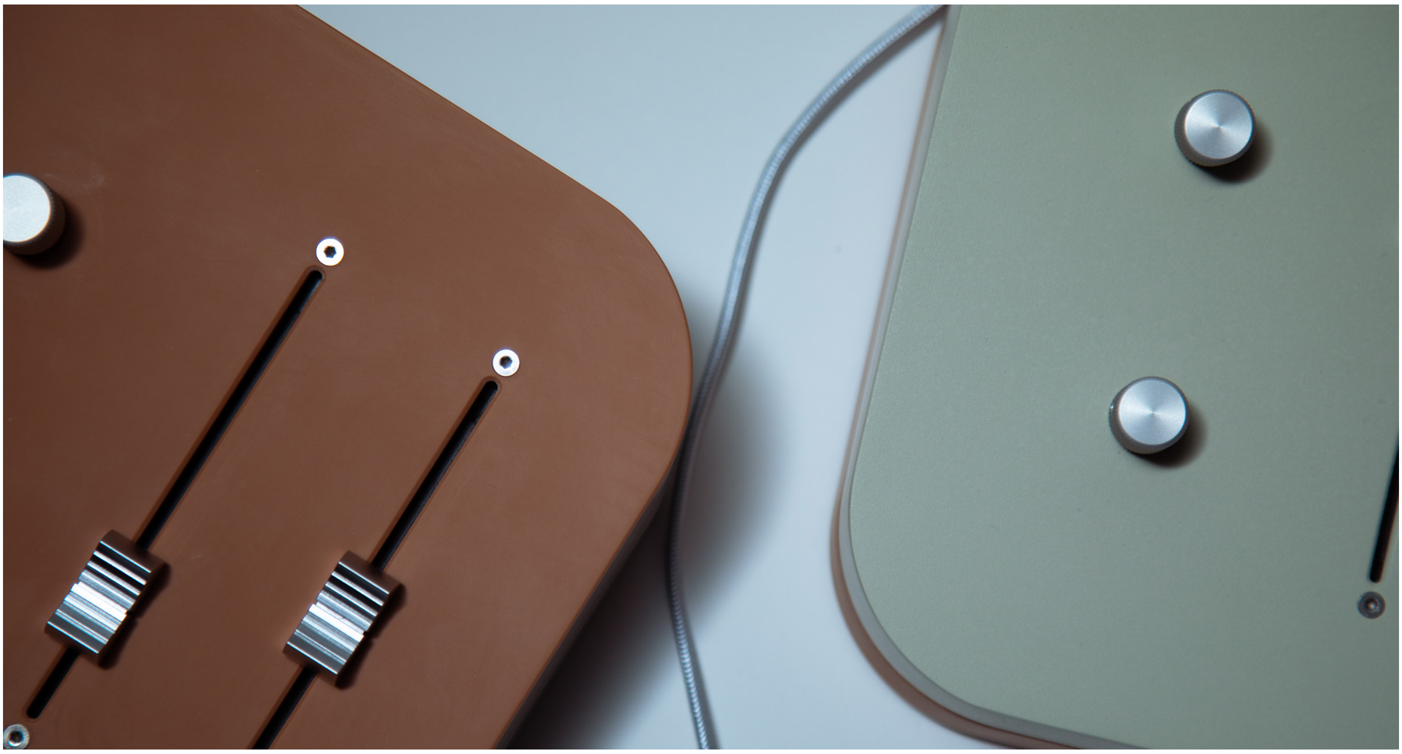
Title:	Waviic
Author:	Svenja Steurer Jene Daniel Treystman
Matrikel-Nr.:	20-191-524 22-531-909
Date:	June 2023
Mentors:	Joëlle Bitton, Verena Ziegler
Typeface:	Fagun IvyEpic



ABSTRACT

This thesis examines the potential benefits of using configurable haptic feedback in musical interfaces to improve the performer's ability to control and manipulate sound in electronic and computer-based music performance. Through literature review, interviews and user testing, we explore how different sensory perceptions are connected and support each other in order to create rich multimodal interactions.

Our research results in an open source MIDI controller with haptic behaviours and a graphical user interface that provides musicians with an additional dimension of software control. The ultimate goal is to contribute to the development of more tangible and adaptable interfaces, notably in the field of electronic music

Acknowledgments

We would like to express our deep appreciation to all the wonderful people who helped us along the way in completing our thesis and project. Our mentors, Joëlle Bitton for her invaluable support, guidance, and insightful questioning that helped us develop our project further. Verena Ziegler for taking her time in the mentoring sessions and helpful support.

We are also grateful to Hanna Järveläinen and Stefano Papetti for taking time out of their busy schedules to share their knowledge and insights with us during the interview session. Pascal Lund-Jensen deserves a special mention for being the first to try our project live on stage, his constructive feedback and for designing the sound for the exhibition.

We would like to express our appreciation to the musicians who participated in the interviews, Marco Milevski, Kay Zhang, Rebecca Becks and Andreas Götz, for generously sharing their practices, ideas, and enthusiasm with us. We are also thankful to Caterina De Nicola, Martin Reck, and Pascal Lund-Jensen for their participation in the workshop and valuable feedback.

Our classmates, Bin Martig, Johannes Reck, and Janosch Tilich, and Luke Franzke and Paulina Zybinska, provided us with much-needed support and feedback throughout the project. We are also grateful to Jacob Wachtl and Julian Gisler for helping us with modelling and printing the enclosure, and to Hans Jörg Steurer and Alexander Treystman for their expertise in mechanical and electronic engineering, respectively.

Marcial Koch for his hard work, making sure we get to present our work in the best possible way, and for assisting with any question and request along the way. Frederic Letsch and Jonas Lauener took their time to meet and support us with the code, and we are so very thankful for that.

To all the participants in our user testings, thank you so much for taking your time and giving much appreciated feedback.

Finally, we would like to acknowledge the support and feedback of all the mentors and classmates who helped us to refine our project and ourselves.

Thank you all for your contributions.

Table of Contents

INTRODUCTION

The use of various interfaces has become ever-present in our daily lives, seamlessly integrating into our routine activities. From the knobs to control the oven to the TV remote control, interfaces have become an intuitive extension of our body and mind. They have been designed to bridge the gap between the physical and the seemingly invisible things we control and enable us to touch what couldn't be touched before. One particular design aspect has a fascinating history, which is the QWERTY type system, and the first prototype created by Christopher Latham Sholes in 1868, which finally created the first commercial typewriter (Edwards, 2022). Enabling the typing of letters through repurposing the existing piano interface, which evokes familiar sense of touch and use, highlights the profound impact interfaces can have on shaping human behaviour and expanding possibilities. Today, the ability to change the language and layout of a computer keyboard to suit different languages underscores the value in considering for whom the interface is designed for and how it influences the quality of the output.

Given the significance of interfaces in shaping behaviour, we aim to examine the application of *Musical Instrument Digital Interface* (MIDI) controllers in electronic music. Although less familiar to the general public, this interface is not so far removed from the examples discussed earlier. In its essence, a MIDI controller is a device that controls software, but what makes it unique is the user's ability to assign its functionality for each component, such as a dial knob. This flexibility allows performers and technicians alike to personalise their control over the software, making it a powerful and multifunctional tool not only in electronic music but also in lighting and other live performance contexts (*MIDI: Your Guide to MIDI and MIDI Controllers*, 2022). The difficulty with a device that can act as a control for anything in a software, is that it may not be intuitive for the user. A level of perplexity arises from the fact that the device is supposed to provide control over multiple functions or softwares, but it may become challenging to navigate due to a lack of familiarity or association. In other words, the device's versatility may come at the expense of its usability, creating a potential barrier in controlling a software.

Building upon the concept of giving physicality to abstract digital information, it is notable that certain types of information feel more comprehensible when they are tactile. Through touch, the characteristics of an object can be noticed which includes shape, weight, texture (Jones, 2018), as well as the sound that it produces when manipulated. This is particularly relevant when visual information is limited or inaccessible, as it allows us to better understand and process our surroundings.

Taking a different perspective, philosopher Robert Passau delves into the definition and perception of sound, positing that objects are the source of sound and thus linking sound to the vibrations of the objects themselves (Pasnau, 1999). This raises important questions within the context of designing objects or devices for sound control, such as their intended function and the location of the sound source. When working with electronic sounds, musicians most often rely on speakers as the output source, which creates detachment between them and the device controlling the sound.

Our research seeks to examine the historical context of electronic music, its evolution and applications, and connect it with the need and desire for physical interfaces as a performance instrument. We are intrigued by the challenge of controlling sound and designing interfaces that tackle the invisible nature of auditory and tactile sensations. We recognise the importance of exploring and understanding the relationship between these elements in order to find the purpose of interfacing for musicians. By doing so, we aim to create tactile musical interfaces that are intuitive, expressive, and responsive to the needs of electronic musicians.
We are diving into the necessity of musical gestures in the act of performance, the origins of the MIDI protocol and the use of computers in music. Following that, an analysis of the relationship between computers and the performative challenges that come with it.

Additionally we will introduce haptic terminology and technologies, and its relevance within human-computer interactions. Further we dissect an overview of relevant existing interfaces and their use cases, and lastly proceed to the research questions, our positioning of motivation and intended contribution.

RESEARCH FIELD

Background and Context

Musical Gestures

Our initial core of investigation lies in connection of sound perception, cognition and sensory-motor. As acoustic instruments and likewise singing require sensory-motor skills, electronic music has by most a missing link to the physical aspects and body involvement, and in such we often can witness computer based performers interacting with the computer in a manner that resembles office work, and does not leave much space for the crowd to engage in the performance (Wessel, 2006).

There is a disconnection between the musician's gesture and the sound (Françoise, 2013), which is known as the *mapping:* essentially, it is the decision to assign a sound or a sound control parameter to a gesture, mediated through an interface. Since the mapping procedure exists in the digital realm and is up to the musician's decisions, it often results in arbitrary connections (Caramiaux et al., 2014).

In the article *"Borrowed Gestures: The Body as an Extension of the Musical Instrument"* by Doga Cavir and Ge Wang (2021), an overview of different angles to the definition of *musical gestures* is given. A musical gesture is one that has the functionality of generating or modifying sound, or as communicative or performative actions which "*...indirectly affect or have no influence on the sound*" (Cavdir & Wang, 2021, para. 15). The essay *"Musical gestures: concepts and methods in research* (Jensenius et al., 2010)", attempts to categorise gestures into three main functions:

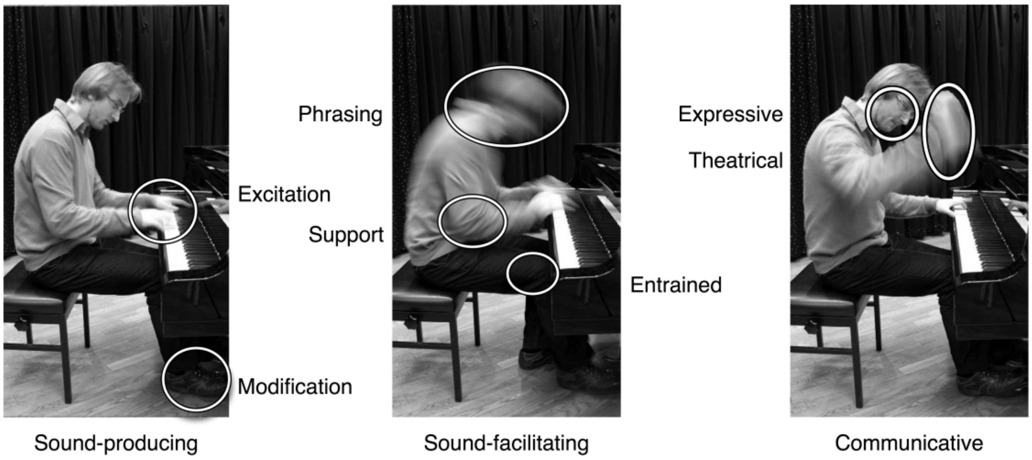
- ***Communication***, as a means of social interaction or human-machine communication.

- ***Control***, parts of a system, e.g controlling interactive systems. Common in the field of human-computer interaction (HCI).

- ***Metaphor***, where gestures are used to represent abstract concepts related to culture through physical movement, sound, or other types of perception.

Through this framework, the paper explores *musical gestures* from a functional angle:

Sound producing gestures, the actions needed for the production or modification of sound.
Communicative gestures, intended for either performer-performer or performer-audience communication.
Sound facilitating gestures are supporting sound producing gestures in various ways, and often intersect with communicative gestures.
Sound accompanying gestures, e.g following sound features through dancing, nodding heads etc.



Jensenius, A. R. (2009). Fig.1: Examples of where different types of musical gestures (sound-producing, sound-facilitating and communicative) may be found in piano performance. DOI:10.4324/9780203863411

Based on these definitions and categorisation we can discuss the term *expressivity*, and start to understand what it means in terms of physical gestures to be expressive. It is important to note that Jensenius et al. did not attempt to create an absolute classification system, but rather to identify their different functions. Many if not all of the above can flow into each other, for example all can be seen as *communicative*, yet the separation of the gestures has been found valuable based on their primary *intention (*Jensenius et al., 2010).

While sound producing gestures in computer based music might come down to a push of a button or a slide of a fader, where large body movement is not necessarily needed, it could be followed or done in parallel with several of the above. For example, head nodding to the beat or dance moves as an accompanying gesture, or body movement that anticipates the push of a button, as a sound facilitating or communicative gesture. Although some interfaces might require big sound producing gestures (e.g drums or accordion) and some only require small (trumpet or the flute), there is room for supporting sound and performance with other types of gestures.

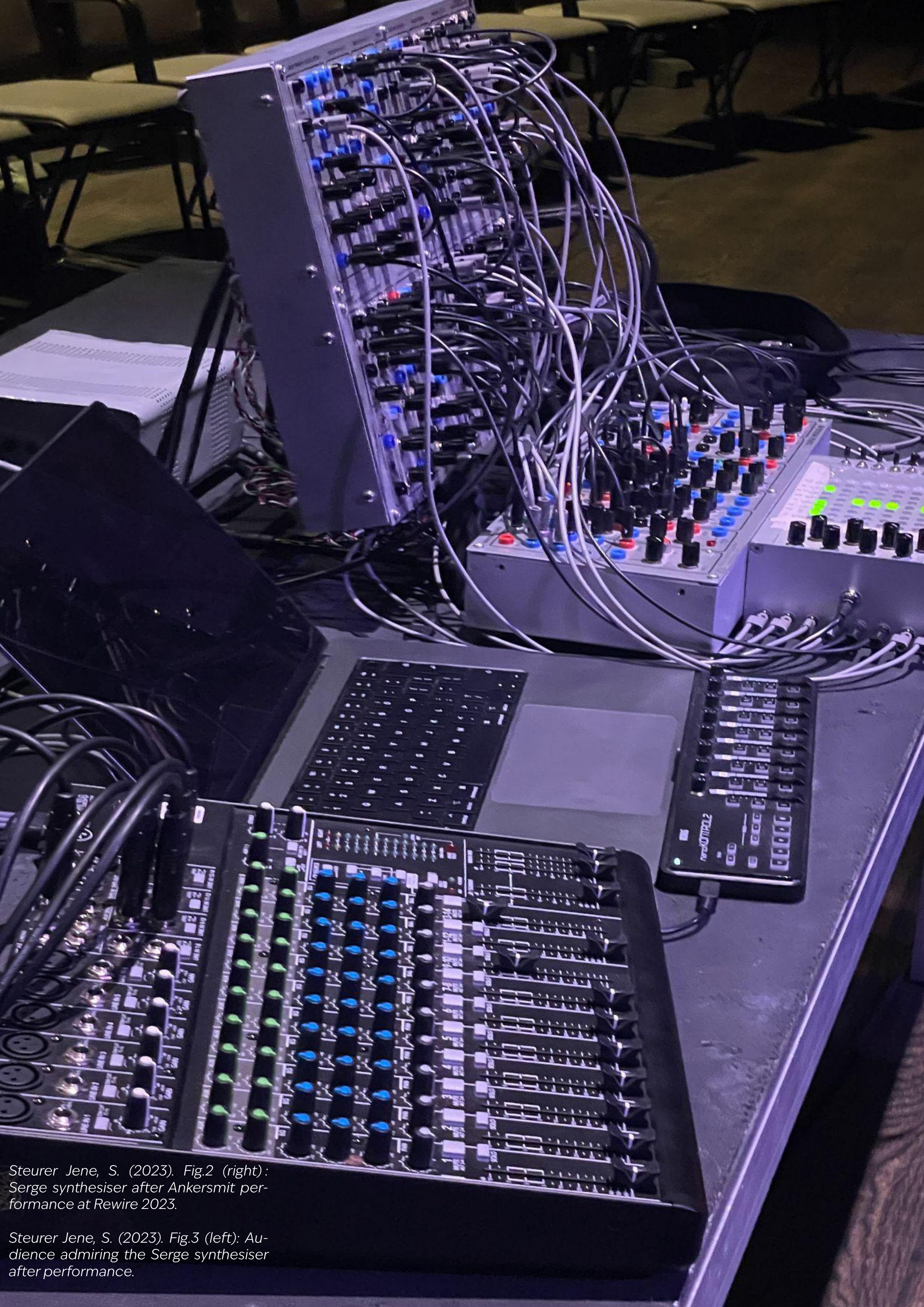
We attended a concert of Thomas Ankersmit, working with a modular synthesiser system, an electronic machine capable of producing and modifying sounds, called *Serge (1972)*. He is known for his investigation and the incorporation of psychoacoustic phenomena in his music (Ankersmit, 2018).

Ankersmit was initially sitting and facing us, and the synthesiser was positioned completely with its back to us, so we were not able to see any specifics of his technique and control. And yet, we were completely engaged in the performance and music. We can explain that by the way Ankersmit engaged himself in the performance: facial expressions, changing positions from sitting to standing, and at times very fast yet calculated movements. We could sense that he was immersed in the action of playing, and so were we.

Given the above, we yet recognise a dichotomy in the gesture-to-sound connection in the scope of free user mapping, meaning endless possibilities of sound versus given physicality due to the mechanics of the interface.

A notable difference between classical and electronic music lies in the way gesture and appearance are perceived.

In western classical music fields not only a strong stage presence is expected, which encompasses everything from the performer's attire to their bold physical expression and gestures, but also adherence to traditional techniques of playing.



Steurer Jene, S. (2023). Fig.2 (right): Serge synthesiser after Ankersmit performance at Rewire 2023.

Steurer Jene, S. (2023). Fig.3 (left): Audience admiring the Serge synthesiser after performance.

For example, classical guitar players are taught to maintain proper posture in order to execute their techniques flawlessly.
While posture and instrument technique are heavily prescribed in western classical music tradition (Davidson, 2012), electronic music musicians are forced to consider forms of interfaces with their composition and choice of expression as an integral aspect of their creative process. There is a notion of freedom in how gestures and movements can be represented or expressed by the intentions of the musician on stage.

To understand the values and constraints of making music with electronic music devices we need to take a look into the origin history of the evolution enabled through the MIDI protocol.

The Beginning of the MIDI Protocol

Nowadays MIDI controllers are a common way of interfacing with softwares, mainly music, light and video editing. It gives the ability for the user to assign the control components (faders, knobs, buttons etc.) to specific parameters in the software (mapping), and so to create a 1 to 1 link between a component and its control parameter.

Some MIDI controllers feature automatic mapping, and they are known as *Digital Audio Workstation* (DAW) Controllers/Mixing control surfaces e.g Avid S3 (2013) and Behringer X-Touch (2014), yet they are not in the centre of our attention, and are usually made and used for audio mixing.

MIDI started as a way of communication and commands protocol between different synthesisers, and later on became a standalone device for controlling softwares. It is unclear what was the first MIDI controller which was not a synthesiser, meaning not having the ability to produce sounds by itself.

In the next few pages we will review how and why MIDI was created, and see the link of MIDI to electronic music and particularly computer based music, from a historical point of view.

Reverb Machine. (2019). Fig.4: Brian Eno with guitar and synthesiser. https://reverbmachine.com/blog/deconstructing-brian-enos-discreet-music/

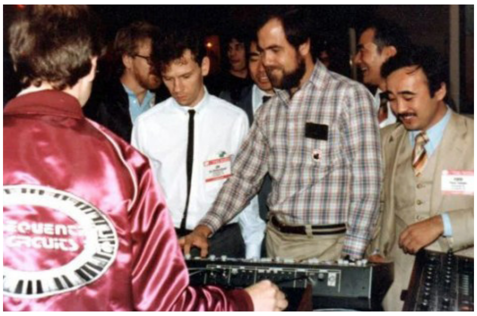
In the beginning of the 1970s, several synthesisers such as the *Minimoog* by *Moog*, the *Electronic Music Studios' EMSVCS3* and the *ARP 2600* were released to the market and gained popularity. They were chosen to be played by artists such as Steve Wonder, Pink Floyd, Brian Eno and The Who (Kovarsky, 2022; The Music Aficionado, 2021). In 1974, Oberheim Electronics and Sequential Circuits were founded. Later that same year, Yamaha came out with their first synthesiser, the *SY-1* (Kovarsky, 2022).

As synthesisers became more common during the 1970s and towards the 1980s, and more companies started to make them, the need for a standardised protocol of communication between the different synthesisers started to arise: A sequencer* made by one company could only control a synthesiser by the same company, which made the market of music instruments and technology very closed and exclusive.

The MIDI protocol essentially allowed for different instruments made by different manufacturers to communicate with each other, which was impossible until that moment. For example, an instrument made by the Japanese company *Korg* could communicate with an instrument of the American company *Oberheim Electronics*.

KVR Audio. (2017). Fig.5: Stevie Wonder with an ARP 2600. https://www.kvraudio.com/interviews/renaissance-music-man-an-interview-with-arp-co-founder-david-friend-37761

* A sequencer is a tool used to arrange and play back musical elements in a specific order.



Dormon, B. (2013). Fig.6: Dave Smith demos MIDI at the NAMM Show 1983. https://www.midi.org/midi/midi-articles/midi-history-chapter-7-midi-associations-1983-1985

Dave Smith, a lead engineer in the synthesisers company *Sequential* initiated a talk at the 1982 *NAMM show** of all the big companies at the time (*Moog, Yamaha, Roland, Korg, Oberheim, Arp* etc.) during which they discussed the design of that protocol. Most companies did not agree to the core aspect of compromising which makes the protocol a unifying one (Chasalow, 2013).

Only a few companies proceeded with the process and so a year later at NAMM 1983 the first two synthesisers made by *Sequential* and *Roland* were presented connected to each other through the new protocol, MIDI 1.0 (Musical Instrument Digital Interface).

Since a few very major companies have implemented this technology, the other companies which didn't take the opportunity to join in the first meeting had been now "forced" to join in order to stay relevant (MIDI History: Ch.6, n.d.).

In 1985 the American *Music Manufacturers Association* (MMA) was established as a "non-profit trade association responsible for development, promotion, and protection of MIDI technology" (About the MMA, n.d.) consisting of individuals from the field of music instruments and music technology companies (Yamaha, Korg, Sonivox to name a few).

In 2016 the MMA created the "MIDI association" as a place for individuals to be part of the MIDI community, by offering free membership that gives access to the MIDI specification, newsletter, webinars and more. It is also a place where corporations who use the MIDI protocol can get a paid membership based on their annual revenue and get access to tools and licensing of the MIDI logo to use on their products (Who We Are, n.d.)

---

* The NAMM show (National Association of Music Merchants) is an biannual convention that presents music related new products and innovations.

Synthpedia. (2019). Fig.7: Yamaha CX5M digital synthesiser and sequencer released in 1984. https://synthpedia.net/yamaha/cx5m/

MIDI and computers

In the early '60s the cost of 1 byte memory was standing at 1£ (equals to about 29.5£ as of April 2023) (Webster, n.d.), where in the early '80s it dropped to as much as a hundredth the price (Manning, 1994). The drop in price and increase in computational power and memory, made computers more accessible to individuals. In parallel to that was the standardisation of the MIDI protocol, which ultimately made it possible to connect each synthesiser to any computer, or "interfacing to digital computers" (Loy, 1985).

Due to the increase of computational power and lower costs, this was essentially the point which enabled the creation of the first home studios (Bateman, 2012). For the first time, a synthesiser could be used to control a software, and a software could be used to control a synthesiser, accessible to the wide public. Different digital audio processing units, expansion cards and later softwares started to appear - for example, the 1984 Yamaha CX5M and Atari ST, which had built-in MIDI ports and therefore was often used by musicians as a MIDI sequencer. A common expansion card was the original *Sound Blaster,* which had a sound chip for audio processing, a MIDI port and a digital to analog convertor (DAC) for analog audio output (Holmes, 2008).

MusicTech. (2018). Fig.8: Atari ST.
https://musictech.com/reviews/vintage-rewind-atari-st-computer/

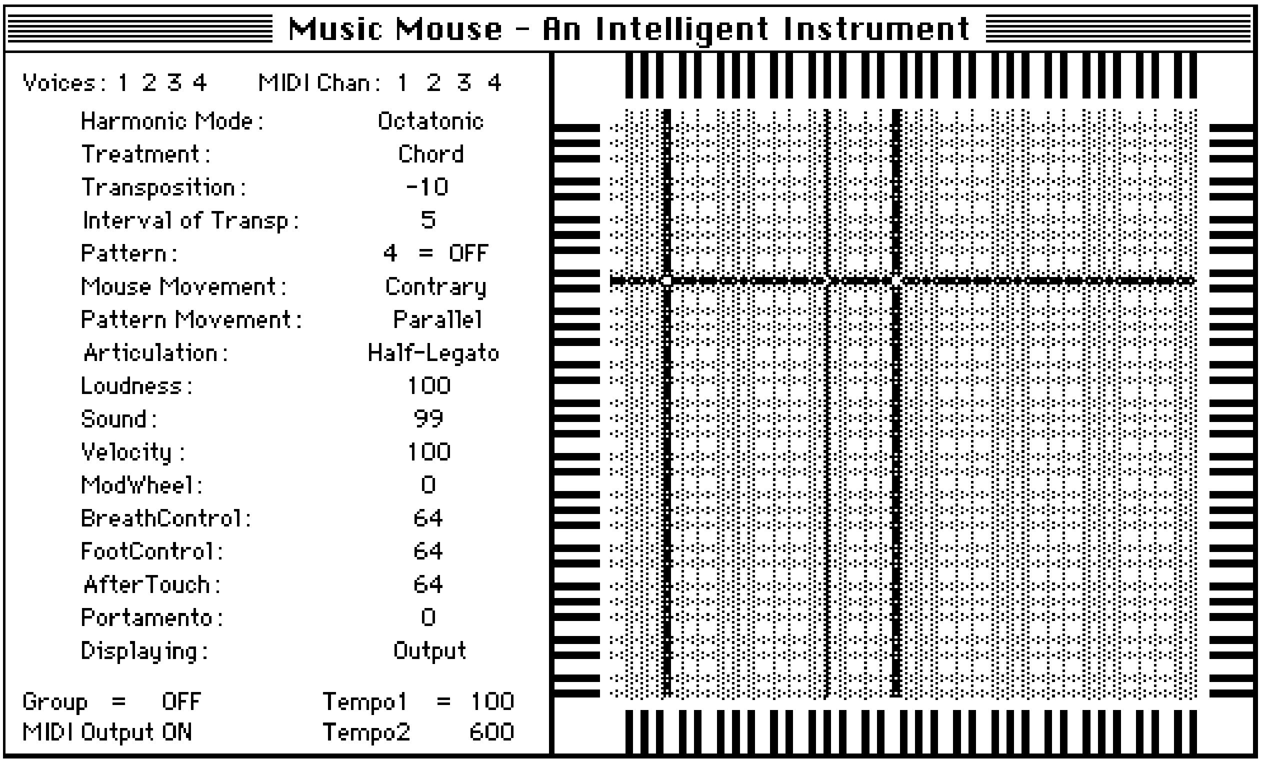
The home computer was utilised first as a MIDI sequencing device as it was not as computational demanding as *digital signal processing* (DSP) and allowed easy and dynamic control over hardware synthesisers. The sequencer determines the pitch, timbre, duration, amplitude etc. and communicates those commands to the synthesiser, which is in charge of generating the sound.
In 1985 the first home use software for sequencing MIDI *Performer* (Mark of the unicorn) was released, and in 1988 *Max* by Miller Puckette was developed and released at Paris' Ircam institute (Holmes, 2008).

Unlike the lower CPU demand of MIDI sequencing, DSP on home computer came later on as computational power increased and essentially made it possible to generate sound using the computer, making the first virtual synthesisers and real-time audio synthesis such as Native Instrument's *Reaktor* in 1993 and the addition of the *Max Signal Processing* (MSP) to Max in 1997.

Interactivity with computers and music softwares

The rise of MIDI and affordable computers had a natural continuation to the making of commercial musical softwares, with a majority of softwares made for MIDI sequencing, the arrangement of MIDI notes on a timeline (Collins et al., 2007). Other softwares were made with more experimental and interactive approaches, such as the *Music Mouse* by Laura Spiegel.

Spiegel writes in her website:
***Music Mouse** differs from other music programs currently available for small computers in that it is not designed for the storage, editing, and replay of musical compositions using keyboards or involving notation.*



Damian, K. (n.d.). Fig.9: Music Mouse - An intelligent Instrument. http://kalvos.org/spiegel.html

Instead, it turns the computer itself into a musical instrument which you can play. (Spiegel, n.d.)

The software was first released in 1986 for the Macintosh 512k and later for the Atari and Amiga computers (Holmes, 2008). It is capable of sending MIDI output to control any synthesiser or device that has a MIDI IN port or utilise the Macintosh's internal sounds and be its own standalone instrument.

The software was an enabler for non-expert musicians to create harmonic music without musical theory knowledge *(Spiegel, n.d.)*.

This was the first time a computer was being utilised as an instrument a novice and non-experts could play, yet was still keeping up its relevance for professional musicians (Collins et al., 2007,).

