, maybe. So yes, that you don't even know what's what's the sound specifically.

(Speaker 1): Exactly. Or with the new tools from ear come, for example, is CAD art, you can just find this corpus. And then you can gesture really just play vocals on that corpus. And then maybe I find something and I can play with that. But I don't know exactly where it is. So I didn't have to play with the moment. And that's, of course, I'm an improviser. I like to, to play with momentum with momentum and with what appears in that moment. And yeah. Yeah. So I don't compose my performances down to each detail on a time max. So they're more kind of sonic ideas or interactive ideas, and then I'm going to play with it.

(Speaker 2): Yeah, okay. So your performances are more about using your voice than using your wearable to create something with the voice or or maybe find something and then expand on what you found.

(Speaker 1): Yes, that's a very important part. Yeah. But then I also have like pre recorded fields in variations, whether it's on a sampler, whether it's on clips, it or it's on it's cut art, or it's so I have all sorts of pre composed, variable buffers. Yeah, if there are clips or whatever, then and I can trigger them. But I also can I then reprocess them, I filter them again, or then I play with loudness and filtering. So I also play with pre recorded, pre composed vocal ideas.

(Speaker 2): Okay.

(Speaker 1): And then often, it gets a mixture between this live voice for me, then the live processing and the pre composed samples, clips, etc. And it's then the the pre composed sounds, that's what's come that what comes out of the speakers. Yes, right. So those components sounds then also become part of the disembodied voice, together with your own voice. Yes.

(Speaker 2): So you, you, you could say that the blend between those two is also sort of an expanding your performance, right?

(Speaker 1): Yes. Yeah. For example, I have an accelerator. Yeah, very can trigger scenes like I work with Ableton. Yeah. Okay. And then, and then the benders, in the benders, I have volume controller. So with the benders, I control control the volume. So I trigger sounds, but at the same time, I control the volume or or I have a kind of a trigger sound. And then with the with the distance controlling, I control not only filtering, but also compression or other stuff, combinations of things that I find attractive to play with. Yeah, or interesting. Yeah. and maybe what's interesting is that I have variations in presets. Yeah. So for the mapping, it's very important that you that the sensors are not always active. So that's why the mapping and the composition with variables, etc. is very, very important for me, because then I can stop and start the the sensors. Yeah, so if you if I can show you here, for example, my job.

(Speaker 2): Oh, very cool.

(Speaker 1): Yeah, for example, here I have a couple, if I wear it, I have a couple of knobs, buttons. And with with those buttons, it's always this one, I just changed the preset to have kind of 15 presets up, down, up, down, up, down. And here, I use mostly this button to unfreeze the ultrasonic sensor. And this I use mostly to unfreeze the vendors. And then I have also knobs here on the fingertips buttons. So and with those, I can also bypass or, you know, to bypass plugins or max MSP patches, etc. And then so it's a combination. So then I may trigger a sound and work with that sound. And then I change preset. And then I I just play with the live voice together with with the pre composed ideas. And so it's, it's a mixture about for the solo performances. Yeah, that it's I compose in a way. So I know, because it's so much, there are so many layers, technological layers. It's like a preparation. Okay, in this piece, I'm going to play with this and this and this and this and that. Yeah. And then there's the next piece, okay, here, I'm going to play with this and this and this and this and this.

(Speaker 2): Yeah. Okay. Yeah. There's a really nice overview of what what a glove can do. I think, yeah, it's very nice to see, because that's kind of, I've not really worked that much with actual wearable controllers. So thank you for showing. That kind of brings me on to another question. Why use only a glove? Or do you see advantages in using a controller that it's not that's not only a glove? Because that's kind of my my, my research project.

(Speaker 1): Ah, I can't show you another one. Wait.

(Speaker 2): Yeah, sure.

(Speaker 1): So the other controller is a ball. I hold in my hand. Okay. Okay. Yeah. So sometimes I only use this one, especially in improvisational context. So I just can lay it. So I'm a singer, I take it. Yeah. So I like to change also between being a vocalist, a purely vocalist, and then starting to work with electronic. Or then of course, I have the MIDI pedals. The, yes, the Macmillan. Yeah, probably you know it, it's a standardized American product. It's very, it's only 500 gram, very light. And you can program just control links or MIDI nodes. And there's also an advanced mapping program that where you could do extremely sophisticated programming. Yeah, but yes, I do it with junction. Okay. So may I ask you, are you developing now wearables? What are you doing?

(Speaker 2): I'm Yeah, that kind of because I'm I'm, I have a research project. So what I'm actually doing is doing research about what's already out there. And yeah, sorry, let me rephrase my my, my goal is to design a wearable voice controller that can be used in voice performance. Yes, which is kind of broad. Yeah, I'd say. And but there are some specifications to that goal. So yeah, he wants to have a controller that interacts more with the human body, so to say. So for example, this, this could be an interface or this could be an interface or this. Right? Cool. So yeah, that's, that's kind of what I thought as well. So what I'm doing is doing research on what's already out there and how I can, how what's needed to create some such a thing. And, yeah, and what artists could possibly do with it, for example.

(Speaker 1): So I just saw, saw on today on Instagram that there's a kind of three days, is it called? At EE Instrument Inventors, they just sent it. Have to check EEE workshop inventors. Ah, miss, show the way. Or maybe I still have it here on the, you are in, in there, you know?

(Speaker 2): Yes. Don't you, do you mean the pressure cooker or?

(Speaker 1): Yes, exactly. Yeah, that's, yeah, that's, I wouldn't say it's a workshop, but I think, I think it's, it's an opportunity for artists to, to engage with some prototypes that students have built here. I, at least that's what he said to me. So maybe that's the relevant part for me. Okay.

(Speaker 2): So yeah, it's the goal that artists get to see my prototype as well during those meetings.

(Speaker 1): Yes. Because I, in the future, I have a couple of projects, also audio visual projects. And of course, I would be very interested to even develop new variables that create other, other approaches, other possibilities, because time is not there anymore. Yeah. So, and I also with costume designers and so, yeah, I would, would be very interested in those connections between what you see and what you hear and yeah. Yeah, yeah, that's, yeah, that's also an aspect of wearable controllers. I'm, I'm researching developing.

(Speaker 2):Okay.

(Speaker 2): Yeah, so actually more on that. I have some, some preliminary designs I made. So ideation sketches. And I wanted to ask you if you would maybe if we could if you would maybe reflect on them a little bit. Yeah. So you just say or your your comments or your thoughts.

(Speaker 1): You present it now and then I should reflect on that.

(Speaker 2): Yeah, it's just some very simple drawings.

(Speaker 1): the thing is, I do not have a professional zoom and it will stop in two minutes 40. And that's three o'clock and at three o'clock I have another zoom meeting. So we would have another 10 minutes or so but then we have to change. Or could you start a zoom meeting now? Have you done this?

(Speaker 2): No, but I guess it's possible, right?

(Speaker 1): Because if we close the test, then I have to wait for five minutes until I'm allowed the next to start the next zoom meeting, because they want me to buy the abonnement and I don't have it.

(Speaker 2): Okay.

(Speaker 1): Or we go back to but on Teams, I don't see you. But you do see me, right?

(Speaker 2): No, I see you. Yes. Yeah. Yes.

(Speaker 1): Yeah, we can do that. I think. Because it's only for the last 10 minutes.

(Speaker 1): Yes, surely do that. So we change so we don't get interrupted. Yeah, show me your drawings. And I'm happy to. Yeah, yes, of course. Okay, let's do that. So we finish here and I will come back to Teams.

(Speaker 2): Yes, very good. Okay, see you there. (Speaker 2): Can you see see my screen?

(Speaker 1): Yes

(Speaker 2): So these are really simple, I guess designs, so really. Preliminary. But these are kind of. Ideations on which I want to build further. So they are based on few on a few few boards on a few technological boards. So these. These can be touch interfaces. For example, the ones you see here. The ones you see here as well. So like a touch screen basically, but then on somebody's body. These two. And these can be can then be be sliders or. Or touch interfaces. These can also be buttons. And this can then be touch screen. For example, again.

(Speaker 1): Cool.

(Speaker 2): Yeah, I'd like to think so, but. Yeah, kind of what I want to know is maybe your your thoughts. So do you see do you see some some? Some future in these.

(Speaker 1): Yes, for sure. I mean, this first one could also be like measuring the breathing if you would have a kind of. Oh, a stretch control.

(Speaker 2): Yeah.

(Speaker 1): OK, of course, it would then just allow to use this movement of. Using the inhalation muscles to to expand the destroy the stretch material and then and then you have to calibrate. I mean, everybody has a different body. And then to touch here, it's also, I mean, if you have a touch control. So what does it mean if if you know, if you see me, I touch the body. You know, if you see me, I touch here, I touch myself here or touch here. Yeah, I make this. So you get also kind of theatrical or meaning making gestures in a sense. Yeah. Or if if I if I touch myself here, where do I touch my body, you know? That could also be funny. It could make like this, no. Or press the nose. No. Yeah. So to or if you would imagine to have here. Hmm. But the touch control, I think the problem is here that you have another assistant. So it means you have to watch. You do not have a haptic feedback on the controller if there is if it's a. It's a touch control. So you don't know whether you've you've touched it or yes. Yeah, that's where you have to watch. You have to you need a screen. Yeah.

(Speaker 2): It's funny you say that because I had an interview before with —–, I don't know if you if you know her, but she's also quite. She does also does all sorts of things with textiles and voice performance. And she is at exactly that. So it should have some sort of feedback. So you know where it's if you have touched it or no. Yes. And I plan I do plan on integrating that. So with, for example, on the back, a kind of a vibration motor or something. Mm hmm. Something like that. That's but yeah, that's definitely something I can take with me.

(Speaker 1): Yes. Vibration motor and probably it's not possible. You know, if you have a fader on a mixing desk, you can touch it and hold it.

(Speaker 2): Yeah. So. Hmm.

(Speaker 1): I mean, on material. Unless you you. Yeah, if it's a touch screen, you cannot do it. Yeah, no. Yeah.

(Speaker 2): Sorry, what do you mean?

(Speaker 1): You know, if you have a touch screen, doesn't have a surface. So it's not possible to to have kind of object that moves on the surface. Like a little button or a little something or a little other textile with another surface that you know where you are. For example, if I want to use the controller here and I want to make the volume higher with something very simple.

(Speaker 2): Yeah. Yeah.

(Speaker 1):And if if on the surface, but probably it's not possible. If the surface would allow to have another textile to show where the movable something that shows where the the fader is. Yeah. Or like you said, you just have a motor that if it's higher up, it gives you a higher vibration or something.

(Speaker 1): Yeah. So it's not possible.

(Speaker 2): Vibration or something. Yeah. Yeah. Or because, of course, this is this is a controller designed for real time use, so you can hear what it's doing. And yeah, I get your point that you can maybe get a little bit lost in parameters. Is that maybe what you what you're referring to?

(Speaker 1): Yes, it depends on how complex you are going to play. If you just have two or three controllers or two or three interactive Modi that you are going to play with, then it's possible. But as soon as you have, like I said before, you want to trigger something and on the same time you want to play with the reverb and you have no visual feedback. Yeah. But I think. Yeah, I think it's good to try with a vibration motor. OK. And then I mean, you create an instrument and then people learn to play with the instrument. Yeah. OK. So it's definitely completely different than playing with the sensor cloth. Yeah. And buttons that you can. So if you have buttons, they must have a resistance, for example. That's always helpful. You know, these little buttons here, if I press them, there's a kind of mechanical resistance. It's like a click. Yeah. So this if. So I think buttons are always very helpful to turn on of things. So if you have, for example, in in the variables, you have the touch screen that maybe you can connect it with some buttons.

(Speaker 2): Yeah. Yeah. Um. Let me quickly see, because this is, for example, a design which has sort of, yeah, in my mind, it's copper conductive, small kind of. Capacitive touch sensors, so very small squares on your room. And when you tap it. You have it's basically a button, but then without the mechanical click.

(Speaker 1): Ah, but the mechanical click is nice.

(Speaker 2): Yeah. Yeah, that's that's right. But apart, a very great part of my my wearable design is also that it should be stretchable and modular to a body. I'm sorry that I didn't make that clear clear earlier.

(Speaker 1): I understand. Yes, of course. Yeah. Cool. Wow. Great. Yeah. Or with LEDs, if you have, for example, LEDs, the color system, then you quickly see where you are. Yeah. Yeah, I have that also here. The first sense of love I had with C++. I mean, here I have a where is it here? I have a screen that it's in. It's a little screen and it shows me the preset, the one, two, three, four, five, six, seven, eight, nine. And then in earlier application, I had just the hexa, what's that hexa nominal. So with four LEDs from one to 15. Yeah. So and then if it's one, two and then three is the first two LEDs, then four. And so, yeah, it was not with numbers, but with hexa system, hexa number system. Yeah. OK. OK, so. But with LEDs, you can have on the arm where it's easy to see. It's a question if it's here or if you would extend to the forearm like a watch. So it shows some information. Maybe to to to summarise a little bit.

(Speaker 2):So you you you would say you do need. Feedback in what kind of in what sense?

(Speaker 1): Yes, whatever sense you get, the more you get, you the less you need the screen in front of you so that you are independent as a performer. And you do not have to have a screen in front of you where you see where you are with your mappings and your playings and stuff. Yeah. OK. Yeah. Well, thank you. And I guess, yes, I have to go.

(Speaker 2): One more thing. So these are like multiple designs, but I'm planning on making one or two designs which can be modular on on your body. So maybe the face would be a little bit hard, but the one can fit on the on the legs as well as on the waist as on the chest. So it's modular. Do you see, do you see any problems with with that? Or do you have any comments on that? Or do you just say from or do you not know that it's also a possibility, of course?

(Speaker 1): Yes, I mean, the way it is drawn here, the first two things. That's why I thought about breathing, because it's the breathing area in picture number one. Yeah. Would you would you think to know this would be a touch controller here? That's what you think. You have to have the touch controller here. And it's different for men and women because women have breasts. And it also gives the meaning if you point on your breast.

(Speaker 2): So, so, yeah, yeah.

(Speaker 1): so probably. Yes, I can I make a can I make a screenshot and reflect a little bit more deeply on that and give you a more detailed feedback? Of course, if you want, that would be amazing. Yeah, yeah, because it's now I really should go and or we can have another talk again.

(Speaker 2): Only if you have the time.

(Speaker 1): Yes. And then it's yeah. Do you have do you have other things you wanted to discuss, like propositions for your variables or your approaches?

(Speaker 2): No, I think we've we've discussed a lot of things about what what I wanted this the goal of this interview was mainly to get a view of what artists and performance are in my field or in the field. Yes. And I think it's so great that you do it because it's what we need in the future. Thank you. So really great.

(Speaker 1): So just let me think a little bit about more about this in depth and give you some feedback, maybe by email. If I think then we still can have a talk. I'm quite busy at the moment. Yeah, until December. Yeah, until mid of December.

(Speaker 2): Yeah, just if if you get the time to reflect on them, maybe that would be great. But if if not, then that's no no problem at all.

(Speaker 1): Yes. No, I would like to do it because it's also something that I'm very interested myself. Yeah, the possibilities. So I definitely will think about it.

(Speaker 2): OK, cool. OK, thanks very much.

(Speaker 1): So then, yeah, let's keep looking. I'm curious what you are doing and how it sounds. And probably for your master project, there will be performances. And so hopefully I will see some videos and see some results then finally.

(Speaker 2): Yeah, I guess I'll see you in the in the pressure cooker as well.

(Speaker 1): I'm not sure if I can make it, because in fact, I already have. It's very short terminated. But OK, and it's not on the corner. It's quite far to go there.

(Speaker 2): Yeah, true. Then I'll then I'll just try to keep in touch with all the work I'm doing as well.

(Speaker 1): But yeah, please, please keep me updated.

(Speaker 2): OK, thank you very much for talking with me. And I hope to see you soon.

(Speaker 1): OK, bye bye. See you.

27.2 Interview 2

(Speaker 1): I'll close it. I think it's still working. Yeah. Okay. So then let's start officially, I think. First, let me introduce myself a little bit. So my name is Lucas. I'm 21 years old and I do a bachelor creative technology at the University of Twente. And for my bachelor thesis, I'm designing a wearable voice controller, to be exact. And this interview is, basically, the goal of this interview is to maybe get a little bit of your insight because you're a lot more experienced in this area than I am. So, yeah, that's kind of the goal.

(Speaker 2): Okay. And your work or your interest is coming from your own artistic practice or you consider yourself more as a designer, engineer? What is your position?

(Speaker 1): I think my interest is, because it's my bachelor thesis, I've been given an assignment, basically, from Jonathan. And for me to do research in wearable technology and e-textiles and you name it. So, yeah, that's kind of my interest. So I want to know more about the subject.

(Speaker 2): But do you consider yourself in the future as a performer yourself to perform in your, the things you are making or you're making it for someone?

(Speaker 1): Oh, no, I'm making it for someone, I'd say. Yeah, I'm making it for someone. But maybe, who knows?

(Speaker 2): Okay. Okay. And your concern is then that for this someone that you're making it for, the functionality of it works the best or is it then about, so what is your success in that way?

(Speaker 1): Oh, my success would be to kind of design a new sort of wearable. So you have all these wearables with voice control like gloves and keyboards as well. And my goal is basically to integrate a controller into a performance in a smooth way. So with wearables, so instead of being chained to a desk, an artist can interact with him or herself to, yeah, to more smoothly control and alter his or her voice. I'd say, yeah.

(Speaker 2): Okay. And you're particularly looking at an artistic work or artistic performance.

(Speaker 1): Yeah. Yeah. I'd say so. Yeah.

(Speaker 2): And then do you consider that the performer could say for the sake of artistic work, that it should be very simple or all the ideas you had could be reduced to one button, for example?

(Speaker 1): It feels like you're interviewing me now. Yeah. Yeah. Exactly. No. So your question is, do you feel like it must be as simple as possible for an interface? What do you mean?

(Speaker 2): No. If your evaluation or your aim is for artistic work, which is different from some kind of functional applications, which you could, this is not the right way to say, but like within the artistic practice, it may be the best that there is nothing. You see? There's nothing. Yeah. So the decision at the end, for the piece, it's better to have nothing, for example. Yeah. Or it's better to mute everything. No, this could be a part of a decision in artistic decision, but which is different from if you're making wearables for, I don't know, for medical purposes, for example, then you could evaluate within the functionality of, which is a functionality for the artistic work. So it's the same, but things that you have planned could be totally defeated for the artistic purposes, right?

(Speaker 1): Yeah. Yeah.

(Speaker 2): And then I wonder how you see this, if you yourself is not the person who is performing?

(Speaker 1): Yeah, that's a good question. I think, yeah, of course I'm not the one performing, but I am going to do a lot of user evaluation in the future. So, and I think my design process also iterative. So I design something, I evaluate it, and then I design it again. So it's also kind of the goal to see, will it add, will my device add something to a performer? And I think it will, but yeah, it's also my goal to prove that hypothesis, I think. Yeah, I think, in that way, my research is done, yeah.

(Speaker 2): Okay. Yeah, but I think I should let you start your interview.

(Speaker 1): Yes, please. We can talk about it later, definitely, because I wouldn't mind. But would you first maybe tell me something about yourself and what kind of projects you're working on currently?

(Speaker 2): Okay. So I do work in artistic field. So I would call myself as an artist. But I also work with the others or work for the others sometimes. And I think why Jonathan pointed me out is that part of the work I did with costumes and performances. So I do work with electronics textiles, and with this, I also made my own piece, I also made my own performance, where the performance comes in to perform. I'm not myself is not a performer. So in this case, then the performer person would come in, or I worked with and for other performance pieces. So in this case, that there is someone directing and having this artistic decisions, and I'm more collaborating or supporting these decisions. Yeah. So and so I did it in both ways. But in terms of costumes and performance, it's much more the later case, or much often that case that I'm not in that sense, so creating or deciding entire artistic decisions, but supporting these ideas or suggesting something that could be enhanced or included in the things that the choreographer or performer wants to do.

(Speaker 1): Okay. So is it fair for me to say then that you're more of maybe more of a designer than a performer?

(Speaker 2): I'm definitely not a performer. And I think in these cases, I think, yeah, I do act more as a designer or engineer in that sense. Okay. Okay. Because I, of course, I scanned through some of your projects with you have a line and I see sometimes your you appear in them. So maybe I thought you were kind of a performer as well. But they don't wear it. Yeah, sometimes with the marching band, for example, and the hoodie, you know, the I think it was so but maybe that's not that's maybe that's not performing but more testing. Yeah, or that was more the emergency case. Yeah, we needed someone to be standing there. Yeah. And in that case, hoodie one was really a special because I usually don't want to go onto the stage. But that was the case that we needed two persons. So yeah, I was a part of it. Okay. Yeah. So you're you're not actually perform not really a performer, but you are part of your own projects, of course. Exactly. And sometimes we as KobaKant, we also directed the piece. So we had a particular idea of a performance project and we asked the performer to join to do certain things. But yeah, this we didn't do very often.

(Speaker 1): Okay. Okay. That's good to know. Um, yeah, well, then I guess I should start with some some questions. So in your projects, you of course use wearable technology in all sorts of forms. I think you use mostly e-textiles, right? So conductive fabrics and stuff. Maybe very, very simple question. But why wearable technology? Why is that like a point for you, where you see artistic possibilities ?

(Speaker 2): Actually, we started with or I started with more the e-textiles. So it wasn't wearable technology. Yeah. But looking into these materials of the electronics textiles and what you can do kind of this margin point between the textiles and textile techniques and electronics and what you can do digitally and technologically. So this was my starting point to look into it and then see what kind of things you can do with these materials. And some point, we started to make garments with them. So something you can wear. Yeah. But then originally, and also like the field I worked in originally is more in the interactive installations. And within the interactive installations, and if you make a garment or wearables, then there's always a problem of would every audience visiting an exhibition wear it? If so, then sizing, wear and tears and all these things are problems. So and the other thing is, if you wanted to make any more complex interaction than you're touching something or you are pushing a button or so, then it starts to become really complicated if the time you have with a visitor is only five minutes. So this is the moment we started to kind of work with or to look into the possibility of doing it as a performance in the way that you can rehearse with a person who is wearing, you know the size of a person. And also you don't have to think about if this interaction too complicated. So you can explore really what you can do when you have some interface you could wear on your body and then interactive settings you have. So this was actually the starting point to look into not only wearables, but things you can wear and then within the performance context.