Intelligent Music, a company led by Joel Chadabe and employing David Zicarelli (later the founder of Cycling '74, makers of Max/MSP) were in charge of the pioneering softwares *M*, *Upbeat* and *Jam Factory*. Upbeat was a rhythmic programming system, essentially a smart MIDI sequencer. Its main difference between a conventional sequencer is its ability to utilise the computer as an entity that also affects the compositions with the option to add probability functions influencing sound characteristics and density of events. Additionally there is the option to dynamically control parameters while the software is running using the mouse (Manning, 1994).

Those are two examples of innovative early experimental music softwares, utilising the computational power as part of the composition process, and the mouse as a handy controller for real time music creation, rather than an administrative tool conservatively used to arrange notes on a timeline.

Beside the fact that the mouse is already paired with the computer, it has few disadvantages: It can control a single parameter (e.g a virtual knob) at a time, or two at the most in XY pads. It lacks any tactile feedback, (e.g for indicating the end of the virtual slider, or the detents in a switch type knob), and lastly it is not a very precise tool and can be hard to control for “fine tuning” or timed actions, which can impact the accuracy in live performance.

Music in Different Spaces

A notable difference between classical and electronic music lies in the way gesture and appearance are perceived. In western classical music fields not only a strong stage presence is expected, which encompasses everything from the performer's attire to their bold physical expression and gestures, but also adherence to traditional techniques of playing. For example, classical guitar players are taught to maintain proper posture in order to execute their techniques flawlessly. Classical music tends to be associated with a cultural significance that is exclusionary and catered to largely white bourgeois individuals who most likely have intensive parenting (Bull, 2019). Providing children with a musical education can be costly, as it requires expenses such as training classes, instruments, clothing, and repairs(Barnes, 2018). This results in exclusion from the working class and marginalised groups through materialistic, educational and identity politics issues (Wood, 2020). It is intriguing to consider the nature of the audience that this elitism represents and the venues where these concerts take place.

In contrast, electronic music has undergone a process of instrumental industrialisation that enables people from the working class to afford electronic music devices, practice in the comfort of their own spaces. The invention of MIDI in 1983 has enabled subgenres, such as techno, house and trance (Martina, 2022), in which people could become autodidact musicians without a music education background in composing music. Places like The Warehouse in Chicago appealed to a wide range of people, fostering an atmosphere where a sense of freedom and self-expression became synonymous (The Warehouse, 2019).

The originally 700 dollars synthesiser *Roland TB-303* is a prime example of how something can become highly valuable when placed in right hands. Originally designed to emulate the sound of a guitar, it fell short of its intended purpose, leading to its availability in second-hand markets for a mere fifty to twenty dollars. This resulted in the infamous *303 sound* which is the essence of the subgenre acid house (Cultures of Resistance Films, 2020).

One reason for this democratisation of electronic music is the accessibility of its instruments. Knobs, faders, and buttons can now all be produced in mass quantities, making them relatively affordable and easily learnable by the masses. This stands in stark contrast to classical instruments, which require considerable financial investment and instruction to master.

MIDI controller

The use of computers became a prominent and core part in the music world, from the commercial recording studio to the DIY performing musician, musical softwares dominates the field with editing, processing, sequencing, recording and synthesising sound.
This has prompted the need for seamless control of musical softwares, specifically virtual synthesisers, in a way similar to the control of hardware synthesisers which either come with built-in interfaces of controls (piano like keyboard, knobs, faders etc.) or are expected to be paired with MIDI interfaces to be able to play them (Holmes, 2008).

Matrixsynth. (2015). Fig.10: Sequential Circuits Prophet 600 Synthesiser. https://www.matrixsynth.com/2015/12/sequential-circuits-prophet-600.html?spref=pi

As a generalisation, synthesisers with keyboards (e.g Sequential Prophet-600, the first MIDI equipped synthesiser) are able to output MIDI commands from their keyboard, excluding the use of knobs or faders as a MIDI transmitter or receiver. As previously mentioned, It is unclear what was the first MIDI controller which was not a synthesiser, that is to say a MIDI controller which was solely for the purpose of controlling other sound generators and did not have the capability of making sound by itself.

Today those MIDI controllers are popular as they are lightweight, relatively inexpensive and often have many variations of physical layouts that do not exist in hardware synthesisers. While some hardware synthesisers can be used as MIDI controllers, most will be limited in the components that could be used for that, and in the different MIDI commands they are capable of producing (Vinnie, 2022).

MIDI controllers enable the computer to behave as a brain and in the case of sound synthesis as the sound generator. It can function as an instrument,

Steurer Jene, S. (2023). Fig.11: Novation Launch Control XL, 16 buttons, 24 knobs and 8 faders.

the top level which is relevant for a fluent interaction, especially in many live performance set-ups where the keyboard and the mouse are limited interfaces.

Until these days, the keyboard is the most popular form for a MIDI controller (Holmes, 2008; Output, 2021), possibly as it lays on the premise that a piano layout is an easy gateway to compose western music as all the notes are layed out, together with an intuitive combination of a percussive interface.

Nevertheless, different parameters other than notes, and different fields of music that are not reliant on notes or western scale, require different types of control forms. A piano layout cannot be utilised efficiently to control a ramp of numbers (1,2,3,4,5...127) as a knob or fader can. For example, these types of control allow for a change in sound characteristics, as in opening a filter, creating pitch glides or increasing/decreasing delay time.

Those examples illustrate how different types of components are useful and can be categorised as follow:

- Momentary behaviour (button, pads)

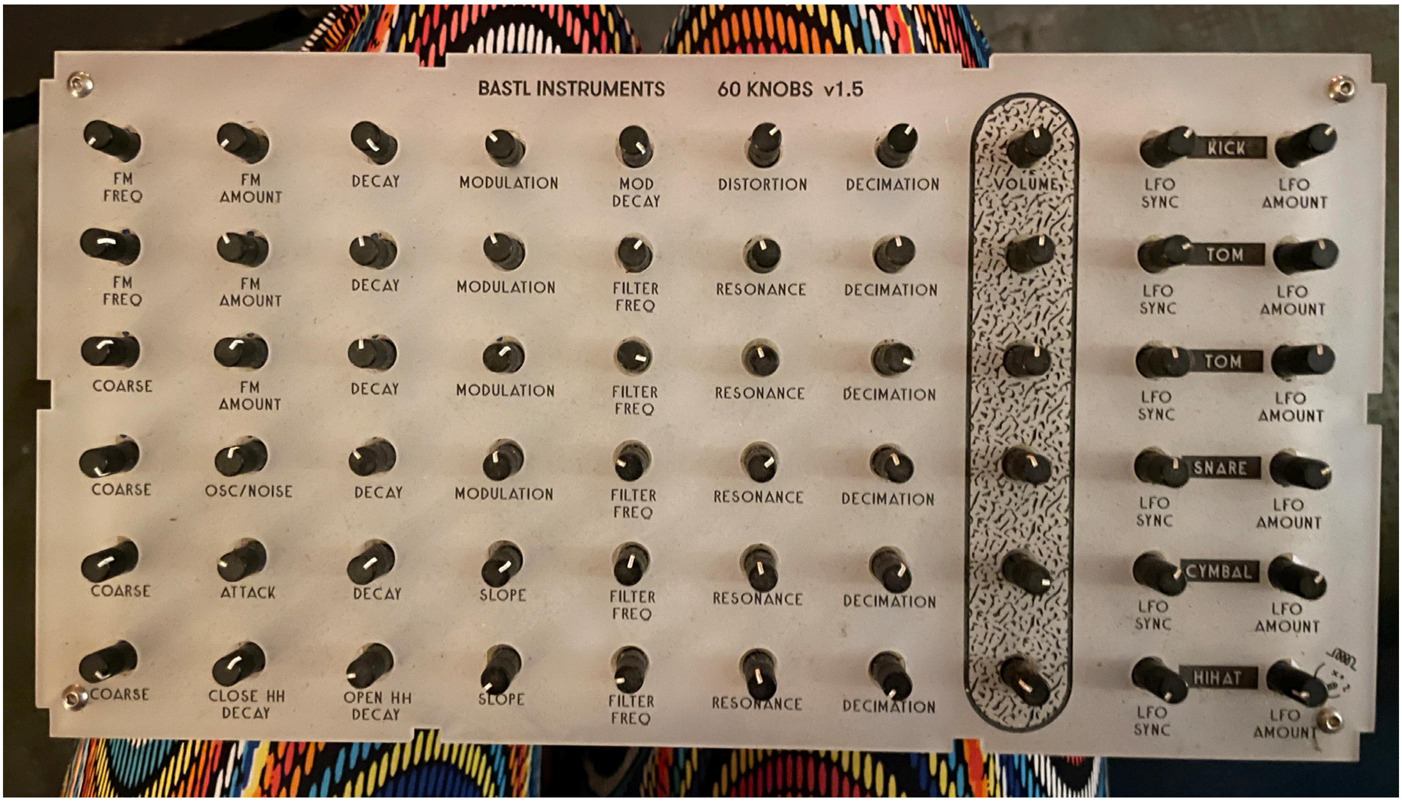
- Toggle behaviour (button, switches)

- Buttons with velocity (pads)

- 1 axis consecutive numbers ramps (knobs, faders, distance sensors)

- 2 axis consecutive numbers ramps (XY pad, joystick. generating two axes of control in one movement)

- 3 axis consecutive numbers ramps (3D buttons or pads)
Keys, traditionally for controlling notes of a 12 notes per octave scale.



Steurer Jene, S. (2023a). Fig.12: MIDI controller Bastl Instruments 60 knobs.

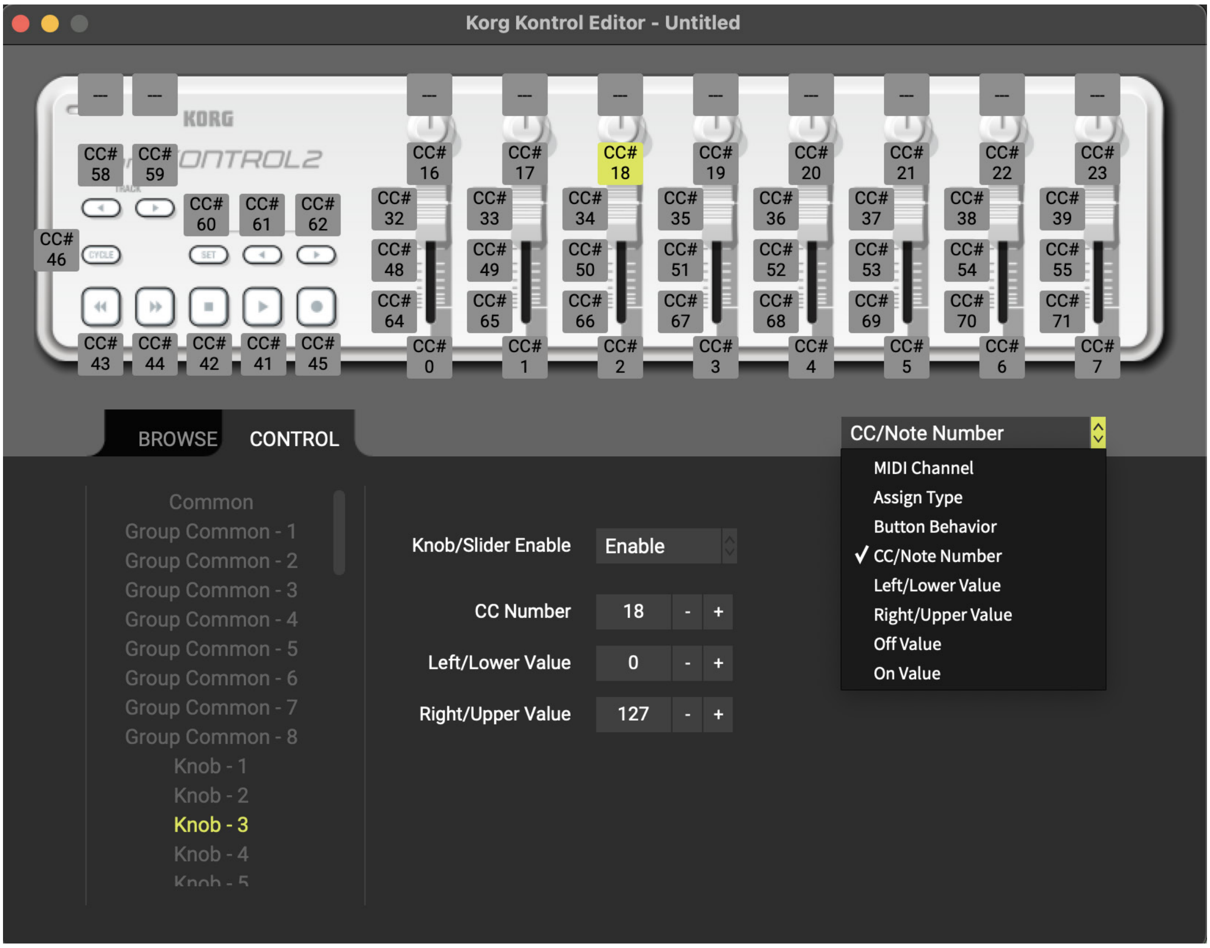
Surface Editor

Modern MIDI controllers often come bundled with a *surface editor*, a software providing users with the options to customise and optimise their MIDI controller.

This software allows users to configure various behaviours and assign specific values to their MIDI controller, such as a button behaviours (momentary or toggle), configure *Control Change** (CC) numbers of the different components or the note value that a component is outputting.

The surface editor can then upload the settings file to the MIDI controller, or read back settings and make it accessible for editing. The settings file can also be stored locally on the computer and uploaded later. In this way, each different performance or session can have different settings which can be quickly retrieved and uploaded to the controller.

* Simply put, the MIDI message's address



Steurer Jene, S. (2023). Fig.13: Korg Kontrol Editor with knob selected

Relevance of MIDI Controllers

Together with the rise of computers in the music field, MIDI controllers became an integral part for many musicians. What makes them relevant and their key strengths:

- Giving a physical interface to the sound generator, essentially embodying the possibility of making an instrument that can be played

- Harnessing the power of computers with physical, tangible controls.

- 1 to 1 mapping (for each parameter there is a designated component)

- Parallel interaction can take place, where few components can be manipulated at once (Hook et al., 2011)

- Giving the audience a degree of audio-visual causality through physical interaction, and so maintaining engagement with them. *"allowing the audience to smell the digital sweat as the artist pushes their instrument to the edge"* (Paradiso, 2005, p.9).

Challenges

We identified flaws and challenges in sound control interfaces and specifically in MIDI controllers (controlling a software), but some do apply also for other electronic music devices.

Lack of direct physical to sound connection: one of the downsides of "classic" electronic music control components, like faders or buttons, is that they lack a direct physical connection to the sound itself. Unlike playing a guitar, where the vibrations of the strings can be felt, these components provide no tactile feedback that corresponds to the sound they produce. As a result, users may feel a reduced sense of physical engagement with the sound they are creating (Papetti et al., 2015). This is of a bigger concern when having MIDI controllers in the scope, as their components control potentially infinite amounts of sounds, which are defined by the user.

Mapping the components to the sound control elements can be a tedious task, due to the unnatural semantics of the MIDI protocol (Wright et al., 2003). Based on personal experience and conducted interviews (see below), we know that the mapping procedure can also lead to confusion and an overall sense of being overwhelmed.

Ease of Use vs Richness: The primary objective of most user interfaces is to make them easy to use. However, when it comes to musical instruments, prioritising ease of use alone may result in a simple device that only holds users' interest for a short time, rather than a tool that they can study and explore for years (Wessel, 2006). Therefore, achieving a balance between ease of use and long-term engagement is critical. An interface that is well designed should aim to achieve this balance, allowing users to get started quickly while also providing a depth of features and controls that will keep them engaged and interested in the long run.

MIDI Controllers in Other Fields

MIDI controllers have found applications beyond the field of music, being used in areas like VJing, which involves real-time creation and manipulation of video, often in performance settings. Many VJs find physical controllers crucial in this context, as their intuitive layout allows for easy access and quick adjustments, in contrast to navigating software interfaces with a mouse. Another point is the physical control property of parallel-concurrent interaction which is the option to manipulate a few parameters at once (Hook et al., 2011).

Generally, any performance that chooses not to have the computer visible, for technical or aesthetic reasons, but still needs control over it, may have the need for MIDI controllers.

An example is the audio-visual performance *Phantom Limb (2023)* by Amos Peled (Disclosure: Daniel Treystman took part in the development of it). Peled is using a medical ultrasound machine as the driving object of the piece, all poetically, visually and technically. The live video stream generated by the interaction with the machine is then fed to a computer and translated

Kers, P. (2023). Fig.14: Amos Peled interacting with the MIDI controller during the performance.

Kers, P. (2023). Fig.15: Setup: ultrasound machine, MIDI controller and the hidden computer with Ableton Live, for the performance Phantom Limb

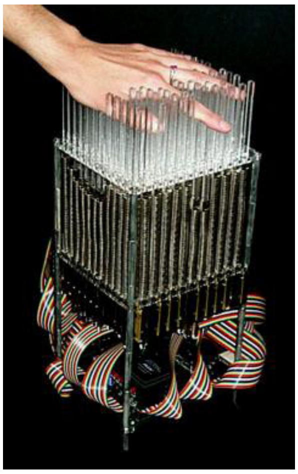
to data points which are mapped to different sound parameters using a *Max for Live* (M4L) device, which is a Max/MSP patch hosted in the DAW *Ableton Live*. The computer is hidden, and the only objects on stage are the machine and the performer. Peled uses the *X-Touch Mini* MIDI controller from Behringer (2014) that is painted to match the colour of the ultrasound machine and mounted on it, seamlessly blending it with the machine's aesthetic and making it visually completely part of it. This allows Peled to run the performance and control its different sounds, lights and scenes while keeping the computer away from the stage.

Musical Interface Community

NIME

NIME (New Interfaces for Musical Expression), started in 2001 as a workshop at the ACM *Conference on Human Factors in Computing Systems*, is a community dedicated to exploring interfaces and controllers, in the form of an annual conference taking place each year in a different city in the world. It is a meeting place for scientists, artists, and designers to gather and present new researches and interfaces, discuss them and watch demonstrations.

Papers presented in the conference are peer reviewed and organised by *NIME* and are publicly available. The range of topics presented is very broad and include DIY repurposing, augmented reality, communication protocols, interactive musical systems and much more.



Goudeseune, C. (2001). Fig.16 (left): The eviolin and motion-tracking antenna. https://nagasm.org/ASL/suac2003/fig06.JPG

Overholt, D. (2001). Fig.17 (right): The Matrix : a novel controller for musical expression https://doi.org/10.5281/zenodo.1176372

DIY MIDI Controller

To this day building a personal DIY MIDI controller is an affordable solution to achieve custom controller needs. An issue with commercial MIDI controllers could be that users have to adapt themselves to the layout defined by the manufacturers. The specific components (e.g. faders, pads) and layout needed for an ideal MIDI controller depend on one's workflow. This flexibility is found in a DIY approach that allows personalised solutions that are tailored to individual needs.

Furthermore, several of the commercial ones are only compatible with a certain type of DAW (*Digital Audio Workstation*, e.g *Ableton Live, Logic Pro, Pro Tools etc.*) which might not give the flexibility that is desired during a creative process (Carrol, 2022). One might argue that a homogenous market might affect the musical outcome in general.

SHIK. (n.d.). Fig.18: N32B DIY KIT Essentials. https://shik.tech/product/n32b-essentials-kit/.

SHIK (2020) is nowadays a one person MIDI controllers company from Israel, run by Shiko Cohen, that started as a DIY project out of a need. In the SHIK blog Cohen says that he struggled to adjust parameters manoeuvring a keyboard and the computer mouse and make fine tunings (Cohen, 2022). That was the initial motivation for creating the arduino based DIY *SHIK N32B* kit which can now be bought for self assembly of the controller. Through everything being configurable and open source, accessible creative freedom does not stay at making music but also extending to constructing one's own tools.

Other pros that come with building DIY controllers is that one's knowledge of the instruments being built grows and updates, or repairs can be taken on autonomously. On the downside, no customer support or warranty is granted. However, there are many open source and DIY platforms that are keen to assist and find solutions. Many of the DIY controllers are based on Arduino or Teensy which have extensive documentions, tutorials and forums. *Autodesk Instructables (2005)*, *Shantea Controls (n.d.)* or *Livid Instruments (2003)*, to list a few.

Haptics, Terminology and Modalities

Haptics are defined as *"a science concerned with the sense of touch" ("Definition of Haptics," n.d.)*, and originally coming from the Greek word *haptikós*, which means *"able to grasp or perceive"* (Jones, 2018, p. 1).

As part of our research we identified the importance of the sense of touch as a way of communication, immersion and multimodal experiences (Gani et al., 2022; Blach, 2008), and an efficient feedback tool (Berdahl et al., 2018). Braille writing, a form of written alphabet based on a tactile system of dots in different patterns, is an example of how the sense of touch can be used to convey information, which is otherwise visual, to visually impaired individuals.

Furthermore, we wish to emphasise on how the language of touch can be meaningful or be represented in a digital space where the screens are predominant. Touch is an intimate sense in which we experience in various ways. Through it, on a more personal note, we create profound connections to our friends, to the cosy embrace of fresh bed sheets, to a hairy peach which caresses the skin or to hidden childhood memories which are evoked through the fidgeting satisfaction of this one exact model of remote (Beolink 1000).

If touch can make us develop a relationship to devices that might be regarded by others as not more than a shell with a microchip implanted, we believe that haptic technologies can give to electronic objects more substance in their personality. It is fascinating to consider the configuration aspect of electronic devices, where customised features can reflect on a user's personal preferences and characteristics.

Nowadays the arrangement of apps on a phone's home screen or the choice of apps on the front page can give clues about the user's identity or aspirations. To further explore this idea, let's take the Apple Watch as an example. This device offers various options for haptic sensations, such as *taptic time*, *digital crown*, or *vibration intensity*. These emerging factors have the potential to enhance

Bang & Olufson. (n.d.). Fig.19: Beolink AV-remote. https://www.bang-olufsen.com/en/se/story/beolink-history our understanding of how we perceive and interpret sensory information. Finally, it is a proposal to create a more sensitive awareness of haptics in interfaces and (ironically) make it more tangible for users.

There are two ways of categorising types of haptic information systems, the *kinesthetic*, which is information coming from the muscles, tendons and joints allowing to perceive limb movement, velocity, weights, resistance and stiffness. The second is the *cutaneous or tactile*, which is perceived through the mechanoreceptors sensors on the skin. (See et al., 2022; Culbertson., 2015;). Through them one can perceive the four submodalities: differentiate and analyse deformation and distortion of surfaces, forming the perception of touch, and perceive temperature, pain and itch (Jones, 2018).

The different haptic modalities and haptic technologies make up an important part of human computer interaction. Through them we can receive information about the system and feedback of our actions, enhance the hedonic of the device (for example, the choice of using keyboard X and not keyboard Y) and lastly create a more embodied interaction, especially with virtual environments, where the mechanics and the haptics of the environments are not given (Bergamasco & Ruffaldi, 2011). Similar to that, is where we see potential of haptics in *Digital Musical Instruments* (DMI) and MIDI controllers. Although electronic sound is often not given with a specific mechanical system behind it, the connection of sound and haptics could be made associatively or based on information. In the case of physical modelling synthesis, where the computer models the actual physics and playing technique of an instrument (Hind, n.d.), the haptics of a device can be directly linked in a one-to-one manner.

Terminology

The terminology of haptics and its subcategories can be confusing, and so it is important for us to identify and categorise the different terms in order to give clarity as much as possible and create a common language.

Passive Haptics

In order to determine weight, size, texture, and other properties of an object, an active touch is required, for example, lifting an object and running the fingers on its surface (Jones, 2018). The haptics of the object are passive, but the exploration is active.

Active Haptics

Active haptics are things which are working against our body, and not vice-versa.
For example, when a pregnant person puts their hand on their belly, they might feel the foetus kick from the inside. In haptic technology, this could be a motor resisting or actuator vibrating the skin (Müller, 2019). The haptics are active, and the exploration is passive.

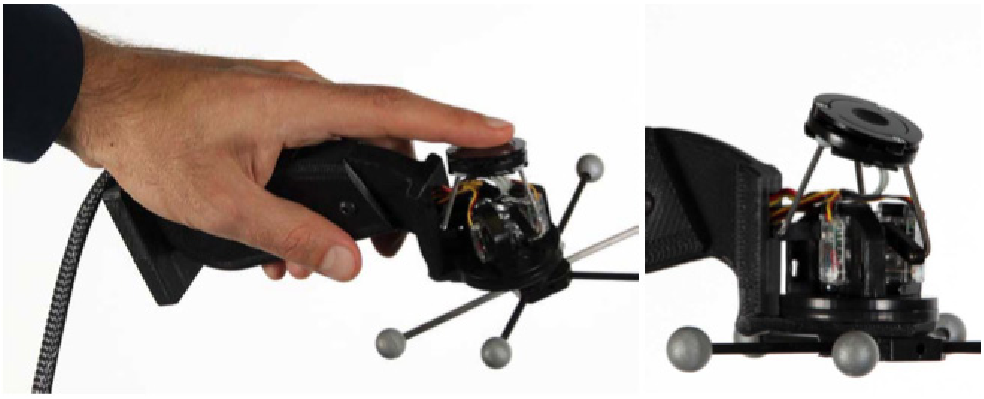
Given haptics / Given Mechanics

The natural physical properties of an object (Müller, 2019), such as wood's texture and weight, or the way a door knob resists the hand when pushed down.

Haptic Technology

Force feedback

Force feedback is used in various fields such as gaming, simulation or in the robotic industry. If we take the example of a wheel controller used in car racing games, the wheel will resist the user turning it while "driving" at high-speed into curves, to simulate the same sensation that happens when driving a real car (Racing, 2021). The wheel can also signal "bumps" in the road by giving a short vibration with the same motor mechanism.
Another interesting example of the use of force feedback is the research project *NormalTouch (Benko et al., 2016)*, a device for a finger, consisting of a moving surface, which is capable of rendering 3D virtual shapes and



Benko, H. (2016). Fig.20: (left) NormalTouch during interaction. (right) Close-up of the tiltable and extrudable platform. https://doi.org/10.1145/2984511.2984526

transforming their proportions into movement, and thus enables one to feel objects in virtual environments.

Mechanical button

Physical buttons demonstrate prominence of haptic responses or the lack of in interactions. The haptics created are more so consequences of the mechanics behind, as an example mechanical keyboard keys which are supported by tactile/clicky switches (Moreira, 2018) which gives the user an haptic and auditory feedback of the action being made by pressing down. This gives the user certainty of their action.

Vibrotactile feedback

As we run our hand over a surface or strike materials with a hammer, skin receptors pick up vibrotactile feedback that conveys information about their roughness. This feedback allows us to distinguish and identify different materials based on the vibrations that they emit (Krueger, 2013).
Machines we use everyday are using vibrotactile feedback, and the most common of them are cell phones or smart watches. Those kinds of devices consist of one or more actuators, and use vibrotactile feedback as a means of confirming actions, enhancing sound or replacing it completely. They also imitate mechanical button push and sometimes also giving confirmation feedback to hidden features which are otherwise not available visually.

Electrotactile feedback

In contrast to vibrotactile feedback, this haptic technology functions with electrical impulses which are felt until the nerve endings. The sensations vary depending on voltage, current, waveform, material, contact force, electrode size, skin type, and even hydration (Kourtesis et al., 2022).

Thermal feedback

To recognise if a material is cold or warm we rely on thermal feedback. It has relevance in VR applications considering the importance of this feeling in real life. PneuMod showcased an interesting approach to simulate the sensation of being touched by a hand. The wearable haptic device created a localised pressure through inflation of air bubbles and heat through thermic actuators. There is potential expanding on the VR experience and maybe an everyday interaction in a digital interaction (Zhang & Sra, 2021).

Pneumatic Haptics

Air vortex

Smoke vortex rings have become a popular trend in vaping culture (vAustinL, 2017) where smoke is pushed from the throat to the mouth and formed into a torus-shaped air vortex ring. Air vortex rings can provide mid-air haptic feedback without visible touch. In the AirWave project (Gupta et al., 2013), researchers investigated the use of air vortex rings for haptic feedback in virtual environments, demonstrating promising early results for incorporating this technology into new and innovative ways of interacting with digital content.

Ultrasonic

Phased array ultrasonic speakers is another technique of creating mid-air haptic feedback. Each speaker is capable of creating sound above our hearing range, and with activation of all the speakers together and a hand tracking system, a calculated pressure point of air molecules can be created at a specific point and felt by the skin, allowing to design mid-air haptic control systems (*Haptics*, n.d.). Researchers have explored the prospect of success of ultrasonic haptics cues in smart glasses because of the wide set of cues and high-resolution (Gil et al., 2018).

Review of Existing Projects

Introduction

We reviewed several innovative projects that take a unique approach to controller design and functionality. Some are concerned with the aspects of modularity: how components can behave in a dynamic manner based on their function, and how the physical layout of the whole controller can be changed by the user.

Other projects investigate the use of haptics to communicate information, enhance expressivity, and enable multidimensional sound control. Some even incorporate haptics as a dynamic component, creating an overlap between these two categories. Finally, we delved into the research field of performing electronic music from the perspective of the computer as an object on stage.

This helped us gain a better understanding of why and how these projects are relevant to musical creation and particularly to music performance. The purpose of this review was to familiarise ourselves with the field and gain a comprehensive understanding of its various use cases.

Modular and Haptic Physical Controllers

In the digital world modularity is quite an evident property, e.g. while a computer can be used as an illustration tool it can equally be used as a calculator. This is more tricky to decipher in a physical interface. It has become apparent that this is an aspect that we are keen to unwrap because of its necessity when working creatively on music. Especially with MIDI controllers that are thought to be customisable but in practice can feel at times constrained.

Special waves are the company creating MIDI controllers with the sole focus to be as modular as possible. Their controller is made out of a main board and different modules which are the different components creating the controller: knobs, faders, endless encoders, pads and buttons. The user is then able to build their own layout for the interface according

Special Waves. (n.d.). Fig.21: Mine S Bundle. https://special-waves.com/shop/mine-s-basic-bundle/

to their needs at that moment. The controller's editor software then automatically recognises the assembled layout and creates a visual representation of it, and so to easily spatially track the different components and assign them different parameters, behaviours and MIDI addresses (Special Waves, 2017). It's a very interesting way of dynamically customising layouts based on setup or occasion. Their core concept relies on the understanding that in terms of layout, each musician has different needs, and those needs can also change from one performance to the other.

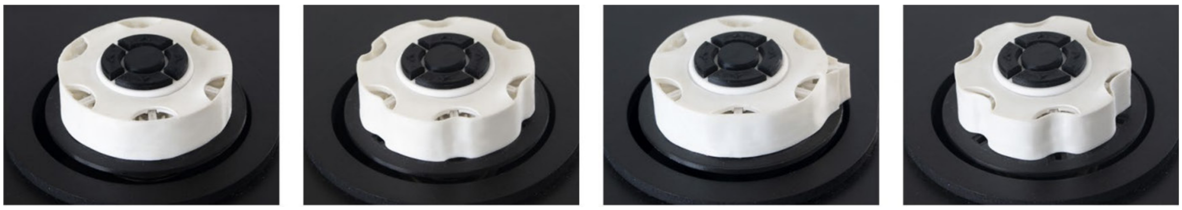
Faderfox's EC4 (2020) is the latest controller by the one person company from Germany. The controller features 16 endless encoders and push buttons in a 4X4 matrix, few buttons to program the interface and its strongest aspect of modularity, the screen. The screen enables one to scroll through the device's menu and configure it on the go, without the need to open up the editor software on the computer. More importantly it enables us to simply know what each knob is assigned to do. The endless encoders make it possible to store 256 sets of the 4x4 knob layout and

Faderbox. (n.d.). Fig.22.: EC4 - Encoder controller. http://www.faderfox.de/ec4.html scroll through them while playing, and the screen completes the picture by dynamically presenting the names and values of those knobs (loopop, 2020). It is one of the most complex MIDI controllers we encountered. On the one hand it is very customisable, but on the other hand it has to be learned and be well understood before operating smoothly.

The *SmartKnob* (Bezek, 2022) is a highly sophisticated open source knob and a button made possible with a brushless motor and an LCD screen. The motor can be programmed so it resists motion in a desired way to create configurable end stops and virtual snap points (scottbez1, 2022). The LCD screen adds a visual layer on the snap points and values, and a vibration motor gives haptic feedback on press of the screen. Those programmable features of a single knob opens up opportunities of an exceptionally dynamic control, housing endless customisable options. The knob can behave as a classic potentiometer like a knob with 270 degrees, a few snap points to jump between different values (known as fixed position knobs), or as an endless encoder, essentially a knob with no start or end point.

Another ambitious project and a study of a knob is the *DynaKnob* by Anke van Oosterhout and Eve Hoggan. Alongside the function of dynamic detents configuration, it can also change its physical shape dynamically, and so to give a feedback on the functionality of the knob. The evaluation

Bezek, S. (2022). Fig.23.: Smart Knob. https://github.com/scottbez1/smartknob



van Oosterhout, A., Hoggan, E., Rasmussen, M. K., & Bruns, M. (. (2022). Fig.24.: DynaKnob left to right: circular, serrated, pointer, and tap knob shape . DOI: https://doi.org/10.1145/3322276.3322321

of the knob brought up the results showing that with the corresponding GUI provided in the tests, haptic force feedback and shape changing didn't increase accuracy, but without the GUI it did show improvement in accuracy (van Oosterhout & Hoggan, 2020; ACM SIGCHI, 2020).
This logic can be useful for live performance, as a means to reduce the interaction of a screen and the performer and provide feedback through haptics. Since the beginning of real time digital sound processing and its use in live performance contexts, the issue of performativity and musical expression with computers arised. The term live music when using a computer became blurry as the complexity of use increased and more musicians chose to use more playback tracks, as in pre-recorded (Henke, 2007).
Furthermore, the use of computers on stage dilutes the connection between physical action and the creation of sound in space (Henke, 2007). With the combination of the fact that computers are multipurpose (they can be used to create music as they can be used to write emails or fill in tax forms) the audience is left out with no connection to the performer and the resulting sound in space and the performance is reduced to mouse clicks and staring at the computer screen (Schloss, 2003).

Haptics in sound control

For humans, a sense of touch helps to interact, navigate and manipulate in our everyday life (Minsky, 1995). Our hands are an essential tool for processing information about our surroundings, including the proximity of objects and the characteristics of their surfaces. Through the sense of touch i.e. haptic perception, we can gather a wealth of sensory data, such as texture, temperature, and shape, that help us to navigate and interact with the world around us. This is why haptics are important in technology, it enables devices to convey digital information beyond the visual realm (Brewster, 2008).

Haptic technology has become increasingly relevant in various industries, such as the automotive industry, where it can be used to transmit spatial information from computer systems to drivers. Haptic seats, in particular, have been shown to improve the reaction time and preparedness of drivers that rely more on automated driving. This feedback can help drivers

react more quickly to potential hazards, reducing the risk of accidents. By incorporating haptic feedback into the driving experience, manufacturers can create a safer driving experience (Telpaz et al., 2015).
At the core of our design ideas, we believe that enhancing control through haptic feedback is essential. By incorporating haptics, we enable users to have an intuitive control that manipulates digital environments. However,

Thoma, F. (2022). Fig.25: Roli Seaboard Rise 2 Roli. https://www.amazona.de/roli-seaboard-rise-2-neue-version-des-mpe-keyboards/

we also recognise that limitations may arise which make it challenging to implement haptic feedback effectively. For example, factors such as cost and power usage (Papetti, & Saitis, 2018).

The company Roli is known for their sleek looking MIDI Polyphonic Expression (MPE) instruments. They make MIDI controllers paired with their own software for perfect integration, but it can be used for any 3rd party software as well. Their latest *Seaboard Rise 2 Keyboard (*ROLI, n.d.) comes with features that have been improved. The 49-key playing surface is soft and made out of a matt silicone, which makes sliding or gliding with fingers smoother. It enables the musician to slide from one note to the other but also to bend the pitch while sliding vertically. This allows the player to play frequencies in between the 12 notes (per octave). Each pressure or playing variety, such as pressing, striking, sliding, gliding, and lift, can be mapped through the *equator** software. (Sanjay C, 2022). This feature enables the user to find natural ways to express the notes being manipulated.

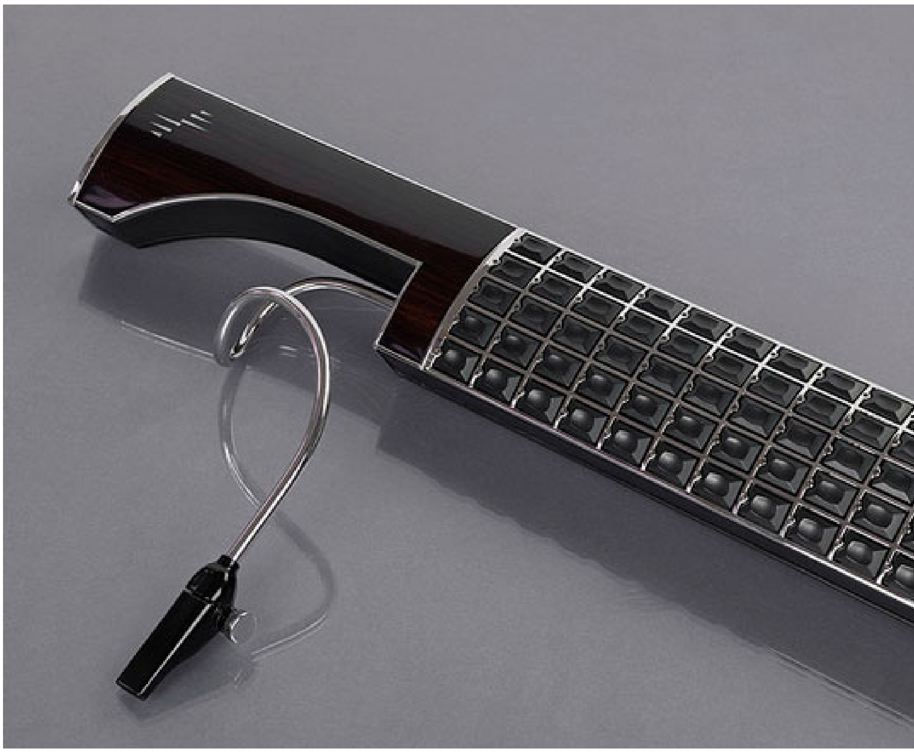
As in the previous model they have honed edges, whereas in the newer Seaboard they implemented additional precision frets to feel where the centre of the key is. It is comparable to a fretboard on a guitar neck that is used to hold

* A synthesiser software made for the Seaboard Keyboards

down the string and make variations of notes. Overall Seaboard 2 reveals how infinite possibilities still need to be contained by some type of guides, in this case frets, for an intuitive play.

Most people will comprehend the use of a fader to increase or decrease a value, the vertical motion showcases the concept on its own. It's where the sense of touch is often left underutilised which disturbs a fluid workflow. The collective *Herrmutt Lobby* saw a potential in elevating this way of working with their *CTRL Caps (2017)* fader cap which is used with a bluetooth connection. Through pressing in different intensity levels, MIDI messages can be generated while simultaneously sliding the fader. It demonstrates a refined way of utilising another tactile capability into a more fluid workflow.

Another example on how to facilitate a multidimensional tactile component are the electronic instruments and MIDI controller made by *Eigenlabs (Eigenlabs*, 2001) The company has by now released three different variations of *Eigenharps*: the Alpha, Tau and Pico. The main distinction is the size and therefore the numbers of keys which differ from a matrix of 120 playing keys to 18. In comparison to common electronic instruments, they stand out with having a timeless design with a metal housing and wooden keys. Additionally, with stripcontrollers and the breathpipe, an authentic musical expression is supported. Next to those specifications, we focus on the velocity sensitive XYZ axis keys which basically function like a joystick. The different axes can be mapped individually (Tunyogi-Csapo, 2020). Though the features allow a smooth play through tactile focused control, the Eigenharp is a fairly costly instrument and musicians need to practise extensively to achieve a certain point to express musically and achieve music mastery.



cdm. (2010). Fig.26: Eigenharp a digital music controller. https://cdm.link/2010/09/alternative-controllers-eigenharp-users-reflect-on-playing-a-new-kind-of-instrument/

Research Question

Digital touch and its possibilities have repeatedly been a subject of discourse, particularly in the HCI community. However, there is a need to further develop beyond the conventional use of touchscreen based vibrotactile applications and actively reconsider what digital touch can mean (Jewitt et al., 2021). It is vital to explore new approaches that can potentially expand our understanding and redefine the scope of digital touch, empowering us to take a fresh perspective on this burgeoning field.

Within our thesis we want to take a closer look into physical controllers for digital interfaces and how the sense of control in a digital space can be materialised. The focus of our research lies primarily in digital music instruments as opposed to studio mixing or DAWs control. To be more specific we are directing our attention towards devices that are used to control parameters of a software, in other words MIDI controllers. While our work may have implications for other domains, our objective is directed towards electronic musicians specifically in the context of live performance, in a range from novice to seasoned professionals.

Although controllers offer the advantage of being able to control any parameter of softwares, there is a discrepancy between the performer's action and the sound that is generated. Most of the mappings are difficult to learn and use which could be attributed to the disconnection of the digital and physical (Poupyrev et al., 2001).

The creation of modular behaviours in individual components shows promise. As the software operates in complete freedom, we intend to emulate as close as possible representation, as an example through haptic feedback or adaptable labelling. Conveying information through haptics can enable users to control and communicate with digital interfaces adhering to a bidirectional interaction. (Verplank et al., 2002).

As stated in the research, the use of computers as an object and mainly of its screen in live performance often causes a reduction in the performative quality (Schloss, 2003; Henke, 2007). It makes sense to focus on exploring the prospect of incorporating haptics to transmit information over the use of GUI.

Considering all of the above, we extracted the following research questions;

Can haptic representation of audio features serve as an alternative to visual information displayed on a screen?

How can a controller dynamically represent various graphical digital interfaces and does it then convey a more intuitive and comprehensible use?

How can a MIDI controller become more embodied and convey a better feeling of an instrument?

Methodology

During our research we understood that creating a dialogue with artists and computer music researchers is essential to advance technological developments in musical expression.
We want to promote creativity through individual solutions on creating a customised tactile interface for any digital sound generator or effects. To achieve this we need to discover new methods to translate music softwares into a dynamic physical interface.

Phase 1 - How Is It Now?

To understand what methodologies we want to apply we need to outline the criterias we are looking for. First we need to evaluate the various controllers which are well-known or we classify as the most relevant ones. In this manner we will be able to extract their usability, entry level of use, intelligibility, haptics and unresolved issues. Through this practice we gain a better comprehension of what is out there and may indicate the limits that are set in technology.

Phase 2 - What Do We Need?

This phase overlaps with the previous one. We have collected insights which we translate in sketches and low fidelity prototypes.

We would like to collaborate with the *ICST* (*Institute for Computer Music and Sound Technology*), located in ZHdK and part of the MA electroacoustic composition department. They have been researching the topic of performing live electronic music (ICST, n.d.) in the past few years and have been developing musical interfaces and devices to perceive music haptically (Papetti et al., 2014; Papetti & Tröster, n.d.))

Additionally, we aim to question our assumptions through interviews with a set of participants from a diverse spectrum of musical backgrounds.
From the interviewees we aspire to get a general overview of wishes and needs. For this purpose we will construct an interview guide and rough concept to discuss and to get immediate feedback.

Phase 3 - Transform Thoughts Into Prototypes

It would be interesting to incorporate a “building workshop” to engage with musicians who use controllers regularly. This way we can get various people to take an active part in the prototyping process. The phase 1 of our journey will help us understand what materials will be needed or will make sense to prepare. We would need to think carefully of what kind of guidelines need to be set to conduct a fruitful workshop. Perhaps collaborating with *Bitwäscherei** could be valuable as they are experienced with this format.

With our sketches, collected data from the interviews and low fidelity prototypes reviewed we advance further to planning the construction of our first prototype.
Here we formulate our vision into the physical world. We focus on the electronics and the inside of the controller and rough editor software. Ideation of modularity and haptics will be applied here.

Phase 4 - How Does It Feel?

It is time to test our first prototype ideally with a mixture of users that took part in the earlier stages and some who are newly introduced to it and so to evaluate our prototype from the previous phase.

Phase 5 - Rethink, Repeat Prototype

After extracting the findings of the evaluation we adapt the prototype into the next version.

---

* A collective Hackerspace in ZWZ Hardbrücke

Motivation and Intended Contribution

Our meeting point in motivation and contribution

As a team we aspire to fuse our individual motivation, and identify the identity our BA thesis and project will carry throughout the closing semester. An essential part of our process is to dive into our divergent backgrounds and interests, to develop a common language where we can meet. With this we can carve a well rounded context to elevate the final outcome into an entity which joined thinking can achieve. Acknowledging our differences and uncertainty we sensed across the research phase, is the seed to initiate a continuous dialogue on distilling what we wish as a unit. We see those conditions and endeavour as excellent starting points for a captivating path with a good deal of sideways we are thrilled to discover.

Through the writing process of the background chapter we could share and discuss the findings and so to create a more joined idea of the project. We are excited to collaborate and get in touch with people from the musical interfaces development communities, musicians and computer music researchers.

Svenja's Statement

During my journey in studying interaction design, I have confronted a personal fear of comprehending technology and venturing into the world of coding. This field initially felt distant and inaccessible, especially with my background primarily focused on more tangible craftsmanship. Perhaps this apprehension stemmed from my belief that I didn't fit the stereotypical image of someone studying in this field.

Throughout this journey at ZHdK I've come to enjoy new design processes and expand my borders of skill sets. My acquired expertise during my work as a professional shoemaker, fashion and costume designer have been helpful in ways I didn't expect. Especially when elaborating concepts, facing prototyping and finding the joy of working in a more self-determining framework. In other words, not only having to deliver a requested product for money but also having the possibility to thrive for the impossible.
Now facing my BA I wish to explore my interest in musical interfaces, a field that I want to understand and help to facilitate the entry level. Even though I have been surrounded by electronic music and their tools for a while, it never felt like I could truly be part of the community. With every attempt to understand and get started with it, it has been an overwhelming challenge because of the massive wide range of choices of physical and digital tools. Most of the time I've been explained on how to use the tools but not how sound works, so facing the wish of getting in touch with creating sound, I only saw a complicated block of cables and blinking lights.

It seems to me that controllers are the shell for musical ideas, therefore some stage of pre-knowledge is required. At the same time, talking with female and non-binary friends who work with music and share a music production studio, shared similar distressing experiences which were difficult stepstones to overcome throughout their career. Certainly having a safer space is one aspect, but then overcoming internalised fears of not being able to get in touch with technical equipment is a problem that might not be solved solely through a MIDI Controller.

This approach and apprehension is the force that I will keep in mind while undertaking musical interfaces and conceptualising a product that can be newfangled. I hope to find solutions that enable a simplification of the technical learning approach for non-experts without making the controller insignificant for experts.

The MIDI controller opened new doors, apart in the process of creating music, but also in how we interact and perform with technology. With that being said, I will keep this in mind to reach our objective in making a valuable tool of musical expression.

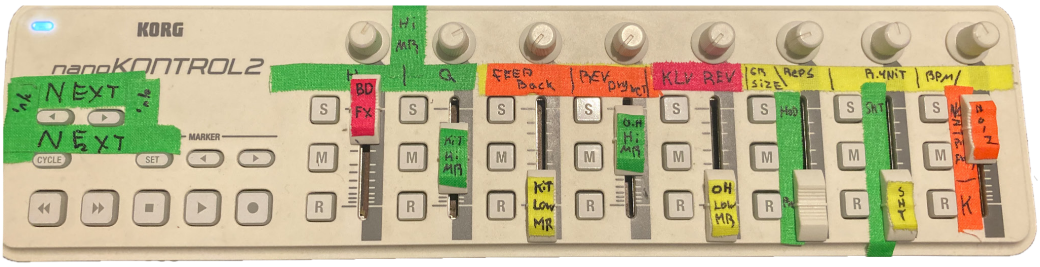
Daniel’s Statement

Common and commercial MIDI controllers are to this day a little messy, which I think the core of it is the fact that it is a non dynamic piece of hardware versus the very dynamic software. The integration of hardware to software is then made challenging - to find how a static piece of hardware can be adapted to an endless different configurations derived from the software it controls. My motivation is to make the controller more “one” with the software and sound, and allow more expressivity in the control and performance of sound.

My motivation is first personal. As a past music student, I have encountered the not so ease-of-use of the common controllers, and recently found myself again encountering that problem when I had to play a concert using one. I was working on it with a friend who has been using the same MIDI controller for over 13 years as he found it the best one available, and yet he finds it extremely limited and restricting.

For example, the button and knobs have to be marked by hand with coloured gaffer tape and handwritten labels in order to know what button does what.
He keeps a set of stickers, which has to be taken down and glued back on with each change of the set or performance. Furthermore there are a very limited number of parameters controls, which is a compromise of portability and compactness. One would have to be very creative and “hack” the system in order to get more out of it, in a way which is very complex to an inexperienced person.
From the perspective of an interaction design student, I can see the potential those controllers could embody.

There is an ongoing academic research in the topic and from the other side a large community of DIY MIDI controllers makers, yet not much innovations has been integrated into a device which is accessible, be it as a product or as a concept which keeps a communicational and conceptual line with past devices which are on the market and can be appealing to a large audience. Having said that, it is important to mention that the accessibility aspect should not be a reducing factor in terms of its capabilities. It should stay relevant for the novice and the professional users.



Treystman, D. (2022). Fig.27: Korg nanoKontrol2 labeling with tape.

CONCEPT
Introduction

Essentially, the core of our concept creation revolves around demonstrating the connection between sound and touch, as we believe this aspect has great potential in bringing a not established layer to MIDI controllers. Additionally we will provide a collection of related projects to display elements that we admire and wish to build on. The anecdotes we have gathered will accompany us throughout the following user testings and experiments where we review our assumptions and anticipate to solidify our purpose and intentions.

Connection Sound and Touch

One may know the feeling of being in a room and sensing from the distance cars or buses driving by down the street. This sensation can be roughly explained by the vibration being created by the humming motor and wheel friction with the street's asphalt. This vibration creates sound, which consists of a back-and-forth motion material that travels through air, and in other words, soundwaves. When this sinusoidal behaviour propagates through another material, vibration is created (Berg, 2022). For instance in the previously described scenario, those cars have induced vibrations in solid objects, such as the windows and walls of a room. These vibrations can be sensed by the human body through the skin and other bodily tissues, resulting in the perception of the sound as a physical vibration.

Vibration creates a layer of musical perception that hearing impaired people are more aware of and experience music through that. When a mallet or stick strikes a percussion instrument the vibration is made visible by the drumhead. With this kind of heightened embodied sensibility, the percussionist Evelyn Glennie is able to "feel" the sound with haptic and visual aid only. (Glennie, 2019). Haptics are not only an essential part of the interaction between a musician and a classical instrument, but also with its audience.

Projects as *Subpac (2022)* and *Music Not Impossible (M:NI) (2018)* focusses on an enhanced experience of sound through the skin which is an opportunity to include various types of people into a digital performance. Musical expression feels more lively because the audience is also able to feel the movement and sound created.

When we think of a virtuous performance it is mostly with traditional instruments where the musician is in unison with them. By traditional instruments we mean acoustic or electro acoustic instruments. The instrument not only is built in a certain way to generate specific types of sounds but already implies how to be held and played with hands, fingers or mouth. It is no coincidence that those body parts are rich in haptic receptors (Papetti et al., 2018). Their nature to send vibrations and haptic cues plays a pertinent role on its hedonistic and creates intimacy between the player and instrument. (Papetti et al., 2018)

Those qualities tend to get lost in digital musical instruments (DMIs) and other electronic musical devices, which seldomly translate the mechanical behaviour of acoustic instruments. This could be viewed as an opportunity for subcultures such as hip hop, where MCs and breakdancers can bring their own unique expressions to the forefront, as the sound accompanying gestures.

There is the factor of DMIs being very versatile and flexible in the output of sound as there is the possibility to control various sounds with different timbres. In comparison to a distinct acoustic instrument being able to create a specific type of sound which cannot offer the same kind of sound varieties.

To think of sound as movement underlines the importance of researching the relationship of the ears and skin. Artists like Margaret (Megan) Watts Hughes, visualised the sound of her voice with powder and pigments on her device called "Eidophone". Instead of having random scattered patterns, the powder formed into perfect geometrical shapes (Mullender-Ross, 2019). Shortly later, the effect of frequencies on organic matter was studied by physician and philanthropist Hans Jenny and coined as cymatics. The vibration was visualised through sand, fluids and dust on a plate connected with an oscillator which also enabled him to hear sound and feel or "listen" to it if he lightly touched the plate (Roibu, 2021).

Roibu, T. (2021). Fig.28: Hans Jenny's research in vibrational patterns produced by vowels. https://geometrymatters.com/hans-jenny-and-the-science-of-sound-cymatics/

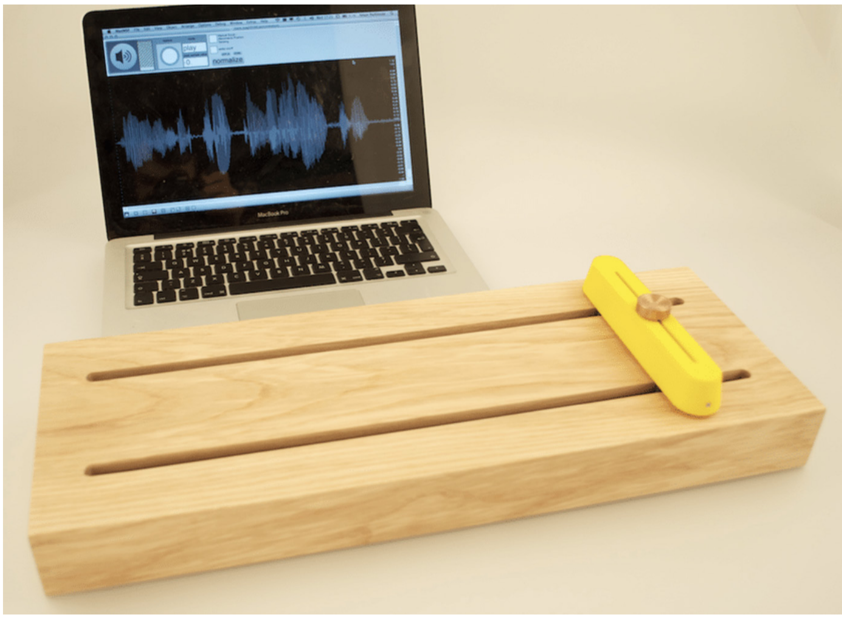
Most DMIs do not link the notion of the force of control, sense of touch and the sound that is generated. In other words, they can sound in any way we want them to but yet the perception of touch is unchanged and static. Unquestionably gestural memory and rehearsal is prevalent in DMIs, as an example in the DJ or turntablist technique (130db, 2016). They practise intense movements, such as scratching where one hand moves a vinyl plate back and forth on a turntable and the other manipulates a crossfader to produce unique sounds, being one of them.

As can be seen, the world of human sense is interlinked and depended on each other. Already understanding speech does not only rely on auditory senses but that the visual one has an impact in the process too. It has been proven by the McGurk effect (BBC, 2010). Additionally researchers have found a connection that aero-tactile information can interfere with the auditory signal simultaneously being sent. Participants listened blindfolded and needed to distinguish combinations as “ba” and “da”. While some received no further input, in other cases they were sent an unnoticeable burst of air from thin tubes that were placed on the hand, neck or ear. 30% to 40% of the time, participants mistook the words. With the air puff the precision increased by 10% to 20% more (Storrs, 2009).

Related Projects

Haptic Wave

The *Haptic Wave* is a device by Adam Parkinson and Atau Tanaka that enables audio engineers who are visually impaired to perceive the intensity of sound by touch, therefore providing them with the same vital information about the audio waveform that sighted engineers can get visually. The device has two sliders built on top of each other, so in one hand movement the two parameters can be perceived. One slider is for the X axis and the other for the Y axis: the X axis is scanning the waveform time while the Y axis is giving information on the amplitude of the waveform (Tanaka & Parkinson, 2016).



Parkinson A., Tanaka A. (2016). Fig.29: Haptic Wave a cross-modal interface for visually impaired audio producers. https://doi.org/10.1145/2858036.2858304

Why is it relevant?

The project demonstrates creativity in the way vibrotactile feedback is used for conveying otherwise traditionally visual information, which in this case makes audio editing accessible for visually impaired people. We see this as applicable not only for impaired individuals, but as a way to enhance other senses and create multimodal embodied interactions, to reduce one of the senses which might be distracting depending on the type of task, or to “free” one of the sense to be concentrated on other part of the task e.g. in live performance situations, instead of looking at the control device or a screen, the musicians can form visual communication with the crowd or other bandmates.

libmapper and WebMapper

WebMapper (Wan et al., 2019) is an open source web based graphical user interface based on the libmapper (Malloch et al., 2013) framework, which is a library that enables real-time communication and mapping between input devices such as different sensors, DMI and other multimedia devices. Webmapper provides a way to visually map, connect devices and edit their input data using a web browser. The library does not have a feature for automatic mapping creation, and its purpose is to provide a platform for "mapping designers" to manually establish connections between signals that are distributed across different devices. To date, there have been a few implementations of the libmapper framework, for example as externals for the *Max/MSP* and *Pure Data* visual programming environments, but those require programming capabilities from the user in order to use them. WebMapper is a graphical user interface that allows the users to interact with the mapping network intuitively, without the need for programming skills.
Another inspiring project that builds upon WebMapper is Force-Host (Frisson et al., 2022), which was presented and published through *NIME (New interfaces for Musical Expression)*. Force-Host is a toolchain for *"generating firmware embedding the authoring (transfer function editor) and rendering (digital signal processing) of audio and force-feedback haptics." (Frisson et al., 2022, para. 2)* By modifying and implementing the system within WebMapper, users can graphically modify the behaviour of their actuators, motors, or other sensors and view their state change for real-time feedback.

Why is it relevant?
Libmapper and WebMapper are fertile ground for the investigation and development of open source projects for the design of DMI. There is a wide range of projects and implementations that utilise the libmapper framework, including those for DMI, virtual synthesisers, GUIs for gesture, sound, and haptics investigation, as well as implementations of the framework in various environments and protocols like Arduino, M4L, MIDI, and TouchDesigner.
We have found that the installation and implementation is not straightforward, and it may pose accessibility challenges for non-expert programmes. Nevertheless, the design of GUIs shows a potential for non-experts to use the system and help them to create and prototype complex behaviours (Kirkegaard, 2020).

Sound of Touch

In relation to making sound tangible the project "*The Sound of Touch: Physical Manipulation of Digital Sound*" (Merrill et al., 2008) made by David Merrill and Hayes Raffled with Roberto Aimi, proposes different types of wands as an interface to instantly record and physically modify those sound samples. As a proposal for "sketching" sound they have iterated four wands that resemble various painting tools, thereby invoking a sense of affordance. The most versatile being a carbon steel painting knife, equipped with an integrated microphone, pushbutton, piezo vibration sensor and embedded wiring which is hidden in the wooden handle. This project has been exhibited in an international computer graphics and interaction conference in August 2007 which invited the guests to explore a multitude of familiar textures. Among them were bathroom tiles, a variety of broom bristles, and metal screens, just to name a few.