(Speaker 1): Okay. So in that performance context, it's like that because you say it's easier to design for a specific performer than for a lot of people.

(Speaker 2): Yeah or you can make an agreement and you can explain the range of interactions you can have and or that's how we started and then the performer can explore this to create an artistic or expressive content. And in the beginning it was much more therefore improvisation. So the performer knew the range of things and then sometimes the rule of the piece, but then the piece itself runs as an improvisational piece. And later on as I started to work with the others and then also creating a content with or for others, then this is not always the case. But that's kind of the reason why I looked into wearable technology and performance together.

(Speaker 1): Okay. Yeah. Okay. I can see why. And in using wearable technology, I guess, in your performances, do you feel like it allows you to achieve your artistic goals?

(Speaker 2): No, I don't think it allows me to achieve my artistic goals or it's hard to say what is an artistic goal, first of all, right? Okay. So you may have something you wanted to explore artistically, for example. And in my case, because I do use a technology and an E-Tech cell as my medium for artistic work, this is kind of all together. So it's not a tool or like I'm not using wearable technology on an E-Tech cell to achieve my goal, but my almost artistic goal, medium itself, is the technology.

(Speaker 1): Okay. Okay. So you would say it's not about, maybe it's not about the goal in the end, but it's more about how you use the technology to get to a certain goal, maybe?

(Speaker 2): Yeah. Or, I mean, just as a kind of thought experiment, if you're a painter, do you use a paint to achieve your artistic goal? Or is the painting and what you're doing a medium itself is, so there is not such a thing as the separation between the goal and the medium you're using or the technique you're using.

(Speaker 1): Okay. Okay. Okay. Yeah, that's a nice thought thing, the painter. So what would you like to explore further than considering the technology or the technological aspects? What do I want to explore?

(Speaker 2): Yeah. Yeah, it's a good question. So I think like there are also different ways I approach in my project. And one of the kind of big chunk of the project that I did is a collaboration with a covacant. So collaboration with Hanna Parna Wilson as a covacant. And within this, I think we were often driven by kind of materiality or a technology. I mean, not technologies per se, but more what this material can do and what we find it interesting. And then together with more our kind of direct comment about how we perceive and use the technology in our everyday life. So these are kind of exploration we have been making and still continuing. And I think one like strong direction I have is to explore more in this direction of kind of materiality, how we deal and work with technology. And then the other part that I started to explore as more solo in my solo practice is to work with performers and seeing or like, yeah, participating in this in their exploration of improvisation, like, or their own body use, and then that connecting with surrounding interactive technologies. So kind of in a way, sometimes it's like extending their their bodily expressions, for example, voice or with a sound, and so on. And there I find it interesting to kind of participate in this negotiations with the technology.

(Speaker 1): Yeah. Yeah, I'd say that is also a little bit of my goal with the wearable. So maybe widen the experience of an artist has, of course, improve on their skill set, because they can already sing and then have the controller add to that. That's I think that's a bit of my my goal as well with the with the wearable control.

(Speaker 2): Mm hmm. Yeah, but the interesting thing is, I mean, as you said, like they can sing. So oftentimes, one doesn't need technology. No, that's true. Yeah. And almost you're unnecessary inserting the technology. And then you have to see where is the point that actually makes sense or where is the point that does more interesting things than, like adding things, because adding something on top, it just doesn't work, actually, oftentimes.

(Speaker 1): Yeah, OK. Yeah, it's also it's also a little bit about what artists what, of course, what what is your performance? What performance does an artist have? Because some performance may already. I think I think it's more about integrating technology, which our artists are already using, I'd say, if that makes sense. So because artists who are already using technology usually use it in the form of like large controllers or keyboards or. Yeah. And I'd say I want to make I want to have more smooth operation of those of those of those controllers by making it wearable, I'd say. Mm hmm. Does does that make sense or?

(Speaker 2): Yeah, yeah, no, but I know what you mean exactly, but there are a lot of dilemmas and difficulties.

(Speaker 1): Yeah, yeah. And that's also what I am exploring with with my research projects, I think. Yeah. And working with the actually the performers who have been doing it for a long time, it's really interesting to learn like what they like skills they have, because I don't know these skills. And sometimes then like suddenly I coming up coming up with something from outside, it's not so easy to be confronted with some things they have been using for a long time or what they're used to or the skills that they already developed by far. Yeah.

(Speaker 2): Yeah. Yeah. And then then I was I was asking this question in the beginning, because it can happen. And I think it's almost good that it happens when they want to turn everything off. Well, it happened once and it was not very nice for a big team that they wanted actually turn everything off. But almost this is this should be also a part of your hypothesis, right? That there should be also a possibility or choice to not to use it. Yeah. Or, or you make wearables and they want to be naked, you know, and then it should be OK also if it makes sense as a piece.

(Speaker 1): Yeah, of course. But it it all it of course, it all starts with does an artist want to use my wearable in user evaluation, because I'm not forcing forcing them to use it. Of course, that's not entirely not my idea. It's more about how I can how can I I say how I think how can I enhance vocal performances with artists who want their vocals enhanced. But yeah, it's always a question what is enhancing.Yeah, definitely.

(Speaker 2): Yeah, I'd say I'd say so too.

(Speaker 1): OK. Then I want to come back to the to the performing side a little bit, if that's OK with you. So how because you make wearable interfaces sometimes with buttons, sliders, conductive fabrics. And how would you say that wearable becomes really part of the performance of an artist musically and theatrically? How does it integrate.

(Speaker 2): Yeah, it's it's also depends on the performance and performers, I think their series of projects I did with like integrated sensors, band sensors. And this one is different from controlling. So it's different from pushing buttons. And this was much more of nuance and the performance really getting like getting into it and rehearsing a lot with it. Yeah, OK. Yeah. And also with this one, I use machine learning. So it was really about, I don't know, learning in what position at what moment you like what happens with the systems. And it was the machine learning, but actually the performers were learning a lot of what happens then. And then them learning it to use it as their own language so that it could be seamless. And then there are also the other things which I had to at the end make clear buttons, which is like a music performance that a person needed a specific control. So very accurate, specific controls. And then usually a performer is using keyboard or foot pedals and so on, which you have a very clear on off and timings. Yeah. And then once you make it in the wearables and in the beginning, I was using a bend sensor and this kind of more analogs input things, then actually she needed much more clear controls. Yeah. Yeah. So yeah. So then it's very different experience and approach that I had to make for people who actually needed the clear, accurate controls. Okay. And what differentiated artists in what they, if they wanted clear and accurate controls or more, yeah, more maybe floaty controls, if that makes sense. So, yeah.

(Speaker 1): Yeah. I mean, I never thought in this way so much, so I'm not sure, but like I think musicians who wanted to use it as an instrument, they needed a very clear control, but they can full control over what's happening.

(Speaker 2): Yeah. And if it's more live like a performance as a choreographic body performances, then for them, it was more about creating kind of digital partners or environment. And it's not so much about this is an instrument that I have full control over, but it was almost like a cue or some inspiration that would also invite them to improvise something. Okay.

(Speaker 1): Okay. So maybe more about if our artist wanted to, yeah, it's more about does an artist want to have full control over everything they're doing? Or does an artist want to create a type of soundscape which can be a little bit more random? So have maybe a randomized experience themselves as well, not only for an audience.

(Speaker 2): Yeah. And then also like, if then also performer wants to intuitively react to what's happening, then don't necessarily want to have always the same things. Yeah. And you almost forget that that was a sound I'm making, but then you are reacting.

(Speaker 1): Yeah. Okay. Yeah. And how do you think e-textiles and conductive fabrics, like kind of help you to get to get that performance out there? So how do e-textiles and wearable technology and conduct fabrics add to this performance, which you have with an artist?

(Speaker 2): I think, so I find e-textiles interesting in these settings, like especially for performers using bodies that you can embed it in everywhere on the garment. So it doesn't have to be a very obvious like joint, but it could be just something you stretch a little bit or you shift the balance and then this balance could be bad and so on. So that's, I find interesting. And then it just being a textile makes it really, you could really embed in the costume. It's not something you wear on top of the actual costume, but it could be a part of costume. And I'm also interested in what it does as an object. So it's not a technology put onto the textile, but it's a costume and textile itself, meaning that it doesn't have to be a hidden layer behind, but it could be also the outer thing, what you see. So it could be a part of a visual element too.

(Speaker 1):Okay. Because it's funny because I'm more, I think designing a wearable which you can, which is not, it's not a goal of integrating it into a costume, but it's more I think maybe more a costume itself. Yeah. So you say that is possible, right? Because I think I'm going to work with a lot of performance, which already have maybe their costume on. Do you think it's possible if that I can add something on top of it, maybe with in designing a wearable controller?

(Speaker 2): Yes. And then also it could be a part, like, I mean, yeah, depends how you collaborate, but it could be also part of the concept too, that it's actually visual and then you also, you as an audience see what's happening. That is a totally different experience than some sensors are behind or hidden underneath, and then you move and something happens, but that is completely different from what you see, or how can I say, you don't see this mechanism behind.

(Speaker 1): Yeah. Okay. Well, I think with my wearable or at least the ideas I have, you can kind of see the mechanism behind because you're, of course, interacting with yourself. That's kind of my goal. So as the audience can more see what you're doing and hear what effects it has.

(Speaker 2): Hmm. But I don't know what you're planning, but if it is, I don't know, a silicon tight glove or early growth, or if it's a, I don't know, silk long sleeve glove, it's a different thing, you see, you know, like you are, you have a different understanding of what it is. Yeah. And then you see an activating line as an audience. You can also see, or this person is wearing just silicon glove, but I have no idea how it's working. Maybe it's a camera behind. I don't know. This is a different experience one can make. And then also, there's a lot of things, costumes and fabrics on its own as an, as a part of a costume, right? As, as a part of performance. And you can take these, what these fabrics are doing or what these costumes are doing in the performance, also a part of your, your interface too.

(Speaker 1): So try to integrate what artists are doing to the wearable into the performance. Is that what you're saying?

(Speaker 2): In a way, yes. Like you could, you could consider what you're, you're, you're creating much more closer to the piece and much more closer to the expression itself. And I think that's, that's, that's, that's, that's, that's closer to the expression itself, rather than there is this expression and then there is this universal black wearables behind or.

(Speaker 1): Okay. Okay. Yeah. That's a good point to keep in mind, I guess, in the design process. Yeah. Okay. No, that kind of brings me on to my next point because what you have the performance, you have the wearable, but what, what should, in your opinion, a wearable actually control? So maybe what effects on the voice or more, do you think it's more the effect or the sounds around the voice?

(Speaker 2): Yeah, this is something, maybe it depends completely with the former, no? What the performer wants to do, I think. Yeah. Yeah. Yeah. It kind of, yeah. Kind of does. And in your, in your performances or in your work, maybe what do you think it, it or maybe it's better to say, how would you use a wearable controller, which I'm designing? You mean, how would I design them.

(Speaker 1): okay. So do you mean, how would I use your design? Or what should it do?

(Speaker 2): Yeah.

(Speaker 1): maybe, maybe it's the right time to ask this question because I have some, some sketches and I wanted to show them to you at like more near the end of the, the interview. Okay. So I guess I should, should save that question for the end, maybe.

(Speaker 2): Yeah. But I think one thing is that I felt very often is that it's, it's good to understand what the performance is or what this performer does. And, and maybe the idea you originally, like a design idea you originally had may not work for this performance or performer or, and, and I find it always really nice to observe what the person naturally do or what this performance naturally do. If, if they touch their hand very often or not, or, you know, where do they actually use an expressive part? And then also like, especially with the music performance, they need to control a lot of things in the side. So sometimes like hand is a very bad place to have because they always have other things to do. Yeah. Yeah. So maybe this kind of observation is a very good thing to do. And then maybe this question of what should it control comes kind of naturally as a proposal.

(Speaker 1): Yeah. So you, maybe your designs or your projects are a lot more from artist to project instead of project to artist. If that makes sense.

Yeah. Or, I mean, it's, it's really, it becomes a parallel, like a together process and not one is developed to the other.

(Speaker 1): Yeah. I guess that's maybe where my research lacks a bit because I try to, to of course keep artists in mind throughout the design process, but I can't, I can't have like this one on one connection with, with an artist through my entire research project. So I'm more designing a general thing instead of something that's catered towards one specific artist.

(Speaker 2): Yeah. Yeah. Do you know, do you know a project called MIMU Grows?

(Speaker 1): Yeah. Yeah.

(Speaker 2): And that, because that one started with a one particular artist, but then they went into this general interface for many different artists. Yeah. Yeah. But they always had a few musicians who work with the team. Yeah.

(Speaker 1): Yeah. Like Imogen herself, right? I think that that's who you mean,

(Speaker 2): Imogen Heap. Yeah. She was the original musician. So the team first adjusted everything for her. Or, I mean, I know it because my colleague was working in that project. Yeah. Oh, okay. I didn't know that. Yeah. Hannah, who is the other side of the Copacanth. So she worked in that early process. Yeah. Yeah. So, so I know a little bit of insight process from her. And so they started off with her particular wish and her particular ways of controlling, for example. But then at some point, they made it more general. So it's not only about her performance, but still, I think a lot of the function stayed from the original, what this one performer wanted to do.

(Speaker 1): Okay. So it's also maybe possible to generalize how one artist is using a wearable towards maybe more people.

(Speaker 2): Mm hmm. But I think it's still, it's probably very valuable to have one, like to at least observe one performer, how they work and what kind of need and wishes they have. Okay.

(Speaker 1): Yeah. that's very good point. Yeah. Mm hmm. Okay. Then I want to continue with maybe a little bit more technological question. So in, in your, in your projects, what, what kind of sensing techniques do you think benefit you the most? So I think like stretch, stretch sensors or stretchable fabrics, capacitive touch points or sliders, even buttons, et cetera. I think what, what's of what sensing techniques do you use most? Or do you find most useful? Yeah.

(Speaker 2): I think, I mean, it really depends, I must say. For, for the body performance, like body movements, related things, I often use stretch or bend sensors. Okay. Or textile bend sensors. And then recently I started to use a lot of capacitive sensors with the drill board. And this for some things, it's very good. And especially if I wanted to do more audience interactions, this is much more easier to kind of offer to many people. Like, so that, so it doesn't have to be, I would say like a threshold for interaction is very low. So I find it very nice way to sensor to use it. And then also it's quite reliable. So that's also another thing. I like it very much. And then recently I was using a lot of contact sensors, actually, and something that simple, like, you know, there's open, open contact, and then open contact. And if you touch both, or if you close both, then you know that it's closed. So this is basically a button, but it doesn't have the shape of the button.

(Speaker 1): Isn't that basically a capacitive sensor or a capacitive touch button? So maybe a drill has an analog read pin. And if you touch it, it sends a signal or isn't that what you mean?

(Speaker 2): Yeah. So you can do that with a drill, but even simpler, if you just have a, like ground and, yeah, ground and the analog in or digital in. And if you drop a metal in between, then you have a contact. So you can create this kind of very simple contact. Basically buttons are like that. And instead of having a button constructions, you can just create like your skin or another metal object that you have in the space as a part of a body and then create this kind of contact switches. And, oh, okay. Yeah. And this is very nice because then the, also the mechanism is very simple. It's very reliable in that sense. And, and it could be very nice or surprising. So for example, have your finger be a ground and then I have several analog reads points on your, yeah, on a wearable. And then once you short it, you get a signal. Yeah. Something. Yeah. Something like this. So you could also create very simple buttons. Yeah. And it may not have a sort of analog rain. It may not have range, but if you wanted to just give a cue. Yeah. Yeah. Is there a lot more reliable than, I think, bend sensors? Yeah, this is tricky. Yeah. Bend sensors are tricky, right? So they, because they deform a little bit. Exactly. So it has hysteresis. So it always goes up and down and then you have to take care of that. And yeah. Yeah. Then you have to calibrate for each artist, which is using it like in the beginning, right? Yeah.

(Speaker 1): Yeah. Okay. So you think buttons and capacitive sensing is very easy, yeah, a very easy way of sensing basically to integrate within your wearables.

(Speaker 2): Yeah. Or it has, you can make it very reliable. So that's a very positive thing. Yeah. But of course, if you wanted to get other types of movements or other types of interactions, then you may not be able to do just with them. Yeah. Yeah. It's maybe I would really start with what interactions you're trying to capture. Yeah. And then, yeah. And then again, like observe what this what's happening there and where is the opportunity to sense in the most simplest way. So therefore that your system becomes robust.

(Speaker 1): Okay. That's, yeah. I'll try to keep that in mind. I see it's already a quarter to five. So time goes really fast, Would you mind maybe having a look at some really, really early sketches I did. And then maybe we can discuss them and see what you think of them. Okay.

(Speaker 2): Yeah.

(Speaker 1): then I'll, I can share my screen real quick. I hope this works. Can you see my screen? No, not yet. I just see your logo or, oh yeah. Yeah. Okay. I do see agenda. Yeah. So these are some, I designed them on two, on the basis of two sort of technologies. So you have Trill, of course. You're familiar with Trill and you have a MuCA board. Do you know that? No. It's based on mutual capacitance. Does that ring a bell, maybe?

(Speaker 2): No. What is a mutual capacitance?

(Speaker 1): So very quick explanation. Mutual capacitance is, I think you can more see it as a touchscreen instead of individual capacitive touch electrodes. Yeah. So it's more like a touch screen or like the surface that you know, the matrix of where it touches. Yeah. Yeah. Exactly. So based on this, I tried to like make some sort of design. So in this one, you can see on the sides of a person, you have the mutual capacitance. So someone can use it as a touchscreen and map it to their own liking. Yeah. This one's the same, but then over the shoulders. This one's more face. I think this one, I had this one based on Trill. So this would be sliders then across your face. This is also more based on Trill. So you have sliders on your arms, and you can also, I thought of these designs to be a little bit modular. So they can be, for example, moved to your upper arms. So you have a slider on your upper arms instead of your underarms, I think. Yeah. And you can also then have it on your legs, for example. So this is more of a slider touch interface on your legs, which can also be based on mutual capacitance, I think, but maybe more, maybe Trill is simpler. Yeah. But I guess I just want your initial thoughts, maybe on them. What do you think?

(Speaker 2): I would say first of all, did you try it? Did I try it? Yeah, did you? No, no, no. These are really early sketches. So maybe for me to get some sort of idea of what I want to do. Okay. So when we work as a KubaCamp for a project, we often do Wizard of Oz, which I think would be very good to try this one on too. So Wizard of Oz is like without any technology, you just pretend. Yeah. And I think you could, I don't know, you could just get a stretchy fabric and cut it in the shape that you sketched, like all these different shapes, and then wear it. And then you could wear it and then in front of the mirror, see what you would do with them. How would you perform? What kind of performance you can do? Yeah. And then I feel like it would already inform you a lot of the questions you have, and including also like, what kind of resolutions you need, for example. Do you need really XY coordinate matrix on the side of the body to be expressive? Mm-hmm. Or are you actually like, you know, and also like that means you're interacting with your hands. So the size of the hand is also incorporated in like how many positions or what kind of interactions you get or what kind of readings you get. It's not a fingertip that is touching, which is different from trackpad or touch screens. So I think all these things, I think there could be a very interesting observations you can make. Yeah. Or the one that you have had on the face, how would I slide? How do they even feel? How do they look like? If it's an upper arm slider or lower arm slider, both make sense or it definitely make one of them more sense. Therefore, do you need a modular design or not? Or even like, is it really the slider that makes more sense when you're performing? And you know, slider means like you are sliding your arm while I'm performing. Yeah. And then all these things, I think it to be very good if you would try out and or, and then you can even do it, not even building a thing, but you could just have a shirt and mark where the, with a, I don't know, washi tape or something, where you thought where the interface is. And then just try it yourself. I think that would be really good now. And then see what artists are doing with it or what they would like to do with it maybe. Yeah. And you can use yourself as a test subject. Yeah, exactly. Because if you feel that this is cool, then likely that the other people feel. And if you feel, okay, this feels very silly, then maybe others do too.

(Speaker 1): Yeah. Okay. Yeah. Because I think, for example, with this one, I really want, because with the sliders on your arms, you have one-dimensional tracking. Yeah. Does that make sense?

(Speaker 2): So you just have like one axis, you mean?

(Speaker 1): Yeah. Yeah. From one, which can be from one to 10 or some sorts. And with such an interface, you can have maybe more, yeah, more of a X and Y axis. So a lot more functionality maybe.

(Speaker 2): But how would you do it? Do you do it here? How do you touch yourself? Like this or like this?

(Speaker 1): Yeah, I guess that's one thing I still have to find out. And then if it's, I don't know, like this or like this, then could you really go X and Y or actually you can only go one direction? You know, all these things I think you can figure out. Yeah. So you would say, try this out. Try to work it on a shirt and see how I use it.

(Speaker 2): Yeah.

(Speaker 1): Okay. Okay. That's a very good start, I think. So thank you.

(Speaker 2): Yeah. I think you have a lot of fun.

(Speaker 1): Yeah, I hope so. Yeah. Do you have any more maybe remarks on maybe designing this or a wearable technology itself? So in terms of this, this as an interface for music playing.

(Speaker 2): Yeah, for voice. For the voice. Yeah. And one thing I also had often encountered is that the musicians need some kind of feedback or ways to monitor the interface. And I mean, they don't necessarily have to see a whole screen monitor, but yes, I think you could consider also maybe after you more decide on like, you know, how this is played, that what kind of feedback do I need to know that, okay, now slider is maximum, or the slider is only half, or it's even got what I did. So did I did my interaction really register as my I changed my slider or not?