Raffle etl al. (2008). Fig.30: The painting knife tool. https://dl.acm.org/doi/pdf/10.1145/1357054.1357171

Why is it relevant?

Next to suggesting an alternative type of interface for recording and editing sound it is also talking loudly about the sounds of textures. The hand-held wand demonstrates how the sound of objects can be altered by incorporating various types of movements. The textures and their sounds have a sense of familiarity in which it makes the interaction intuitive in its use and output. We aim to contribute to this exploration in our own project through questioning ourselves and our users, what haptics do contribute to the sound we are hearing? We want to bring those physicality to sound control and also imply that synthetic sounds indeed have tactility associated with them.

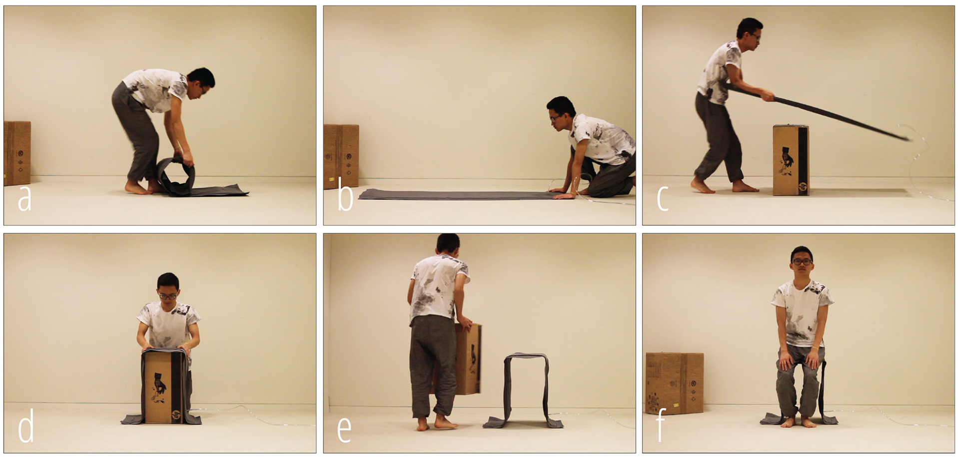
jamSheets

jamSheets (Ou et al., 2014) is a project developed at *MIT Media Lab* under Tangible Media Group (1995), which explores *layer jamming*, a method of placing 2D sheets of soft materials inside an airtight bag, and with the use of a vacuum regulator changing its state from soft and flexible to rigid (Shah et al., 2020). The project explores a way of using the method to create *"...enabling technology for designing deformable, stiffness-tunable, thin sheet interfaces"* (Ou et al., 2014, para. 1).

Their developed system is capable of sensing user input and computer input, which creates a potential for a sophisticated computer control interface. They further present a few prototypes to demonstrate use cases and applications: the *Deformable Furniture*, *Stiffness-Changing Display*, and *Jamming Shoe*. The last in the list are shoes with adaptable stiffness, based on the activity of the user wearing them. For example, when playing basketball, part of the shoes become stiffer to provide extra stability, and when jogging, the same part turns softer for absorbing impacts.

Why is it relevant?

In addition to its capabilities for rapid and intuitive design of materials and shapes, the project underscores the potential of property-changing objects and their application in human-computer interaction. By allowing the object to react as an input or output device, a bidirectional and flexible system is made. And such, the device adapts itself to the right application and its relevant means of interaction. We take that as inspiration for creating an adaptable system for both different virtual control types, and for different musical needs.



Ouel et al. (2014). Fig.31: JamSheets: Thin interfaces with tunable stiffness.
https://tangible.media.mit.edu/project/jamsheets/

Field Research
Interviews

For our further understanding of how and what kind of MIDI-controllers are being used and what are the different ways people choose to control software, we interviewed musicians who use controllers in their musical practice. We conducted 3 interviews from which the interviewees had between 3 to 20 years of musical practice.
The interviews were done in a semi-structured style (Adams, 2010), meaning that we prepared a list of questions, but had only a rough guideline of their order, and let the conversation unveil what we wanted to know and beyond.
All interviews were recorded with the permission of the interviewees, and so we could focus on the conversation and the answers, and could then revisit everything afterwards.

It was important for us to learn about their musical and electronic music background in general and how many years of experience they have working with computers and controllers. Additionally, we thought it was important to know their current practice and setup and what hardware and software they are using. This later helped us to analyse their responses with context. We then asked questions regarding computer and controllers specifics: what and how do they use, what do they like and dislike, their frustrations and wishes.
Lastly, we asked about the software integration, representation and mapping procedures.

We also had the opportunity to interview Hanna Järveläinen and Stefano Papetti, long time researchers in the field of sound and haptics from the *Institute for Computer and Music Technology* (ICST). We shared our research and upcoming project plans with Järveläinen and Papetti, seeking their feedback and insights. During the interview, we also posed our research, as we hoped to benefit from their extensive expertise in the field.

Treystman, D. (2023). Fig.32: Interview over Zoom with Marco Milevski.

Marco Milevski

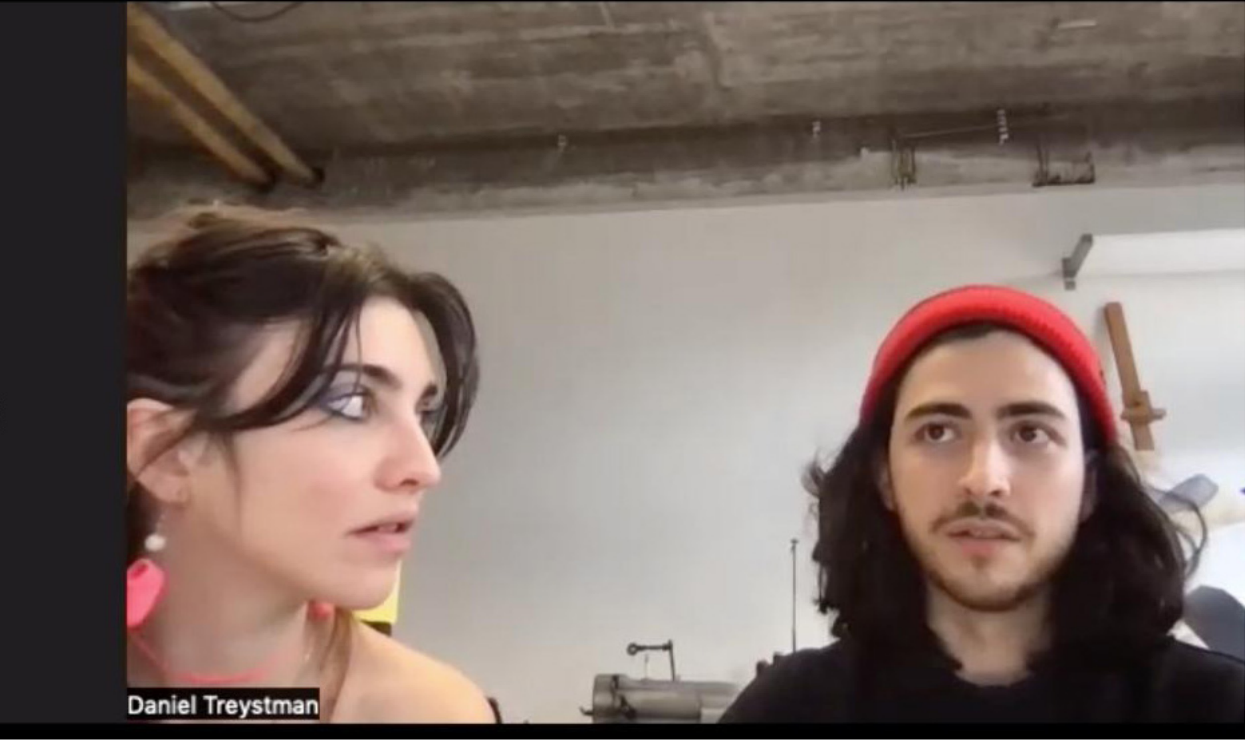
Our first interview was conducted with Marco Milevski (1990), a musician and sound technician based in Jerusalem, Israel. Milevski has played drums since he was a teenager, and is a graduate of Musrara School of Art's New Music department. In the past 8 years he has been part of the audiovisual trio *Wackelkontakt* (2015), where he plays a hybrid setup of electronic and acoustic drums. We chose to speak with Milevski who has about 14 years of experience in producing and playing electronic music, specifically live performance and the use of digital instruments.

We conducted a one hour video-call interview with Milevski in which we discussed our concept and received insights on Milevskis workflow and relations with MIDI controllers.
Milevski's setup is the hybrid drums set including acoustic and electronics pads, which he controls using several midi controllers.

The main one, mounted next to him on the left side, is the Korg NanoKONTROL2, a compact controller with a layout of eight control groups, resembling the tracks layout of most DAW. The other controller is a simple foot pedal used to change envelopes and sensitivity. The last one is a self made controller, consisting of two very long faders, used mostly as volume control of two groups of the different drums.

Though it is handy, when possible Milevski tries to keep them out of the setup. The less control components he needs to handle the more focused he can be on the act of playing the drums.

He does point out that he would have liked to have a controller that will allow him more flexibility, for example multilayered layout and a controller



which has feedback from the software so it could react and change itself dynamically, similarly to digital audio mixers used by audio technicians.
Throughout our conversation, Milevski mentioned that his main controller is rather simple, almost a "stupid" device. We asked him what made him keep using that controller for the past 10 years. The main reason is that it is slim and compact, it can be carried away everywhere, but it still has quite some functions. There is nothing else quite like it, and the little bigger ones are more oriented towards DJing or studio setup. What he doesn't like about it, is that it "glitches" once in a while, cheaply made and the layout is still oriented towards studio work and mixing.

We continued to discuss the gestural affordances his setup has, where he uses the whole body. Milevski explained that it is a communication tool for him and his bandmates. For him, being physical and expressive is what can make the difference between a bad show and a very good show. It is a way of "putting yourself out there" as opposed to restrain, say with triggering sounds with pads.

We asked how it is for him the administrative moment of sitting in the studio and taking decisions of how and what to map to the controller, both from a psychological and technical perspective, and Milevski replied that it is already intuitive, mostly as a result of experience using the same DAW and the same controller, yet he must stay on top of himself in order to get those mapping properly made.
He added that one of the reasons that it is intuitive is also due to the simplicity of the controller, unlike more "sophisticated" controllers like the Keith Macmillen K-mixl which has 3 axis buttons (xyz). Due to their editor software and the way some DAWs like Ableton Live manage mapping, the way to map is rather simple and limited. This makes the tasks of mapping of more complex controllers long and counter intuitive. This was to highlight the importance of the software side of the controller, which can have a

big impact on how the user interacts and manages the administrative moments of configuration.

Conclusion

There is some love - hate relationship with the midi controller. On one hand, it allows in its core to give physicality to the control of digital sound, but on the other hand, it is very limited and restricting. The musician must adapt to the device and find workarounds, which are complex and time consuming. Labelling is time consuming and not as flexible.
Administrative habits in the mapping of the parameters make it easier to remember when changing setups.
The significance of the software side of controllers and devices was highlighted, as the way the software manages mapping and configuration can have a significant impact on how the user interacts with the device and manages the administrative moments of configuration.

Kay Zhang

We had the chance to interview Kay Zhang (1990), an electroacoustic musician and sonic artist. Zhang started playing classic saxophone when they were 10 years old, and since then had in their musical resume contemporary music, chamber music, improvisation and experimental and noise. They have been combining electronics in their practice for the past 4-3 years.
Their current setup is fluid and depends on the occasion and musical style, and can vary from a computer only, amplified objects, saxophone and guitar pedals. They do, although, try to get away from the computer, as they feel that it takes away some of the concentration in the performance, and can generate flat soundscapes. Zhang recently started to use MOD dwarf (2021), which is a device capable of hosting different sound processors such as reverb, distortion etc. The device is primarily made for guitar players, and so it is designed as a guitar pedal, allowing it to be played with both hands and feet.
They have several MIDI controllers and keyboards, some which they use mainly for composing, (i.e studio work practice), as for their bigger size. It is important for them that a live performance gear is compact and can fit easily in a backpack.
Their big pain point with MIDI controllers and their use in live performance is the unreliability, where they experienced them failing in the middle of a concert. Therefore they usually prefer to build a setup that doesn't completely rely on them. Another is the device's high cost.
For them, the mapping procedure is not that intuitive, and requires tutorials and understanding of the device, i.e it is a time and concentration demanding procedure.
Zhang expressed the need of knowing the device and learning it, essentially like one learns an instrument, which can be overwhelming to achieve with the vast amount of different controllers, softwares and mapping techniques. At the end, it also goes back to the fact they don't want to rely solely on MIDI controllers and electronics in their practice.

Conclusion

As for our previous interview, Zhang said *"I have this love-hate relationship with these objects"*, meaning with MIDI controllers and electronic musical equipment in general.
Zhang's musical practice involves a combination of electronics and acoustic instruments, and their setup is fluid and depends on the occasion and musical style. We as interface designers need to understand and accommodate the specific needs and preferences of different musicians and musical practices to create effective and useful musical instruments and devices. Compact and portable instruments can be crucial for musicians who need to transport their gear to different venues, while versatile instruments and devices can enhance their creative possibilities for different styles and occasions.

Andreas Götz

We met and interviewed Andreas Götz (1990) in his shared studio, an electronic musician for the past 4 years and a DJ for the past 10 years. He does not have much experience in performing live and mainly produces tracks. He works with a hybrid setup of analogue and digital gear. The analogue consists of synthesisers and drum machines, and in the digital realm he uses Ableton Live, controlled at times by Ableton Push 2, which is a controller designed to perfectly interface Ableton Live.
Götz uses Novation launch control XL and a 60 knobs MIDI controller design to control specifically the DIY LXR drum machine by Sonic Potions and Erica Synths (2014). Since they are made specifically for the LXR, they are already mapped and pre labelled.
Götz added that even while using the Launch control XL, he always uses just the knobs, never the faders or buttons. We asked him why, and he answered that for him knobs match more the visuals on the instruments and devices in Ableton, which are most often represented by an image of a knob.

He found out that most commercial MIDI controllers are designed to integrate with audio channels, meaning that in their layout they have more faders (which are mostly used to control the channel volume), and a few buttons for on/off, solo and arm. Even though each component can be mapped to control anything, this layout is leaning towards studio work and mixing and is less comfortable for controlling many parameters of one device. It is a combination of not enough knobs, which for him mentally is more fitting for instrument control, and a layout arrangement which has a different purpose, the mixing logic.
He does interfaces which include faders, but they are in his mixing space and are solely for the purpose of studio work.

We discussed how the choice of using knobs only is also influencing the music itself, or maybe how the music is influencing the choice to use knobs only. The music could not obtain sharp changes in timber, sudden mutes or generally any fast musical gesture, as knobs commonly are used for creating ramps of data, or to put in simply, a continuous change.

The way Götz is handling mapping is through a habit he built for himself, which is essentially trying to represent the virtual instrument on the controller visually as precious as possible. In this way he knows that a knob in the middle of the controller should correspond to a parameter approximately somewhere in the middle of the virtual instrument. This habit, and partially the explanation of why he prefers knobs over faders, is an outcome of the fact that Götz relies on his computer screen while interacting with the controller. In his practice, the MIDI controller did not yet make it into being a device standing for itself. He tells us he still needs to check whether he is turning the right knob, and he gets that feedback from the screen.

Conclusion

The MIDI controllers that Götz is using are not giving him enough information, mostly regarding which component corresponds to which parameter. For that, he relies on the computer screen. He has several techniques to make that correlation between the controller and the screen: The virtual and the physical components (in this case knobs) have the same visual resemblance. The order of the parameters mapped on the controller should correspond to the order of the virtual instrument. Similarly to Milevski, Götz also has habits regarding the mapping.

There are associative and psychological explanations regarding the preference of one component over the other, even when their output is the same. In Götz case:

1. The attempt to visually represent the virtual instruments
2. Faders are associated with mixing desks and are meant only for volume control, knobs are for playing.

Lesson Learned from Musicians

It was important for us to understand that no single MIDI controller can fit the needs of all musicians, as each musician's musical practice and preferences are unique and require individual considerations. While MIDI controllers can provide physical control to digital sound, their limitations require musicians to adapt and find workarounds, and administrative habits and software management play a significant role in user interaction. Visual and associative cues can help with mapping and memorising parameters, and compact, portable instruments can be crucial for musicians who transport gear to different venues, while versatile instruments can enhance creative possibilities for different styles and occasions.

Interview with Hanna Järveläinen and Stefano Papetti

Järveläinen and Papetti, together with other researchers from the ICST, conduct the research about Musical Haptics for the past 10 years. It started with the collaboration research with ETH titled Audio-Haptic modalities in Musical Interfaces (Papetti et al., 2014), and with the latest titled Audio-Haptic Technology, supported internally by the ZHdK. In the research they design and investigate different interfaces that incorporate tactile and kinesthetic feedback in DMI (Digital Musical Interfaces). We presented our research and emerging project directions to Järveläinen and Papetti and conducted an interview. Our goal was first to hear their remarks on our project, and second to get their thoughts on several questions we had in mind, which we believed could be relevant based on their vast experience of the topic.

Our first question was: *Do you think that next to enhancing expressiveness, haptic feedback can enable a sense of modularity in the instrument?*
To that Järveläinen and Papeti answered that haptic feedback can simulate different types of controllers, for example a knob with different detents or create an illusion of different button behaviours. It arose that this type of technologie is very challenging to design and integrate, as well as limitations of high costs, high power consumption and weight.
We continued with the question: *"Besides aiding visually impaired people, what other significant uses do you see for haptic feedback technology in minimising visual attention?"*
We got the feedback that the answer has two parts:

1. Mapping audio haptic modalities in a rather arbitrary way that the user learns and know how to extract information out of it
2. Using the haptic channel as an enhancement to the auditory congruently

The congruent auditory and haptic is where the idea of enhancing expressivity can be utilised, yet measuring expressivity is a hard task. They used several methods of user testing to try and measure expressivity, but found it difficult to define and show a definite increment to any direction.

Papetti added that he understands well the issue of the "separation" of the MIDI controller and the computer screen, where the tactile doesn't give much information on what is happening in the screen and where the visuals of the device itself are arbitrary. Yet, the use of haptics to convey information is very limited as the sense of touch is not as detailed, so high-resolution information will not be able to be perceived through it. On the other hand, the solution of small screens on the controller itself can bring back the relevant visual into the device itself.

The research of Papetti and Järveläinen consistently showed that the device is perceived as of a higher quality when it consists of haptic and vibrotactile feedback, as well as the "livelihood" of the device and the sense of embodiment in its use.

Commenting on our interest in linking force feedback and audio features, they added that a way to see what effect it will have is to measure whether people with and without the force feedback produce more "naturalistic" patterns, such as running patterns of acceleration, deceleration and braking. For this, they suggested we first find out what is perceived as a more natural or more musical.

As we encountered ourselves in previous projects incorporating vibrotactile and with our series of 2 user testing done so far, we asked them if they came across this phenomena of desensitisation of touch, and how they dealt with it in their research.
We learned that the body has a rather low threshold for vibration, and that vibrotactile information shouldn't be present for a long period of time. The amplitude is also should be set carefully to not over stimulate the body. One might want to make the vibrotactile feedback as perceviable as possible, but that might be counterproductive in the longer term. Best practice would be to try to find the minimum threshold of perception to try to avoid fatigue and desensitisation. In conclusion, they added that the amplitude question is a big theme in the field which is still left open and undefined, as it will require a very big amount of data to determine it and it has not yet been recorded.

They added that it is important that the perceptual aspect be considered in the light of technological limitations, as in terms of haptic technology, there are still many challenges.

We discussed the HSoundplane (Papetti et al., 2015)which is a modified version of the Soundplane (Madrona Labs, n.d) implementing vibrotactile actuators. As part of this research, they fed the actuators with 3 different types of signals:

1. Sine wave, extracted from the auditory signal as the fundamental frequency.
2. Audio signal generated by the *HSoundplane*, bandpass filtered to 10-500Hz
3. White noise, bandpassed.

From a perceptual point of view, the audio signal has the most consistency and gives overall a better experience. Furthermore, they found out that the sine wave gave the same performance, and that It was perceived to be the same as the sound one heard.
The white noise was proven to neither increase nor decrease the perceived quality of the device, unless the signal played was noise as well, but even then the noise perceived through the actuators is not as precise, and can be described as very "grainy".

Conclusions

Incorporating haptic feedback in DMI has the potential to enhance the expressiveness of the instrument and create a somewhat more modular device. However, it's not an easy technology to design and prototype due to the high costs, power consumption, and weight limitations. Despite this, haptic feedback can minimise visual attention needed for playing and enhance auditory feedback to create a more immersive experience for the musicians. However, from a perception point of view, the sense of touch is limited in how detailed it can convey information, and a support of visual sensory could be beneficial.

Measuring expressivity is a challenge, and there's no clear definition of what it means, and so it is hard to measure and evaluate in user testing. On the other hand, haptic and specifically vibrotactile feedback can improve the perceived quality of the device and create a sense of embodiment in its use. The amplitude of the vibrotactile feedback must be carefully considered and tuned in order to avoid desensitisation.

Concept and Approach

“Car les idées musicales sont prisonnières, et plus qu’on ne le croit, de l’appareillage musical, tout comme les idées scientifiques de leurs dispositifs expérimentaux.”
(Pierre Schaeffer,1977, pp. 16-17)

We essentially started our project with the notion of working on a compact, modular and unlike others; MIDI-controller. Frankly we did not anticipate how deep in the rabbit hole of sound and haptics we would find ourselves by digging into DMIs (Digital Musical Instruments). In contrast to where we stood in the early beginning, we no longer carry the illusion of creating a perfect interface that fits them all, considering that the needs of each musician are individual with their own associations. Understanding the influence of haptics on our body and perception of sound, made it apparent that this is a path worth pursuing.

Haptic technology has started to root itself into day to day devices, e.g. Apple’s Trackpad in Macbook laptops where you get the impression of a click or action without mechanically doing so (Charlton, 2021). However, haptic development only tiptoes around DMIs. The constant evolution in the area of haptic technology calls for a deeper understanding and an elegant approach to integrating it into musical devices. In light of this, we perceive the potential in working on MIDI controllers because components are configurable in what they control but not in how they feel. Incorporating haptic feedback into our controller will not only enhance the musician’s sensory experience but deepen their connection to their instrument.

For the following steps we intend to grasp which kind of haptics could be integrated to a musical interface and how they can be interpreted individually by the users. We choose to concentrate our work on conventional types of controls such as faders, buttons and knobs. One of the reasons for this approach is to maintain a sense of familiarity with interface practices that are commonly used by electronic musicians. Additionally, by adding dynamic and communicative elements to a static-looking device, we hope to create a relationship between the musician and the components, and through that make it feel more alive and communicative, reflecting in the expressivity of the performance.

To empower a dialog between musician and controller, we first need to establish what cues would be natural and also enable an intuitive use. During the research we got the impression that controllers are oftentimes deemed to be as a means to the end. Our intention is to present the ideology that controllers can be viewed as an instrument and organically communicate back to the user's action, which then would be closer to an embodied interaction. We are missing an organic flow of information that got lost or did barely evolve in the creation of MIDI controllers. Perhaps a step forward to remove screens in performative or jamming situations.

Modular synthesis is a prime example of using randomness as a compositional tool, which is still relevant and accessible to music producers today. Modular synthesisers are electronic musical instruments composed of various components that are connected using patch cables, switches, faders, and patch panels to produce music. The hardware can be manipulated using random numbers or voltage control, resulting in more organic and analog experimentation (Vail, 2000). This differs from MIDI controllers, where meticulous mapping is necessary, as the controller itself does not produce sound and the output is chosen by the performer. With MIDI controllers, the gestures and movements vary depending on where the mapped sounds are placed and in our case equally influenced by haptic properties.

With the advent of industrialisation, components such as knobs, buttons and faders became a convenient way to interact with their softwares, including the MIDI controller. Thus electronic musicians have developed a deep understanding of the instrument's affordances, connections, and vocabulary, allowing them to tailor its components to fit their specific needs and composition (Brett, 2011). The choice of movement and gestures are in the hands of the musicians themselves, they can decide if their interaction corresponds directly or if they wish to make the interaction veiled (Jensenius et al., 2010). The relationship between action and meaning involves a connection between the physical and digital worlds. Paul Dourish suggests in his book *"Where the Action Is: The Foundations of Embodied Interaction"* (2004) that the perspective shift should not be focused solely on mapping symbolic representations onto physical counterparts, but on understanding the relationships between them. In our approach, we aim to connect the physical components to the digital world.

Designers in the interaction design field often struggle with the challenge of efficiently developing sonic interactions due to a lack of expertise in sound-related skills such as the necessary vocabulary to convey concepts or even just in prototyping. While designers generally excel at visual thinking, they may face difficulty in translating this into interactive sound (Rocchesso et al., 2013). In our design process, we recognise parallels between the complexities faced in crafting a compelling narrative for us to follow but also formulating methods for sound control.

One of the methods that is too often forgotten is to cultivate awareness to the soundscape we move in. American composer R. Murray Schafer suggested in his *"Book of Noise"* to close the eyes and listen carefully for 5 mins, comparing the ears to our original instruments (Schafer, 1970). It's the practice of walking around and exploring the soundscape like a tourist would, engaging in active listening and attentiveness (Schafer, 1970). The reaction to John Cage's controversial work "4'33"", is a hinge to the fact that then and now, listening is deplorably forgotten (Ross, 2010). In this regard the dichotomy of sound versus noise, the definition of the latest, is often depicted as unwanted or a malfunctioning sound (Schafer, 1970) whereas noise music artists, such as *Merzbow* would argue that noise is not unintentional (Cornils, 2022).

In the automobile industry, the issue of noise pollution has been a concern from the beginning and still persists. But now the development of quieter engines and the introduction of electric cars made sound design a critical aspect of car manufacturing. For example, designing the sound of the blinker, switches or opening car windows has become a consideration to represent the branding of a car (Bijsterveld & Krebs, 2013). A side effect of this progression has been in fact the absence of such sounds that pose a risk to pedestrians who may not hear an electric car approaching at low speeds (Stinson, 2017).
Designing objects should involve considering sound as a fundamental component of their identity. The material and shape of an object have unique sound characteristics and impacts, whether they are being manipulated, placed on another material, or combined. It's essential to integrate aesthetics, auditory, tactile and environmental considerations with functionality in the design process.

Issues that an eye has to be laid on are the methods we want to incorporate in defining the response to an action of the user. In contrast with traditional instruments, haptic cues are given, while in controllers we have the advantage of programming custom cues. We want to dissect which haptic technology could be implemented and moreover the question of how do we establish an intelligible configuration and mapping interface, i.e. MIDI controller surface editor, for the user.

After conducting our research and conceptual phase, we have come to the realisation that most editors do not receive much attention from users nor from us designers and are left to be an insignificant bystander. As a result, our priorities in conception have shifted. We believe that editors have the potential to be the first meaningful interaction between musicians and DMIs and a digastable introduction to MIDI-controllers. On account of this, we have decided to make our musical device more accessible and hackable for users, allowing them to have greater autonomy in designing their own instruments.

In order to achieve our goals, we will use a combination of conceptualisation through prototyping and user testing methods. These techniques will allow us to refine our ideas and create a final instrument that meets the needs and desires for an individual musical tool. This methodology will provide insight in designing for a liveliness control of sounds and hopefully a more instrument-like feel to the device. With this in mind we will engage ourselves into the affordance each component could represent. Finally we wish to incorporate musicians in our design development through a collaborative design workshop. We see value in opening up our ideas and sharing knowledge to move a step further in a meaningful project within the electronic music community.

User Testings

Our work focuses on the perception of touch in correlation of associating sound to it. As we have our own preconceptions and associations with these senses, we feared it was inevitable to fall into our assumptions and needed to check which thoughts were biassed and which were not. To counter this we have decided to iterate in forms of user testing which represent them, to be able to document and build on first hand experiences.
The first speculation concerned whether tactile interactions with surfaces, materiality, textures and affordances effortlessly evoke a recollection of sounds, which guided us to prototype components and low-fi suggestions of haptic features.
Our second hypothesis was aimed at exploring the users' behaviour and preferences during a mapping scenario. Specifically, we wanted to investigate whether they feel inclined towards certain associations between touch, sound, and visual perception. We also examined whether such associations could be easily formed by the users.

#1 - Haptics and Audio Features

In the initial user testing with our low fidelity prototype, we aimed to test the assumption that different haptic behaviours could be linked to specific audio features. To do this, we selected two audio features, Spectral Flatness (could be described as noisness) and Loudness (Meyda, n.d.), and two haptic modalities, kinesthetic and cutaneous.

To test these assumptions, we created a box with two types of slider-like components. The first slider, called the "texture slider," was a strip of non-slip tape that was sanded down to create a gradient of roughness. The second slider, called the "resistance slider," was a potentiometer fader modified with a rubber band that increased resistance as the slider was moved upwards.

The sound related to Spectral Flatness was generated using a virtual synthesiser, interpolating between a simple sine wave and a square wave. The Loudness feature controlled the volume of a sine wave. Both sounds were played at a constant C3 note.

We used the Wizard of Oz prototyping technique to test the sliders. Users interacted with the sliders while we observed and reproduced their movements using a functional MIDI controller. We tested each slider with each sound, the texture and resistance sliders controlling noisiness and loudness in sequence.

Our assumption, based purely on testing it out ourselves, was that the texture slider corresponds to the noisiness, and the resistance slider corresponds to the loudness.