(Speaker 1): Don't you think hearing it is enough. So of course, it's meant to be in real time. So if an artist slides something, it should be audible. Don't you think that is enough or maybe from experience?

(Speaker 2): Yeah, I think I mean, if it if you're always manipulating something that is just in the foreground, you can hear. But if you're manipulating something like loop or parameters in the loop, or some parameters in the filter, I'm not sure if you can always feel it. Okay. And if you look at a lot of is musical instruments, they always have interface or some kind of indicators of your manipulation. So I mean, maybe not always necessary, but that's something that I didn't consider before. And it became a bit of an issue.

(Speaker 1): Yeah. Okay. That's good to keep in mind. Okay. Yep. I think, yeah, I think we're also almost out of time. Okay, I'll quickly stop sharing my screen. and I guess I'd really like to thank you for for helping me and getting more insight into this into the subject because you clearly know a lot about it. So, yeah, I think, yeah, I think that that's what I want to say. I want to thank you.

(Speaker 2): Well, you're welcome. And very much looking forward for what you are going to develop now, then. And I will be mostly most likely coming to this event in December. Oh, okay. Yeah. So okay, I hope to see some of your new development from this then.

(Speaker 1): Yeah, I guess we'll see each other then. And then I hope I have some good prototypes that I can show you and maybe we can we can talk about it together. If you if you'd like that to be really nice.

(Speaker 2): Okay. Okay. Well, then that's it, I guess. Thank you again. And then I guess I'll see you in December.

(Speaker 1): Okay, then see you then. See you. Bye bye.

(Speaker 2): Bye.

27.3 Interview 3

(Speaker 1): Yes, okay nice. So hello and welcome and thank you for agreeing to interview. I'll first tell a little bit about myself and what's the purpose basically of this interview. So my name is Lucas, I'm 21 years old and I study creative technology at the University of Twente. For my bachelor thesis I'm designing a wearable controller which is basically a touch interface which artists and voice performance can interact with to broaden their performance abilities. So it's basically stretchable material sensor skins to be used in voice performance and that's kind of what the interview is about today as well because you're obviously a very very experienced performer in the yeah all sorts of things actually very very broad. So I guess my first question is would you like to tell me something about yourself and what you do?

(Speaker 2): Yeah sure, yeah my name is Stephanie Pan. I'm a performer, I'm a singer, composer, maker and designer recently like knitwear designer. So in performance I work a lot like in my compositions and a lot of my performances I work mainly with the voice as like my central instrument and then I have a lot of synths and gear some like toy synths, sound makers, some effects pedals, a lot of keys and sort of trying to build sound from that and then sometimes playing with ensembles so I can then I fill that out but my the foundation of my sound is really built around these sort of hardware instruments and the voice. I have some loopers as well and stuff like that. Yeah and I was just I almost I almost forgot I was just plugging in my new toy. I just got this hologram microcosm which is a hardware glitch machine that I'm planning to use on the voice. so basically something granular or a sampler thingy. Yeah exactly with lots of different modes so you can and you can change really easily between the different modes so yeah it's a I was just just playing with it for the first time and then I was like oh my god.

(Speaker 1): Okay so to kind of have an overview of what you do but I obviously I looked through some of your projects and I was kind of curious to yeah to ask you how would you describe the fields you're you're performing in so yeah.

(Speaker 2): I work in anything across the spectrum from like improv free improv music like purely music to like totally composed to like theatrical sort of music theater to theater occasionally sort of installation. I work in make sound like film soundtracks usually with my partner but yeah a lot of like I like almost generally like in the broadest sense sort of time-based arts let's say. Time-based arts could you explain a little bit what that is? Things that move in time so that can be theater that can be dance but I of course not the dancer but I have worked in physical theater music things that change over time let's say things where time is a component so no paintings no well actually it's not true like knitwear I guess it's not well it's time-based but yeah I'd say like sound wise I operate in the realm between yeah like free improv to some contemporary music out to like my own work being I would describe it as sort of experimental electronic art pop

(Speaker 1): okay, okay

(Speaker 2): and that's where I'm sort of when I do my own thing I'm really interested in sort of the real edges of like pop is maybe not the best word for it but like yeah like art pop I'm not I'm like less interested in really formal settings of like concert halls where everybody knows when to clap and whatever I'm really much more interested in spaces where public is allowed to have a kind of spontaneous reaction and be sort of honest about how they I mean there's some honesty in the in the concert hall as well you know you hear it in the end but there's this like very formalized way of communicating with each other like you have a captive audience they sit quietly and at the end they let you know what they thought of it you know and like I'm much more interested in sort of like pop settings club settings where you really people are free to talk if they want or walk out if they want you know and like I think this is or be really excited and and and you know I think that's a really interesting challenge to work with

(Speaker 1): okay so more live-based performances.

(Speaker 2): yeah yes yes I mean over time I've become more friendly with the studio yeah so I spend quite a bit of time also in the studio so if we're doing film track soundtracks of course it's a lot of work there's a lot of time in the studio yeah but I started let's say really as a live performer and that's still a pretty central part of what I do okay okay so in that sense what's performance wise what are you what are you meaning to achieve what are you aiming to achieve in those performances in every performance you do basically do you have a goal in a way I think the the thing that I find really magical particularly with music let's say is that there's the possibility of communicating in a way that is really beyond normal conversation like things that you can say and feel that sort of beyond language so I think what I'm really looking for is a very like primal connection with the audience I think that's something that's really important to me something where you you know it goes really from like the heart or like my center into the the listener center you know or like because I think you know you're asking a lot from people to to have them as a captive audience you know like why are you here why are you listening so for me that's really important I think this kind of very magical conversation that can happen or this dialogue that can happen between a performer and the public that is very like or you know you can't there's no words for it yeah so I think that's something that's really whatever it is whatever the topic is I think that's something that like means a lot to me

(Speaker 1): okay so you would say the interaction betweenthe audience and you maybe or the audience and your music is a form of communication.

(Speaker 2): yeah and that's what I think it needs to always have you know like I'm asking people to be there for a reason so it's not about me I think it has to be about this thing that happens yes this interaction.

(Speaker 1): okay and doing this interaction or performing this interaction between the the audience and you, what kind of technologies do you usually use with that so what kind of maybe soundboards or mixers.

(Speaker 2): yes so I have yeah I'm usually amplified I don't have that much stuff anymore purely acoustic so I've always got a mixer basically on stage I have my current setup I have a polyphonic synth the Waldorf micro q a micro brute which is a mono synth yeah I think the microcosm is about to become part of that zoom zoom multi-stomp as an effects pedal oh yeah I've got a feedback chain with an octaver a tube screamer I think and there used to be a holy grail but that died piece of shit yeah so now the multi-stomp is part of the feedback chain what else I have like a couple dumb little toy synths so like a couple pocket operators I have a thing called a bit beat bot by about to novello which is like a 8-bit I love chaos generators so I have what is it called a postcard weevil from Tom bugs bug brands and a board chirper also from bug brands so those are just like chaos machines randomizers maybe they're no they're like glitch machines they're really like they don't take input they're just generating glitch okay and then you can play with them they've got a bunch of nods with a couple oscillators and just doing crazy shit okay and I just generate whatever I mean very specific kind of whatever but yeah yeah an auto harp I play with as my as another instrument an omni chord like Suzuki omni chord which is like an 80s version electronic version of an auto harp wine glass I use a lot of wine glass whirly tubes Tibetan bowls like little crappy toys that bounce around and make noise egg shakers like anything like a lot I love I love objects I love ridiculous objects like toys and things just because they're also I find them very expressive as visual objects like really trying to play with this notion of being serious or you know like I love absurdity so things that look a bit silly and kind of make amazing sounds you know occasionally I'm looking at my melodica I have a couple like is this Ukrainian like the toy harp I used to play with sometimes this trapezoidal harp that people have sometimes it's like this and it has a bunch of strings lots of things lots of things yeah like I have a pretty big collection of noisemakers and then so per performance I'll sort of pick out my instrumentarium and put together different things depending on what I'm looking for

(Speaker 1): yeah okay

(Speaker 2): and they're working with like theatrical elements so like the next piece is gonna have a couch and possibly an ice cream maker I don't know

(Speaker 1): okay so would you say you base you you have an idea of a sound you want and then you pick random objects or random sound generators or to fit that idea of or the other way around so just pick and then see a little bit the other way around.

(Speaker 2): yeah let's say like I will hear something I mean I think like I have certain you know I really love feedback noise I am oh I have a drum do I have a drum root no what do I have a circuit rhythm circuit rhythm is not the some kind of yeah some kind of drum synth for making some beats and songs I know that like I like to write big songs so I think I so I usually need something that can play bass lines

(Speaker 1): okay

(Speaker 2): or I'm with the auto harp so I can play some kind of weird chords and my auto harp is detuned so I can't play a normal series of chords okay so I have two notes that have been flattened so that it gives me like I kind of you know I sort of have to play around like what court is that I don't know because it's not it's not what's notated I so I think it kind of it's like kind of both ways let's say like I kind of have a sense of what kind of sounds I might be interested in making and then you expand on that yeah or sometimes I just put things together or I hear something you know like this so the latest piece I was like I had tried to do something with a drone and it wasn't really working so it's kind of scrapped it I was like all right well never mind and then I was making ice cream with my ice cream maker and I was like oh my god this is this is part of the piece now so I you know I sampled the ice cream maker and then that becomes the basis for you know a pretty big session the piece actually so it can kind of go always I think you're sort of like once you're sort of used to it then you're starting to like listen around all the time

(Speaker 1): okay so it's really what you say it's kind of both both ways it's just where you get your inspiration from

(Speaker 2): yeah, because I think it's not so you know I have a lot of instruments but they're all like fairly specific okay so if I'm always like it's it's fun to really sort of look around a little bit or like let things happen and see what happens to sort of get new ideas because otherwise you end up in the same place all the time

(Speaker 1): yeah okay so do you feel like these technologies and devices or effects you use do you feel like they allow you to achieve your your artistic goals.

(Speaker 2): I think they're tools yeah I mean I think they're really important for yes I think yes actually like I think they're because I like what I'm really interested I think in a way is this dialogue between like the analog world and the digital world so I talk about my work a lot about being analog digital so I'm not so interested in I'm not so interested in technology itself in a way like I just don't care that much I want to know how I can use it and how it can help me do what I'm trying to do and and what I really like is to reflect back so I really love digital aesthetics but I I love trying to do things myself and I love the wonkiness of being human so a lot of the things I have have beats but everything's like slightly falling apart or slightly but it just is barely hanging together and I think this is like me trying to play a beat consistently but it's not actually quite working because I'm not a computer and so I like this this notion of instability while still really reflecting on like contemporary aesthetics because I think digital aesthetics are kind of amazing you know we've been able to create all these really weird sounds but what does that mean for us like we're not computers so yeah so in a way like definitely I think all these instruments are really important to my sound like I'm not the same I'm not the same without them like my my compositions really depend on this combination of like my voice which is like classically trained I don't use it exactly that way but it's definitely like grounded in that technique with all of this like weird glitchy stuff that's part of the aesthetic yeah and that's really important to me.

(Speaker 1): yeah yeah I guess that's also the the feel of of music a little bit because music yeah a lot of people say that that music isn't supposed to be perfect that's also why a lot of people prefer the sound of of LPs over mp3 for example because it has that that analog touch yeah you can hear the needle or I mean you can hear mp3s also it really hurts your ears after a while

(Speaker 2): yeah for sure I think that's like it's part of you know like I think it's this thing that music is supposed to be at its heart a way of us communicating with each other right so it's about communicating human experience so when things are like super clean and super polished and everything's perfectly I don't know some people maybe like it but I like hate it it has no heart it has no like expression

(Speaker 1): yeah we're all just making do you know and it yeah so yeah yeah that's also I think I talked about it with —- I think you know her yeah and she said there's all sorts of plugins now that try to create imperfection basically and that's kind of weird because we've been going from imperfection to perfection and then back again

(Speaker 2): yeah oh and ultimately like I was talking about this with someone like it's so crazy like now also you know you get to back to like what technology was it like you go you do these like ridiculous circles to come back to like a Nokia phone or something like a dial-up phone you know or whatever it is like eventually what was it now I'm trying to think there was something that had like gone like was coming full circle but there's all this technology that basically does this you know like for a long time it's like no no we're gonna do this with it and then like ten years later like no it's better like this and it's like but that's how we started but now it's much more complex and like much more complicated you know like instead of just being imperfect yeah you have to have a software that makes things imperfect for you it's like yeah it's crazy

(Speaker 1): yeah it's funny to think about it though okay I gotta get take it back a little bit to my own GP because of course I'm designing a wearable so that's kind of it kind of is the the aspect of technology yeah and of course you've spoken to —- and she has the glove which she uses in her performances so kind of the question to you is do you think such a wearable would benefit your performances

(Speaker 2): so yeah so it was yeah John had told me a little bit about what you were doing and I think what would be interesting like I think with a lot of these interfaces they become a kind of performative act in and of themselves yeah you know like they become this thing which I kind of sometimes have a real problem with because I just like this has nothing this means nothing to me like having to do this to trigger something means nothing to me yeah like that so you have this kind of acts that aren't expressive and become really like and they they really take over the sort of I mean of course it's about learning an instrument you know like becoming handy in something but I think there could be some like interesting things to sort of consider in building something like that because I think there have been a lot of times where it's like has come up if I were you know because if I was if I had a wearable or something there are certain things that would like my hands could be free in a different way you know yeah so like on the one hand yes I think it could be interesting like yeah I had spoken to John because the reason I mentioned the microcosm is because it's something that I'm really kind of interested in sort of diving into because like in the past I have you know I have my effects pedals and I'll basically like turn something on for an entire song right so that's the effect for my song because I'm doing other things so I don't I can't and it's also like the pedals I've had until this point doesn't they don't really give me many other options so the thing that the microcosm allows me to do is that it's got all these different settings and you can move really quickly between them yeah and you can you can sort of turn things on and off which I find pretty fascinating yeah which I'm starting to dive into so that I think the notion of like a wearable where there's like this idea of triggers or these things like or like a gestural things I think could be kind of interesting like I was trying to think about what kind of gestures I would like if I were doing something with a wearable you know like what kind of movements would make sense to me so I think that's a sort of interesting question of like how do you build something that builds on a movement that makes sense to me you know what I mean from an X like you know like if like like a what does it mean to like stroke an arm

(Speaker 1): yeah

(Speaker 2): or like you know touching things that are much more sort of functional gestures as opposed to yeah as opposed to like a glove you know there have been like so many glove wearables that I've like never never wanted to work with just because I don't know they become they become so much their own thing

(Speaker 1): yeah

(Speaker 2): like they just feel very gimmicky to me I think that's the thing that I'm very like that's the thing that I tend to be very resistant to things that become a gimmick like all these people who do this stuff it's like them and the hand yeah you know what I mean like it's it becomes so much about the technology itself but then I don't feel like you're being expressive you know like I think the expression becomes sort of secondary it becomes like a sort of display case for for what you can do with your wearable so I think I think the like it's absolutely the potential is there to like use it as a tool to do really amazing things but then the question is like how how to build that into the thing does that make sense to you like how to build I mean I you know maybe I just also like you could probably also do it with a glove you know I mean if there's like it just depends on approach maybe it's like a personal approach question

(Speaker 1): yeah

(Speaker 2): so because I'm not I don't want to be like like regressive or something you know it's not about like old-fashioned and like you should just play instruments it's definitely not about that but yeah yeah I'm sure just sort of interested in like how yeah like when I perform I use my hands a lot my arms move a lot like yeah they're very expressive so it would be really interesting to see if that kind of thing can be built into a wearable for example yeah that's sort of like it can be taught or something like this to be part of the larger expressive language of a performer you know I mean yeah yeah because I don't know yeah I would love to hear more about like what exactly as a wearable like what what kind of things are you looking at

(Speaker 1): yeah well I have some some preliminary sketches so and I was thinking we could maybe look at them in a minute just just quickly glance over them maybe have your your thoughts would you also say like this gesture is kind of gimmicky

(Speaker 2): yeah well it depends I think I mean I don't know no I said that and maybe I should rephrase it a little bit I'm not sure I because I wonder if it's maybe not a question of approach it's hard to say because the thing is I have seen I've seen a bunch of people use different like mainly like hand interfaces yeah and and I just like it becomes so much about the interface itself that I just look like it feels like I'm watching a demonstration more than watching performance you know and and I have one friend who uses it really in performance and it still becomes like a sort of well yeah I mean I use it also like theatrical act but that can be like and that was probably one of the more convincing times I've seen it like I kind of like it in that set when it's like part of a much larger thing and you really just a building sound in an interesting way.

(Speaker 1): what is your friend called.

(Speaker 2): Tom Mermal Tom Mermal yeah and why are yeah he's a theater director and he's he has a band with his wife on a spiggle who's also like amazing amazing singer there I think they were like stepped out a bit to go to the States because he's American she's Israeli and they're back in Amsterdam and they have a band called control you spell that or control our CEO and TR OLL

(Speaker 1): okay

(Speaker 2): and he performs with the glove he I think from Balde this this glove but I think it's like it there's one he doesn't use it all the time so he uses it for certain numbers and then because it's there because when it's there it's very very present like it has to and I get the sense that it has to be held in a certain position in order to like if this becomes the zero position then it has to stay in this position so then there's this kind of thing of the the hand being present like this so I think that's one of the things that I but I think yeah I think it might just be a question of approach so like Tom you know sort of takes it on and off and uses it when he pleases him and then he puts it away okay yeah so yeah I mean in principle I think everything is possible I think everything can be used and you know and being able to to to use the body in a different way I think is in principle very interesting but I haven't seen so many convincing versions of it let's put that way.

(Speaker 1): okay well then yeah I guess we can quickly take a look at some sketches maybe then you'll get a also a better of what I'm trying to make yeah maybe so yeah I'll share my screen can you see it

(Speaker 2): yes

(Speaker 1): okay yeah so to give a quick overview I designed these sketches based on two boards and the two boards facilitate basically 1D touch and 2D touch where for example this one has more to the touch interface along the the chest this one as well but along along the legs I envision this as then more one-dimensional touch so one dimensional touch is like just is it like on off trigger like what's the difference between one yeah yeah so well what I mean with 2d is basically a touchscreen so your smartphone for example and one D is individual points okay which can also be placed in succession to make a slider for example

(Speaker 2): okay

(Speaker 1): so yeah these sketches are based on those types of technologies I think and coming back to what you said about wearables do you have any comments on these this kind of wearable maybe

(Speaker 2): yeah no I mean I think it's like I would say the one of the first one you showed that one yes yeah oh wait I'm trying to figure out so are the sensors on the back

(Speaker 1): no this so yeah I'm sorry the the on the chest area so here that is all that this is all a sensor so it's basically a touchscreen and on the back is just microcontrollers and yeah so yeah 2d is in where you have like an X plane and a Y yeah you have like a whole surface that you can work with

(Speaker 2): yeah and then then show me the other ones also

(Speaker 1): so yeah so this one is on the legs on the arms lower arms a waist face so then so you have like 2d on most of them except for on the upper I thought of it like because for 2d you need a larger surface area right so these will then probably be 1d because the surface area is a bit smaller and this one as well okay yeah and these ones for example with the larger surface area are yeah are 2d

(Speaker 2): so I guess the hand operates everything

(Speaker 1): yeah it's a touch interface

(Speaker 2): yeah I mean I think that's pretty interesting you like I think you have a lot of options there like you you create a very large playing field for yeah for sensing right like you have almost the whole body so I think in that sense it's pretty interesting just in like in sort of potential of what you can do you know you can make sort of selections also of I think that can be pretty interesting as well sort of like figuring out for an individual which which things work best right

(Speaker 1): yeah what they prefer to use more or whatever I think it's also the idea that it allows for artists to map it exactly how they want yeah so it's maybe it can be seen as a standalone controller but then wearable

(Speaker 2): yeah very abstract so you're developing just like the hardware itself like the skins themselves and then people decide how they want to use them

(Speaker 1): yeah yeah

(Speaker 2): interesting

(Speaker 1): thank you

(Speaker 2): yeah um it's impossible to make a controller which fits all artists the same

(Speaker 1): yeah

(Speaker 2): so well I mean uh um with voice effects or something or with modulations because every artist wants something else so that's also why a controller that is mappable is a lot better because then artists can do whatever they want with it and it becomes a part of their uh performance and do you see it as like does it become a single suit or how do you wear it.

(Speaker 1): um well so the the goal is that the the wearable should be modular so it would should have modular sections which can be placed on the chest for example on the waist or on the legs so for example this one is specific for the chest but I'm planning on making a design which fits the chest the waists and and for example the upper legs so multiple sections of the body

(Speaker 2): okay I mean I would say a little bit with the chest one there's a little bit like just in terms of like fit and logistics it sort of ends in a pretty awkward place for women so that's I think something to sort of look into like you're either there like what probably makes sense is ending up a little bit higher frankly

(Speaker 1): yeah or lower I guess

(Speaker 2): yeah but then you're like groping yourself on stage which like some people can you know what I mean like that you end up just like not using part of the sensor because it's basically coming over your breasts and like you have to want to do that

(Speaker 1): yeah yeah no I mean I mean under under the chest then so like here so it's more I guess uh where is it like this one

(Speaker 2): yeah like I think then you've got this place and you can do with that and then there's the one over the shoulder which is like actually like a nice place to be able to play but you know like once you get past the armpit you're basically like very like on the breasts yeah which is a pretty awkward place I think for a woman to use as a sensor section like it has lots of implications it has many many connotations so it's like how to deal with that

(Speaker 1): yeah yeah so maybe focus a little bit more on the waist and shoulders instead of the chest

(Speaker 2): well I mean I think no no but I really like like here you have a huge yeah surface right this is something that um and it's like feels very natural to touch actually here it's just that where it ends maybe needs to be um looked at or adjusted a little bit that it sort of ends a little bit higher just in terms of design you know what I mean that you're really coming across the top of the chest yeah as a sort of limitation because because like because it's also much more reachable like the thing is you need to have like a reasonable amount of dexterity to even just you know depending on who you are it can be kind of hard to reach directly under the chest like that requires some mobility in the shoulders

(Speaker 1): um yeah like it's also why it's modular so you can place it on multiple sections like that so that middle section is for certain people.