We had 12 individuals testing the sliders. Seven out of them defined themselves as having some degree of musical background. The users were from the Interaction Design department, mostly students from different classes, and one staff member. They were asked for their participation personally. The result were inconclusive and are laid out in the following table:

Audio Feature/Slider	Resistance slider	Texture slider
Spectral Flatness (Noisiness)	4	6
Loudness	5	3
Spectral Flatness + Loudness	2	1
Sum	11	10

Conclusion

In conclusion, our study yielded inconclusive results, suggesting that there may not be any objective psychological commonalities between haptic modalities and sound features. However, to verify this conclusion, we may need to conduct further tests with a larger number of participants. During our testing, we also noted that some users interacted with the faders in unexpected ways, which prompted us to consider the limitations of the Wizard of Oz prototypes. To improve future iterations of the faders, we recommend making them more similar to each other in terms of their length, and possibly recording and comparing user gestures with a normal feeling slider without texture or resistance. While we acknowledge the lack of objectivity in the link between haptic modalities and sound features, we are interested in exploring whether adding texture and resistance to the faders can enhance playfulness and interaction. To do so, we plan to develop guidelines for what constitutes playfulness and a valuable change in interaction.

#2 - Haptics and Sound Associations
In our next user testing we added three more interfaces:

1. Rigid metallic spring, laid out horizontally
2. Paint roller, connected vertically
3. Smooth wavy metal sheet, laid out horizontally

Unlike the first user testing, where we asked the users to control sound, this time we asked them to imagine the sound each interface would make while wearing earplugs to dim the acoustic sound generated by interacting with the interfaces.

We seeked to understand if we find common ideas within the users in the way they imagine the connection of the physical interfaces and the sound. Another factor was to get ideas from the users of how the interface can be mapped or used.
The user testing was filmed professionally and visibly in a studio, and the material was edited and used to convey the general idea of our project in the *BA concept seminar* presentations.

7 individuals from the Cast, Interaction Design and Game Design departments were recruited by personal request. They participated one after the other, and tested each one of the interfaces.

Treystman, D. (2023). Fig.33: Interfaces of "Haptic and Sound Associations" User Testing

Conclusion

We did not find conclusive evidence of similarity in the responses, yet we got interesting insights into how each interface could be used to manipulate sound. This is a good method for generating ideas for interfaces and sounds.

#3 - Memory Game

In the *Memory Game* user testing we aimed to explore the correlation between touch and visual perception and their association with sound. We had 8 participants, from the Interaction Design and Cast department.
The user testing focused on the concept of memory and seeked to determine whether linking sound with texture or visuals can make it easier for users to memorise information.

To achieve this goal, the user testing was designed in a comparative manner and had three phases with similar procedure of actions and controller surfaces to interact with. The difference between each phase was in the senses it asked to investigate.

Setup

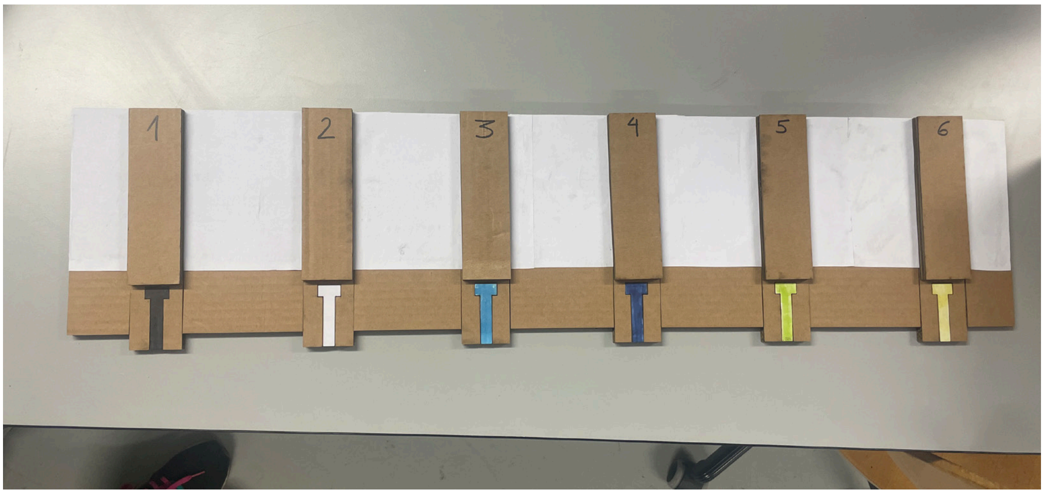
We made two controllers, both made out of cardboard. On their base are six narrow rectangles, which are the interaction component for the users.
Controller number 1#: has a “T” shaped slit underneath each rectangle, and paired with the cutout “Ts” next to them.
Controller number 2#: each rectangle is hidden behind a set of curtains, which block the users from seeing them, but allow access for the hand to reach and touch them. This approach was taken to eliminate the influence of visual texture perception (Zhou, 2006), which relies on the ability to visually observe and categorise textures.

Onto each of the rectangles a different material was glued, resulting in an array of six different textures. From left to right:

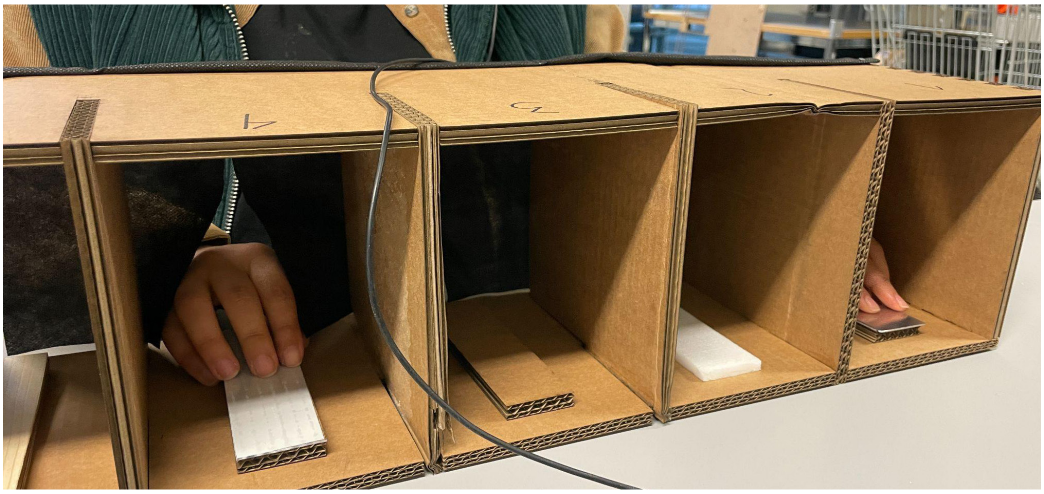
1. Polished aluminium
2. Polystyrene
3. Cardboard
4. Plexiglass
5. Wood, not sanded
6. Smooth matte cardboard, taken from old Apple’s iPad box

We chose surfaces which are not extremely different from each other, based on what we learned in our research, which is that the perception of tactile sensing is limited in its resolution. We applied the idea of configurable and dynamic vibrotactile which can be achieved with electronic components programmed differently (e.g vibration motors) that have themselves limitation in how different they can feel.

There was a computer screen displaying a simple GUI (graphical user interface) of 18 faders, departmentalised into three sections. The GUI was created utilising *M4L* (*Max for Live*), an *Ableton Live* host for the visual programming environment *Max/MSP*. The users could interact with the faders using a computer mouse. Each fader controls the volume of a different sound, playing from within *Ableton Live*, and output to headphones.



Steurer Jene, S. (2023). Fig.34: Colour-marked sliders used for phase two of the "Memory Game" user testing



Steurer Jene, S. (2023). Fig.35: Texture sliders used for phase three of the "Memory Game" user testing

Phase one: Neutral / Position

Each participant has 30 seconds to interact with the GUI and get familiar with the sounds of the first six faders. After that, we ask them to "place" each sound on each of the rectangles, one sound to one rectangle. The users could choose that based on their liking or logic, and no guidelines were provided.

They would tell us where they want to place it, and we map them to a MIDI controller, which will later be used as the *Wizard of Oz (UX4Sight, 2023)* device. To help remember which rectangle slider has been already mapped, they could insert a "T" into the slit and so to mark it.

The *mapping* part is going through the decision making process similar to mapping parameters into MIDI controllers.

Afterwards, the participant has 30 seconds to play the cardboard controller with their fingers. Behind the scenes, we played the MIDI controller which we mapped based on their decisions, to output sound to the users.

We then played them the sounds, one by one, and checked if they remembered on which rectangle they placed each.

Phase two: Visual

The process in phase two is identical, with only difference in the introduction of new sounds. That is to avoid the users from reusing their order from the previous phase.

The only difference in the control surface is that the participants can now mark their rectangles using a provided set of coloured "Ts". They could choose freely in which order to place them.

Phase three: Textures

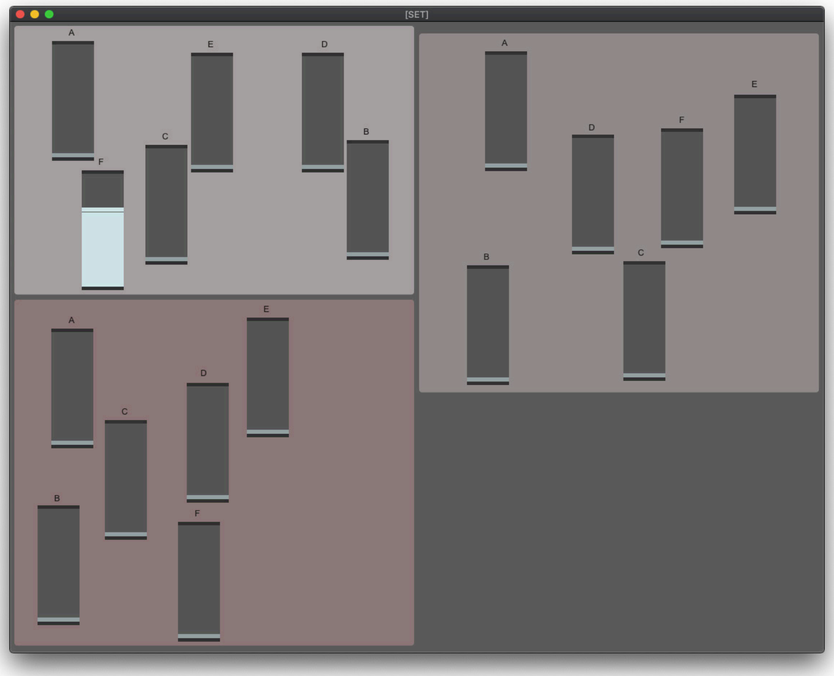
In the third phase we introduced the new control surface, where behind each curtain there is a different texture.
The rest of the procedure is the same as in phases one and two, but with a new set of sounds.

Conclusion

Phase one and two were producing similar results in terms of accuracy, where phase three was producing a higher rate of mistakes compared to the first two. This can be explained by two factors:

1. The textures are not so easy to differentiate by touch only, as expressed by all users.
2. Textures could be sensed one after the other or two at the time at the most. It is harder to get an overview unlike position based or position-colour based memory, where all components can be observed at once.

Although memorising information based on colour did not lead to better outcomes then , it was still regarded as the preferred method by most users. They found it to be the easiest approach as it allowed them to add an extra layer of colour to their location-based decision-making process. By incorporating colour as an additional element, users were better able to reinforce their choices with greater confidence and assurance.
Some users reported making abstract associations to the sound as part of their sound-colour matchmaking. For example, one user reported he matched one of the sounds to yellow, as both gave him a feeling of something “heavenly”, and another connected a sound and the colour blue, as both were associated for them with “ocean”.
Some users said they would have liked to have the option to arrange the position of the textures themselves, as opposed to having it already given and fixed. For example, one said they would have liked to arrange them as a gradient of roughness, unlike the “random” distribution they were given to interact with.



Treystman, D. (2023). Fig.36: GUI for the user testing “Memory Game”

PROJECT DEVELOPMENT
Planned Trajectory

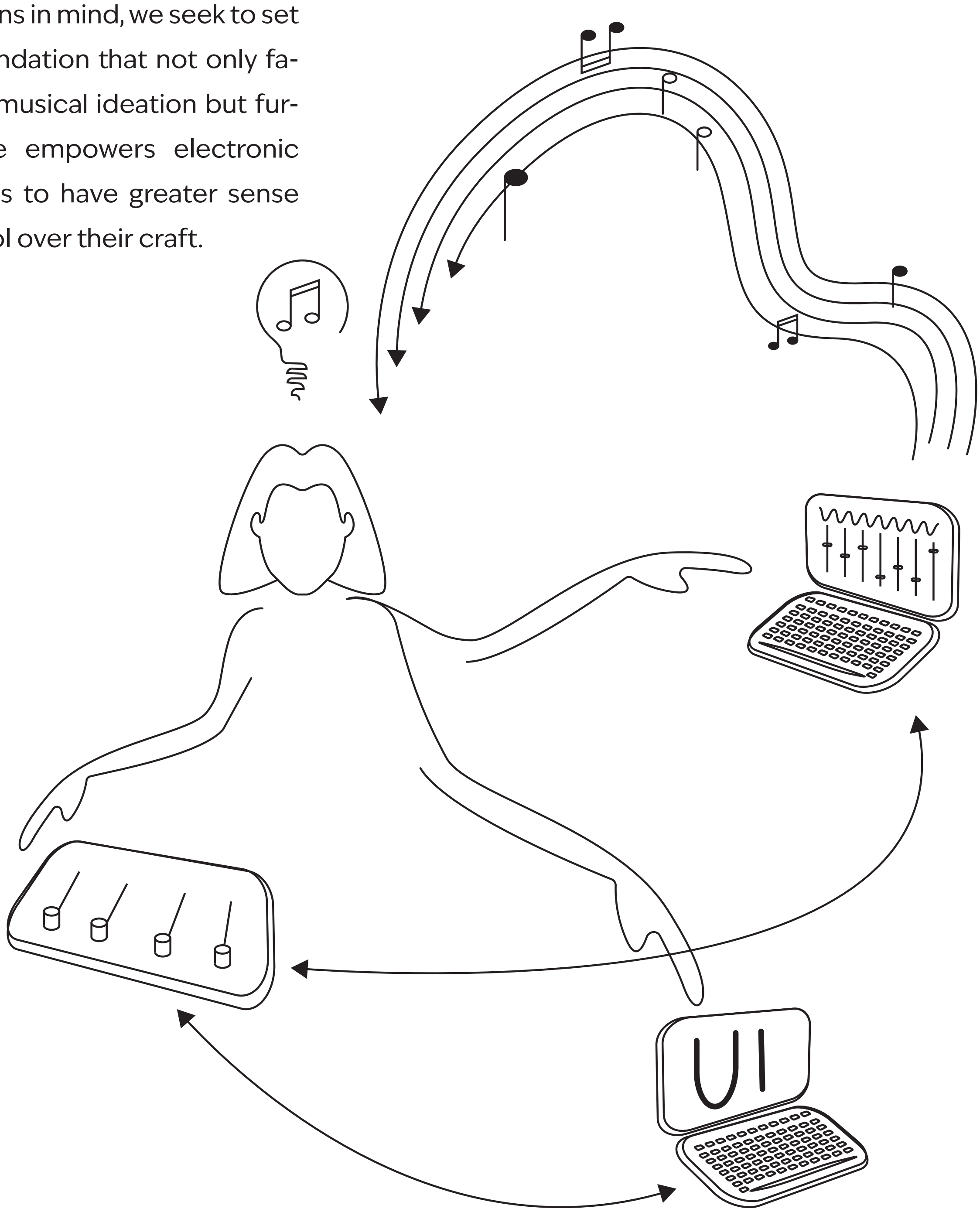
During our previous user testing stage, we have been committed to challenging our assumptions by engaging with people and being receptive to their feedback. This approach has been crucial in helping us to understand the meaning and associations that our concept has induced to the participants in these curated situations. We have found that some of the most valuable feedback has come from informal conversations that took place during or after the testing, likely due to the more relaxed and open dynamic that naturally develops in eye to eye conversation versus the "user and tester" setting.

To enable exactly those moments we chose to prepare a workshop involving two to three experienced electronic musicians that work with MIDI controllers in their practice. The workshop will consist of one set of components and a rudimental GUI for each participant, which can be tested and mapped with their own collection of sounds. We are looking to get instant reactions to our prototypes and ideas from musicians, and understand different needs and setups. The benefit of having a smaller group of participants is that we can assist them with more attention and adapt haptic behaviours according to their design wishes.

This workshop can be seen not only as a prototype testing but moreover as a proof of concept of the physical part of our project. In favour of a fathomable "components hacking" for the user we are looking at our key element, the surface editor.

The current objective is to elevate the relevance and usability of the surface editor, while also seamlessly integrating the mapping of haptic feedback. This presents an additional layer of complexity, but we are committed to finding a solution that not only enhances the editing process but also makes it more accessible and engaging for electronic music making.

Our aim is to construct an intuitive logic for mapping that anticipates the various stages the user goes through before working with the hardware. By understanding the journey prior to physical use of the MIDI controller, we hope to foster creativity and inspire new musical possibilities. Through this we wish to establish a framework that encourages musicians to explore and experiment with the hardware, even before they physically interact with it. With these aspirations in mind, we seek to set up a foundation that not only facilitates musical ideation but furthermore empowers electronic musicians to have greater sense of control over their craft.



Steurer Jene, S. (2023). Fig.37: Interaction system of working with MIDI controllers

Concept Prototype

To encapsulate our research from the implication of the emergence of MIDI to the value of haptics, and further in challenging our gathered assumptions, we have brought a large baggage to unpack into our final project. Our thesis delves into the issue of physical sound control in a digital environment, exploring the divide between what a MIDI controller can communicate versus what the software can execute.

Could the issue be attributed to the affordances of the interface? After all, there exists a broad spectrum of physical engagement when it comes to music devices. This spectrum ranges from simply sitting in front of a computer to using the entire body embellished with sensors to control sounds. Each approach to make or control sound in the electronic music field has its own legitimacy, as the individual needs and preferences of musicians result in similar diversity. To provide a further view, every musician has their own unique performative style or artistic statement, which may even be similar to the calculated and disconnected performances of SND (Fell, 2012).

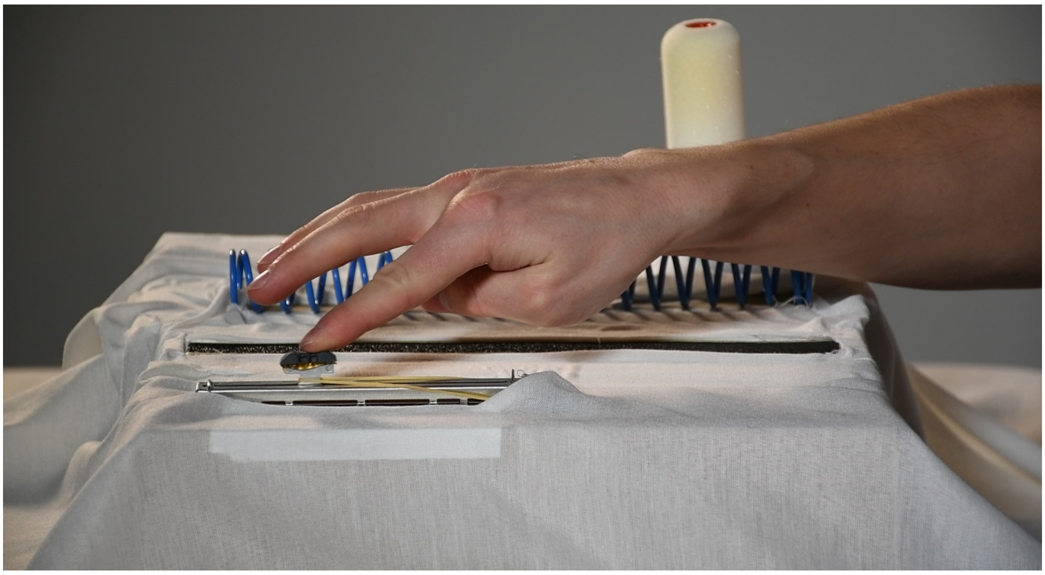
At this stage, we have come to the realisation that there is no "one size fits all" interface solution. Nevertheless, we want to make a case for the idea that seemingly inflexible devices can actually offer valuable features. MIDI controllers that feature faders and knobs harken back to the analog era of music production, on which Digital Audio Workstations (DAWs) are based.

Metaphors of these physical components continue to exist in music software, through MIDI they can still be mapped in an incongruent manner. In addition to being symbolic of control and precision, electronic musician Julian Meier has noted that faders allow for more accurate value handling, as he expressed during an informal conversation. Additionally, in the case of faders, a few of them can be controlled with the whole hand at once, which is an acquired skill that electronic musicians gain throughout their career.

Our main focus for the physical prototype is to identify the relevant behaviours that musicians would require and appreciate. To achieve this, we have decided to work with existing types of components from the world of sound, such as faders and knobs, instead of introducing an entirely new control mechanism which needs extensive introduction in mapping, new vocabulary and usage.

By building on the existing knowledge and experience of musicians, we see potential in experimenting with haptic features that can be instantly adopted and incorporated into their musical workflows. Ultimately, our goal is to design an interaction that is not only functional and effective but also practical and easy to use, allowing musicians to focus on their art without investing too much time in operating foreign controls.

We are of the belief that adhering to the straight forward aesthetics of faders and knobs, we gain a chance of versatility within the hardware. To underscore, we are also suggesting that motorised faders can incorporate an infinite range of characteristics that may facilitate certain controls or make other types of control more difficult.



Steurer Jene, S. (2023). Fig.38: A user testing the rubberband fader

Steurer Jene, S. (2023). Fig.39: Rubberband fader enclosed in a box

During our initial user testing, we developed a rubberband behaviour by attaching a rubber band to the fader cap. This behaviour makes the otherwise effortless pushing motion more challenging. While some may view this as a disruptive feature, we see its potential in precisely this quality. It allows the musician to consciously control the sound in situations where a gradual, slow movement is necessary.
Conversely, in other cases, this feature may be the reason why a musician

wants to engage with force which could reflect through the gestures of the performance. Let's not overlook what happens when the fader cap is released, the tension of the imaginary rubber band energetically pushes the fader cap back. The fader itself has a physical response to the user's action which influences the sound without being manipulated in this moment. With this in mind, the MIDI controller becomes relatable to idiosyncratic or independent traits.

Earlier, we mentioned versatility, which pertains to the ability of a single motorised fader to exhibit completely new behaviours or even characteristics which can be attributed. For instance, consider now the fader cap that always snaps back to the centre position. To begin with, using and mapping sound to this component alters the way we think about usability. Secondly, it completely transforms the way musicians interact with sound and their approach of operating the fader. Finally, it should be noted that the fader is capable of assuming new characteristics, including but not limited to being silly, stubborn, or balanced. Furthermore, these characteristics can be subjective and may vary depending on the musician's perception or influence.

Shifting our focus to the knob, we enter an area of more introspective expression. Technically speaking, what we commonly refer to as a knob is a rotary encoder that can turn endlessly in either direction without reaching a mechanical endpoint. The haptic feedback is generated by a *linear resonant actuator* (LRA) that produces vibrations based on the programmed behaviour.

Unlike the fader, the knob's behaviour is not visually apparent, but only perceptible to the user through touch. It could be compared to a privacy screen protector for phones that blocks out prying eyes from interpreting what's being felt. The underlying concept promotes an intimate connection with the knob, as it enables an internal dialogue with the user. This could involve intensifying vibrations, which in turn haptically enhances changes with the sound values.

Furthermore, it can vary depending on the musician's associations, such as expressing reluctance to go to the user-defined "danger zone". These are just a few examples of possibilities and associations that can arise from interacting with our components, as there is a wide spectrum of possibilities and outcomes depending on the individual musician's needs and preferences.

Moving to the digital aspect of our prototype, achieving simplicity during the configuring phase of the MIDI controller, which is the moment where the user makes the tool their own, and what we aspire to see as "instrument design". The key challenge we face is the integration of haptic behaviours without overwhelming or cluttering the surface editor, which we will refer to as the *haptic editor*.

We want to give the musicians greater autonomy with their instrument. One way to achieve this is by enabling free customisation and modification of the actual haptic behaviours on a GUI. However, we also considered the potential complexity of such a system if it were to be too open-ended. During this discussion, we debated the level of openness that our system should have. Would it be appropriate for it to become a comprehensive programming-like environment? While this approach would make it fully accessible to those with coding skills, what about those who do not have or are not interested in gaining such skills?

In line with our thesis framework, we have opted to share our work on GitHub, a platform that is recognised for its thriving open-source community. While we acknowledge that the reach of our work may be restricted, we maintain that it is a topic that warrants ongoing discussion in the future.

With those guidelines, we are confident to kick off the development of our project.

Open Source

As part of our developed concept, we understood that a key element is the accessibility to the knowledge we gathered, together with the ability to technically create and modify the prototype. As such, we decided to share everything on a *Github* repository, including all necessary parts: electronics, arduino code, and GUI code.
GitHub is a website that serves as a hub for sharing code and hardware projects, managing code versions, and facilitating remote collaborations (Lutkevich & Courtemanche, 2023).
Our repository will accommodate all the information upon completion of the project, and can be found in the following link:

https://github.com/dtrejst/Haptic-MIDI-controller

Why open source?

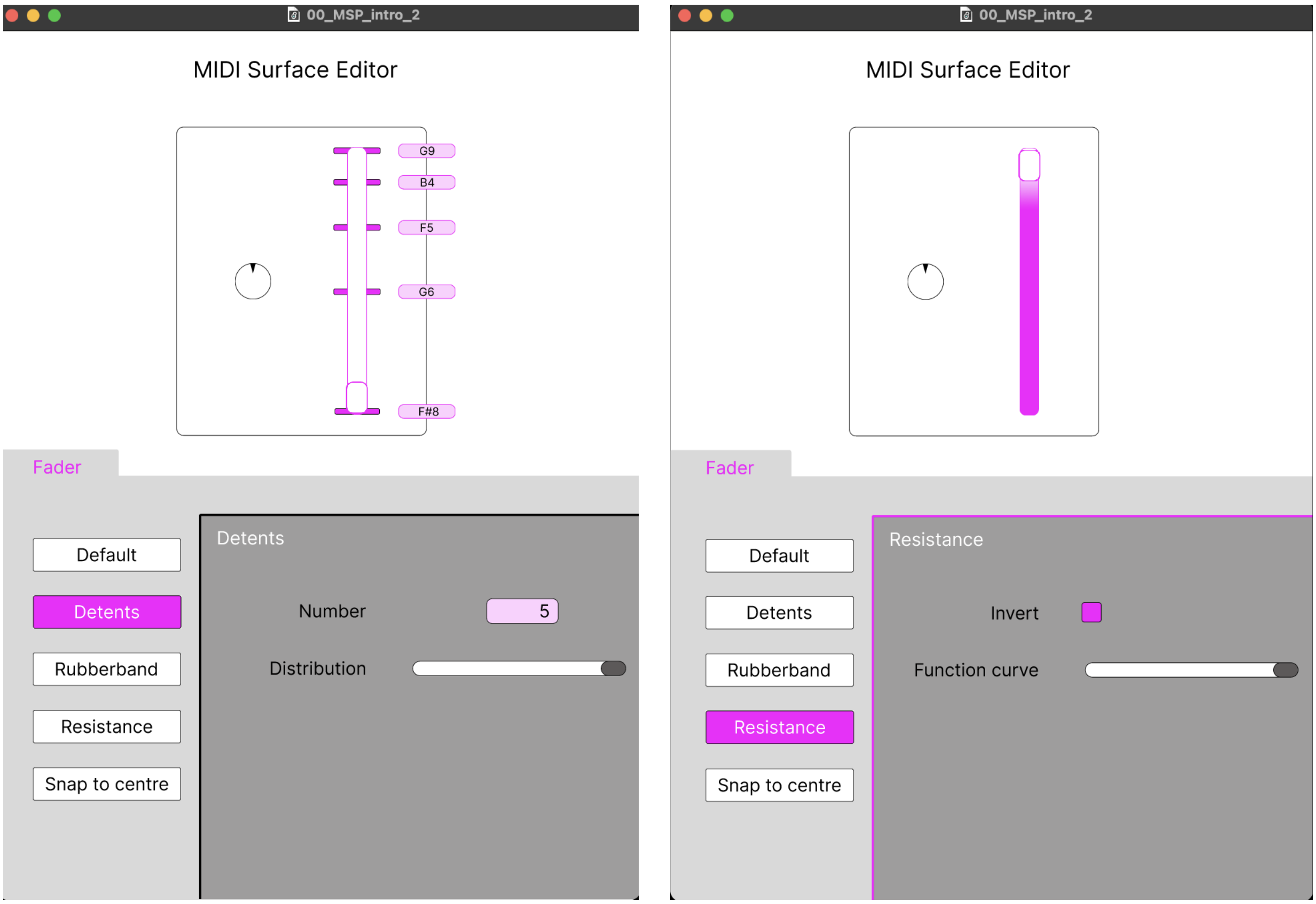
As we have come to learn that a "one size fits all" controller's layout does not apply, an open source concept could accommodate individual needs and allow users to tailor the layout to their liking. In addition, our goal is to create a community or contribute to already existing communities that are engaged in the development of dynamic haptic interfaces, such as the thriving community on the SmartKnob Discord channel. This community has evolved beyond the SmartKnob and now includes participants who are showcasing and sharing other exciting projects in this field. Our hope is that our project will extend beyond our own contributions, and that we will witness people modifying, customising, and advancing it. We look forward to fostering a community of individuals who are dedicated to its growth and development. We also recognise a potential in implementation of the concept and technology in other fields such as light control, smart home interfaces and virtual reality.

Development Components

Haptic Editor

The MIDI surface editor is the initial point of interaction and customisation for musicians with the MIDI controller. This interface gives agency to the users, providing a sense of control to construct their own tool. In our case, this is where users can map and decide on the haptic behaviours needed. We want to highlight the meaning behind the mapping process of a musician.

This decision making does not only revolve around what a component controls, but also how it should feel so the musician can experience the control through touch. It is also the moment where musicians are confronted with what kind of gestures they wish to perform. Do they want to map the sound into a more straightforward association of the component, e.g. loudness controlled by fader with force feedback resistance, or do they wish a more manufactured and unnatural mapping to convey a different awareness to the sound. Ultimately, the haptic editor allows musicians to construct their own instrument and tailor it to their needs and preferences.