(Speaker 2): yeah um but that's generally not gender specific that's more depends on your build depends on you know shoulder mobility and um with the thighs those are all like but there's like something very specific sort of to gender yeah a little bit like gender politics like who are you developing the work for who are you thinking about with the chest one because I really like I think this one's quite interesting the one that that comes over the top here just because it feels more natural to do this like this is something you can as a gesture I think also has a lot of meaning like it's um we use this space a lot yeah but in your drawing it comes like here

(Speaker 1): yeah

(Speaker 2): yeah you know what I mean so just like in developing that because the sides are like those are also things that can be used but they're a bit more like the center of the waist of course is pretty easy for people to reach but if you're going to go all the way up which is kind of cool it's interesting but it just kind of it it requires different things and you know like yeah I don't know it's interesting but I think it's nice it's cool

(Speaker 1): yeah yeah well thank you um then I guess a last last question based on on these do you see yourself using these and that's not as an implication as you need to use this but if you would use a wearable controller how would you use it.

(Speaker 2): so I imagine like what would probably like um I would probably use it for things like effects and like trying to trigger um different kind of processing on instruments on the voice stuff like that um I wouldn't I probably wouldn't use it to like control um really uh fundamental blocks of a piece for example I mean I think it would be interesting like if you were gonna like start like you could always like a trigger is of course something that's possible and that could be pretty use like could be pretty interesting but for me would probably like I just feel like adds so much sort of unpredictability yeah to to a performance like so much complexity and I think what's interesting is to sort of um have possibilities for for like building sound but also have space for what I imagine would be slightly chaotic like with sensor you know like you can't know that you're gonna do exactly this every single time you know so like how how precise is the sensor so um I guess that would probably be my first thing I saw a p I saw um I'm gonna look up her name give me one second

(Speaker 1): okay sure

(Speaker 2): I post a lot here um shegal she's a she's a programmer and a like a singer-songwriter

(Speaker 1): okay

(Speaker 2): and she has this music performance I don't think it's a fantastic example to be totally frank and it's one of the things that makes me really like generally allergic to these kinds of things um so it's a bit of a negative example but what's what's she called shegal like mark shagal like mark shagal c-h-a-g-a-l-l

(Speaker 1): okay mark shagal

(Speaker 2): yeah but she had this you know she's got these gloves um and like foot like foot pedals that she triggers all these things she controls the lights she controls all this thing so like in principle the technology is pretty impressive but she basically uses it to like trigger karaoke like like she does this and then it moves to the next chord or like so it's all playback basically you know but that's I think that's maybe more in implementation than it is about the tool itself which is why I mentioned this uh sorry she uses the uh the the mimu gloves right or I'm not sure I'm not sure she has this bionic assistant for becoming yourself I'm not sure what she's done um maybe yeah but I'm not like I'm not what I'm not sure what technology she has um

(Speaker 1): I'll look into it yeah

but like in terms of implementation that's exactly what I really don't like to do

(Speaker 1): yeah

(Speaker 2): you know it's I think there are so many other things like francisca bauman I think of course is doing more uh you know she uses more for I think processing no like her glove what she does yeah I think yeah her glove is also more processing her own vocals and just also more chaotic maybe yeah um so yeah I don't I don't know I think it's uh but yeah I think what's nice with what's what you're thinking about is just that it has a lot like um it has a lot of possibilities you know

(Speaker 1): yeah

(Speaker 2): it's pretty customizable like for me I think the face section I would probably not like the head one I would probably not like to use just because it like gets it like gets in my way you know like I don't like I don't not sure if it wraps around the ears which is like a total no no yeah no no it goes in front of the ears what's was my idea yeah yeah um for me it would just be like visually very like it's very central you know becomes part of your face and then yeah so I think my um my initial reaction would probably be not like I wouldn't I would have less of a tendency to want to do that just because it becomes very specific to your whole look

(Speaker 1): yeah

(Speaker 2): whereas the other sensors I think have a bit more um separation you know they're they're more like costume in a way and like what as soon as you put something on your face then it becomes very much part of your yeah whole look yeah I can see that yeah um but that's personal you know maybe someone really likes that yeah they don't have to think about costume you know

(Speaker 1): yeah yeah that's also true um

(Speaker 2): I definitely wouldn't want you to like take it because I really like you know have like I have a little like body armor like a costume piece that is exactly yeah uh it's from Thierry Mullier like very well known a designer from the 80s maybe okay um it's gold leather and it's got like a little mock neck and it comes up and it's a little bit like a body armor so it like stops just like this so it's like strictly non-functional in a way but it has this like that piece in particular I think has like a really yeah it's kind of like body armor it's kind of cool I don't know I think this is really nice and you know arms of course are like and especially if those become like us that that that can be like a single track that you can have a kind of array of sensors that goes the entire length of the arm I think that can be really beautiful just like the idea of like stroking things you know like having movement that's really fluid um but that like really that's something that you can like really sort of code the whole length of the arm I think is nice okay um with a long area maybe yeah I mean also because this has like very like you know when it's just the forearm it has like very sci-fi implications

(Speaker 1): yeah

(Speaker 2): which could be really fun but like this like once you're doing this then you're actually like I just like things that have a sort of inherent expressive potential like and this kind of thing is the thing you do when you're comforting people or you're comforting yourself or you're doing you know like it has a kind of there's something very expressive about the gesture and the possibility of that kind of gesture I think is something that's sort of interesting

(Speaker 1): yeah okay um it's good to hear some insights

(Speaker 2): like the legs and the waist I think are are pretty interesting but they get away from the sort of standard performative gestures let's say or like the express like standard expressive gestures but I don't think that means if they're not possible or something you know what I mean like why not you know I would I'd have to like try it out and see and it depends on how many things you're controlling and um will you be able to like for example could you trigger the same thing with your leg and that like is that a question of patching or it is like

(Speaker 1): yeah I think that's a question of of mapping yeah because that's totally up to the artists

(Speaker 2): I think it's also very very experimental the the whole thing because um something the gloves a glove like controller has been done before yeah but such a thing um hasn't really done been done before in any performance art I think so um there have been textiles and uh wearable yeah wearable technology but not really in a sense that it really controls your voice uh on a on on I guess a high detailed level with the touch interfaces

(Speaker 1): yeah

(Speaker 2): I'd be really curious to see what the resolution is and what kind of control you have

(Speaker 1): me too

(Speaker 2): yeah how much expressivity can you get out of it yeah

(Speaker 1): yeah that's also gonna be I think I'm gonna see that in testing as well so yeah

(Speaker 2): yeah I mean it's interesting like why that hasn't like I guess hand gestures are very like you can kind of you have digits you know so it's sort of useful you can trigger things with a finger but then it becomes such a yeah it becomes its own thing you know

(Speaker 1): yeah

(Speaker 2): I really kind of I'm quite curious to see what would be possible with something like this like what kind of how precise do you need to be

(Speaker 1): yeah well that's exactly what I plan on finding out yeah with all the research and making actual prototypes I guess that's everything uh I have to ask you as well for uh for the interview

(Speaker 2): okay nice

(Speaker 1): yeah it's really nice talking to you and uh and getting your insights of course because you have a lot of more experience in in these in voice performance and uh in various fields so

(Speaker 2): yeah but did I like answer your questions

(Speaker 1): um yeah well I had some questions in mind of course but the interview was also more to get an overview or an idea of what performers actually want or do and yeah yeah to get more of an overview of the the users basically

(Speaker 2): yeah I think there's a lot of gimmicky yeah stuff being developed and and that's one of the reasons I really don't use this stuff but I think when there's a tool that comes that can be quite expressive and and sort of leaves things open or like finds a way to sort of become more functional in a way like in less less about itself I think that's that can be quite interesting but yeah

(Speaker 1): well yeah we're gonna see yeah thank you very much

(Speaker 2): I hope there's something useful there

(Speaker 1): yeah definitely definitely and um yeah maybe I'll see you again in user testing or somewhere else

(Speaker 2): yeah very good good luck with everything

(Speaker 1): yeah thank you and maybe I'll see you

(Speaker 2): yeah yeah sounds good

(Speaker 1): see you

(Speaker 2): okay bye

27.4 Interview 4

(Speaker 1): Okay, then I guess I'll start with a little introduction about myself, if that's okay with you. So my name is Lucas, I'm 21 years old and I study creative technology here at the University of Twente. And for my bachelor thesis, I'll be designing a wearable controller to be used in voice performance. So basically a wearable touch interface, which artists can map in any way they want in order to aid in their voice performances. And this interview is basically about some aspects of wearable technology, maybe voice performance as well, because you're obviously a little more experienced in it than I am. I've looked at some of your projects with e-textiles and stuff.

(Speaker 2): Okay, yeah. So you know that I'm not like a musician. No, no, no. I've just been on a lot of collaborative projects with musicians and that relate to sound through e-textiles.

(Speaker 1): Yeah, so that's really nice to get a conversation about that, I guess. So yeah, would you like to tell me something about yourself and what you do?

(Speaker 2): Yeah, sure. I mean, so at the moment I'm a postdoctoral researcher at Queen Mary University of London. I work at the moment, I work with soft robotics and I'm teaching also around, it's about digital design methods and principles. And I met John when I was in Iceland where I did a postdoc where I was working with the Intelligent Instruments Lab that John is also affiliated a little bit. So that's that context. But my background really is in textile design and fashion design. So before going into research, I worked as a fashion designer. That's where my textile kind of focus comes from. In fashion and textile design, I've always specialized in knitwear design. So that's kind of like my expertise area. But in terms of work that's relating to your research or to your thesis is that I've been working with textiles for musical interfaces, wearable and also not wearable, for designs on the body and off the body, but basically to imagine or to envision textiles as a musical interface and to kind of ask questions around what happens when musical instruments become soft and flexible and or can even be wearable. What changes about the design of that? So that's kind of some questions that I've been addressing through my work.

(Speaker 1): OK, and have you found some answers to those questions?

(Speaker 2): Yeah, I mean, I think that the gestures that are possible changes with the material. So it's not just that I think textiles are kind of the only material that is worth exploring, but I think it's generally interesting to see what changes in human interaction when we change the material. So when we change other conventions about musical instrument design. So you know, because often instruments are like made of wood or metal or something like this. And then what happens when there's another material? How do we then play this instrument? So how do we play textiles? And I've addressed some of these questions by like me working on some projects. So I have been, for example, working, I have been working on a project that's called No Input Textiles. That was something recent that was also in collaboration with the Intelligent Instruments Lab in Iceland with a PhD student called Victor Shepperton. And that was to have a mixing desk, but have a textile interface instead of the mixing desk.

(Speaker 1): So to basically mix sounds, but with textiles.

(Speaker 2): So I made a textile sheet, basically, like a piece of fabric, one that was woven and one that was knitted, and it integrated conductive thread. So thread that can conduct electricity, yeah, you know that. And that we connected to the mixer, to a no input mixer, that's why it's called No Input Textiles. So that means that the mixer kind of creates sounds with its own feedback loop. So instead of having the knobs and the sliders that are made of plastic and that are hard and just kind of allow you to make this gesture. So just to kind of touch the button, touch the knob or press the button. You could take the textiles and kind of stretch it and, you know, twirl it up or twist it or like squeeze it. So that was a recent project where I explored these questions.

(Speaker 1): Okay. In doing that research, do you think such a wearable controller or made out of textile, could it benefit vocal performers? Do you think?

(Speaker 2): Yeah, I mean, I also worked with a vocal performer. I don't know if you've heard of Courtney Reed, maybe John has mentioned her. It does ring a bell, but I'm not sure. I'm sure she would be happy to talk to you as well, because she's a singer, but also a researcher around wearable technology and human computer interaction. So I collaborated with her when she was still doing her PhD at Queen Mary University of London. That's also where I did my PhD and where I'm still working. And she wanted to have a wearable that would capture her muscle movements while singing and that would then translate that muscle movement into something where she could augment her singing voice.

(Speaker 1): Yeah.

(Speaker 2): So I designed a knitted collar that just looked like a turtleneck collar of a jumper or something, but it was just a collar, and had knitted electrodes at the inside and at the positions where the crucial muscle movements happen when someone is singing. And then she designed a circuit board, so she did the rest of the electronics basically. And then she performed with that. So then she put it on and she was singing and these electrodes could measure the muscle movement that would then kind of augment the performance or kind of enhance the performance. So in that sense, it was a wearable kind of, not so much a controller, but yeah, like a co-performative piece. I think the thing with textiles is that it's still kind of difficult to have a very precise control.

(Speaker 1): Yeah. I get that. Yeah.

(Speaker 2): Have you worked with electronic textiles?

(Speaker 1): No, not with electronic textiles yet, but I have worked with or I have tried to create my own wearable controller, first prototype. So maybe a little bit. Yeah.

(Speaker 2): I mean, textiles, I think they can have two roles in when you think about wearable technology. One is that they provide the shell of the electronics. So if you have small electronics, like I just finished a project where, for example, it was about haptic feedback for a virtual reality application. And I designed and made a garment that would house these haptic actuators, so these haptic motors.

(Speaker 1): Yeah. So that are like vibration motors, right?

(Speaker 2): Yeah, exactly. Yeah. They look like little cylinders and I work together with an engineer. And we had the entire circuit and the electronics integrated in the garment, but the electronics themselves were not replaced by textiles. So that's one option. So to use the garment as a shell or as a housing to protect the electronics and to make them wearable. You know?

(Speaker 1): Yeah.

(Speaker 2): And the second is that you replace the electronics or some of the electronics with textiles. So with like smart textiles or electronic textiles. Yeah.

(Speaker 1): OK. So maybe capacitive touch points.

(Speaker 2): Exactly. Yeah, exactly. Or what I've been working with a lot is pressure sensors or stretch sensors, because there's a lot of commercial conductive fabric out there or also thread that you can very easily integrate or make kind of use like a normal fabric or like a conventional fabric.

(Speaker 1): Yeah.

(Speaker 2): But that you can use as a pressure sensor, as a stretch sensor or capacitive touch sensor or a simple switch or something like that. So that's also something I've been working with. So these electrodes, for example, on that collar that I mentioned, that was fabric. That was not an electrode, but it was a piece of conductive fabric that was with a thread then stitched to the microcontroller. So the only rigid piece was the battery in the microcontroller. Something else. And flexible.

(Speaker 1): Yeah. That's the whole point, right? In wearable technology. It should be flexible.

(Speaker 2): Yeah, exactly. So that's the advantage of e-textiles also, that you don't have to use a cable that can be a bit like rigid, but you can use a thread instead that also feels and looks like a thread, like a piece of fabric.

(Speaker 1): Yeah. Yeah, I guess because I'll be making more of a touch interface. So I think that's a little harder to do with just textiles, because you need to like swipe over it.

(Speaker 2): Yeah, but it has been done. I can point you to some work where people have been making music controllers with fabric only.

(Speaker 1): Yeah, definitely. Definitely send me some links or something. Yeah.

I mean, I can email them to you. You can also post them in the chat now.

(Speaker 1): Sure. Yeah.

(Speaker 2): So there's, for example, one work by, it's two French guys who've been working on it, Cedric Onet and Morin Donan. That was like a famous project where they made an e-textile matrix. So they had a very kind of high resolution matrix and you could also like swipe over it.

(Speaker 1): Oh.

(Speaker 2): And just kind of, you know, and there's a lot of projects like that. So there's this idea of a matrix other people within the e-textile world have been doing. And they put it on the table, so in that sense it was not wearable. But other e-textile researchers, for example, also my previous PhD supervisor, Becky Stewart, she has made another sample of a capacitive touch textile matrix where textiles work as a touch interface. And that worked really nicely. I can point you to these projects.

(Speaker 1): Yes, please. Yes, it would be very helpful.

(Speaker 2): Yeah, because also there are instructions on how to recreate those.

(Speaker 1): Even better.

(Speaker 2): That's something you want to do. Because that's also what I, this matrix from the French guys, I also used as a base for my PhD design because I had, I used it as pressure sensors within a garment to capture body movement. That was my PhD research. I had trousers with a matrix of pressure sensors across the legs and they would measure postural movement.

(Speaker 1): So that's mutual capacitance, right? So multiple electrodes woven into the fabric, I think?

(Speaker 2): Yeah, it's, I mean, I used it as pressure sensors. So it's three layers. It's two conductive layers and the resistive layer in between. And you measure the change of resistance in the resistive layer, basically. So that the conductive layers, they act as connectors, basically.

(Speaker 1): Okay. Well, yeah, definitely send that to me.

(Speaker 2): Yeah, yeah. And also, I mean, many of the e-textile providers, like the companies who sell these products in case you want to work with those, for you, it's probably easy to get because a lot of them are in Belgium, in Germany.

(Speaker 1): Yeah. I get that. Definitely send them to me and I can look more into them.

(Speaker 2): Yeah, sure.

(Speaker 1): Well then, I guess going on about materials, do you have any, because I'll be designing a controller myself, basically. So do you have maybe any specific materials which you can recommend for that purpose?

(Speaker 2): I think it depends what exactly you want to do with it. So you want it to be wearable and you want it to be an interface for music or for voice performance, right?

(Speaker 1): Yes.

(Speaker 2): So for voice performance, do you have the interaction in mind, like what do you want to do?

(Speaker 1): Yeah. I'll show you. This is, for example, a prototype I made. It's based on Trill. I guess you've heard of it, right?

(Speaker 2): Yeah.

(Speaker 1): Oh, nice. Okay. And you can wear it like this.

(Speaker 2): Nice.

(Speaker 1): And then it becomes sort of a slider with multiple touch points. So that's one. And I'll be using another technology which is based on mutual capacitance. So that's like electrodes based in a grid array, which is basically a touchscreen. And if you embed those electrodes into silicon or something, it becomes stretchable. So you can basically wear a touchscreen.

(Speaker 2): Oh, nice. Okay.

(Speaker 1): That's the way I'm going in. Yeah. For my project.

(Speaker 2): Nice. Yeah.I mean, if you want to have it on a sleeve, it doesn't, I mean, so the two basic kind of materials that in kind of textiles you can choose between is knitted and woven.

(Speaker 1): Yeah.

(Speaker 2): Knitted is like your hoodie or like my cardigan. So it has more stretch naturally to it. Whereas woven fabrics like denim fabric, you know, like your jeans or shirts or something. That's naturally not stretchy. You can make it stretchy by including a stretchy thread, but by itself a woven fabric is not stretchy. But it can be more robust if you want it to maintain the shape. So that's just, I'm just asking what I asked about your interaction, because that's kind of where you can already make a distinction between, okay, if I make a sleeve, do I want it like a, you know, like a leg warmer or so that I just pull it over, then maybe knitted fabric is better. So do I want it to be a sleeve like for a denim jacket that is kind of more robust than, you know, denim jacket fabric, like denim fabric is also fine. So that's like these two basic distinctions. And for like, if you want to work with capacitive touch, then you want to have very conductive material, not really any resistive. So there's a lot of fabrics I can point you to, like again, woven or knitted fabrics. If you, yeah, I don't know, there's also I think smaller quantities you can order. I will just send you a list of companies or maybe like products that might be relevant for you in particular, because I would then if you want to work with capacitive touch and you have, for example, a not stretchy fabric, there is copper fabric that is very easy to cut. You can even glue it onto something, but it stays flexible. Copper fabric.

(Speaker 1): Yeah. Okay.

(Speaker 2): The fabric made of copper, the same exists with silver. And then there's also stretchy fabric made from silver, like jersey fabric, more like t-shirt fabric, basically. So for capacitive touch, I guess that would be something more relevant for you rather than the more resistive materials. And so for the touch interface, you can use that, for example. That works really well. And you can cut it. You can sew with it in the sewing machine. You know, it's kind of usable like a conventional fabric. Like the copper fabric is a bit more stiff. It's more like a taffeta, like when you think of a ball gown fabric or so. But there are some that are more flexible as well. So depending on your need, there are different products.

(Speaker 1): Okay.

(Speaker 2): And then for if you want to have the entire circuit flexible and you don't want to use cables, there's also textile cables, you know, basically, so threads that you can sew. Some of them come with an insulation already, so it's really like a wire and you can solder them at the end or you get a conductive thread that you insulate yourself. There's also very nice instructions online from a practitioner and researcher in Austria called Irene Posch. And she kind of her research is about making tool kits, like electronic tool kits, but for textiles. So she has instructions online on how to make textile cables in an easy way, you know.

(Speaker 1): Oh, wow. Would you mind sending me that?

(Speaker 2): Yeah, of course. Yeah.

(Speaker 1): It would be really nice because they can they stretch as well or stretchy cables? I mean, the cables themselves, the ones, I mean, if you make them into like one little braid or like if you make one row of loops, then they are stretchable. But the thread itself is not stretchable.

(Speaker 1): Okay.

(Speaker 2): But there's some something I can find there. And also if you stitch it into a fabric, it will become stretchable. Like you know, if you, it depends on the surface. Yeah, like in a zigzag, for example, or like a knitted or crocheted loop, then it becomes stretchable.

(Speaker 1): Yeah. But for the mutual capacitance thing, I basically need like a grid of wires, which and the wires should be then flexible because you want to.

(Speaker 2): But that you can you could do that by making that grid in a knitted piece of fabric, for example. Then because knitting is like you have a thread that itself is not flexible, but the structure is that you create loops and these loops interlock and that makes it stretchable. So if you take these fabric wires and kind of integrate them or stitch them into a knitted fabric, they can become flexible or like stretchable.

(Speaker 1): Okay. That's good to know.

(Speaker 2): But yeah, I mean, there's also very conductive stretch fabrics that come in like stripes Like zebra fabric.

(Speaker 1): I should look into those as well.

(Speaker 2): And there's a lot of tutorials online on how to work with these materials.

(Speaker 1): Yeah.

(Speaker 2): So that's, I mean, that's something you could try if you want to make a wearable, like flexible controller.

(Speaker 1): Yeah.

(Speaker 2): I mean, of course, the prototype you have, it already looks really good, I think.

(Speaker 1): Thanks.

(Speaker 2): So I also, you know, like textiles are not the solution for everything. They're great. But, you know, if you have something that works really well for your purpose, you don't need to reinvent the wheel.

(Speaker 1): Yeah.

(Speaker 2): Of course, like using textile makes it a bit more ubiquitous and, you know, kind of can prove the wearability comfort. So it makes sense. To try, at least anyway. But also, you know, maybe you find in the end that that's not what you were looking for. So even though I like working with textiles, I'm just saying that, you know, I don't want to force people to use it.

(Speaker 1): Yeah, I get that. I guess that that kind of leads me then to another, to a more general question. In designing such a wearable, what are things that I'll probably run into? Because, of course, you've designed some things yourself.

(Speaker 2): Yeah, I mean, something I always found that's important when designing wearables is that you need to accommodate or you need to account for time to just familiarize yourself with kind of the materials. Because if you make these sensors yourself, if you make the circuit yourself, if you embed that in a wearable device, there's always more challenges than having a static one. So also, if you work with Bluetooth or things like this, it's always more tricky than having something that's more static.

(Speaker 1): Yeah.

(Speaker 2): So I think it's important to just from the very beginning account for that, because, for example, I've often worked with computer scientists or engineers who wanted to use these textiles. And then they got very impatient about, you know, that the sensor didn't behave the way that the off-the-shelf pressure sensor behaves. And I was like, yes, of course it doesn't, because we make the sensor ourselves. So it takes a bit more time to understand the behavior of the sensor. Even if you cut exactly the same shape twice, it will behave differently, you know?

(Speaker 1): Yeah.

(Speaker 2): And that's kind of the tricky thing about this material, that it has a behavior that is repetitive and that gives you useful data. But you need to kind of spend a bit more time in the beginning to like observe the behavior and to see how to best work with it. And that's something I, especially if you haven't worked with it before, that, you know, that I just want to point to that, you know, don't get frustrated with it too easily because it's just the nature of these materials and the nature of making your own like wearable sensors or interfaces that they don't behave like off-the-shelf sensors. So there's a lot of like iterative prototyping and by choosing the right materials, you know, you can, you know, you can get to the solution quicker. So some of the learning processes that other people have been going through, you can take on board and apply that.

(Speaker 1): Yeah

(Speaker 2): like when I worked with different sensors on different projects, the early prototyping stage is really important because you want to find all the mistakes soon, like early on, rather than you rush through them and then at the final stage you discover something that's fundamentally wrong. So I spent a lot of time on just testing different materials, testing different ways to process the data, what's the safest way to collect the data and so on, you know, and I was always very, I mean, maybe I was particularly slow in that because I don't have a computer science background, so I wanted to make sure that I'm doing things the right way. But yeah, I think working with this material, it's just kind of useful to account for enough time to understand the material. That's kind of one advice I would give. Yeah, a main takeaway.

(Speaker 1): Yeah. Yeah, okay.

(Speaker 2): And yeah, and also just not get frustrated because these materials behave differently. So if you're used to off-the-shelf sensors, these textile materials will not behave the same way. But yeah, I mean, a good thing is that they are, you know, if you cut something and then you realize, oh, I've cut it too big or too small, you can just do it again because these materials are relatively cheap, cheaper than buying 10 pressure sensors. You know, so that's one advantage.

(Speaker 1): But then they do all your different cuts behave differently, right?

(Speaker 2): Yeah, I mean, but you can, for example, with the copper fabric or also with the silver like woven fabric, you can also laser cut them.

(Speaker 1): Yeah, okay.

(Speaker 2): If you need to have more sensors that are exactly the same size or something. But yeah, I mean, something that is probably more on the software side is that when observing the data to just kind of, you know, just kind of try out a lot what happens if you press, if you kind of interact with that material, just look at some data stream to see, okay, what does this material actually do? Because then it's easier for you to adapt like how to write the code for processing this data, like something where, for example, I've tried things where it kind of recalibrates itself every time you switch it on, because it can be that the values are very different or that you apply like or that you just collect the raw data. That's usually what many people advise me to do. You collect the raw data, then you do everything post processing, like then you apply a filter, then you apply like a moving average to smoothen the data, something like that.

(Speaker 1): Yeah.

(Speaker 2): And yeah, so I think in general, if you collect the data or like, I mean, for you, I don't know if you want to have like some real time processing then in the end.

(Speaker 1): Yeah, that's the idea.

(Speaker 2): Yeah, I mean, I think there are libraries for that already that are useful for that. Yeah, so maybe then, because I never did like real time. Like for my work, I didn't do real time and then Courtney, who was performing with the collar, she did it in real time. So I don't know if you want or you need more people to interview, but she's probably a very good person to interview as well.

(Speaker 1): Yeah, I'm a little later already in the thesis process, so I don't think so. And I delayed the interview for a few weeks now.

(Speaker 2): No, that's no problem at all. But I can send you the paper that Courtney and I wrote about this collar because it describes there how to do the things and what, you know, it's a long paper on the design process as well. So maybe there will be some aspects that are helpful.

(Speaker 1): Yeah, it would be very nice. Yeah, definitely.

(Speaker 2): Yeah, so I mean, that's the I don't know, I would if you work with textiles, I would also use textile techniques to make the thing. So I just mentioned this because I've seen computer science students who use e-textiles, but then they glue it on or something.

(Speaker 1): Yeah.

(Speaker 2): And with textiles, you can use all the kind of very low key textile techniques like a sewing machine or just by hand, you know, threading something. You don't need to like hammer it in or kind of glue it or something, you know. And that's robust enough, actually. The most kind of error prone element within a flexible circuit is always the hard soft connection. So solder points or something.

(Speaker 1): Yeah.

(Speaker 2): So that's why often circuit boards, they have holes that are big enough for conductive threads to fit through and the sewing needle to fit through. Yeah. So you don't have to solder. And that's then a very robust solution.

(Speaker 1): That's also something I noticed because I used wires that were a little bit too stiff. And I think I broke the Trill as well. So, it did send data, but now it doesn't anymore, which is kind of sad.

(Speaker 2): Oh, no.

(Speaker 1): But I learned something out of it. So. Yeah. Gen 2.

(Speaker 2): I mean, for a first prototype, it looks really good. And that's why you do these prototypes, you know. You're prototyping in order to make the mistakes early and not late.

(Speaker 1): Yeah. Yeah, of course.

(Speaker 2): Oh, it's good that you found that mistake.

(Speaker 1): Yeah.

(Speaker 2): It would have been not been nice if this was the final version.

(Speaker 1): Yeah.

(Speaker 2): I mean, I'm also, if I can help you with any like prototyping, I would be happy to do it. So, I mean, I can also send you maybe some sample fabrics. I have some like leftovers. It's like small quantities, but I'd be happy to send it.

(Speaker 1): Yeah. Yeah, I guess. But yeah, I'm really on a sort of a time constraint. Okay.

(Speaker 2): So, what is your time problem? Like, what is your schedule?

(Speaker 1): Well, it ends in February, the beginning of February. But I have the pressure cooker. I don't know if Jonathan told you about it. Yes, it's that. Yeah, it's early December. He invited me to that.

(Speaker 2): Yeah. Unfortunately, I can't come. but It looks fantastic.

(Speaker 1): yeah, But by then, I want to have like, I think, two working prototypes. One with the sliding and one with the touch screen.

(Speaker 2): Yeah. Okay.

(Speaker 1): So, maybe I can ask you what kind of methodology would you use to develop a wearable? Do you mean design methodology?

(Speaker 2): Like, in order to get to the design? Or what do you mean?

(Speaker 1): Yeah, What aspects to consider, I guess.

(Speaker 2): I mean, I think it's good to have the final interaction in mind. Like, what do you want the people to do? And then you need to engineer from there. Because you want to, if you do something wearable, it needs to be beneficial for the wearer in a way, you know.

(Speaker 1): Yeah.

(Speaker 2): So, imagine the person that you want to wear your piece. What should they do? And be clear about that. And then from that, that will answer some design questions. Because then every idea you have, if it's like a sleeve, then you can think, okay, but does that benefit the interaction the wearer should have? And then it's sometimes easier to say, okay, yes or no, you know.

(Speaker 1): Yeah.

(Speaker 2): Do you want to have it, for example, that you can wear it on either?

(Speaker 1): Yeah. It should be modular.

(Speaker 2): If it should be modular, then it can't have any, like, side-specific designs, you know. Then it should be maybe symmetric. Or then it should, in terms of the software, have something where it doesn't matter whether you slide this way or this way. Because that will change from the side, you know. Or if you need to have an area where it's side-specific, then maybe you need to integrate signifiers on the wearable. I don't know, little signs of embroidery where there's, I don't know, like green and red or plus and minus where the person knows which way to slide or whatever, you know, as an example.

(Speaker 1): Yeah. So, maybe a sort of correct way to use it.

(Speaker 2): Yeah, exactly. Because the person who uses it, they don't want to think about it that much, you know. They don't want to have a lot of errors. It should be intuitive. So, everything that is clear from the very beginning is good. Everything where the wearer needs to think more is bad.

(Speaker 1): Okay. Yeah. Nice.

(Speaker 2): So, but you're working on one design or that has this mutual capacitance or?

(Speaker 1): Well, that kind of leads me to another point. Because I've, yeah, because I had some, I did some ideation, of course. And I was wondering, can I maybe share the ideation with you and we can talk about them together?

(Speaker 2): Yeah, definitely.

(Speaker 1): Yeah. Okay. Because I have them on my PC, so I can just share my screen, if that works.

(Speaker 2): Yeah, definitely.

(Speaker 1): So, can you see my screen?

(Speaker 2): Yes.

(Speaker 1): Okay. Yeah. So, these are just a couple of designs and I designed them based on two technologies. So, the 1D touch and 2D touch, basically. And these designs with like a larger surface area, I wanted to, were meant to be the 2D touch. So, the mutual capacitance. And then, for example, the smaller surfaces could be sliders or capacitive touch points for the 1D touch. As well, yeah, this one I tried to make. So, that's kind of like that one. This one really looks like that, but then with capacitive touch points instead of a slider. And this one, again, is a touch interface. And it should be, I should, because these are multiple designs. But in the end, the goal is to have one design which can fit on multiple body places.

(Speaker 2): Okay.

(Speaker 1): Yeah. That's why I'm trying to make one design based on the 2D touch, which fits on multiple places and one design based on the 1D touch. So, for example, the one I just showed you.

(Speaker 2): 1D touch, you mean one area to take it off and to put it on?

(Speaker 1): No. I'm sorry. I brushed over that. So, the 2D touch is basically touch screen.

(Speaker 2): Oh, right. Okay. Yeah. 2D. Like, okay. Two dimensions.

(Speaker 1): Yeah. And yeah, for the 1D touch, you can use it as slider or points, individual points.

(Speaker 2): Okay.

(Speaker 1): But for example, this one, which I just made, I can adapt it or have straps. So, it can also fit the legs, for example, or the upper arms. And for example, this one could be, instead of a more 2D touch option, but I can redesign it to also fit like around the waist or somewhere on the shoulders.

(Speaker 2): But with the one that is around the waist, my question would be, how do you imagine the people to wear it? Underneath their clothes? On top of their clothes?

(Speaker 1): Yeah, on top of the clothes.

(Speaker 2): Would that affect the design? Which clothes someone is wearing?

(Speaker 1): I don't know.

(Speaker 2): I feel like something that is not around the torso is sometimes a bit more comfortable for people.

(Speaker 1): Yeah.Okay.

(Speaker 2): I mean, I really like this one. I really like this one. Because it kind of covers the chest area also. That is kind of where the singing, like the voice comes from, you know?

(Speaker 1): Yeah.

(Speaker 2): So, if you want to, the interaction is one person, right? So, the person touching themselves.

(Speaker 1): Yeah.

(Speaker 2): Or is it also other people involved?

(Speaker 1): It can be other people. Yeah.

(Speaker 2): I mean, just my personal kind of just an idea I had to kind of develop it further is with this one, you could, it looks a bit like a collar, which I kind of like, because it's very flexible in terms of sizes.

(Speaker 1): Yeah.

(Speaker 2): You can have elastic bands here to adapt or to hold it in place. And it can be a collar or like a cape you just put on the shoulders, you know? It doesn't have to be tight, actually. And it can be like a cape. And then people can, yeah, I don't know, it depends. Like the interaction, if it's like this, maybe that's a bit weird. But if it's like this...

(Speaker 1): Yeah.

(Speaker 2): If you cross your arms, that's maybe a nice gesture, a nice like performative posture when it comes to singing.

(Speaker 1): Yeah.

(Speaker 2): So, when picking the design, I would think about that as well as to like what, yeah, as I said, like what the final interaction should look like. What do you want the person to do?

(Speaker 1): Yeah.

(Speaker 2): You want them to touch their legs? Do you want them to like, how should it look like if it's like part of a performance or something?

(Speaker 1): Yeah.

(Speaker 2): Or with the face. I mean, that's very beautiful as well. But if you want singers to wear it, sometimes they... I mean, I imagine this could be super beautiful, but I'm wondering whether singers like to have something in their face. Maybe not.

(Speaker 1): Yeah, I can get that.

(Speaker 2): So, in that sense, the easiest is maybe as you tried the sleeve, because that's very flexible. You can put it here, here on your feet. You can have it here or here, you know, if you want to do this or this. That's kind of very artistic in terms of what movement it kind of allows.

(Speaker 1): Yeah.

(Speaker 2): So, that's very nice as well. And maybe that's the easiest way in terms of making the entire circuit. That's the most modular maybe. So, yeah, I don't know. Maybe for what you want to do, maybe the sleeve is a good solution, because also you've started working on it and given a time constraint, maybe that's also the easiest design. Because for this, I mean, even though I find it very beautiful to imagine it as a like cape or collar, it also has something very Dutch. These white collars.

(Speaker 1): Okay.

(Speaker 2): 17th century, I don't know, 17th century Dutch costumes.

(Speaker 1): Yeah.

(Speaker 2): They had all these wide collars. I'm obsessed with Dutch costume history. That's why I mentioned it.

(Speaker 1): That's why you like it.

(Speaker 2): Yeah. Yeah, but also it reminds me of that. You know, all these like scholars, the paintings you see, they have these like wide flat collars.

(Speaker 1): Yeah.

(Speaker 2): And I find it very nice. But yeah, it's maybe for if you're on a time constraint, maybe then the one that you showed me, the sleeve is a good solution because it's flexible.

(Speaker 1): Yeah.

(Speaker 2): And yeah, you can make it in either with out of a stretchy material or you can make it out of a robust like woven fabric and have maybe two, like two settings for sizing that you can make it tight or not so tight.

(Speaker 1): Yeah.

(Speaker 2): I was thinking about something like a corset.

(Speaker 1): Yeah.

(Speaker 2): Or even like a Velcro, you know, that's maybe easier because you can have a large area of Velcro and then you can make it as tight or loose as you want.

(Speaker 1): Yeah. Okay. That's also a good one.

(Speaker 2): And there is Velcro that you can even like stick that is very sticky on the back. You can just for a prototype stick it on the fabric.

(Speaker 1): Oh, okay.

You know, that's a quick solution.

(Speaker 1): Yeah. That's a very good one too. Yeah.

(Speaker 2): I can send you a link to, I mean, you can find it everywhere, like on Amazon for three times, but I can send you a link.

(Speaker 1): I really do want to want to continue with the sleeve. But that's then one design. In the end, I would like two designs and then one design based on the 2D touch. So I think I have to reimagine this one so that it fits.

(Speaker 2): Can you show me the others again?

(Speaker 1): Yeah. Of course.

(Speaker 2): Was this the face, this sleeve?

(Speaker 1): Another sleeve.

(Speaker 2): Okay. I mean, that I would also see is like what the sleeves can be. You can pull them up to the thigh in a way. But I think then the sleeves are more for the for the arms and legs. And then I have to make a 2D touch idea based on or which would fit the waist, the torso. So I have to think about that. I mean, if I'm thinking, so all the suggestions I make now are considering your time constraint. But a simple solution is to make like a rectangle that either can be a scarf or like a collar or like a stole or like a cape. So you can just put it on. So it would go back to the collar, to the chest thing idea that you had there. But simplified. Maybe I can draw something.

(Speaker 1): Sure, if you want. Yes.

(Speaker 2): I don't know if you have, because then you can buy a piece of fabric and just, you know. And integrate it.

(Speaker 1): I have some fabric lying here.

(Speaker 2): Perfect. I mean, that's, for example, how it could look like very quick, very bad sketch. But if you have a piece of fabric like this, you cut in here. You can put it around the body like this. Okay, the two pieces here and the front. Like this is where the head goes through. And it's like, yeah, it just hangs on your shoulder. Would that fit the waist as well? If you make it long enough, yeah. Yeah, but that you can wear it over your shoulders, but also on your waist. I mean, if you can then put here and here together and then it's like. I'm trying to. So basically, if you fold it here, then you. So basically the same as here, but you just add this corner to this. And then it's like a big sleeve, like a big armhole. You know.

(Speaker 1): Yeah, OK. That's a very simple, just rectangular shaped thing.

(Speaker 2): Yeah. And it gives you a large surface area to house all the electronics. So this is the front and the back. Sorry, do you understand my crude drawings?

(Speaker 1): Yeah, yeah, I do.

(Speaker 2): OK. So because then here you can have the capacitive surfaces. And then here in the back, you can house all of the electronics. Like here, for example. And then it goes.

(Speaker 1): Yeah. And do you think it would be possible to like combine these two designs? So the one on the shoulders and then this one into something that.

(Speaker 2): I mean, again, it depends what you want to do like this. This rectangle is kind of versatile. The corset together with voice control. I'm a bit skeptical, I have to say. OK.

(Speaker 1): Because I know from people that if I mean, I don't know what you imagine. Do you have a specific performer you are working with or should it fit a lot of different people? Should fit different people. OK, then, you know, some people don't want to have something tied around their waist.

(Speaker 2): Yeah. Because then they are wearing something maybe loose and then they have to put it around. It's kind of some some people can find it uncomfortable. If it doesn't have to be very tight fitted, it can be this large like cape so that the interaction area can be here, but also in the waist. Because it's like a large, almost like a scarf that you can also basically have two scarves that you kind of sew together in the middle, but only halfway. And then you can, you know, you can just kind of put it around. And then again, if you fold it and you can just kind of, if you want to have it closed, you can make, I don't know, either a button here and a buttonhole. So you can either have it as a cape or also close the button and have like a large sleeve or something. It's just like the most simple way you don't need to pattern cut or think about anything.

(Speaker 1): Yeah.

(Speaker 2): Just rectangles. Yeah, I don't know.

(Speaker 1): No, that's very good input. Thank you. Because then you don't, I wouldn't like over engineer the, I wouldn't make it too complicated because you, if you, especially if you want to make two designs.

(Speaker 2): Yeah. I would keep it also open because if it should fit a lot of different people, maybe everyone wants to interact in a slightly different way. So maybe some people want to touch here and some people want to touch here or some people, I don't know, want to touch in the waist. And if you have a large area, you can be flexible as to even if the whole area doesn't have to be capacitive. But even if you have a small area, if it's a loose fitted piece, you can just kind of, you know, you can pull it a bit down, pull it a bit up and the area where you interact with moves.

(Speaker 1): Yeah.

(Speaker 2): It's flexible. Yeah, but a performance should also be able to move around while it not like falling down something. Yeah, true. Something to consider. That's where you can close it on the side.

(Speaker 1): I guess I can, I can take that with me then. That's, yeah, very nice. Thank you.

(Speaker 2): Yeah, I don't know. Like brainstorming, feel free to like totally ignore it.

(Speaker 1): No, no, that's no, this is a good, it's like a good starting point or direction to head in, maybe. But yeah, I wouldn't like here, for example, it looks like, I mean, here it's good because everything is in one place. But if some other designs had like, because I guess that's the microcontroller or like the board. Yeah, there.

(Speaker 2): And if you go to the collar design, can I just see?

(Speaker 1): This one?

(Speaker 2): Yeah. So it has two boards or what?

(Speaker 1): Yeah. So it's a crude sketch. But yeah, on each sketch, I tried to make the band here on the chest the same so they can.

(Speaker 2): Yeah. So basically a person should could wear all these at the same time. Oh, I see.

(Speaker 1): Yeah.

(Speaker 2): But I mean, here also with the sleeve, you could integrate the controller in the sleeve.

(Speaker 1): Yeah.

(Speaker 2): Then you don't need a band here, no?

(Speaker 1): Yeah, that's true. But then again, this was made so that they could, so that all the designs could be fit at once.

(Speaker 2): Oh, but should the capacitive touch surfaces of one design, should they be used to interact with the other?

(Speaker 1): Sorry, what do you mean by that?

(Speaker 2): Sorry, if you have, for example, the sleeve. And then this, the collar, the shoulder piece. Should the sleeve be used to interact?

(Speaker 1): No, no, it's just the person's fingers.

(Speaker 2): Okay, because then you need to think about how these two, if you want the person to wear both designs at the same time, how they would interfere with each other, if that's actually a good thing.

(Speaker 1): Yeah. Yeah, well, yeah, I guess these were made to all fit one at once, but that's not what I'm actually going to do. But I have two designs which should fit at once. So then I thought it was good to have a central position for the microcontroller. And the battery and stuff.

(Speaker 2): Yeah, I mean, that will be problematic for the sleeves because the good thing about the sleeves is that you can just put them on and pull them on and pull them off. Yeah, but you can, I guess you can put them on your wrist, plug them in on your back and then just go with it. But that just fits the interactions.

(Speaker 1): Yeah, well, not if you make like a stretch cable, which is long enough, I guess.

(Speaker 2): I don't know if that's so comfortable.