Steurer Jene, S. (2023). Figma prototype of the Haptic Editor. Fig.40: (left) Setting number of Detents (right) Setting resistance function curve

An appropriate option for us to develop a functional editor is using *M4L*, a collaborative product by *Ableton* (*Live*) and Cycling '74 (*Max/MSP*). It is a *Max/MSP* patch hosted within the DAW *Live*, in a way which looks and feels like a native effect or instrument of the software, and referred to as a "M4L device". Both of the above companies created an *Application Programming Interface* (API), essentially allowing to control, modify, and retrieve information from Live to M4L, exposing the internals of the software and allowing anyone to program devices, and create plugins, effects and virtual instruments for *Live*. Additionally, M4L devices are open source in their nature, as they cannot be traditionally compiled and exported, leaving anyone with the device the option to instantly open its "insides" and copy or modify it to their liking.

By programming the editor in this environment, musicians who create and perform music in the DAW *Live* can integrate the editor within it, and to easily access it. Moreover, it can set the ground for creative modification of the editor for anyone with Max/MSP programming skills, which is a widely used programming environment in the field of electronic music and computer music.

In parallel, we wish to accommodate the needs of others who choose to use other DAWs and softwares, and create the editor as a standalone software, programmed in Max/MSP. This version will behave as any software, which can be easily downloaded and installed on the computer. This option answers the needs of not only the ones who work with other DAWs, but also with various other softwares in different fields, such as lighting and visual softwares like *Resolume Arena* and *MadMapper*, as well as video editing software such as *Adobe Premiere Pro* and *Final Cut Pro*.

Haptic Behaviours Conceptualisation

During the ideation process, we have come to the realisation that haptics are at the heart of our thesis, as they allow for a stronger representation of modularity within the same components, and besides make the components become more lively. However, we have encountered difficulties regarding what other possibilities exist beyond programming haptics.

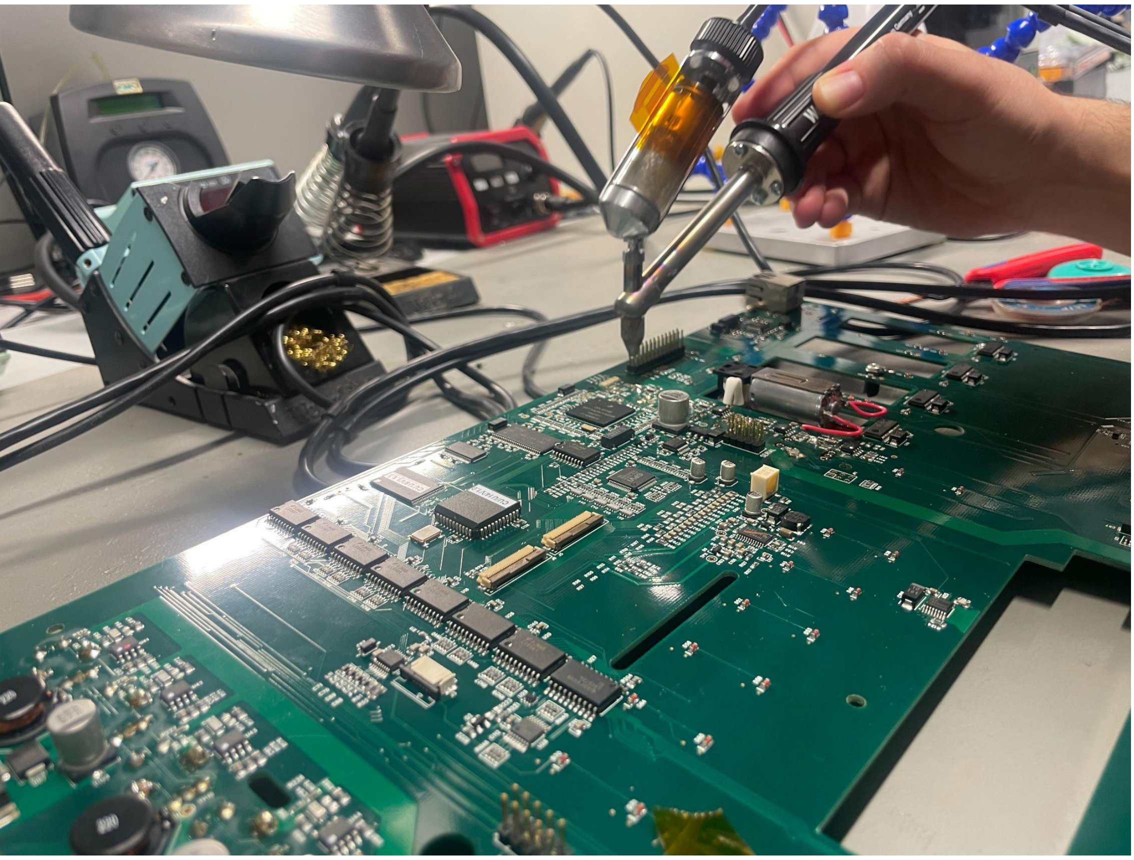
In the field of HCI, metaphors have been utilised for a considerable period to facilitate the acceptance of certain digital objects, such as the desktop metaphor from *Windows (Darling, 2019)*. *Apple Macintosh* has employed a similar approach with auditory icons, where sounds are used to represent objects and actions. For instance, the sound of crumpling paper is associated with folders (Visell et al., 2013).

Similarly, the Moose project suggests navigating on a Graphical User Interface (GUI) through a powered haptic mouse that enables users to feel the interface through using touch-based cues. Its primary function is to differentiate between the borders of the screen and icons on the desktop, enhancing the user experience. In addition, The Moose employs metaphors to create feedback for each digitally visually represented element. For example, a checkbox is represented as a border with a repelling block at one end, which when selected becomes an attracting spring.

Our evaluation suggests that these are methods we can rely on to design haptic behaviours. In certain cases, we may rely on one-to-one examples of the mechanical version of the component, while in other cases, we may draw inspiration from the metaphorical sphere.

Fader

We were looking to purchase motorised faders to start experimenting with them, when we were fortunate enough to come across an old, partially disassembled controller in the school's circulation zone, equipped with several motorised faders made by Alps, which we were able to desolder from the PCB.



Steurer Jene, S. (2023). Fig.41: Sourcing components from the found PCB

Since these faders have built-in motors, we assumed we could assign them force feedback behaviours, taking inspiration from the *SmartKnob*. We initially tried programming the fader behaviours ourselves, but we didn't achieve the desired results. Fortunately, we found a script that did exactly what we wanted after doing some technical research and watching the YouTube video *"Taking a look at a motorized linear potentiometer"* by the user (Critters, 2015).

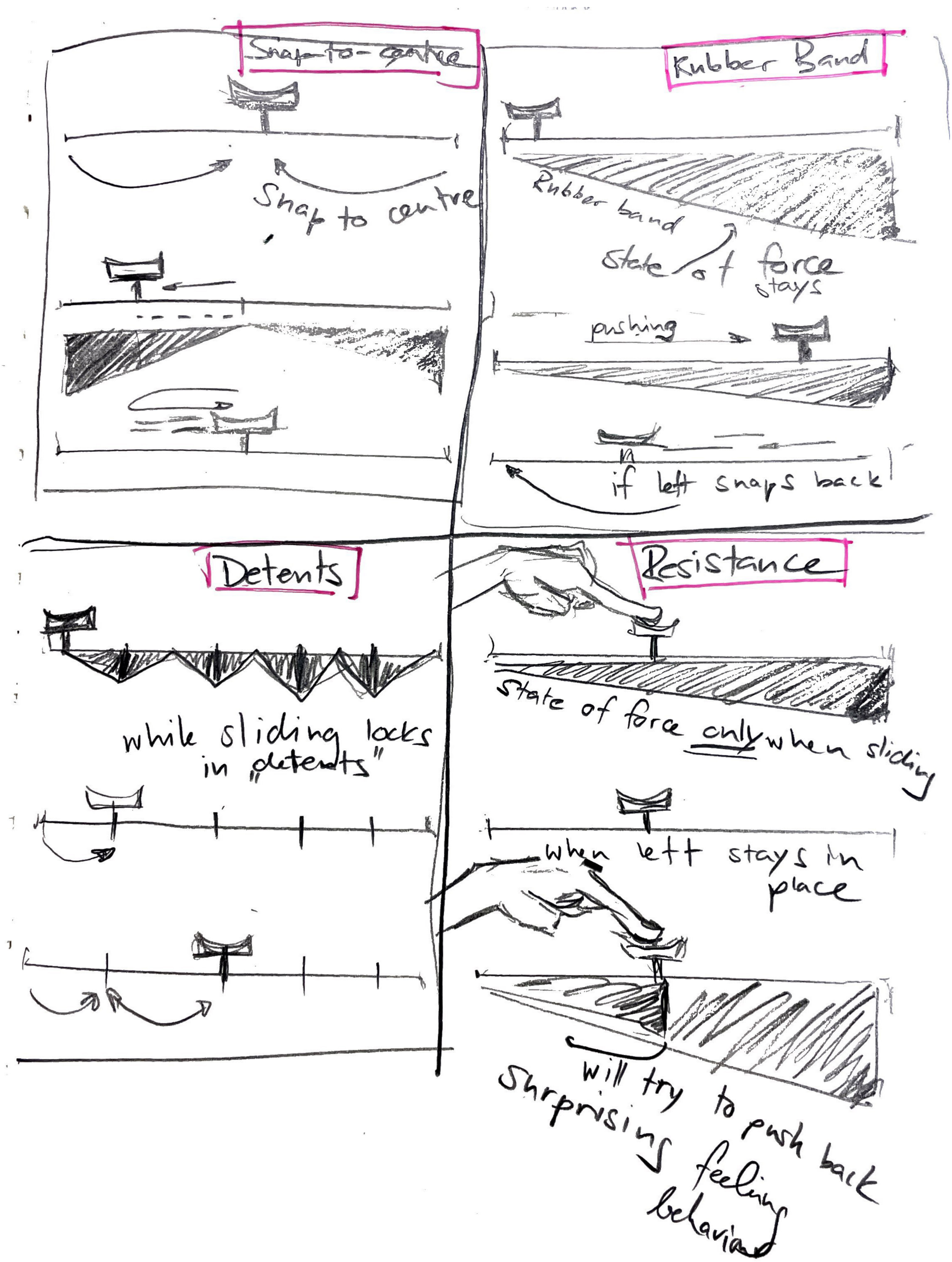
After successfully hacking the behaviour of the faders we assigned them new meanings:

Rubberband: By moving the fader into higher values, the motor starts working harder against the finger and creating pressure on it. When lifting the finger, the fader snaps back to zero. It could be used as an expressive mean, e.g "feeling" the nosiness of the sound or the amplitude becoming stronger.

Resista**nce:** Similar to the rubberband behaviour, but doesn't snap back when released but stays in place. This was achievable using touch detection. This is one of the most interesting behaviours which is rather counterintuitive and unnatural, giving it interesting playful properties.

Notches: The motor simulates the feeling of detents or steps throughout the lowest and highest distance, making the fader's control non-linear. This could be used for a selection of one out of several discrete values, for example: transposing octaves up or down, selecting notes, changing time signature etc.

Centre: the snap-to-centre feature creates resistance when pushed to either side and returns to the centre when released. This behaviour Wcould potentially be popular for vibrato, or commonly for pitch bending, as it behaves similarly to pitch-bend wheels found on common electric piano keyboards.



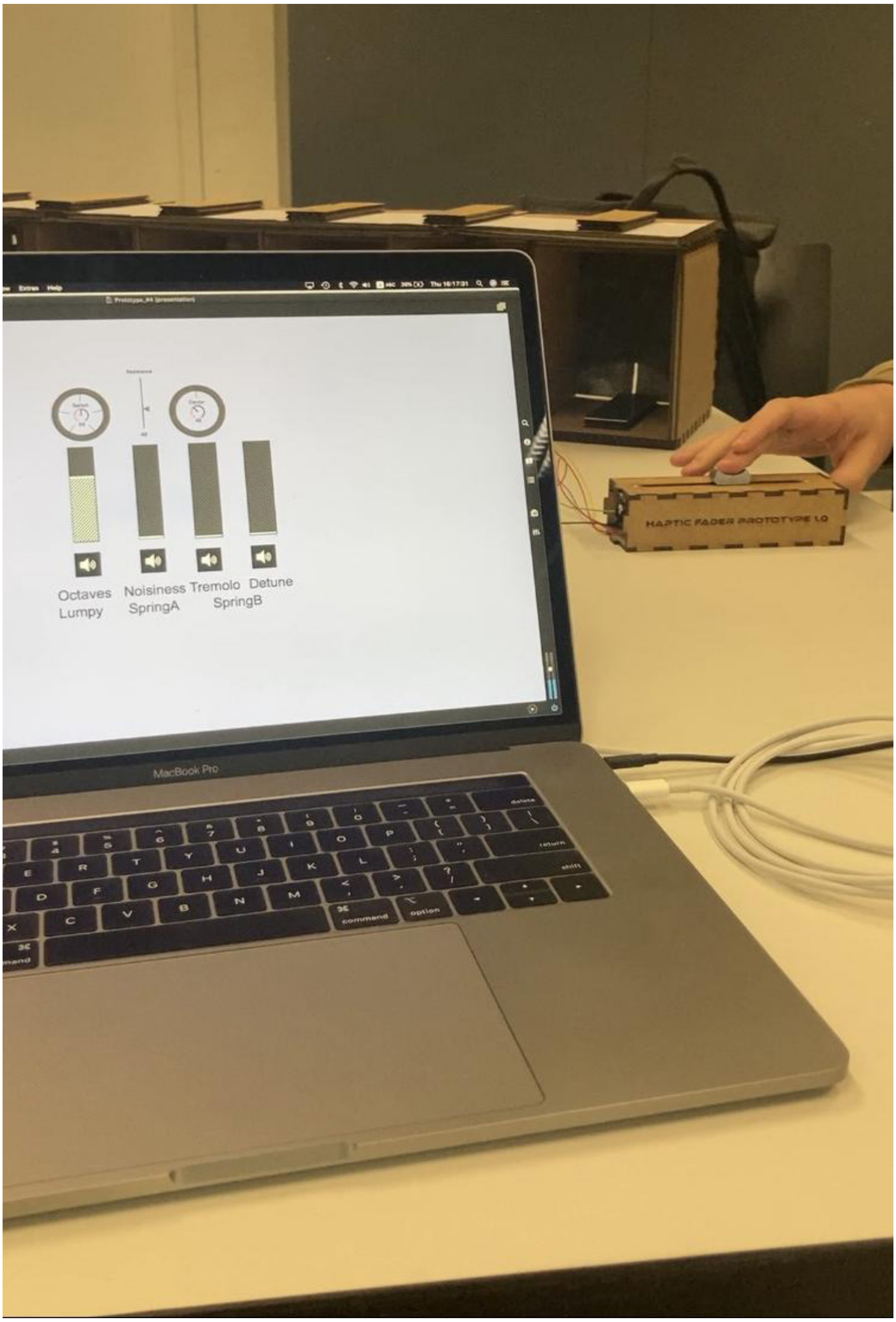
Steurer Jene, S. (2023). Fig.42: Skecth of haptic behaviours of the fader

Despite the satisfying haptic sensation, we are facing the problem of the motor's generating sound when being pushed. The issue resides in the use of PWM (Pulse width modulation) to control the motors, which is essentially inputting a frequency to the motor.
Although in one of our user testings the user expressed joy in playing these mechanical sounds, mechanical sound does not work with our concept, as the only main sound should be produced and chosen by the musician, and cannot be a by-product of the intended behaviour and physical interaction. Other people that interacted with the device and some of the mentors expressed that they find the sound irritating, almost like an error sound which is then not inviting to interact with.
We learned that it is possible to achieve the desired behaviour without the side effect of unwanted sound (Huber et al., 2004) using different means of motor control, but it requires more research and many extra steps to achieve which seemed out of scope. Nevertheless, we managed to get rid of 99% of the sound by finding balance between the right PWM frequency and the right PWM duty cycle, and by optimising the arduino code.

We could find one commercial device using force feedback faders, and stumbled across it after we made our own version.
The *M4* (Der Mann mit Der Maschine, n.d.) is a 4 faders module for Eurorack modular synthesisers format, which can create virtual notches or Snap-to-Centre behaviour. From the webpage of the module: *"Another unique feature is the "haptic feedback". If a fader is used, for example, in a sequencer to select a note from a scale, you can feel each individual note like an artificial notch. ...Due to the haptic feedback you don't need any display for seeing what you are doing. You can concentrate on making music and play very intuitively"*. (*M4 - Motor Fader Controller*, n.d.) .
It is also worth mentioning the excitement of the comments for the YouTube video showing Mathias Kettner, the creator of the device, demonstrating how it works (sonicstate, 2021):
"*At first I thought "well this is a stupid gimmick" and then I saw it in action. Wow, that's really cool. It makes a modular* (system) *a lot more "p(l)ayable""*
(BigHairyCrank, 2022)
"those notches when selecting notes is so insane!!" (aaiieenn, 2022)
"What an exciting thing, congrats !"
Those and many more comments gave us the confidence that we are on the right track.

In the second prograss session, we demonstrated a fader with the *rubberband*, *notches* and *centre* behaviours as our prototype. We paired them with sounds we found fitting for each physical setting. For example, the rubberband was mapped to a sound which got noisier as the finger travelled upwards, and the *centre* was mapped to a tremolo effect.
After having the prototype open for testing in the second progress session, we got a batch of excitement and interest from our classmates and other

interaction design students. Although the majority of them do not create electronic music, they still found it intriguing how a component can physically behave in different haptic ways, and found it sensuously satisfying. One guest shared that he works a lot with lights, and can see it very applicable in the field of lights control as well.

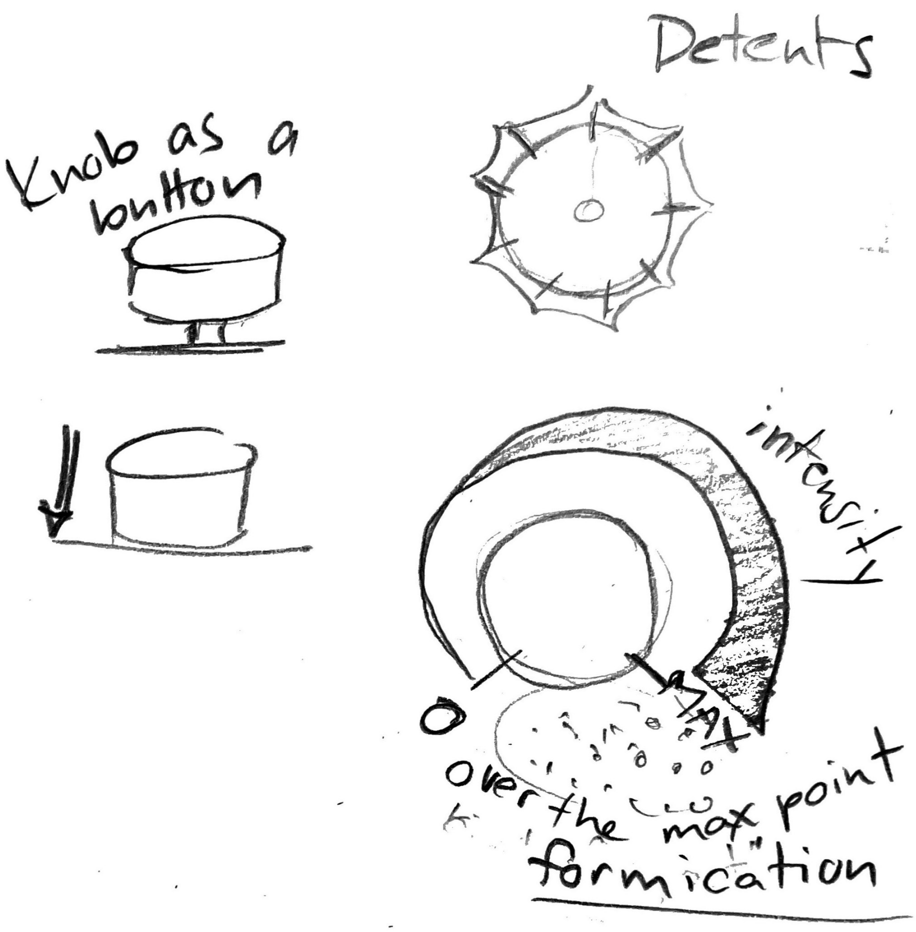


Treystman, D. (2023). Fig.43: Controlling sound using the detents function in progress session 2#.

Knob

We are using common incremental encoders with no detents which we found on the same motherboard on which the faders were, also made by Alps. They also combine a push button as part of the control shaft, known as knob or cap. It can simply be pushed down, so a signal of either 0 or 1 is being output. These rotary encoders have no physical limit to their rotation i.e they can rotate endlessly, unlike rotary potentiometers which typically can rotate 270 degrees until they meet a physical limit.

We used the DRV2605L haptic driver with a LRA actuator made by Pimoroni, and attached them underneath the encoder and so transmitted vibration through its body up to the knob shaft.
We fed the value of the encoder to the haptic driver to create a direct link between them, and experimented with a few different behaviours:



Steurer Jene, S. (2023). Fig.44: Skecth of haptic behaviours of the encoder

Intensity: A sequence of quick, sharp clicks made through vibrations. The time between each click decreases as the encoder's value increases, resulting in a faster succession of clicks with shorter intervals between them. This could be used to signal the intensity of the value growing. We believe that the use of constant vibration which intensifies might cause sensory overload, and that short clicks can prevent that. Further testing is needed to confirm those assumptions.

Detents: Sharp clicks based on the angle of the encoder, imitating detents. Can be configured to signalies and reassure the user of how much they have turned the knob.

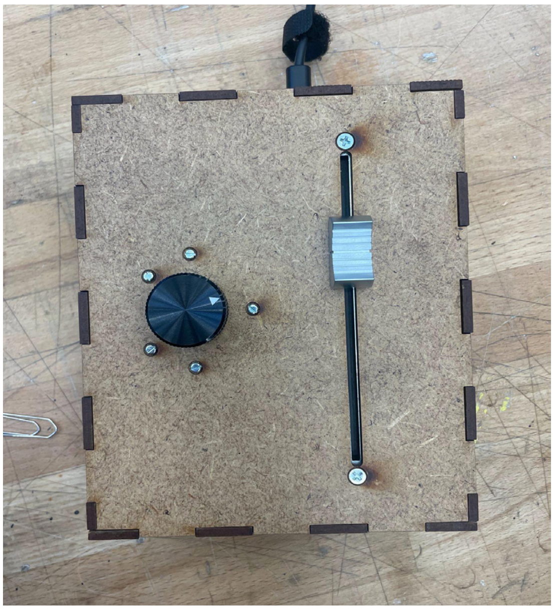
Limit single: When the encoder reaches its output limit (in the case of MIDI it is usually 0-127) a vibration will signal it, assuming that this way the user will know that further rotation will not create a change in the parameter it is controlling.

Direct Audio: Feeding the audio directly into the actuator, so the user could "feel" the sound directly on their fingertips. This should be done carefully and with precious amplitude tuning to not cause sensory overload.

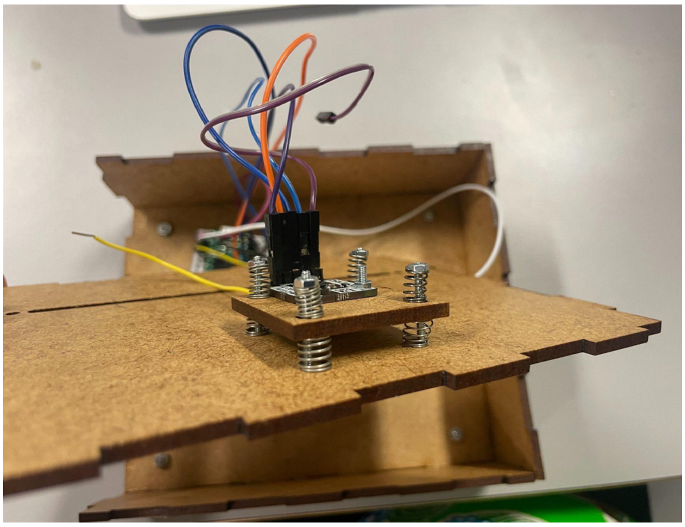
First Enclosed Prototype and Performance User Testing

While building the mechanical components for the encoder and haptic actuator, unexpected engineering challenges arose. One issue was finding a way to direct vibration towards the encoder instead of it being dispersed onto the surrounding enclosure or table. To solve this, a mounting system was devised that isolated the enclosure from vibration and disconnected the knob from the casing. Additionally, larger diameter springs were used in the screw attachments to minimise vibration. However, a problem occurred when the encoder was required to function as a button, resulting in an unintended "springing" sensation when pressed. This is why we have added two screws to create 2mm distance so no parts that vibrate are connected to the enclosure, but while pressing they will support the encoder to not be pushed backwards.

We programmed a simple GUI for setting basic behaviours, so the user testers will be able to set it up themselves, to match their own preferences.



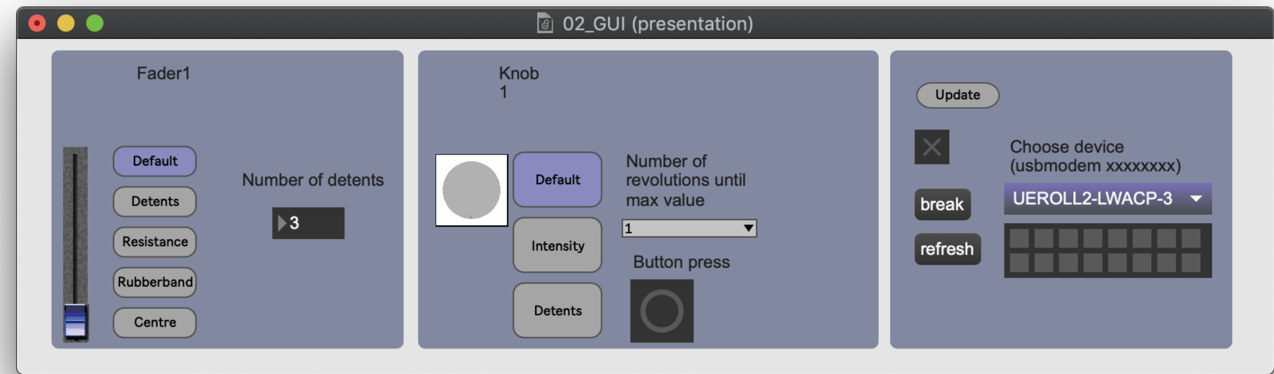
Steurer Jene, S. (2023). Fig.45: First enclosed prototype



Steurer Jene, S. (2023). Fig.46: Prototype of Sunspiension system, directing the vibration to the encoder and isolating it from the box

We were lucky to form a connection with an MA student in electroacoustic composition at ZHdK, Pascal Lund-Jensen. We were not previously acquainted with him, and got his contact through his classmate, Martin Reck, whom we had known from before. Lund-Jensen is working mainly with Max/MSP, and in his musical work he commonly designs sounds which embody in their characteristics physical behaviours, and so is his gesture control. During our first meeting where we discussed our future workshop plan and demonstrated our prototype, he mentioned an interesting aspect of his control methodology. He shared with us that he incorporates his body as a component of the control mechanism, and creates corresponding gestures that align with the sound being produced.

For instance, while turning a knob, he positions his arm in a way that causes a stretching sensation in his muscles, which mirrors a sound that has those organic, stretchy qualities.



Treystman, D (2023). Fig.47: Early version of the functional GUI

Following our demonstration, Lund-Jensen showed significant interest in our project and offered that he will test the prototype in a live performance setting at *Lange Nacht* at ZHdK's main Campus, Toni Areal. We were thrilled at the opportunity, as we recognised that aside from testing the various behaviours and their clarity in conveying functions in a controlled and calculated environment, testing the prototype in a live performance context would provide us with in depth insights and ideas. Furthermore, it will allow us to observe their contribution to enhancing performance expressivity in a way that other types of user testing might not have been able to achieve (see interview with Järveläinen and Papetti)

Findings and conclusion

During the performance, at the 8-minute and 37-second mark, Lund-Jensen introduced a captivating alteration in the soundscape by engaging the slider with the rubber band behaviour. He designed the sound in a way which associatively matched the stretching sensation of using that behaviour while travelling with it upwards. While the fader was travelling down, a "whooshing" sound was introduced. Interestingly, Lund-Jesen further programmed an impact sound as the fader snapps down and hits the lower limit. The impact's sound amplitude depends on the acceleration on the way down, and so he created an organic and direct connection between the mechanical, physical behaviour and the sound it controls.

In the days following the performance, we had the opportunity to discuss his experience with the hapticable MIDI controller. One of the initial observations was that Lund-Jensen's attention was primarily drawn to the fader, and he confirmed that its active and responsive nature was highly appealing. Notably, in comparison to the knob, it was intriguing to observe that the detent signal operates in the opposite manner. To elaborate, the detent of the fader is a no-motion, no vibration area, and the motor "drags" the finger in. On the knob, the detent is signalised by a short and sharp vibration click, while the non vibrating areas signlines the inbetween of each detent.

Lund-Jensen would have needed more time to get used to this behaviour, which he felt like in the very few days he had he could not dive deep enough into it. Another reason for his preference is his general desire to incorporate more faders in his setup, as they allow him to simultaneously manipulate multiple parameters. He has techniques to modify two knobs simultaneously but it is admittedly uncomfortable. The most significant outcome was the transformative effect of the Waviic fader on his approach to sound creation. Typically, he would compose his sound and then proceed to the mapping process. However, with Waviic, he automatically began contemplating the behaviours and how they could generate sound, effectively transforming the controller into an instrument.