(Speaker 1): No.

(Speaker 2): I mean, do the sleeves have to be connected? Is there one microcontroller that powers both?

(Speaker 1): Yeah. They all send data to one controller, which then sends that data to another.

(Speaker 2): I think what I would do is to have one sleeve. And one like other design, whether it's this or if you want to have something else. Because otherwise, I think it will be too much. And if you use your hands to interact, you can't, you only have two hands. So if you have interfaces here and then the ones on your sleeve, you would need four hands to interact with it. At the same time.

(Speaker 1): Yeah.

(Speaker 2): But I don't know, especially for performers who are not used to this technology. It's very quickly, very overwhelming. You know, they are happy if they can have maybe three modes of interaction and they can control it.

(Speaker 1): Well, yeah, they can map it, map it how they want.

(Speaker 2): Do you know the MIMO gloves?

(Speaker 1): Yeah. It's my state of the art for this.

(Speaker 2): I mean, so the people that you look to to try this are singers or voice performers.

(Speaker 1): Yeah, performers. What are you thinking about?

(Speaker 2): I'm just thinking about whether you have enough time or even for that event in December. If you have two prototypes, they don't need to be functioning, but just the fabric or just the it can be a sleeve. And it can be if you want to go for this and this kind of solution, like a very simple piece of that and then put it on the people without any electronics, without any sensors and ask them to perform and see what they do.

(Speaker 1): Yeah.

(Speaker 2): So with the housing a bit.

(Speaker 1): Yeah.

(Speaker 2): Like kind of observe them what how they use their hands. And and then see how your design can fit into that. Because then I think you will see whether it would make sense to have two or only one or whether I don't know if they do a lot like this, then maybe it would interfere if they have the sleeve and something on their shoulder or chest. You know, or when they are singing and you have something on the waist. I mean, and you want the hands to be the kind of interacting piece of the body.

(Speaker 1): Yeah.

(Speaker 2): Do they even touch their waist when they sing?

(Speaker 1): I don't know.

(Speaker 2): Maybe not.

(Speaker 1): Yeah. Well, it's also it. Maybe they touch their belly. It becomes also an instrument itself, I think the controller.

(Speaker 2): Yeah. But if it depends on hand interaction, it needs to be in touch with the hand. So when it's a singer, I mean, I don't know. But often they do like this when they sing, they kind of touch their chest area. Or their belly. They haven't seen a singer like touching their waist. For example, you know.

(Speaker 1): No, that's good to know. It's good to see.

(Speaker 2): I mean, you know, it's we can make this a three year PhD project or we can also make it quick. It's just some questions that, you know. Maybe useful to think about. I think as one design, the sleeve is a really good idea. Because it is flexible. It does fit a lot of people. Given that you only have until February, I mean, that's not a very long time. Maybe it is enough to have one sleeve.

(Speaker 1): Yeah.

(Speaker 2): Because then you can make it so that you can wear it on the right or the left hand or on the right or left foot. And that's already great if that works, to be honest. And then if you want to have a second design. Yeah, it can be as simple as a rectangle. And then you can have it as a scarf, as a like, yeah, tuna or what's it called?

(Speaker 1): Like a cape?

(Speaker 2): Yeah. Because the cape, you can then also or if it's a scarf, you can also just bind around your waist. And it's like super flexible. If you basically have a piece of rectangular fabric. You can put it on your shoulder. You can put it on your head. You can put it around your waist. And yeah, I mean, I would, the sleeve you have here, that's kind of self-contained. That doesn't have long, like a long wire going to another microcontroller, right?

(Speaker 1): No, no.

(Speaker 2): I think that's good. Yeah, but yeah, if you have a long like wire that goes somewhere, I think it would restrict how people move their arm.

(Speaker 1): Yeah.

(Speaker 2): Well, that's something to keep in mind. Because it's like a leash, even if it's a flexible band, but it's like a restriction, basically.

(Speaker 1): Yeah, but they can walk around because it's going to be wireless.

(Speaker 2): But if there's like a leash from the body to the arm. I don't know. I would feel like I have to be very careful in what I do with my arm. Just from a very basic like human perspective. Like I've worked with a lot of humans and I know that especially if they don't know the technology, they can be very hesitant and they try not to break anything. But that, you know, creates a bias as to how they move.

(Speaker 1): Yeah. But it also takes some time, right? If they perform with it and then notice, OK, this is durable, then. yeah.

(Speaker 2): It depends. I mean, how much time you give everyone and what like I don't know what the setting is of the people that should wear it. If they have time to like familiarize themselves with it.

(Speaker 1): Yeah. It's I guess you can see it as the Mimiu gloves. So it's an instrument.

(Speaker 2): I'm thinking of. You could make the sleeve a bit longer so that it can connect to the to the cape and just be tipped on like at the shoulder, for example. And it doesn't have to be a free floating like wire or so. Let me see if I can draw it. I know that you just make make it a bit longer that you can clip it onto the scarf, for example.

(Speaker 1): Mm hmm.Yeah. That was kind of my idea. So to have it along the arm.

(Speaker 2): Yeah. I mean, that's a good idea. I just I was just hesitant to about the idea to have like free floating like free floating.

(Speaker 1): No, that's not. That's not really the idea.

(Speaker 2): Then that's fine.

(Speaker 1): I'm thinking about just trying to integrate. It should not be in the way, of course.

(Speaker 2): Then that's great. I mean, there's a lot of design engineering work that can go into this. That's why I would suggest to keep it simple.

(Speaker 1): Yeah, exactly.

(Speaker 2): I would especially if you're not like used to sewing or like working with textiles, working with a rectangle is probably doable.

(Speaker 1): Yeah.

(Speaker 2): But yeah, I mean, I also have a bit more time now in the next weeks. So if you want to have another call to run through some ideas. Maybe I can show you the prototypes if I have them.

(Speaker 1): Yeah, Sure.

(Speaker 2): And I'll send you all the links I mentioned.

(Speaker 1): Yeah.

(Speaker 2): Very nice projects. Awesome.

(Speaker 1): Thank you very much.

(Speaker 2): And yeah, I mean, it sounds exciting. I would love to see it.

(Speaker 1): I hope it all ends up going well.

(Speaker 2): Well, I'm sure. Is it your undergrad project?

(Speaker 1): Undergrad?

(Speaker 2): Are you a master's student?

(Speaker 1): Oh, no. Bachelor's. Bachelor's.

(Speaker 2): OK. Was that useful for you at all?

(Speaker 1): Yeah. I was about to say, I guess we've talked about everything I had in my mind at least.

(Speaker 2): OK. I mean, feel free to get in touch. I will be better in replying from now on.

(Speaker 1): Yeah.

(Speaker 2): I was traveling before, and I had a big project that I finished last week. So from now on, I'm a bit better with things.

(Speaker 1): Sure.

(Speaker 2): Yeah. Maybe we'll keep in touch then.

(Speaker 1): Yeah, definitely.

(Speaker 2): I'll email you with the things I mentioned.

(Speaker 1): Thank you very much. If you want, I can send you these sketches as well.

(Speaker 2): Sure.

(Speaker 1): Well, thank you very much for your time and helping me with the things.

(Speaker 2): It's exciting. It sounds great.

(Speaker 1): Yeah.

(Speaker 2): I guess I'll speak to you again.

(Speaker 1): Yeah. See you.

(Speaker 2): Have a good day.

(Speaker 1): Yeah, you too.

(Speaker 2): Thank you. bye.

28 Esp, Python and SuperCollider Code

28.1 SuperCollider

```
/* ————————————————————————————————

Reads incoming OSC / sends OSC commands to Serial2OSC.py connected to an
   ESPNow coordinator.
Using Lucas' 4th prototype which has the touch pad configuration in Trill
    DIFF mode of....




--------- 12
--------- 11
--------- 10
--------- 9
--------- 8
--------- 7
--------- 6
--------- 5
--------- 4
--------- 3
|    |    |
0    1    2

[TRILL CONNECTOR]

Mapping for Notey Synth:
0-12 all correspond to pitch values, keyboard style.. but remember that
   we don't get discrete keyboard-style control so easily
with a trill configured this way. Touching one sensor pad will always
   give you some capacitive "spillover" into the surrounding pads.


Mapping for FX Synth:
0, 1, 2 activate control over Reverb, Distortion and Delay FX
   respectfully
3-12 works as an intensity slider for the currently active FX

————————————————————————————————*/

// Boot the server
(
s.options.memSize = 2 ** 16;
s.waitForBoot {
        s.meter
};
);

( // Basic Incoming OSC test.. just print whatever Python is sending us.
OSCdef(\esp32, {|msg| msg.postln }, "/esp32");
);
OSCdef(\esp32).clear;
```

```
( // Basic Stereo Audio Test. Some stereo Sine waves
Ndef(\audiotest, {
        Splay.ar(SinOsc.ar(Scale.minor.ratios * 300) * 0.2);
}).play;
);
Ndef(\audiotest).clear; // destroy the synth



/*------------------------------------------------------------------------










                                                                  */
( // Vocoder OSC Processing
OSCdef(\esp32, {|msg|
        var gains = Array.newClear(13);
        msg = msg[2..15];

        // Map all 13 sensor values to gain levels for each "note"
        13.do {|idx|
                var param = "v%".format(idx+1).asSymbol;
                gains[idx] = msg[idx].explin(50, 300, 0.0, 1.0, clip: \
                   minmax); // map range 50:300 to 0.0:1.0 with
                   exponential curve
                Ndef(\synthpatch).set(param, gains[idx]);
                //"% %".format(param, gains[idx]).postln;
        };
        //msg.join(":").postln;
        //gains.postln;
}, "/esp32");
);
Ndef(\audiotest).clear; // destroy the synth


( // Notey Vocoder Synth
Ndef(\synthpatch, {|pregain=1.0, gain=1.0|
        var pitchratios = ((Scale.major.ratios / 2) ++ Scale.major.ratios
           )[..12]; // experiment with other distributions of pitch
           ratios
        //var pitches = (Array.series(13, 1, 3) + 36).midicps;
        var voicein = SoundIn.ar(0);
        var sig, shifted, voxmix;
        var volumes = [
                \v1.kr(0.0, 0.1),
                \v2.kr(0.0, 0.1),
```

```
                \v3.kr(0.0, 0.1),
                \v4.kr(0.0, 0.1),
                \v5.kr(0.0, 0.1),
                \v6.kr(0.0, 0.1),
                \v7.kr(0.0, 0.1),
                \v8.kr(0.0, 0.1),
                \v9.kr(0.0, 0.1),
                \v10.kr(0.0, 0.1),
                \v11.kr(0.0, 0.1),
                \v12.kr(0.0, 0.1),
                \v13.kr(0.0, 0.1),
        ];

        shifted = PitchShift.ar(LPF.ar(voicein, 4000), 0.2, pitchRatio:
           pitchratios, pitchDispersion: 0.01, timeDispersion: 0.01);
        shifted = shifted * volumes;

        //sig = Splay.ar(shifted); // spread voices across the stereo
           field
        //sig = Pan2.ar(Mix(shifted), 0.0); // mix down to mono and pan
           how you like
        sig = GVerb.ar(Mix(shifted), 50, 2, 0.5, 0.5, 5, 1, 0.5, 0.3); //
            run into a stereo reverb
        sig = sig * gain;
        Limiter.ar(sig);

}).play;
);

( // Notey Sinewave synth (voice input is ignored)

Ndef(\synthpatch, {|pregain=10.0, gain=1.0|
        //var pitches = ([1,2,3,4,5,6,7,8,9,11,12,13] + 36).midicps;
        var pitches = (Scale.major.ratios ++ (Scale.major.ratios * 2)) *
           200;
        var sig;
        var volumes = [
                \v1.kr(0.0, 0.5),
                \v2.kr(0.0, 0.5),
                \v3.kr(0.0, 0.5),
                \v4.kr(0.0, 0.5),
                \v5.kr(0.0, 0.5),
                \v6.kr(0.0, 0.5),
                \v7.kr(0.0, 0.5),
                \v8.kr(0.0, 0.5),
                \v9.kr(0.0, 0.5),
                \v10.kr(0.0, 0.5),
                \v11.kr(0.0, 0.5),
                \v12.kr(0.0, 0.5),
                \v13.kr(0.0, 0.5),
        ];
        sig = RLPF.ar(SinOsc.ar(pitches) * 0.3 * volumes, 2000, 0.4);
        sig = sig + CombC.ar(sig, 1.0, 0.01, 2.5);
        sig = Pan2.ar(sig.sum.tanh, 0.0);
        //sig = Splay.ar(sig.tanh, 10, 1.0, 0.0);
        Limiter.ar(sig * gain);
```

```
}).play;

);


/*------------------------------------------------------------------------









                                                            */
( // Reverb OSC Processing
~current_slider = 0;
~current_smallslider = 0;
OSCdef(\esp32, {|msg|
        var smallslider = [msg[2], msg[3], msg[4]];
        var intensityslider = msg[4..15];
        var valueschanged = false;
        var smallintensity = smallslider.maxIndex; // 0-2
        var intensity = intensityslider.maxIndex; // will be an intensity
            index from 0-9


        if(smallslider.sum > 40) { // threshhold
                ~current_smallslider = smallintensity;
                valueschanged=true;
        };
        if(intensityslider.sum > 200) { // threshhold below which slider
            touches are ignored..
                ~current_slider = intensity;
                valueschanged=true;
        };

        if(valueschanged) {
                var distlevel = ~current_smallslider.linexp(0.0, 2.0,
                    0.1, 0.8);
                var drylevel = ~current_smallslider.linlin(0.0, 2.0, 0.7,
                     0.3);
                var revtime = ~current_slider.linexp(0, 9, 2, 20);
                "Set distlevel: %  Revtime: %".format(distlevel, revtime)
                    .postln;
                Ndef(\synthpatch).set(\drylevel, drylevel, \distlevel,
                    distlevel, \revlevel, 1.0, \revtime, revtime, \damp,
                    0.5);
        };

        "SLIDER: %   SMALL SLIDER: %".format(~current_slider, ~
            current_smallslider).postln;
```

```
}, "/esp32");
);
OSCdef(\esp32).clear;


( // Distorted Reverb Synthesis Patch
Ndef(\synthpatch, {|pregain=1.0, gain=1.0, drylevel=0.1, distlevel=0.9,
    revlevel=1.0, revsize=50|
        var revsig, distsig, distmix, mix;
        var voicein = SoundIn.ar(0) * pregain;
        distsig = Compander.ar((voicein * 100).softclip, voicein, 0.4,
            2/1, 1/100);
        distmix = (voicein * drylevel) + (distsig * distlevel);
        revsig = GVerb.ar(distmix, revsize, revtime: \revtime.kr(1.0,
            0.5), damping: \damp.kr(0.7, 0.1), drylevel: 0, earlyreflevel:
             0.2, taillevel: 0.3, maxroomsize: 300);
        mix = distmix + (revsig * revlevel);

        Limiter.ar(mix * gain);
}).play;
);
Ndef(\synthpatch).clear;


Ndef(\synthpatch).set(\drylevel, 0.2, \distlevel, 0.5, \revlevel, 0.9, \
    revtime, 20, \damp, 0.6);
```

28.2 Python

```
##################################################################
#   Convert incoming Serial from an Arduino sketch to OSC
#
#   Jonathan Reus 2023
#
#   Dependencies: pyserial, python-osc
#
#   TODO: set up argparse for command line arguments
#   TODO: implement OSC comms
#   TODO: make some kind of gui for all this
#
#   Run with: python Serial2OSC.py -p /reciever/serial/port
#
##################################################################

import sys
import os
import time
import re
import glob
import multiprocessing
import traceback
import logging
import serial

serial_pattern = re.compile('[a-z0-9]+:[0-9]+', re.IGNORECASE)

def serial_ports():
    """ Lists serial port names

        :raises EnvironmentError:
            On unsupported or unknown platforms
        :returns:
            A list of the serial ports available on the system
    """
    if sys.platform.startswith('win'):
        ports = ['COM%s' % (i + 1) for i in range(256)]
    elif sys.platform.startswith('linux') or sys.platform.startswith('
       cygwin'):
        # this excludes your current terminal "/dev/tty"
        ports = glob.glob('/dev/tty[A-Za-z]*')
    elif sys.platform.startswith('darwin'):
        ports = glob.glob('/dev/tty.*')
    else:
        raise EnvironmentError('Unsupported platform')

    result = []
    for port in ports:
        try:
            s = serial.Serial(port)
            s.close()
            result.append(port)
        except (OSError, serial.SerialException):
            pass
```

```
    return result

def proc_osc_server(pipe_to_main: multiprocessing.Pipe, msg_queue:
   multiprocessing.Queue, server_addr: tuple[str, int]) -> None:
    """
    Meant to be run in its own process.
    Sets up an OSC server and pipes incoming messages to a queue in the
       main process.

    pipe_to_main    Interprocess communication pipe to main process
    msg_queue       Interprocess message queue, gets filled with incoming
        messages to be consumed in main process
    server_addr     (ip, port) of the OSC server
    """

    from pythonosc.dispatcher import Dispatcher
    from pythonosc.osc_server import BlockingOSCUDPServer

    # There are a few options for server request handling. Here use the
       most basic BlockingOSCUDPServer
    # See: https://python-osc.readthedocs.io/en/latest/server.html

    def default_handler(address: str, *args) -> None:
        # Pipe everything to the main process
        msg = { 'address': address, 'args': args }
        msg_queue.put(msg)

    state = type('OSCServerState', (), {})()
    state.main_pipe = pipe_to_main

    # Set up OSC Dispatcher and server
    print(f"Starting OSC Server in process {os.getpid()}")
    state.dispatcher = Dispatcher()
    #state.dispatcher.map("/misc/*", misc_handler)
    state.dispatcher.set_default_handler(default_handler)
    state.addr = server_addr
    state.server = BlockingOSCUDPServer((state.addr[0], state.addr[1]),
       state.dispatcher)

    try:
        print(f"Listening for incoming OSC on: {state.addr}")
        state.server.serve_forever()  # Blocks forever
    except KeyboardInterrupt as e:
        print("WARNING: Got KeyboardInterrupt in OSC Server Process")
    except Exception as e:
        print(f"ERROR: Encountered unexpected error in OSC Server Process
           : {e.__class__.__name__}: {str(e)}")
        traceback.format_exc()
        # TODO: Here I should let the main proc know something went wrong
           ...
        #   or rather, the main proc should recognize the text proc
           failed
        #   and try to recover, or do something else...

    print("Exiting OSC Server Process")
```

```
def write_read_serial(hardware: serial.Serial, osc_msg_queue:
    multiprocessing.Queue, verbose: bool) -> dict[str,int]:
    """
    Write whatever is in the send queue to the reciever.
    Read whatever is coming from the reciever & send to local software
        via OSC.

    hardware    the open serial port

    Returns any recieved data package as a dict of param_id->value pairs
    """
    res = None

    # 1) Process all messages currently in the OSC queue
    if not osc_msg_queue.empty():
        for i in range(osc_msg_queue.qsize()):
            oscmsg = osc_msg_queue.get()
            # write all the data to Serial
            print(f"Write to serial: {oscmsg}")
            node,actuator,target_value = oscmsg['args']
            serial_str = f"{node},{actuator},{target_value}"
            hardware.write(bytes(serial_str, 'utf-8'))

    # 2) Read any incoming messages from the coordinator
    raw_recieved_data = hardware.readline()
    if raw_recieved_data:
        #print(f"RCV: {recieved_data}")
        recieved_data = raw_recieved_data.decode('ascii') # decode from
            byte string

        # Assuming data is coming in the format "ad:12837,bc:123,c2:8762"
        if serial_pattern.match(recieved_data):
            res = dict()
            vals = recieved_data.split(',')
            try:
                for val in vals:
                    param_id, value = val.split(':')
                    res[param_id] = int(value)
            except ValueError as e:
                print(f":! {raw_recieved_data}")
                res=None
        else:
            res=None
            if raw_recieved_data != b'\r\n':
                if verbose:
                    print(f": {raw_recieved_data}")
            else:
                print(":")

    return res


def run_main_loop(osc_client, serial_conn: serial.Serial, osc_msg_queue:
    multiprocessing.Queue, verbose: bool) -> None:
    """
```

```
    Main application loop.

    """
    print("Begin serial read loop")
    while True:
        time.sleep(0.005) # serial read rate...
        datablock=write_read_serial(hardware=serial_conn, osc_msg_queue=
            osc_msg_queue, verbose=verbose)

        if datablock is not None:
            builder = osc_message_builder.OscMessageBuilder(address="/
                esp32")
            for param_id, value in datablock.items():
                builder.add_arg(value)
            msg = builder.build()
            #Send out to OSC client
            osc_client.send(msg)
            if verbose:
                print(f"{datablock}")



if __name__=="__main__":
    import argparse
    from pythonosc import osc_message_builder
    from pythonosc import udp_client

    parser = argparse.ArgumentParser(description='Utility to convert
        incoming serial data from an ESP32 reciever to OSC.')

    parser.add_argument('--list_ports', action='store_true', default=
        False, help='List all available serial ports.')
    parser.add_argument('--verbose', action='store_true', default=False,
        help='Print incoming sensor data as it arrives.')

    parser.add_argument('--serial_port', type=str, help='Choose serial
        port the ESPNow coordinator is connected to, by default uses the
        first port found with --list_serial')
    parser.add_argument('--serial_baud', type=int, default=115200, help='
        Choose serial port baud rate, must match baud rate in the
        coordinator firmware. Uses 115200 by default.')

    # Outgoing OSC parameters
    parser.add_argument('--osc_addr', type=str, default='localhost
        :57120', help='Destination address and port to send OSC data to.
        By default sends to localhost:57120')
    parser.add_argument('--osc_path', type=str, default='/esp32', help='
        The OSC path of messages sent by this app. Uses /esp32 by default
        .')

    # Incoming OSC parameters
    parser.add_argument('--osc_server_addr', type=str, default='localhost
        :1337', help='OSC ip/port of this app for recieving OSC messages
        from client software. By default listens on localhost:1337')
```

```
args = parser.parse_args()

if args.list_ports:
    print("Available Serial Ports")
    print(serial_ports())
else:
    VERBOSE_PRINT = args.verbose
    OSC_DESTINATION_IP, OSC_DESTINATION_PORT = args.osc_addr.split
        (':')
    OSC_DESTINATION_PORT = int(OSC_DESTINATION_PORT)
    OSC_SERVER_IP, OSC_SERVER_PORT = args.osc_server_addr.split(':')
    OSC_SERVER_PORT = int(OSC_SERVER_PORT)
    SERIAL_PORT = args.serial_port
    SERIAL_BAUD = args.serial_baud
    if SERIAL_PORT is None:
        ports = serial_ports()
        if not ports:
            raise ConnectionError("No Serial Ports can be Found")
        SERIAL_PORT = ports[0]

    # Create OSC client & connect to Serial port
    print(f"Opening serial port {SERIAL_PORT} at {SERIAL_BAUD}")
    osc_client = udp_client.SimpleUDPClient(OSC_DESTINATION_IP,
       OSC_DESTINATION_PORT)
    hardware = serial.Serial(port=SERIAL_PORT, baudrate=SERIAL_BAUD,
       timeout=.1)

    # Create OSC server process
    server_addr = (OSC_SERVER_IP, OSC_SERVER_PORT)
    parent_conn, child_conn = multiprocessing.Pipe()
    msg_queue = multiprocessing.Queue()

    osc_proc = multiprocessing.Process(target=proc_osc_server, args=(
       child_conn,msg_queue,server_addr,))
    osc_proc.start()


    try:
        run_main_loop(osc_client=osc_client, serial_conn=hardware,
            osc_msg_queue=msg_queue, verbose=VERBOSE_PRINT)
    except:
        # Stop main loop & osc_proc
        osc_proc.join()
```