Co-designing Workshop

We invited Caterina De Nicola, Martin Reck and Pascal Lund-Jensen, musicians who regularly use computers and MIDI controllers in their musical practice and performance, to try out the prototype and participate in a co-design workshop. The objective of the workshop is to get impressions, understand potential use cases and create an environment for experimentation. As ideas and feedback will be generated by the participants, we will implement them in real time and test them out together, making it a collaborative process where musicians can actively contribute to the design of the controller.

The participants will be able to experiment with the prototype on their own laptop and setups, so they can be in their familiar "environment" as much as possible.

What do we want to find out?

We want to get an overall reaction to the controller-haptic editor system we created, and so we will also document it on film which will be part of our BA final Video. But moreover, we want to observe how the participants use the haptic behaviours we identified and to what extent the haptic editor already allows them to implement their wishes, or whether it is necessary that the system will be even more open, meaning allowing for even more specific, customised behaviours to be set. This could be achieved by listening to their wishes and ideas, and first check if they are already available to configure through the GUI, or if we need to program them. Then, when the desired behaviour is programmed and tested, we can evaluate together with them whether or not this behaviour is valuable for them. It is important that we later analyse the ideas that came up, and understand if they should be featured in the GUI or if the system by itself should allow for that open configuration environment that we discussed.

We are interested to observe and listen to how they create sound to touch connections. Musicians practice often is very individual and since sound spreads in 360 degrees, in the exploration phase they will be working with headphones. This is why we decided that towards the end of the workshop we will have a short demonstration from each participant followed by a discussion, as a method of coming together and exchanging not just between us and each musician, but also within the musicians themselves.

This workshop aims to be an experimental evidence and validation for the concept and as a starting point for engaging in a dialogue with musicians.

Brunner, D. (2023). Fig.48: Daniel demonstrating the haptic configurations on the editor

Brunner, D. (2023). Fig.49: Martin Reck in the mapping process

Brunner, D. (2023). Fig.50: Caterina De Nicola explaining her mapped sounds

Brunner, D. (2023). Fig.51: End of feedback session

Evaluation

We divided the workshop into three main phases: introduction to the project and the device, testing and playing, and lastly miniature concerts by the musicians and a discussion round. The excitement to tryout our MIDI controller was already present during our introduction .With that we kicked off the 1 ½ hour testing and playing phase, and after short troubleshooting and making sure it is all working, the musicians started to experiment with the device, each one individually on their own laptop.

The first idea that popped up was from De Nicola, where she said it would be nice if the button on the knob could reset its values back to zero. Lund-Jensen and Reck, each one individually, assumed that the touch detection capabilities would also output a MIDI value, though we used them only "internally" in order to program some behaviours, so it was a valuable request which was also specific for our device, and we intend to implement that.

We were happy to observe and later receive the feedback that our GUI was very intuitive and easy to work with. They each had to re-configure the device multiple times, and it took them only a few seconds to do so.

We then moved location to the ICST Composition Studio for the performance stage. Each musician played what they worked on, and then explained what they did. It was very touching to see that this demonstration was not only valuable to us, but also for the other musicians. They each asked questions and were curious to try out each other's configuration and mapping themselves. It also showed the way musicians converse with each other about ways of interfacing and performing their sounds. The auditory result of the sounds varied from player to player even if the mapped sounds were the same. It came down to who is playing and how they interpret the usage of the MIDI controller.

Lund-Jensen used the snapping back of the rubber band behaviour to support a physical modelling device, linking the physical behaviour directly to sound in a way which resembles real physics. He added that while he could trigger a sound with conventional controllers, this device allows him to truly "play" the sound unlike any other. Reck mentioned that it would be interesting to turn around the device and instead of dragging the fader up and releasing, to pluck it similarly to the bass guitar plucking technique. This is easily programmable even though the idea of physically changing the affordance during the act of playing gives off virtuosic trades that you see in instruments.

De Nicola used the detents to control a virtual switch control with multiple discrete steps and used the rubberband in a way which made her very active.

Reck worked a lot with time based sound control, and wished to have a control over the *time* aspect, meaning that you can make the whole device move faster and slower e.g how long it takes for the faders to snap back. He really liked the fact that the faders have life of their own, and can move with you, and with time control you can set *how* they will move.
He added that the detents function and the way De Nicola was using them, are quite amazing as it now enables a fader to be good at something it was never capable of doing.

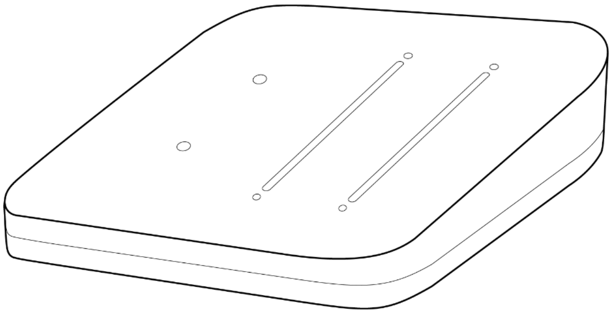
We naturally then moved to a discussion round, where they shared with us their ideas and experience. De Nicola mentioned that she really likes the vibrotactile quality of the knobs, as you can simply feel where the value is at on the range, which is something that is traditionally being done using LEDs. She is used to working with rotary encoders, but doesn't like their strong visual aspect especially in performance context.
Both Lund-Jensen and Reck appreciated how it forces the player to be active, for example in keeping the position of the fader.
We were so touched to hear that Reck said he just wants to keep on playing with it, even during the conversation he just had the urge to keep on touching and playing it.

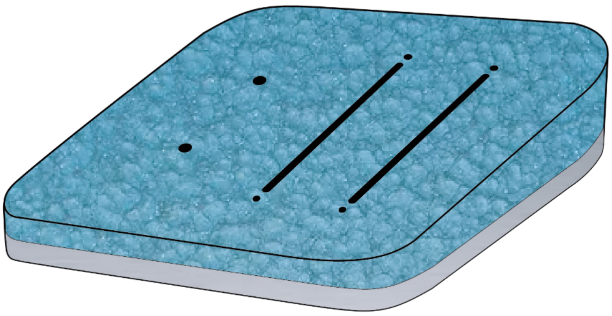
We asked them what they think of the *Haptic Editor* GUI - did it answer their need of configuration, or shall the system be more open for personalisation, which shifts it more towards a light programming environment?

De Nicola suggested that maybe there could be two modes: one more advanced and one as it is now. Reck thought it is probably enough to just be able to change them on the go, and so more play it and chain behaviours rather than program them. Additionally he believes that our project has a low entry level and potential for a learning curve for musicians who want to become proficient in this kind of control. In general, at this point and the amount of time they had to test it so far, it didn't seem to bother them.
This workshop has been an enriching and validating experience, and we were thrilled to see the effortless and engaging exchange of ideas that happened during it. Having professional musicians being involved and genuinely interested in our work was the proof of concept we needed to move on with our future steps.

Final Prototype

Two units of the final prototype were built to ensure that workshop participants do not have to wait too long before trying it. The decision was made to incorporate two knobs and two faders, striking a balance between feasibility and providing enough components for instrument control. Instead of opting for the common knob-above-fader arrangement typically associated with studio or mixing work, we chose to arrange them in pairs.

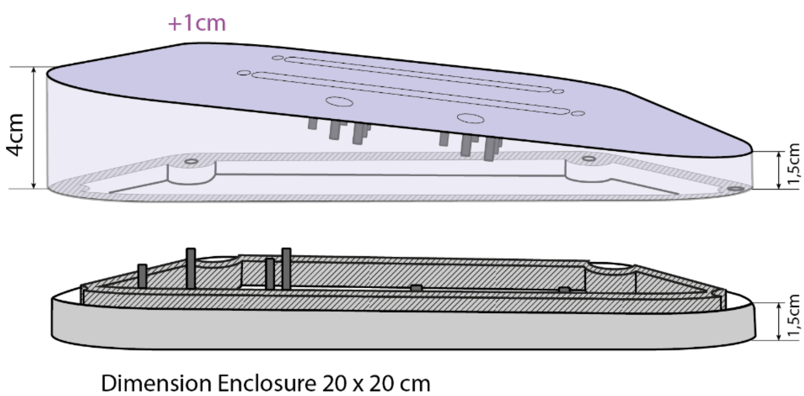




Steurer Jene, S. (2023). Fig.52: Colour test

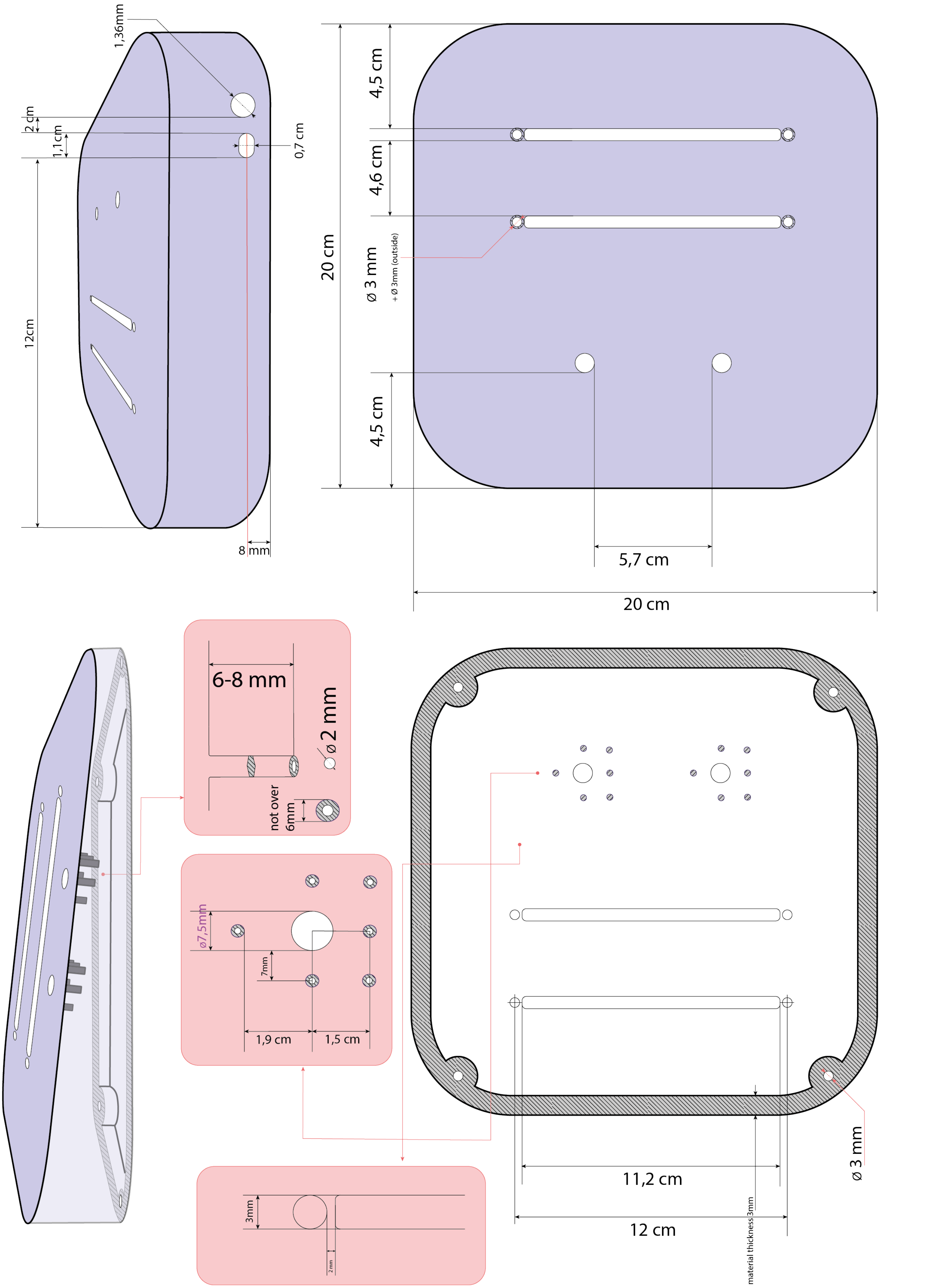
An enclosure box with a slope was designed for several reasons. Firstly, it allows for easier hand access, facilitating user interaction. Secondly, this design choice enabled us to create a slimmer enclosure, considering that most electronics require space at the back of the housing.

We decided to 3D print the enclosure, as it is an accessible way of fabricating it. Luckily, we had our friend Julian Gisler assisting us with the 3D modelling of the device, and Jakob Wachtl resin-printing it in his atelier. We liked the clay-like colour of the resin, and decided to keep parts of the enclosure in its natural colour.



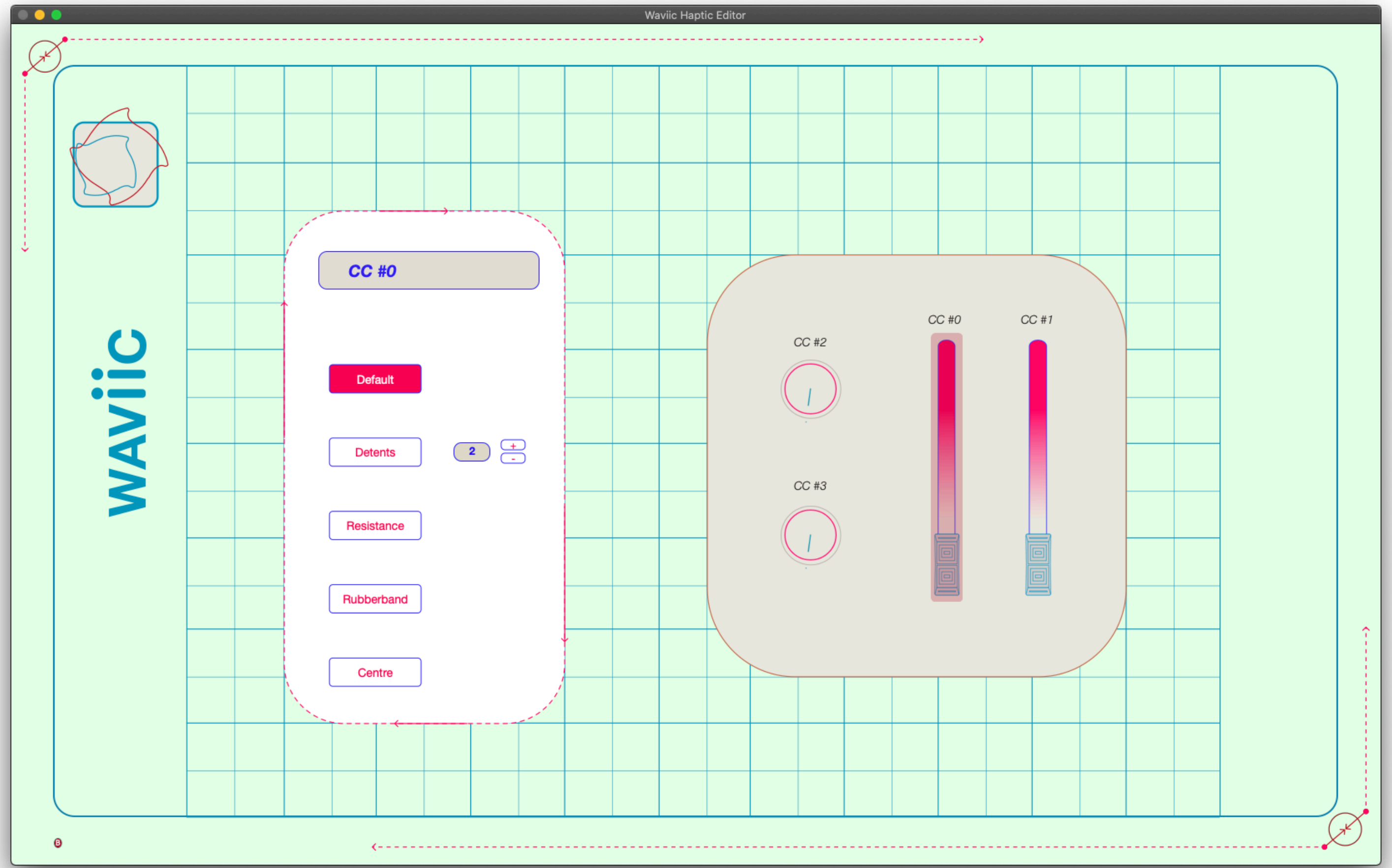
Steurer Jene, S. (2023). Fig.53: Technical drawing for 3D modelling

A 1 cm metal piece was added inside the box to make sure the controller is heavy enough to avoid it sliding when using the



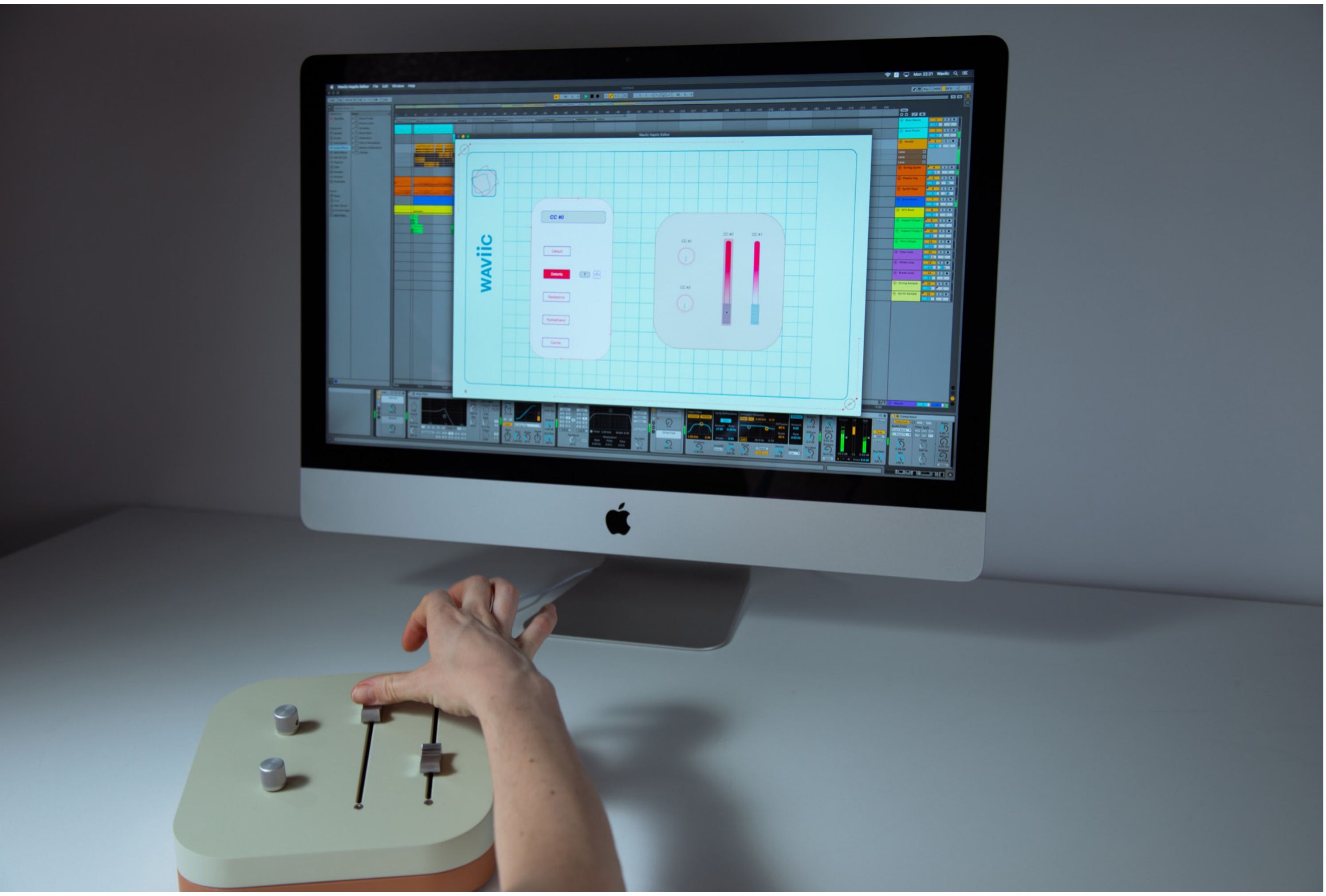
Steurer Jene, S. (2023). Fig.54: Technical drawing for 3D modelling force feedback behaviours such as the rubberband.

The GUI was programmed in a way that made the navigation through the components very intuitive. We created a representation of the controller, and by clicking on a fader or knob, its relevant settings will appear and make it possible to configure. We exported the GUI as a standalone software build, which makes it easy for anyone with or without Max/MSP or M4L to use it.



Treystman. D. (2023). Fig.55: Final GUI

Steurer Jene, S. (2023). Fig.56: Waviic top view



Treystman, D.. (2023). Fig.57: Interaction with the controller, In the background the "Waviic Haptic Editor" and Ableton Live

Treystman, D.. (2023). Fig.58: Mint and Clay Waviic

CONCLUSION

Throughout the research chapter, we explore the elements that contribute to a performance.

The field of electronic music feels a prejudice directed towards them around the lack of engaging and expressive performances due to the use of computers and electronic equipment. What makes an engaging performance? We see musical gestures as an engaging virtue but they are not necessary for playing an instrument. Trained performers of classical music tend to exhibit these characteristics more prominently than those in the electronic music field. As a result, we are left to ponder whether our perception, expectations, and preconceived notions of what constitutes a performance, shapes the prejudice of absence surrounding electronic music plays.

It is also crucial to consider the historical context to comprehend the evolution of electronic devices and their user base. Additionally, a notable distinction is the type of instruments utilised. For instance, a guitar can provide rich haptic cues, while a MIDI controller does not offer the same level of physical feedback. This is a key element to our research questions:

How can a controller dynamically represent various graphical digital interfaces and does it then convey a more intuitive and comprehensible use?

How can a MIDI controller become more embodied and convey a better feeling of an instrument?

In response to the first research question, we have reached the conclusion that, to some extent, haptic technology can support and represent the absence of screens. Initially, we explored the possibility of completely removing screens through haptics, but a more grounded perspective emerged from our interview with Hanna Järveläinen and Stefano Papetti. We came to terms with the fact that the sense of touch can convey multiple layers of information, but the human brain has limitations in processing a vast amount of tactile information simultaneously. Moreover, we value the multimodal sensing in HCI, and understand the interconnection of the different sensory perception which can create a well rounded interface.

Despite this limitation, our exploration of haptic technology has led us to discover alternative possibilities. Throughout our work, we have been driven by the desire and a strong sense of value to explore hardware components of a MIDI controller, such as knobs and faders. This exploration is not solely due to the historical origins and the overall acceptance of the components in the electronic music community, but also their potential for modularity within one component, which may not be immediately apparent from an external perspective. If haptics can represent what the device is doing and basically reacts back, the more holistic the overall experience becomes.

The second research question introduced various aspects and dimensions to our work. For instance, if we think of instruments like the violin, which inherently provides haptic feedback to the musician through its physical construction and enables a stronger embodied connection to the instrument. This is something that devices like MIDI controllers lack. However, the advantage that electronic music devices have over acoustic instruments is that their physical properties can be modified without changing their fundamental purpose. Throughout prototyping haptics we have found that we could attribute various kinds of characteristics to a component. In addition, the musician's mapping of a MIDI controller allows them to make decisions about how it functions and responds to their musical creations. This process can elicit a sense of intimacy through the haptic behaviours and associations it creates for those who interact with it.

In conclusion, the use of haptics in MIDI controllers is only one example of its potential in the music field. Further we are honoured to have dedicated our attention to a device that might be overlooked in advancements of electronic musical devices and misunderstood by laypersons in the controllers role.

Despite our extensive research and passion for this topic, we believe that we have only scratched the surface and this fills us with excitement. There is much more to be unravelled and explored!

Contribution

The initial motivation behind our decision to focus our Bachelor of Arts studies on MIDI controllers stemmed from our observation of their widespread usage coupled with a paradoxical love-hate relationship among users. We also noted that for non-electronic musicians, the concept of a MIDI controller remains largely invisible and unfamiliar.

Our research comes down to exploring how different sensory inputs are connected and support each other to create multimodal interactions. We hope and believe that our work with haptics can be relevant in other fields such as information communication for impaired people, for video jockey (VJ) and immersive experiences.
It further adds to the discussion of design with and for sound, and opens up new ways of thinking and talking about sound control.

By unravelling the intricate mechanisms of multimodal interactions, we uncover fresh perspectives and frameworks for conceptualising and discussing sound control. This opens up new avenues for creative exploration and innovation, fostering a deeper understanding of the role of haptics in various contexts and inspiring novel approaches to its intentional manipulation and utilisation.

Additionally, we have been gratified by the stimulating discussions that our project has sparked among musicians we have talked to. These conversations have highlighted the potential for further collaborative development and expansion of our project beyond the scope of our Bachelor's degree.

Lesson Learned

Through our research and project, we have gained a wealth of valuable insights and transformative lessons that have profoundly shaped our comprehension of effective communication, visualisation, and mediation across diverse fields. In particular, we have come to recognise the pivotal role of interaction designers in seamlessly navigating between expert domains and bridging the gap by utilising a language that resonates with a broader audience. This realisation has illuminated one of the fundamental responsibilities and contributions of interaction designers in facilitating meaningful connections and fostering inclusive experiences.
Our deep dive into the electronic music sea showed the vast knowledge of interfaces that has enriched our design process and are approaches that we can take in our skills backpacks for the future journey.

Working with haptic technology has presented us with multifaceted challenges that have fueled our determination and made us proud of the knowledge we have acquired. One of the challenges we have faced involves hardware limitations that directly affect the precision of haptic feedback. These limitations, in turn, make it challenging to iterate and refine various haptic behaviours.

Generally we also cherish the exchange with musicians which kept us going and truly underlined that our project is meaningful.

Future Steps

We plan to continue working on the project beyond the bachelor as we sincerely believe in it and in its potential. We are looking forward to later on gathering a small team of people who share this vision with us, and to further refine *Waviic*.

Integration of Scott Bezek's Smartknob

We recognised the potential of the SmartKnob and believed it could be further investigated since it had not been integrated into any particular field. In the context of MIDI controllers, this knob could be a game changer, given the need for versatile components that also provide a tactile experience to improve playability. We were also excited about the possibility of collaborating on this project and sharing our contributions.

Due to the popularity of the SmartKnob and incredibly specific components it requires, the motor, which is the heart of the device, was unfortunately long out of stock through the main distributor, SparkFun. Most motors in the market do not meet its specifications, as It is a high torque and low cogging gimbal motor. We contacted the manufacturer in China and requested 10 custom motor samples. Surprisingly, they answered positively. As they shipped the motors to us, SparkFun announced a restock, which we believe was due to us triggering a new production pulse.
Unfortunately, the delivery time for the motors did not align with the timeline of our bachelor project, so we were unable to experiment and incorporate it into our MIDI controller at that time. Nevertheless, the wish to build one and the final arrival of the parts in due course has provided us with insight into its technology and enabled us to better understand how it could be integrated into our concept and design in the future. We feel compelled to its potential and its open source nature motivated us throughout our thesis.

Furthermore, we received the feedback that the force feedback and the visual aspect of the motorised faders is more engaging than the more passive nature of the knobs. By pairing the knobs with motors we can achieve a similar result but together with the affordance and broad preference for knobs.

Displays and Light

For future work on the prototype, we will incorporate the visual sense and its use in MIDI controllers. One of our objectives is to reduce the necessity for performers to interact with computer screens during live performances, and create an instrument that stands by itself. After conducting interviews with musicians, we recognised that for users it is often very important to be able to view the assigned parameter directly on the controller, which is mainly done today by manually creating sticker labels for each component, a heavily time consuming method. Initially, we hoped that haptic properties alone could communicate labels and mostly eliminate the need to rely on the computer screen, and so to free the visual attention to be concentrated on fellow musicians or the crowd. However, we discovered that this would still be impractical as users would still need to actively interact with each component to feel what it is controlling, unlike watching the device and getting all information in one glimpse. Moreover, is the issue of limited sensory resolution when it comes to differentiating vibrotactile behaviours. This has been confirmed by memory game user testing #3 and our interview with Stefano Papetti and Hanna Järveläinen. Interestingly, participants displayed a high level of confidence in associating specific sounds with colours and visual imagery such as yellow for a bell-like sound. This inspired the idea of incorporating coloured screens into our design. Each component and layer can be assigned a specific colour, label or icon image to aid with easy recognition and recall. Adding dynamic visual aspects to the device can deepen the multimodal interaction of sound and touch, and add another layer of sensory perception of the device and its output.

BIBLIOGRAPHY

Academic Thesis

1) Culbertson, H. M. (2015). *Data-driven haptic modeling and rendering of realistic virtual textured surfaces* (Dissertation). University of Pennsylvania.
2) Huber, R., Kretz, A., Fjeld, M., (2004). *Force-feedback human interactive device (Semester Thesis)*. ETH Zürich.
3) Minsky, M. D. R. (1995). *Computational haptics: The sandpaper system for synthesizing texture for a force-feedback display* (Thesis). Massachusetts Institute of Technology.
4) Müller, T. (2019). *Designing with Haptic Feedback* (Thesis). Umeå University.
5) Zhou, D. (2006, February 22). *Texture analysis and synthesis using a generic Markov-Gibbs Image model* (thesis). University of Auckland.