28.3 Esp Sender

```
/**
   ESPNOW - GENERAL FIRMWARE FOR A COORDINATOR COMMUNICATING WITH
   1-way sensor or actuator nodes.

   Depending on configuration of preprocessor flags, the coordinator will
      :
    * recieve sensor data from one node
    * send actuator signals to one node

  For the basis of ESPNow Arduino programming see: https://
     randomnerdtutorials.com/esp-now-esp32-arduino-ide/

  2023 (C) Jonathan Reus
  https://github.com/jreus
*/

#define ENABLE_SENSOR_NODE
//#define ENABLE_ACTUATOR_NODE
#define COORDINATOR_AP_MODE // uncomment to run coordinator in AP-mode /
   broadcasting a network ssid
#define ESPNOW_CHANNEL 11 // ESPNow channel, must match nodes firmware

// PC Communication
#define PC_SERIAL_BAUD 115200 // Serial to PC baud


#if defined(COORDINATOR_AP_MODE)
const char* coordinator_ap_ssid = "rcv_cordcordcord"; // Set this to your
    AP coordinator's SSID, with prefix
#endif

#if defined(ENABLE_ACTUATOR_NODE)
//uint8_t actuator_node_mac[6] = {0xE8, 0x9F, 0x6D, 0x2F, 0x64, 0x10}; //
    ESP32 v2 a
uint8_t actuator_node_mac[6] = {0xE8, 0x9F, 0x6D, 0x2F, 0x48, 0x54}; //
   ESP32 v2 b
#endif

#if defined(ENABLE_SENSOR_NODE)
//uint8_t sensor_node_mac[6] = {0xE8, 0x9F, 0x6D, 0x2F, 0x64, 0x10}; //
   ESP32 v2 a
uint8_t sensor_node_mac[6] = {0xE8, 0x9F, 0x6D, 0x2F, 0x48, 0x54}; //
   ESP32 v2 b
#endif


// Sensors used by node
//#define USE_ADXL313 // using an ADXL313 3-axis accelerometer
//#define USE_TRILL        // uncomment if using a Trill sensor
//#define TRILL_SENSOR_MODE 1     // 0 for DIFF, 1 for CENTROID

// Actuators used by node
//#define USE_SERVO180
#define USE_NEOPIXEL_STRIP
```

```
#if defined(ESP32)
#include <esp_now.h>
#include <WiFi.h>
#endif

#if defined(ESP8266)
#include <ESP8266WiFi.h>
#include <espnow.h>
#endif

#if defined(ENABLE_SENSOR_NODE)
// Sensor Output Data package, must match data package format in node
    firmware
// ESPNow spec limits this to around 250 bytes
typedef struct sensor_data_package {
#if defined(USE_TRILL)
  #if TRILL_SENSOR_MODE == 0
  // Trill DIFF parameters
  uint8_t numSensors = 30;
  int sensorValues[30];      // raw sensor values minus baseline
  #else
  // Trill CENTROID parameters
  int numTouches = 0;        // number of activate touches
  int touchLocations[5];     // touch location points
  int touchSizes[5];         // touch centroid sizes
  bool touchActive = false; // touch active
  #endif
#endif
#if defined(USE_ADXL313)
  int ax = 0;
  int ay = 0;
  int az = 0;
#endif
  char msg[8];
} sensor_data_package;
sensor_data_package dataIN;

#endif


#if defined(ENABLE_ACTUATOR_NODE)
// Actuator Input Data package, must match data package format in
    Coordinator firmware
// ESPNow spec limits this to around 250 bytes
typedef struct actuator_data_package {
  #if defined(USE_NEOPIXEL_STRIP)
  uint8_t light_position = 0; // simplified control, set a led strip
      position from 0-255
  //uint32_t led_colors[neopixel_led_count]; // careful, this can fill up
       the max 250 byte data package very quickly!
  #endif
  char msg[8];
} actuator_data_package;
actuator_data_package dataOUT;
```

```
#if defined(ESP32)
esp_now_peer_info_t actuator_node;
#else if defined(ESP8266)
uint8_t actuator_node_role = ESP_NOW_ROLE_SLAVE;
uint8_t actuator_node_key[0] = {};//////////no key
//uint8_t actuator_node_key[16] = {1,3,3,4,j,9,8,6,t,v,l,2,5,d,b,1};
uint8_t actuator_node_key_len = sizeof(actuator_node_key);

#endif

//timer for transmission rate
unsigned long timer = 0;
//const int transmissionPeriod_ms = 15;   // desired transmission period
    in milliseconds
const int transmissionPeriod_ms = 3500;   // desired transmission period
    in milliseconds
const bool verbose = false;          // verbose serial output

#endif





// Init ESP Now with fallback
void InitESPNow() {
  //WiFi.disconnect();

#ifdef ESP32
  if (esp_now_init() == ESP_OK) {
    Serial.println("ESPNow Init Success");
  }
  else {

    Serial.println("ESPNow Init Failed");
    // Retry InitESPNow, add a counte and then restart?
    // InitESPNow();
    // or Simply Restart
    ESP.restart();
  }
#endif

#ifdef ESP8266
  // Init ESP-NOW
  //if (esp_now_init() == 0) {
  if (esp_now_init() == ERR_OK) {
    Serial.println("ESPNOW INIT SUCCESS");
  } else {
    Serial.println("Error initializing ESP-NOW");
    ESP.restart();
    //return;
    delay(100);
  }

  // Serial.println("Set role to ESP_NOW_ROLE_CONTROLLER");
  // esp_now_set_self_role(ESP_NOW_ROLE_CONTROLLER);
```

```
  Serial.print("Add peer on chanel "); Serial.println(ESPNOW_CHANNEL);
  int add = esp_now_add_peer(actuator_node_mac, actuator_node_role,
     ESPNOW_CHANNEL, NULL, 0);
  Serial.print("Add actuator node as peer: ");
  if(add == 0)
    Serial.println("Pairing Success " + String(add));
  else
    Serial.println("Pairing Failed " + String(add));

#endif


}

#if defined(COORDINATOR_AP_MODE)

// config AP SSID
void configDeviceAP() {
  bool result = WiFi.softAP(coordinator_ap_ssid, "rcv_1_Password",
     ESPNOW_CHANNEL, 0);
  if (!result) {
    Serial.println("AP Config failed.");
  } else {
    Serial.println("AP Config Success. Broadcasting with AP: " + String(
       coordinator_ap_ssid));
    Serial.print("AP CHANNEL "); Serial.println(WiFi.channel());

  }
}

#endif


#if defined(ENABLE_SENSOR_NODE)

// TODO: Test this on an ESP8266
#if defined(ESP8266)
void OnDataRecv(uint8_t *mac_addr, uint8_t *incomingData, uint8_t
   data_len) {
#elseif defined(ESP32)
//void OnDataRecv(const esp_now_recv_info *mac_addr, const uint8_t *
   incomingData, int data_len) {
void OnDataRecv(const uint8_t *mac_addr, const uint8_t *incomingData, int
    data_len) {
#endif
  char macStr[18];
  memcpy(&dataIN, incomingData, sizeof(dataIN));
  uint8_t mac_str[6] = {actuator_node_mac[0], actuator_node_mac[1],
     actuator_node_mac[2], actuator_node_mac[3], actuator_node_mac[4],
     actuator_node_mac[5]}
  snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
           mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr
              [4], mac_addr[5]);
  Serial.print("Last Packet Recv from: ");
  Serial.println(macStr);
```

```
  // Package sensor data for Python client

#if defined(USE_TRILL)

  #if TRILL_SENSOR_MODE == 0
  // Recieved trill data in RAW/DIFF mode
  Serial.print("ns:"); Serial.print(dataIN.numSensors);
  for(uint8_t i=0; i < dataIN.numSensors; i++) {
    int data = dataIN.sensorValues[i];
    Serial.print(",t"); Serial.print(i); Serial.print(":");
    Serial.print(dataIN.sensorValues[i]);
  }
  Serial.println();

  #else
  // Recieved trill data in TOUCH/CENTROID mode

  Serial.print("nt:"); Serial.print(dataIN.numTouches);
  Serial.print(",ta:"); Serial.print((int)dataIN.touchActive);
  for(int i=0; i<dataIN.numTouches; i++) {
    Serial.print(",tl"); Serial.print(i); Serial.print(":"); Serial.print
       (dataIN.touchLocations[i]);
    Serial.print(",ts"); Serial.print(i); Serial.print(":"); Serial.print
       (dataIN.touchSizes[i]);
  }
  Serial.println();
  #endif

#endif

  Serial.print("Bytes recieved: "); Serial.println(data_len);
}

#endif


#if defined(ENABLE_ACTUATOR_NODE)

// send data to actuator node
void sendData() {


  #if defined(ESP32)
  const uint8_t *peer_addr = actuator_node.peer_addr;
  esp_err_t result = esp_now_send(peer_addr, (uint8_t *) &dataOUT, sizeof
     (dataOUT));
  #endif

  #if defined(ESP8266)
  int result = esp_now_send(actuator_node_mac, (uint8_t *) &dataOUT,
     sizeof(dataOUT));
  #endif

  Serial.print("Send Status: ");
/*
Here's what the error codes generally mean in ESP-NOW:
```

```
ESP_OK (0): Operation completed successfully.
-1: Generic error.
-2: ESP-NOW is not initialized properly.
-3: Peer is not found during send operation.
-4: Cannot allocate memory for internal data structures.
-5: Operation not allowed in the current state.

If you are encountering an error code of -3,
it suggests that the specified peer (the one you are trying to send
data to) is not currently in the list of known peers. Make sure that
you have successfully added the peer using esp_now_add_peer before
attempting to send data to it.
*/


  #if defined(ESP32)
  if (result == ESP_OK) {
    Serial.println("Success");
  } else if (result == ESP_ERR_ESPNOW_NOT_INIT) {
    // How did we get so far!!
    Serial.println("ESPNOW not Init.");
  } else if (result == ESP_ERR_ESPNOW_ARG) {
    Serial.println("Invalid Argument");
  } else if (result == ESP_ERR_ESPNOW_INTERNAL) {
    Serial.println("Internal Error");
  } else if (result == ESP_ERR_ESPNOW_NO_MEM) {
    Serial.println("ESP_ERR_ESPNOW_NO_MEM");
  } else if (result == ESP_ERR_ESPNOW_NOT_FOUND) {
    Serial.println("Peer not found.");
  } else {
    Serial.println("Not sure what happened");
  }
  #endif

  #if defined(ESP8266)
  // See: https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api
      -reference/network/esp_now.html
  if (result == 0) {
    Serial.println("Success");
  } else if (result == 1) {
    Serial.println("Error 1: Send Failed!");
  } else {
    Serial.println("Error Code "); Serial.print(result); Serial.println("
         ... Not sure what happened");
  }
  #endif

}

// callback when data is sent to node
#ifdef ESP8266
void OnDataSent(uint8_t *mac_addr, uint8_t status) {
#endif
#ifdef ESP32
void OnDataSent(const uint8_t *mac_addr, esp_now_send_status_t status) {
```

```
#endif
  char macStr[18];
  if(verbose) {
    snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
           mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr
               [4], mac_addr[5]);
    Serial.print("Last Packet Sent to: ");
    Serial.println(macStr);
    Serial.print("Last Packet Send Status: ");
    #if defined(ESP32)
    Serial.println(status == ESP_NOW_SEND_SUCCESS ? "Delivery Success" :
        "Delivery Fail");
    #endif

    #if defined(ESP8266)
    Serial.println(status == 0 ? "Delivery Success" : "Delivery Fail");
    #endif
  }
}

#endif


// Check if the nodes are paired. If not, make a pairing
bool manageNodes() {
  #if defined(ESP32)
  if (actuator_node.channel == ESPNOW_CHANNEL) {
  #else
  if (true) { // TODO: Some other way to test is actuator node exists..
  #endif
    //if (DELETEBEFOREPAIR) deleteActuatorNode();
    Serial.print("Reciever Status: ");

    // check if the node is registered as a peer
    #if defined(ESP32)
    bool exists = esp_now_is_peer_exist(actuator_node.peer_addr);
    #endif

    #if defined(ESP8266)
    bool exists = esp_now_is_peer_exist(actuator_node_mac);
    #endif

    if ( exists) {
      Serial.println("Already Paired");
      return true;
    } else {
      char macStr[18];

      #if defined(ESP32)
      // attempt pairing with node ESP32
      esp_err_t addStatus = esp_now_add_peer(&actuator_node);
      if (addStatus == ESP_OK) {
        // Pair success
        uint8_t mac_addr[6] = {actuator_node_mac[0], actuator_node_mac
            [1], actuator_node_mac[2], actuator_node_mac[3],
            actuator_node_mac[4], actuator_node_mac[5] };
```

```
      snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
         mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr
             [4], mac_addr[5]);
      Serial.print("Actuator Node added to peer list with mac ");
      Serial.println(macStr);
      return true;
    } else if (addStatus == ESP_ERR_ESPNOW_NOT_INIT) {
      // How did we get so far!!
      Serial.println("ESPNOW Not Initialized!");
      return false;
    } else if (addStatus == ESP_ERR_ESPNOW_ARG) {
      Serial.println("Invalid Argument");
      return false;
    } else if (addStatus == ESP_ERR_ESPNOW_FULL) {
      Serial.println("Peer list full");
      return false;
    } else if (addStatus == ESP_ERR_ESPNOW_NO_MEM) {
      Serial.println("Out of memory");
      return false;
    } else if (addStatus == ESP_ERR_ESPNOW_EXIST) {
      Serial.println("Peer Exists");
      return true;
    } else {
      Serial.println("Not sure what happened");
      return false;
    }
    #else if defined(ESP8266)
    // For ESP8266 you need to use a different add peer function
    // See: https://github.com/esp8266/Arduino/blob/master/tools/sdk/
        include/espnow.h
    int addStatus = esp_now_add_peer(actuator_node_mac,
        actuator_node_role, ESPNOW_CHANNEL, actuator_node_key,
        actuator_node_key_len);
    if (addStatus == 0) {
      // Pair success
      uint8_t mac_addr[6] = {actuator_node_mac[0], actuator_node_mac
          [1], actuator_node_mac[2], actuator_node_mac[3],
          actuator_node_mac[4], actuator_node_mac[5] };
      snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
         mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr
             [4], mac_addr[5]);
      Serial.print("Actuator Node added to peer list ");
      Serial.println(macStr);
      return true;
    } else {
      Serial.print("Error code "); Serial.print(addStatus);
      Serial.println(" ... Not sure what happened");
      return false;
    }
    #endif


  }
} else {
  Serial.println("No Actuator Node found to process");
  return false;
```

```
  }
}


////////////////////////////////////////////////////////////////////////

void setup() {

  Serial.begin(PC_SERIAL_BAUD);
  delay(1500);
  Serial.println("Booting ESPNow Reciever");

  #if defined(ESP32)
  Serial.print("USING ESP32 CHIP IN");
  #endif

  #if defined(ESP8266)
  Serial.print("USING ESP8266 CHIP");
  #endif

  #if !defined(ESP32) && !defined(ESP8266)
  Serial.println("UNKNOWN CHIP! PROBABLY VERY LITTLE WILL WORK...");
  #endif

  #if defined(COORDINATOR_AP_MODE)
  // Set up coordinator in AP mode, with its own network SSID
  // that is discoverable by nodes.
  Serial.println("AP MODE");
  WiFi.mode(WIFI_AP);
  configDeviceAP();
  Serial.print("AP Config Successful with SSID "); Serial.println(
      coordinator_ap_ssid);
  Serial.print("AP MAC ADDRESS: "); Serial.println(WiFi.softAPmacAddress
      ());
  #else
  Serial.println(" STA MODE");
  // Set device in STA mode.
  // Add peer nodes directly by MAC address.
  WiFi.mode(WIFI_STA);
  delay(100);
  Serial.print("Station MAC Address ");
  Serial.println(WiFi.macAddress());
  #endif

  // Init ESPNow with a fallback logic
  InitESPNow();
  delay(100);
  manageNodes();


  #if defined(ENABLE_SENSOR_NODE)
  Serial.print("dataIN from sensor node has length "); Serial.println(
      sizeof(dataIN));
  esp_now_register_recv_cb(OnDataRecv);
  #endif
  #if defined(ENABLE_ACTUATOR_NODE)
```

```
  Serial.print("dataOUT to actuator node has length "); Serial.println(
      sizeof(dataOUT));
  esp_now_register_send_cb(OnDataSent);
  #endif


}


void loop() {

#if defined(ENABLE_ACTUATOR_NODE)

  // 1. Read any incoming messages from Python/PC into dataOUT

  if((millis() - timer) > transmissionPeriod_ms) { // transfer rate timer
    if (actuator_node.channel == ESPNOW_CHANNEL) { // check if
        actuator_node channel is defined
      // Add actuator node as a peer if it has not been added already
      bool isPaired = manageNodes();
      if (isPaired) {


        // 2. For now just create some random data....
        #if defined(USE_NEOPIXEL_STRIP)
        dataOUT.light_position += 1; // 0 - 255
        if(dataOUT.light_position > 255)
          dataOUT.light_position = 0;
        Serial.print("Set light_position to: "); Serial.println(dataOUT.
            light_position);
        #endif
        strncpy(dataOUT.msg, "SENTLPS", 7);
        dataOUT.msg[7] = '\0';
        Serial.print("Set msg to: "); Serial.println(dataOUT.msg);

        // 3. Transmit data to actuator node
        sendData();

      } else {
        Serial.println("Unable to pair with actuator node!");
      }
    }
    else {
      Serial.println("No actuator node configuration available!");
    }
    timer=millis();
  }


  // 1. read any serial messages available from python
  if (Serial.available() > 0) {
    String cmd = Serial.readString();
                Serial.println(cmd);
    // Populate dataOUT & send
    //esp_err_t result = esp_now_send(nodeAddress, (uint8_t *) &
        BME280Readings, sizeof(BME280Readings)); // Send message via ESP-
```

```
        NOW
    // if (result == ESP_OK) {
    //   Serial.println("Sent with success");
    // }
    // else {
    //   Serial.println("Error sending the data");
    // }
  }

#endif

}
```

28.4 Esp Receiver

```
/**
   ESPNOW - GENERAL FIRMWARE FOR A 1WAY SENSOR/ACTUATOR NODE
   This firmware sketch is meant as a starting point for creating custom
      sensor or actuator nodes.
   Depending on configuration of preproce ssor flags:
    * this firmware sends sensor data to a coordinator (NODE_MODE=0)
    * or recieves actuator signals from a coordinator (NODE_MODE=1)

  For the basis of ESPNow Arduino programming see: https://
     randomnerdtutorials.com/esp-now-esp32-arduino-ide/

  2023 (C) Jonathan Reus
  https://github.com/jreus
*/

//#define NODE_MODE 0 // 0 == SENSOR (SENDER) NODE
#define NODE_MODE 1 // 1 == ACTUATOR (RECIEVER) NODE
#define COORDINATOR_AP_MODE // uncomment if coordinator is running in AP-
   mode and broadcasting a network ssid
// Configure ESPNOW
#define ESPNOW_CHANNEL 11          // pick a channel (good to choose one
   not being used by ambient wifi)
#define ESPNOW_ENCRYPTION 0        // no encryption
#define PRINTSCANRESULTS 0
#define DELETEBEFOREPAIR 0

// Enable sensors - flags must match coordinator
//#define USE_ADXL313 // using an ADXL313 3-axis accelerometer
//#define USE_TRILL        // uncomment if using a Trill sensor
//#define TRILL_DEVICE_TYPE 1  // 0 for CRAFT, 1 for FLEX
//#define TRILL_SENSOR_MODE 1    // 0 for DIFF, 1 for CENTROID

// Enable actuators - flags must match coordinator
//#define USE_SERVO180 // use a standard servo/linear servo with
   operational values in degrees from 0-180
#define USE_NEOPIXEL_STRIP // use a strip of neopixels

#if defined(USE_NEOPIXEL_STRIP)
#include <Adafruit_NeoPixel.h>
// On ESP32 pins 6-11 are connected to SPI flash.
const uint8_t neopixel_dpin = 12; // use a pix appropriate to your ESP
   board
const uint8_t neopixel_led_count = 17; // how many neopixels are in the
   strip?
Adafruit_NeoPixel strip(neopixel_led_count, neopixel_dpin, NEO_GRB +
   NEO_KHZ800);
// Argument 3 = Pixel type flags, add together as needed:
//   NEO_KHZ800  800 KHz bitstream (most NeoPixel products w/WS2812 LEDs)
//   NEO_KHZ400  400 KHz (classic 'v1' (not v2) FLORA pixels, WS2811
   drivers)
//   NEO_GRB     Pixels are wired for GRB bitstream (most NeoPixel
   products)
//   NEO_RGB     Pixels are wired for RGB bitstream (v1 FLORA pixels, not
    v2)
```

```
//   NEO_RGBW    Pixels are wired for RGBW bitstream (NeoPixel RGBW
    products)
#endif



// Set coordinator SSID prefix, or coordinator MAC address
#if defined(COORDINATOR_AP_MODE)
const char* coordinator_ap_ssid_prefix = "rcv_"; // Set this to your AP
    coordinator's SSID prefix
#else
// Coordinator is STA mode. Set this to your coordinator's MAC address so
     that this node will be able to find it.
//uint8_t coordinator_sta_mac[] = {0xE8, 0x9F, 0x6D, 0x2F, 0x64, 0x10};
    // ESP32 v2 a
//uint8_t coordinator_sta_mac[] = {0xE8, 0x9F, 0x6D, 0x2F, 0x48, 0x54};
    // ESP32 v2 b
uint8_t coordinator_sta_mac[] = {0xE8, 0x9F, 0x6D, 0x32, 0xFF, 0x50}; //
    ESP32 v2 c
//uint8_t coordinator_sta_mac[] = {0x5C, 0xCF, 0x7F, 0xEF, 0xBD, 0x81};
    // ESP8266 r
#endif

#if defined(ESP32)
#include <esp_now.h>
#include <WiFi.h>
#include <esp_wifi.h> // only for esp_wifi_set_channel()
#endif
#if defined(ESP8266)
// TODO: ESP8266 compatible version of this firmware
#endif

#if defined(USE_ADXL313)
#include <Wire.h>
#include <SparkFunADXL313.h>
ADXL313 accel3x;
#endif


#if defined(USE_TRILL)
#include <Trill.h>
Trill trillSensor;
boolean trillTouchActive = false;
bool trillOK = false;
#if TRILL_DEVICE_TYPE == 0
const Trill::Device trillDevice = Trill::TRILL_CRAFT;
#else
const Trill::Device trillDevice = Trill::TRILL_FLEX;
#endif
#if TRILL_SENSOR_MODE == 0
const Trill::Mode trillMode = Trill::DIFF;
#else
const Trill::Mode trillMode = Trill::CENTROID;
#endif
#endif
```

```
#if NODE_MODE == 0
// NODE_MODE == 0 - REMOTE SENSOR NODE
// Sensor Output Data package, must match data package format in Reciever firmware
// ESPNow spec limits this to around 250 bytes
typedef struct sensor_data_package {
#if defined(USE_TRILL)
  #if TRILL_SENSOR_MODE == 0
  // Trill DIFF parameters
  uint8_t numSensors = 30;
  int sensorValues[30];      // raw sensor values minus baseline
  #else
  // Trill CENTROID parameters
  int numTouches = 0;        // number of activate touches
  int touchLocations[5];     // touch location points
  int touchSizes[5];         // touch centroid sizes
  bool touchActive = false; // touch active
  #endif
#endif
#if defined(USE_ADXL313)
  int ax = 0;
  int ay = 0;
  int az = 0;
#endif
  char msg[8];
} sensor_data_package;
sensor_package dataOUT;

#else

// NODE_MODE == 1 - REMOTE ACTUATOR CONTROL
// Actuator Input Data package, must match data package format in Coordinator firmware
// ESPNow spec limits this to around 250 bytes
typedef struct actuator_data_package {
  #if defined(USE_NEOPIXEL_STRIP)
  uint8_t light_position = 0; // simplified control, set a led strip position from 0-255
  //uint32_t led_colors[neopixel_led_count]; // careful, this can fill up the max 250 byte data package very quickly!
  #endif
  char msg[8];
} actuator_data_package;
actuator_data_package dataIN;

#endif



esp_now_peer_info_t coordinator;
//timer for transmission rate
unsigned long timer = 0;
const int samplingPeriod_ms = 15;   // desired transmission period in milliseconds
const bool verbose = false;         // verbose serial output
```

```
////////////////////////////////////////////////////////////////////////////////


// Init ESP Now with fallback
void InitESPNow() {
  WiFi.disconnect();
  if (esp_now_init() == ESP_OK) {
    Serial.println("ESPNow Init Success");
  }
  else {
    Serial.println("ESPNow Init Failed");
    // Retry InitESPNow, add a counte and then restart?
    // InitESPNow();
    // or Simply Restart
    ESP.restart();
  }
}


#if defined(COORDINATOR_AP_MODE)

// Scan for coordinator AP network with SSID including
   coordinator_ap_ssid_prefix
void ScanForCoordinator() {
  int16_t scanResults = WiFi.scanNetworks(false, false, false, 300,
     ESPNOW_CHANNEL); // Scan for networks on ESPNOW_CHANNEL
  // reset on each scan
  bool coordinatorFound = 0;
  memset(&coordinator, 0, sizeof(coordinator));
  Serial.println("Scanning for coordinator AP networks on channel ");
     Serial.println(ESPNOW_CHANNEL);
  if (scanResults == 0) {
    Serial.println("No WiFi devices in AP Mode found on channel");
  } else {
    Serial.print("Found "); Serial.print(scanResults); Serial.println("
       devices on channel");
    for (int i = 0; i < scanResults; ++i) {
      // Print SSID and RSSI for each device found
      String SSID = WiFi.SSID(i);
      int32_t RSSI = WiFi.RSSI(i);
      String BSSIDstr = WiFi.BSSIDstr(i);

      if (PRINTSCANRESULTS) {
        Serial.print(i + 1);
        Serial.print(": ");
        Serial.print(SSID);
        Serial.print(" (");
        Serial.print(RSSI);
        Serial.print(")");
        Serial.println("");
      }
      delay(10);
      // Check if the current device starts with RCV_PREFIX
      if (SSID.indexOf(coordinator_ap_ssid_prefix) == 0) {
```

```
        // SSID of interest
        Serial.println("Found the Coordinator.");
        Serial.print(i + 1); Serial.print(": "); Serial.print(SSID);
            Serial.print(" ["); Serial.print(BSSIDstr); Serial.print("]");
             Serial.print(" ("); Serial.print(RSSI); Serial.print(")");
            Serial.println("");
        // Get BSSID => Mac Address of the Reciever
        int mac[6];
        if ( 6 == sscanf(BSSIDstr.c_str(), "%x:%x:%x:%x:%x:%x",  &mac[0],
             &mac[1], &mac[2], &mac[3], &mac[4], &mac[5] ) ) {
          for (int ii = 0; ii < 6; ++ii ) {
            coordinator.peer_addr[ii] = (uint8_t) mac[ii];
          }
        }

        coordinator.channel = ESPNOW_CHANNEL;
        coordinator.encrypt = ESPNOW_ENCRYPTION;

        coordinatorFound = 1;
        // Break after we find one matching AP network / coordinator
        break;
      }
    }
  }

  if (coordinatorFound) {
    Serial.println("Coordinator Found, processing..");
  } else {
    Serial.println("Coordinator Not Found, trying again.");
  }

  WiFi.scanDelete(); // clean up memory
}
#endif

// Check if the coordinator is already paired with this node.
// If not, make a pairing
bool manageCoordinator() {

  if (coordinator.channel == ESPNOW_CHANNEL) {
    if (DELETEBEFOREPAIR) deleteCoordinator();


    // check if the coordinator is registered as a peer
    bool exists = esp_now_is_peer_exist(coordinator.peer_addr);
    if ( exists) {
      if(verbose) {
        Serial.print("Coordinator Status: ");
        Serial.println("Already Paired");
      }
      return true;
    } else {
      // attempt pairing with coordinator
      esp_err_t addStatus = esp_now_add_peer(&coordinator);
      if (addStatus == ESP_OK) {
        // Pair success
```

```
        Serial.println("Coordinator added to peer list");
        return true;
      } else if (addStatus == ESP_ERR_ESPNOW_NOT_INIT) {
        // How did we get so far!!
        Serial.println("ESPNOW Not Initialized!");
        return false;
      } else if (addStatus == ESP_ERR_ESPNOW_ARG) {
        Serial.println("Invalid Argument");
        return false;
      } else if (addStatus == ESP_ERR_ESPNOW_FULL) {
        Serial.println("Peer list full");
        return false;
      } else if (addStatus == ESP_ERR_ESPNOW_NO_MEM) {
        Serial.println("Out of memory");
        return false;
      } else if (addStatus == ESP_ERR_ESPNOW_EXIST) {
        Serial.println("Peer Exists");
        return true;
      } else {
        Serial.println("Not sure what happened");
        return false;
      }
    }
  } else {
    if(verbose) Serial.println("No Reciever found to process");
    return false;
  }
}

void deleteCoordinator() {
  esp_err_t delStatus = esp_now_del_peer(coordinator.peer_addr);
  Serial.print("Coordinator Delete Status: ");
  if (delStatus == ESP_OK) {
    // Delete success
    Serial.println("Success");
  } else if (delStatus == ESP_ERR_ESPNOW_NOT_INIT) {
    // How did we get so far!!
    Serial.println("ESPNOW Not Init");
  } else if (delStatus == ESP_ERR_ESPNOW_ARG) {
    Serial.println("Invalid Argument");
  } else if (delStatus == ESP_ERR_ESPNOW_NOT_FOUND) {
    Serial.println("Peer not found.");
  } else {
    Serial.println("Not sure what happened");
  }
}



#if NODE_MODE == 0
// OUTGOING SENSOR DATA FUNCTIONS...

// read sensors & load readings into dataOUT
void readSensors() {
  delay(50); // delay for stability
```

```
  #if defined(USE_TRILL)

  #if TRILL_SENSOR_MODE == 0
  if(trillOK) {
    trillSensor.requestRawData();
    if(trillSensor.rawDataAvailable() > 0) {
      readRawTrillData(trillSensor);
    }
  }
  #else
  // Read TOUCH/CENTROID data
  trillSensor.read();
  dataOUT.numTouches = trillSensor.getNumTouches();
  if(dataOUT.numTouches > 0) {
    for(uint8_t i = 0; i < dataOUT.numTouches; i++) {
      dataOUT.touchLocations[i] = trillSensor.touchLocation(i);
      dataOUT.touchSizes[i] = trillSensor.touchSize(i);
    }
    dataOUT.touchActive = true;
  }
  else if(dataOUT.touchActive) {
    // One reading with no touches, set touchActive to 0
    dataOUT.touchActive = false;
  }
  #endif

  #endif

  #if defined(USE_ADXL313)
  if(accel3x.dataReady()) // check data ready interrupt, note, this
     clears all other int bits in INT_SOURCE reg
  {
    accel3x.readAccel(); // read all 3 axis, they are stored in class
       variables: myAdxl.x, myAdxl.y and myAdxl.z
    dataOUT.ax = accel3x.x;
    dataOUT.ay = accel3x.y;
    dataOUT.az = accel3x.z;
  }
  #endif

  // Set sensor read info message, can be 7 characters max
  dataOUT.msg = "ALLGOOD";

}

uint8_t data = 0;
// send data to coordinator
void sendData() {
  const uint8_t *peer_addr = coordinator.peer_addr;
  esp_err_t result = esp_now_send(peer_addr, (uint8_t *) &dataOUT, sizeof
     (dataOUT));

  #if defined(USE_TRILL)

  #if TRILL_SENSOR_MODE == 0
  // Trill RAW/DIFF data
```

```
  for(uint8_t i=0; i < dataOUT.numSensors; i++) {
    int data = dataOUT.sensorValues[i];
    if(data < 1000)
      Serial.print(0);
    if(data < 100)
      Serial.print(0);
    if(data < 10)
      Serial.print(0);
    Serial.print(data);
    Serial.print(" ");
  }
  Serial.println("");
  #else
  // Trill TOUCH/CENTROID data
  Serial.print(dataOUT.numTouches); Serial.print(" touches: ");
  for(int i=0; i < dataOUT.numTouches; i++) {
    Serial.print(dataOUT.touchLocations[i]); Serial.print(" ");
    Serial.print(dataOUT.touchSizes[i]); Serial.print("  ");
  }
  Serial.println();
  #endif

  #endif

  #if defined(USE_ADXL313)
  // ADXL x/y/z values
  Serial.print("x:"); Serial.print(dataOUT.ax);
  Serial.print("y:"); Serial.print(dataOUT.ay);
  Serial.print("z:"); Serial.print(dataOUT.az);
  Serial.println();
  #endif

  Serial.print("Send Status: ");

  if (result == ESP_OK) {
    if(verbose) Serial.println("Success");
  } else if (result == ESP_ERR_ESPNOW_NOT_INIT) {
    // How did we get so far!!
    Serial.println("ESPNOW not Init.");
  } else if (result == ESP_ERR_ESPNOW_ARG) {
    Serial.println("Invalid Argument");
  } else if (result == ESP_ERR_ESPNOW_INTERNAL) {
    Serial.println("Internal Error");
  } else if (result == ESP_ERR_ESPNOW_NO_MEM) {
    Serial.println("ESP_ERR_ESPNOW_NO_MEM");
  } else if (result == ESP_ERR_ESPNOW_NOT_FOUND) {
    Serial.println("Peer not found.");
  } else {
    Serial.println("Not sure what happened");
  }
}


// callback when data is sent to coordinator
void OnDataSent(const uint8_t *mac_addr, esp_now_send_status_t status) {
  char macStr[18];
```

```
  if(verbose) {
    snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
           mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr
              [4], mac_addr[5]);
    Serial.print("Last Packet Sent to: ");
    Serial.println(macStr);
    Serial.print("Last Packet Send Status: ");
    Serial.println(status == ESP_NOW_SEND_SUCCESS ? "Delivery Success" :
       "Delivery Fail");
  }
}


#else
// INCOMING ACTUATOR DATA FUNCTIONS...

//callback when data is recieved from coordinator
void OnDataRecv(const uint8_t * mac, const uint8_t *incomingData, int len
   ) {
  Serial.print("Data Recieved: ");
  Serial.println(len);


  memcpy(&dataIN, incomingData, sizeof(dataIN));

  /*
  uint8_t light_position = 0; // simplified control, set a led strip
     position from 0-255
  //uint32_t led_colors[neopixel_led_count]; // careful, this can fill up
      the max 250 byte data package very quickly!
  #endif
  char msg[8];
  */

  #if defined(USE_NEOPIXEL_STRIP)
  Serial.print("lp:");
  Serial.print(dataIN.light_position);
  #endif

  Serial.print(",msg:");
  Serial.print(dataIN.msg);
  Serial.println();

}

#endif


////////////////////////////////////////////////////////////////////////

void setup() {
  Serial.begin(115200);
  delay(1500);
  Serial.println("BEGIN ESPNOW 1WAY NODE");

#if NODE_MODE == 0
```

```
//====== SETUP SENSORS========
  Serial.println("RUNNING AS SENSOR NODE / SENDER");
  Serial.print("dataOUT has length "); Serial.println(sizeof(dataOUT));

  #if defined(USE_TRILL)

  int ret = trillSensor.setup(trillDevice);
  delay(50);
  trillSensor.setMode(trillMode);
  if(ret != 0) {
    Serial.println("failed to initialise trillSensor");
    Serial.print("Error code: ");
    Serial.println(ret);
    trillOK=false;
  } else {
    Serial.println("Trill was detected!");
    trillOK=true;
    printTrillInfo();
  }

  #endif

  #if defined(USE_ADXL313)

  #if !defined(USE_TRILL)
  Wire.begin(); // this gets called in trillSensor.setup()
  #endif

  if (accel3x.begin() == false) //Begin communication over I2C
  {
    Serial.println("The ADXL313 sensor did not respond. Please check
       wiring.");
    while(1); //Freeze
  }
  Serial.print("The ADXL313 Sensor was detected and is connected properly
     .");
  accel3x.measureModeOn(); // wakes up the sensor from standby and puts
     it into measurement mode

  #endif

#else
//====== SETUP ACTUATORS ========
  Serial.println("RUNNING AS ACTUATOR NODE / RECIEVER");
  Serial.print("dataIN has length "); Serial.println(sizeof(dataIN));

  #if defined(USE_NEOPIXEL_STRIP)
  // strip.begin();           // INITIALIZE NeoPixel strip object (
     REQUIRED)
  // strip.show();            // Turn OFF all pixels ASAP
  // strip.setBrightness(50); // Set BRIGHTNESS to about 1/5 (max = 255)
  #endif


#endif
```

```
  // Setup ESPNOW...
  WiFi.mode(WIFI_STA);
  esp_wifi_set_channel(ESPNOW_CHANNEL, WIFI_SECOND_CHAN_NONE);
  Serial.println("Configuring ESPNow Node");
  Serial.print("STA MAC: "); Serial.println(WiFi.macAddress());
  Serial.print("STA CHANNEL "); Serial.println(WiFi.channel());

  // Init ESPNow with a fallback logic
  Serial.println("Initializing ESPNow");
  InitESPNow();

#if NODE_MODE == 0
  // Once ESPNow is successfully Init, we will register for Send CB to
  // get the status of Trasnmitted packet
  Serial.println("Register OnDataSent Callback");
  esp_now_register_send_cb(OnDataSent);
#else
  // Register recieve callback
  Serial.println("Register OnDataRecv Callback");
  esp_now_register_recv_cb(OnDataRecv);
#endif

  // Register reciever as a peer
  #if defined(COORDINATOR_AP_MODE)
  ScanForCoordinator();
  #else
  memcpy(coordinator.peer_addr, coordinator_sta_mac, 6);
  coordinator.channel = ESPNOW_CHANNEL;
  coordinator.encrypt = ESPNOW_ENCRYPTION;
  #endif

  // Register coordinator as peer
  while( ! manageCoordinator() ) {
    delay(3000);
    Serial.println("Retry connection to coordinator...");
  }

}

void loop() {

#if NODE_MODE == 0
//SENSOR SAMPLING

  if((millis() - timer) > samplingPeriod_ms) { // transfer rate timer
    if (coordinator.channel == ESPNOW_CHANNEL) { // check if reciever
        channel is defined
      // Add coordinator as a peer if it has not been added already
      bool isPaired = manageCoordinator();
      if (isPaired) {
        readSensors();
        sendData();
      } else {
        Serial.println("Unable to pair with coordinator!");
      }
```

```
    }
    else {
      Serial.println("No coordinator configuration available!")
    }
    timer=millis();
  }

#else
// ACTUATOR CONTROL
  bool isPaired = manageCoordinator();
  delay(1000);
#endif

}


#if NODE_MODE == 0 && defined(USE_TRILL)

/////// TRILL HELPER FUNCTIONS ///////
void printTrillInfo() {
  int address = trillSensor.getAddress();

  Serial.println("Trill Device Details: ");
  Serial.print("\t- I2C address: ");
  Serial.print("#");
  Serial.print(address, HEX);
  Serial.print(" (");
  Serial.print(address);
  Serial.println(")");

  int deviceType = trillSensor.deviceType();
  Serial.print("\t- Trill device type: ");
  switch(deviceType) {
    case Trill::TRILL_BAR:
      Serial.println("bar");
      break;
    case Trill::TRILL_SQUARE:
      Serial.println("square");
      break;
    case Trill::TRILL_HEX:
      Serial.println("hex");
      break;
    case Trill::TRILL_RING:
      Serial.println("ring");
      break;
    case Trill::TRILL_CRAFT:
      Serial.println("craft");
      break;
        case Trill::TRILL_FLEX:
      Serial.print("flex");
      break;
    case Trill::TRILL_UNKNOWN:
      Serial.println("unknown");
      break;
    case Trill::TRILL_NONE:
      Serial.println("none");
```

```
      break;
  }
    int firmwareRev = trillSensor.firmwareVersion();
    Serial.print("\t- Firmware version: ");
    Serial.println(firmwareRev);

    int mode = trillSensor.getMode();
    Serial.print("\t- Sensor mode: ");
    switch(mode) {
      case Trill::CENTROID:
        Serial.println("centroid");
        break;
      case Trill::RAW:
        Serial.println("raw");
        break;
      case Trill::BASELINE:
        Serial.println("baseline");
        break;
      case Trill::DIFF:
        Serial.println("differential");
        break;
      case Trill::AUTO:
        Serial.println("auto");
        break;
    }

    Serial.print("\t- Number of available centroid dimensions: ");
    if(trillSensor.is1D()) {
      Serial.println(1);
    } else if(trillSensor.is2D()) {
      Serial.println(2);
    } else {
      Serial.println(0);
    }

    int numChannels = trillSensor.getNumChannels();
    Serial.print("\t- Number of capacitive channels: ");
    Serial.println(numChannels);

    int numButtons = trillSensor.getNumButtons();
    Serial.print("\t- Number of button channels: ");
    Serial.println(numButtons);
}

void readRawTrillData(Trill & trill) {
  uint8_t i = 0;
  while(trill.rawDataAvailable() > 0) {
    dataOUT.sensorValues[i] = trill.rawDataRead();
    i++;
  }
}

// See: https://github.com/BelaPlatform/Trill-Arduino/blob/master/Trill.
    cpp function begin()
String decodeTrillError(int errcode) {
  String res;
```

```
  switch(errcode) {
    case -2:
      res = "i2c address does not match known i2c addresses for Trill
         boards";
      break;
    case 2:
      res = "Unable to identify device";
      break;
    case -3:
      res = "Unknown device type";
      break;
    case -1:
      res = "Unknown device mode";
      break;
    case 0:
      res = "Successful intiialization";
      break;
    default:
      res = "Unknown error code";
      break;
  }
  return res;
}
#endif
```