Book Chapter

1) Schaeffer, P. (2016). *Traité des objets musicaux*.(pp.16-17). Média Diffusion.
2) Adams, W. C. (2010). Conducting semi-structured interviews. In J. S. Wholey, H. P. Hatry, & K. E. Newcomer (Eds.), *Handbook of practical program evaluation*. John Wiley & Sons.
3) Berdahl, E., Pfalz, A., Blandino, M., & Beck, Stephen David . (2018). Force-Feedback Instruments for the Laptop Orchestra of Louisiana. In Stefano Papetti & C. Saitis (Eds.), *Musical Haptics* (pp. 171–191). Springer.
4) Bijsterveld, K., & Krebs, S. (2013). Listening to the Sounding Objects of the Past: The Case of the Car. In K. Franinović & S. Serafin (Eds.), *Sonic Interaction Design* (pp. 3–29). MIT Press.
5) Blach, R. (2008). Virtual Reality Technology - An Overview. In D. Talaba & A. Amditis (Eds.), *Product Engineering: Tools and Methods Based on Virtual Reality* (pp. 21–64). Springer Science & Business Media.
6) Dourish, P. (2004). Physical and symbolic. In *Where the Action Is: The Foundations of Embodied Interaction*. MIT Press.
7) Holmes, T. (2008). *The Microprocessor Revolution*. In Electronic and experimental music (pp. 271-293). Routledge.
8) Holmes, T. (2008).*The Voltage-Controlled Synthesizer*. In Electronic and experimental music (pp. 239-268). Routledge.
9) Jensenius, A. R., Wanderley, M. M., Godøy, R. I., & Leman, M. (2010). Musical gestures: Concepts and methods in research. In R. I. Godøy & M. Leman (Eds.), *Musical gestures: Sound, movement, and meaning* (pp. 14–19, 23-24, 25). Routledge.
10) Jones, L. A. (2018). Haptic Perception. In *Haptics* (pp. 43–64). MIT Press.
11) Jones, L. A. (2018). How We Perceive the World via Touch. In *Haptics* (pp. 1–21). MIT Press.
12) Jordà, S. (2007). *Interactivity and live computer music*. In N. Collins & J. d'Escriván (Eds.), Electronic Music (pp. 89–106). Cambridge university press.
13) Krueger, L. E. (Ed.). (2013). Editor's Introduction. In *The World of Touch* (pp. 1–17). Psy-

chology Press.
14) Manning, P. (1994). *From Microcomputer to Music Supercomputer.* In Electronic and Computer Music (pp. 324-353). Oxford Univ. Press.
15) Manning, P. (1994). *The Birth of Computer Music.* In Electronic and Computer Music (pp. 213-252). Oxford Univ. Press.
16) Papetti, S., Saitis, C. (2018). *Musical Haptics: Introduction*. In *Musical Haptics* (pp. 1–5). Springer.
17) Papetti, S., Saitis, C., O'Modhrain, S., & Brent Gillespie, R. (2018). Once More, With Feeling: Revisiting The Role Of Touch in Performer-Instrument Interaction. In *Musical Haptics* (pp. 11–27). Springer.
18) Rocchesso, D., Serafin, S., & Rinott, M. (2013). Pedagogical Approaches and Methods. In K. Franinović & S. Serafin (Eds.), *Sonic Interaction Design* (pp. 125–147). MIT Press.
19) Schafer, R. M. (1970). The Soundscape. In *The Book of Noise* (p. 3, p.4, p. 28). print. by Price Print.
20) Vail, M. (2000). Buchla's first modular system. In *Vintage Synthesizers: Pioneering Designers, Groundbreaking Instruments, Collecting Tips, Mutants of Technology* (pp. 105–109). Backbeat Books.
21) Visell, Y., Murray-Smith, R., Brewster, S. A., & Williamson, J. (2013). Continuous Auditory and Tactile Interaction Design. In K. Franinović & S. Serafin (Eds.), *Sonic Interaction Design* (pp. 77–115). MIT Press.

Comments

1) @micowata1101 (2022)*What an exciting thing, congrats ![*Comment on the video "SUPERBOOTH 2021 - Der Mann mit Der Maschine - Motorised Faders for Eurorack]. *YouTube*. https://www.youtube.com/watch?v=-WYYDAlfkxs
2) aaiieenn (20*22) those notches when selecting notes is so insane!![*Comment on the video "SUPERBOOTH 2021 - Der Mann mit Der Maschine - Motorised Faders for Eurorack]. *YouTube*. https://www.youtube.com/watch?v=-WYYDAlfkxs
3) BigHairyCrank (2022*)At first I thought "well this is a stupid gimmick" and then I saw it in action. Wow, that's really cool. It makes a modular (system) a lot more "p(l)ayable [*Comment on the video "SUPERBOOTH 2021 - Der Mann mit Der Maschine - Motorised Faders for Eurorack]. *YouTube*. https://www.youtube.com/watch?v=-WYYDAlfkxs

Conference Article

4) Benko, H., Holz, C., Sinclair, M., & Ofek, E. (2016, October 16). NormalTouch and texture-touch. *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. http://dx.doi.org/10.1145/2984511.2984526
5) Françoise, J. (2013, October 21). Gesture--sound mapping by demonstration in interactive music systems. *Proceedings of the 21st ACM International Conference on*

Multimedia. http://dx.doi.org/10.1145/2502081.2502214
6) Frisson, C., Kirkegaard, M., Pietrzak, T., & Wanderley, M. M. (2022). ForceHost: An open-source toolchain for generating firmware embedding the authoring and rendering of audio and force-feedback haptics. *NIME 2022*. http://dx.doi.org/10.21428/92fbeb44.76cfc96e
7) Gil, H., Son, H., Kim, J. R., & Oakley, I. (2018). Whiskers. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3173574.3174232
8) Gupta, S., Morris, D., Patel, S. N., & Tan, D. (2013). Airwave: non-contact haptic feedback using air vortex rings. *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. https://doi.org/10.1145/2493432.2493463
9) Hook, J., Green, D., McCarthy, J., Taylor, S., Wright, P., & Olivier, P. (2011, May 7). A VJ centered exploration of expressive interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. http://dx.doi.org/10.1145/1978942.1979130
10) M. Bergamasco and E. Ruffaldi, "Haptic interfaces for embodiment in virtual environment," in In Proceedings of RO-MAN 2011, 2011.
11) Malloch, J., Sinclair, S., & Wanderley, M. M. (2013, April 27). Libmapper. *CHI '13 Extended Abstracts on Human Factors in Computing Systems*. http://dx.doi.org/10.1145/2468356.2479617
12) Merrill, D., Raffle, H., & Aimi, R. (2008, April 6). The sound of touch. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. http://dx.doi.org/10.1145/1357054.1357171
13) Ou, J., Yao, L., Tauber, D., Steimle, J., Niiyama, R., & Ishii, H. (2014, February 16). jamSheets: thin interfaces with tunable stiffness enabled by layer jamming. *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*. http://dx.doi.org/10.1145/2540930.2540971
14) Papetti, S., Schiesser, S., & Fröhlich, M. (2015). Multi-point vibrotactile feedback for an expressive musical interface. *New Interfaces for Musical Expression (NIME)*.
15) Poupyrev, I., Lyons, M. J., Fels, S., & Blaine (Bean), T. (2001). New interfaces for musical expression. *CHI '01 Extended Abstracts on Human Factors in Computing Systems - CHI '01*. https://doi.org/10.1145/634067.634348
16) Shah, D. S., Yang, E. J., Yuen, M. C., Huang, E. C., & Kramer Bottiglio, R. (2020). Jamming Skins that Control System Rigidity from the Surface. *Advanced Functional Materials*, *31*(1), 2006915. https://doi.org/10.1002/adfm.202006915
17) Tanaka, A., & Parkinson, A. (2016). Haptic Wave: A Cross-Modal Interface for Visually Impaired Audio Producers. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/2858036.2858304
18) Telpaz, A., Rhindress, B., Zelman, I., & Tsimhoni, O. (2015). Haptic seat for automated driving. *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. https://doi.org/10.1145/2799250.2799267
19) van Oosterhout, A., & Hoggan, E. (2020). Reshaping interaction with rotary knobs. *Proceedings of the 2020 ACM Designing Interactive Systems Conference*. https://doi.org/10.1145/3357236.3395536

20) Wan, J., Malloch, Jospeh, Sinclair, Stephen, Wilansky, Jonathan, Krajeski, A., & Wanderley , M. M. (2019). Webmapper: A Tool for Visualizing and Manipulating Mappings in Digital Musical Instruments. *Proceedings of the 14th International Symposium on Computer Music Multidisciplinary Research (CMMR)* .

Essay

1) Paradiso, J.A. (2005). Electronic Controllers for Musical Performance and Interaction. Draft 1.0 for MIT Press.
2) Wessel, D. (2006). An Enactive Approach to Computer Music Performance. *Center for New Music and Audio Technologies* (CNMAT).
3) Wright, M., Freed, Adrian, Lee, A., Madden, T., & Momeni, A. (2003). Managing Complexity with Explicit Mapping of Gestures to SoundControl with OSC. *Center for New Music and Audio Technologies* (CNMAT).

Interview

1) Ankersmit, T. (2018, November 13). *THOMAS ANKERSMIT, psychoacoustic properties of sound* (A. Gardner, Interviewer) [Interview]. https://clotmag.com/sound/thomas-ankersmit-exploring-psychoacoustic-properties-of-sound
2) Fell, M. (2012, May 10). Interview: Mark Fell (L. Blanning, Interviewer) [Interview]. In *Red Bull Music Academy Daily*. https://daily.redbullmusicacademy.com/2012/05/mark-fell-interview

Journal Article

1) Brewster, S. (2008). The Impact of Haptic 'Touching' Technology on Cultural Applications. *ResearchGate*. https://www.researchgate.net/publication/29815508_The_Impact_of_Haptic_'Touching'_Technology_on_Cultural_Applications.
2) Bull, A. (2019). Locating classical music in culture. *Class, Control, and Classical Music*, 1–26. https://doi.org/10.1093/oso/9780190844356.003.0001
3) Caramiaux, B., Françoise, J., Schnell, N., & Bevilacqua, F. (2014). Mapping through listening. *Computer Music Journal*, *38*(3), 34–48. https://doi.org/10.1162/comj_a_00255
4) Cavdir, D., & Wang, G. (2021). Borrowed gestures: The body as an extension of the musical instrument. *Computer Music Journal*, *45*(3), 58–80. https://doi.org/10.1162/comj_a_00617
5) Culbertson, Heather Marie, "Data-Driven Haptic Modeling and Rendering of Realistic Virtual Textured Surfaces" (2015). Publicly Accessible Penn Dissertations. 1674.
6) Gani, A., Pickering, O., Ellis, C., Sabri, O., & Pucher, P. (2022). Impact of haptic feedback on surgical training outcomes: A Randomised Controlled Trial of haptic versus non-haptic immersive virtual reality training. *Annals of Medicine & Surgery*, *83*. https://doi.org/10.1016/j.amsu.2022.104734
7) Jewitt, C., Price, S., Steimle, J., Huisman, G., Golmohammadi, L., Pourjafarian, N., Frier, W., Howard, T., Ipakchian Askari, S., Ornati, M., Panëels, S., & Weda, J. (2021). Manifesto for digital social touch in crisis. *Frontiers in Computer Science*, *3*. https://doi.org/10.3389/fcomp.2021.754050
8) Kourtesis, P., Argelaguet, F., Vizcay, S., Marchal, M., & Pacchierotti, C. (2022). *Electro-*

tactile feedback applications for hand and arm interactions: A systematic review, meta-analysis, and future directions. Institute of Electrical and Electronics Engineers (IEEE). http://dx.doi.org/10.36227/techrxiv.14588250.v3

9) Loy, G. (1985). *Musicians make a standard: The Midi phenomenon.* Computer Music Journal, 9(4), 8. https://doi.org/10.2307/3679619
10) Papetti, S., Järveläinen, H., & Schiesser, S. (2021). Interactive vibrotactile feedback enhances the perceived quality of a surface for musical expression and the playing experience. *IEEE Transactions on Haptics*, *14*(3), 635–645. https://doi.org/10.1109/toh.2021.3060625
11) Pasnau, R. (1999). What is Sound? *The Philosophical Quarterly*, *49*(196), 309–324. https://doi.org/10.1111/1467-9213.00144
12) Schloss, W. A. (2003). Using contemporary technology in live performance: The dilemma of the performer. *Journal of New Music Research*, *31*. https://doi.org/10.1076/jnmr.32.3.239.16866
13) See, A. R., Choco, J. A., & Chandramohan, K. (2022). Touch, texture and haptic feedback: A review on how we feel the World Around Us. *Applied Sciences*, *12*(9), 4686. https://doi.org/10.3390/app12094686
14) Wessel, D. (2006). An Enactive Approach to Computer Music Performance. Center for New Music and Audio Technologies (CNMAT).
15) Zhang, B., & Sra, M. (2021). PneuMod: A modular haptic device with localized pressure and thermal feedback. *Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology*. https://doi.org/10.1145/3489849.3489857

Video

1) 130db. (2016). *Crossfader hand training without Dj mixer*. *YouTube*. https://www.youtube.com/watch?v=3eENm4XXjD8.
2) ACM SIGCHI. (2020, August 10). *Reshaping Interaction with Rotary Knobs: Combining Form, Feel and Function*. YouTube. https://www.youtube.com/watch?v=NFtvBzQzKxg
3) BBC. (2010). *Try this bizarre audio illusion! - Bbc*. *YouTube*. https://www.youtube.com/watch?v=G-lN8vWm3m0.
4) Critters. (2015). Taking a look at a motorized linear potentiometer. *YouTube*. https://www.youtube.com/watch?v=r12wG7ebvnY
5) Cultures of Resistance Films. (2020, January 17). *Modulations - Cinema for the Ear | Documentary*. YouTube. https://www.youtube.com/watch?v=icpDt6aQDww
6) Eric Chasalow. (2013). *Dave Smith on Midi*. *YouTube*. https://www.youtube.com/watch?v=Jq6_vy4Pcwk&t=67s.
7) Glennie, E. (2019). *Feeling Sound with Evelyn Glennie*.. YouTube. https://www.youtube.com/watch?v=Gl2a6w6sTAs&t=46s.
8) Herrmutt Lobby. (2017, March 20). *CTRLCap - Squeeze your fx*. YouTube. https://www.youtube.com/watch?v=_MgdBYXMjUg
9) Kirkegaard, M. (2020). TorqueTuner - Presentation for NIME 2020. *Vimeo*. https://

vimeo.com/423615656?embedded=true&source=vimeo_logo&owner=111972308
10) loopop. (2020, January 28). *Faderfox EC4 Review // Compact MIDI control with digital labels*. YouTube. https://www.youtube.com/watch?v=-6OtUPaB9bM
11) Racing, O. (2021). What is Force Feedback. *YouTube*. https://www.youtube.com/watch?v=1ri_OXzT9Mg
12) Sanjay C. (2022, September 22). *SEABOARD RISE 2 - Everything you want to know*. YouTube. https://www.youtube.com/watch?v=6uJo_bs6iS0
13) scottbez1. (2022, March 11). *DIY haptic input knob: BLDC motor + round LCD* . You-Tube. https://www.youtube.com/watch?v=ip641WmY4pA
14) sonicstate. (2021). SUPERBOOTH 2021 - Der Mann mit Der Maschine - Motorised Faders for Eurorack. *YouTube*. https://www.youtube.com/watch?v=-WYYDAlfkxs
15) Specialwaves. (2017). *Mine - Modular Controller*. Vimeo. https://vimeo.com/190926471
16) vAustinL. (2017). *Amazing Vape Trick Compilation*. *YouTube*. https://www.youtube.com/watch?v=zVXR7xttUeo.

Website Article

1) Barnes, A. (2018, September 5). *The cost of giving our children a musical education*. The Billfold. https://www.thebillfold.com/2018/09/the-cost-of-giving-our-children-a-musical-education/
2) Bateman, T. (2012, November 28). *How MIDI changed the world of music.* BBC News. https://www.bbc.com/news/technology-20425376
3) Berg, R. E. (2022, December 8). *Sound*. Encyclopædia Britannica. Retrieved March 27, 2023, from https://www.britannica.com/science/sound-physics
4) Brett, T. (2011, February 8). *On becoming A virtuoso of knobs, buttons, and sliders*. Brettworks. https://brettworks.com/2011/02/08/on-becoming-a-virtuoso-of-knobs-button-and-sliders/
5) Carrol, L. (2022, February 24). *How to Make Your Own DIY MIDI Controller.* The Modern Record. https://www.themodernrecord.com/how-to-make-your-own-diy-midi-controller/
6) Cohen, S. (2022, August 17). *The right midi controller*. SHIK. https://shik.tech/the-right-midi-controller/
7) Cornils, K. (2022, December 19). *Merzbow and the value of noise*. HHV Mag. https://www.hhv-mag.com/feature/merzbow-und-der-wert-des-krachs/?lang=en
8) Darling, N. (2019, August 19). *How the desktop metaphor helped windows take over the world*. Psychology Today. https://www.psychologytoday.com/us/blog/thinking-about-kids/201908/how-the-desktop-metaphor-helped-windows-take-over-the-world
9) Davidson, E. (2012, August 10). *The problem with conservatory training*. Historically Incorrect. https://emilyplayscello.wordpress.com/2012/08/10/the-problem-with-conservatory-training/
10) Edwards, B. (2022, March 28). *The QWERTY keyboard is tech's biggest unsolved mys-*

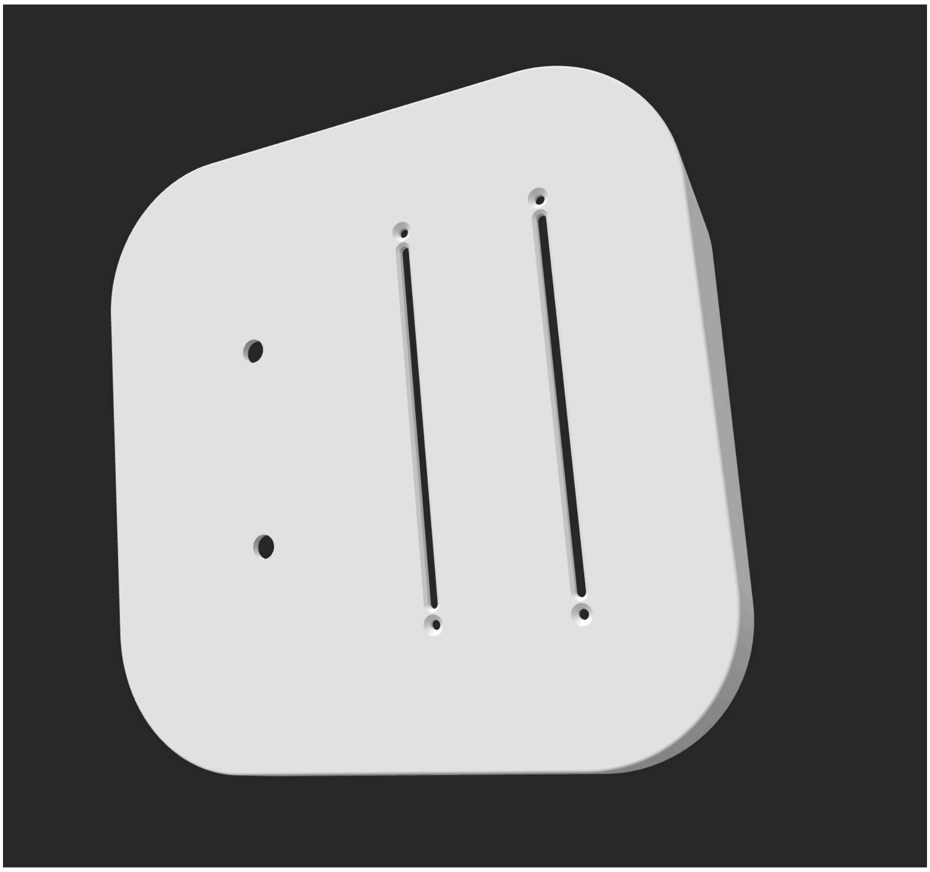
tery. How-To Geek. https://www.howtogeek.com/789822/the-qwerty-keyboard-is-tech's-biggest-unsolved-mystery/
11) Henke, R. (2007). *Live performance in the Age of Supercomputing* . Live Performance in the Age of Supercomputing. https://roberthenke.com/interviews/supercomputing.html
12) Kovarsky, J. (2022, April 27). *History of the synthesizer, part 1*. Yamaha Music. https://hub.yamaha.com/keyboards/synthesizers/history-of-the-synthesizer-part-1/
13) Lutkevich, B., & Courtemanche, M. (2023, February 21). GitHub. *TechTarget*. https://www.techtarget.com/searchitoperations/definition/GitHub
14) Martina. (2022, July 25). *The history and evolution of electronic music*. iMusician. https://imusician.pro/en/resources/guides/history-evolution-electronic-music
15) *MIDI history: Chapter 6-Midi is born 1980-1983*. (n.d.) https://www.midi.org/articles/midi-history-chapter-6-midi-is-born-1980-1983
16) *MIDI: Your guide to MIDI and MIDI controllers*. (2022, November 15). Native Instruments Blog. https://blog.native-instruments.com/guide-to-midi-and-midi-controllers/
17) Mullender-Ross, R. (2019, November 27). *Picturing a voice: Margaret Watts Hughes and the Eidophone*. The Public Domain Review. https://publicdomainreview.org/essay/picturing-a-voice-margaret-watts-hughes-and-the-eidophone
18) Output. (2021, April 28). *The Ultimate MIDI controller buying guide*. Output. https://output.com/blog/choosing-midi-controllers-guide
19) Roibu, T. (2021, August 11). *Hans Jenny and the science of sound: Cymatics*. Geometry Matters. https://geometrymatters.com/hans-jenny-and-the-science-of-sound-cymatics/
20) Ross, A. (2010, September 27). John Cage's art of noise. *The New Yorker*. https://www.newyorker.com/magazine/2010/10/04/searching-for-silence
21) Spiegel, L. (n.d.). *What Music Mouse Is*. Laurie Spiegel's Retiary Ramblings. http://retiary.org/ls/progs/mm_manual/mouse_manual.html
22) Storrs, C. (2009, November 26). *People hear with their skin as well as their ears*. Scientific American. https://www.scientificamerican.com/article/skin-hearing-airflow-puff-sound-perception/
23) *The story behind the EMS VCS3 in the 1970s, part 1*. The Music Aficionado. (2021, June 26). https://musicaficionado.blog/2020/09/02/ems-vcs3-in-the-1970s-part-1/
24) Tunyogi-Csapo, P. (2020, May 5). *Eigenharp Pico test: Einzigartiges Musikinstrument*. delamar.de. https://www.delamar.de/test/eigenharp-pico/
25) Vinnie. (2022, October 23). *Hardware synth vs. Midi Controller: Which is better for you?* Home Studio Expert. https://homestudioexpert.com/hardware-synth-vs-midi-controller-which-is-better-for-you/
26) Wood, R. J. (2020, December 10). *The stubborn classism of classical music*. The New Republic. https://newrepublic.com/article/160469/insidious-classism-classical-music

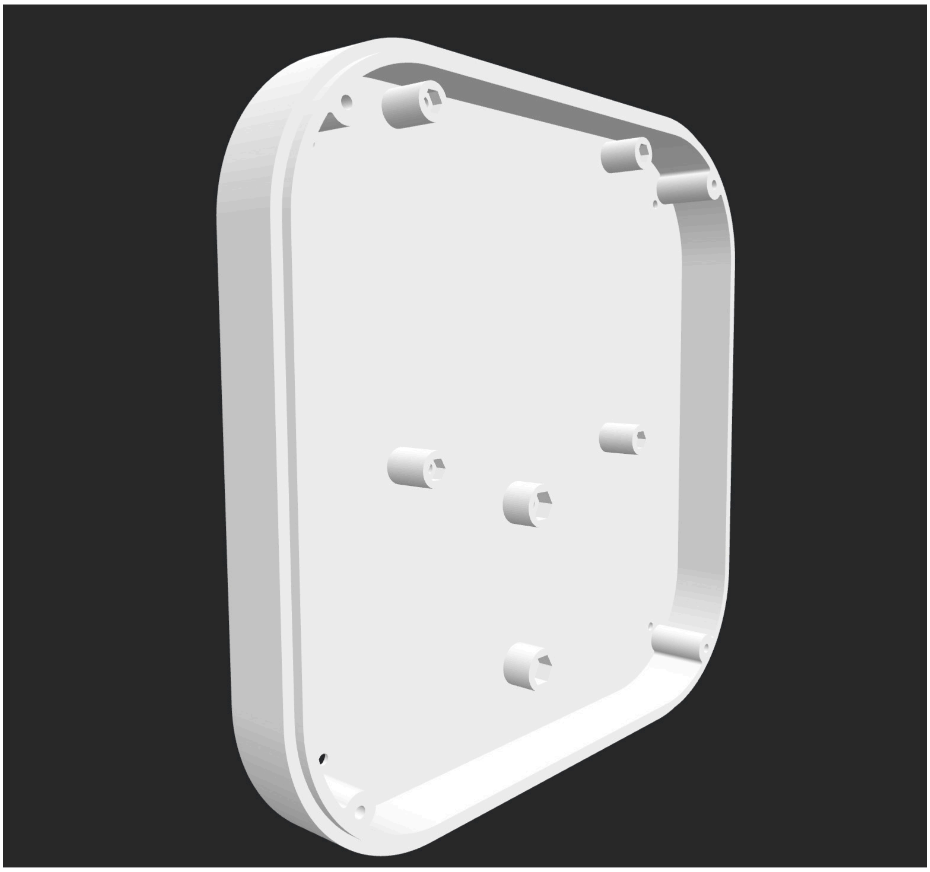
Website

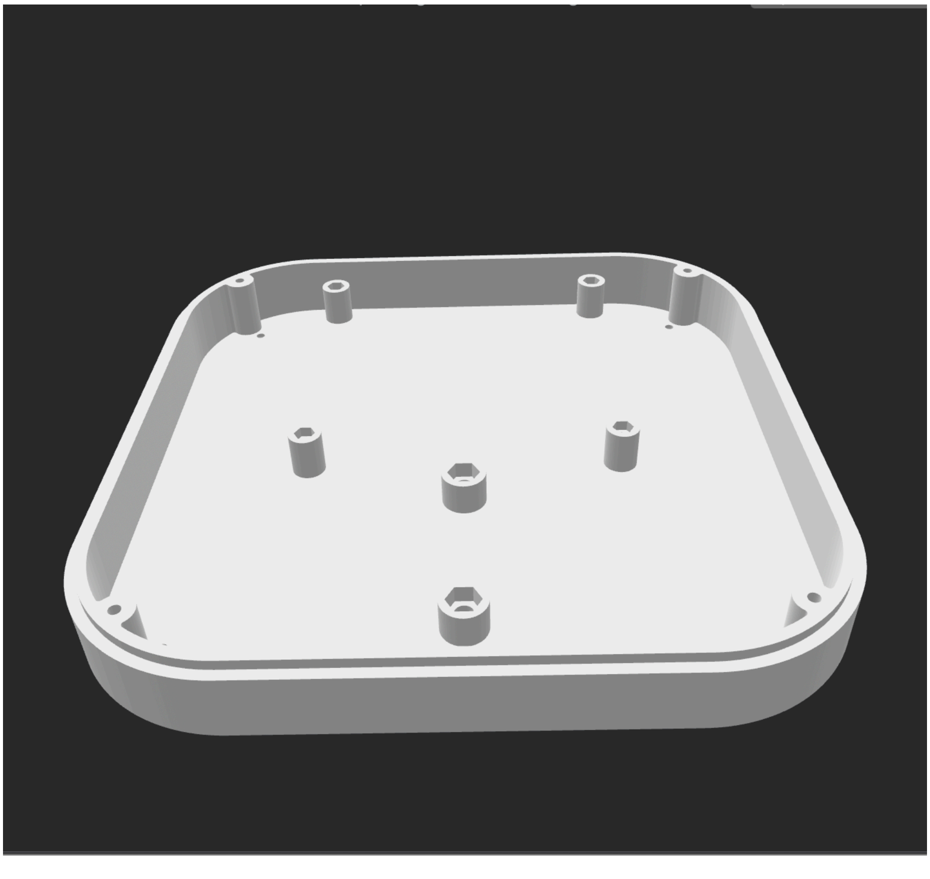
1) *About Eigenlabs*. Eigenlabs - About us. (n.d.). Retrieved January 3, 2023, from https://web.archive.org/web/20100914203008/http://www.eigenlabs.com/about
2) *About the MMA*. (n.d.). Retrieved December 5, 2022, from https://web.archive.org/web/20160116011459/http://www.midi.org/aboutus/aboutmma.php
3) *Audio-haptic modalities in musical interfaces*. ZHdK. (n.d.) https://www.zhdk.ch/en/researchproject/426334
4) Bezek, S. (2022). *Scottbez1/smartknob: Haptic input knob with software-defined end-stops and virtual detents*. GitHub. https://github.com/scottbez1/smartknob
5) Charlton, H. (2021, March 9). Apple exploring wider use of haptic feedback on mac-books. *MacRumors*. https://www.macrumors.com/2021/03/09/apple-exploring-wid-er-haptic-feedback/
6) Definition of haptics. (n.d.). In *Merriam Webster*. Retrieved May 8, 2023, from https://www.merriam-webster.com/dictionary/haptics
7) *Haptics*. (n.d.). Ultraleap. Retrieved May 9, 2023, from https://www.ultraleap.com/hap-tics/
8) *Heal the split,* Wackelkontakt. (2020, March 1) https://wackelkontakt.bandcamp.com/album/heal-the-split
9) Hind, N. (n.d.). *Physical modelling*. CCRMA, Standford University. Retrieved May 8, 2023, from https://ccrma.stanford.edu/software/clm/compmus/clm-tutorials/pm.html
10) ICST. (n.d.). *Performing live electronic music*. ZHdK. https://www.zhdk.ch/en/research-project/558720
11) *M4 - Motor fader controller*. (n.d.). Der Mann Mit Der Maschine. Retrieved May 9, 2023, from https://shop.dermannmitdermaschine.de/products/m4
12) Midi Fighter. (n.d.).https://www.midifighter.com/
13) Moreira, I. (2018, October 4). *Anatomy of a mechanical keyboard*. Drop. https://drop.com/talk/10016/anatomy-of-a-mechanical-keyboard
14) Papetti, S., & Tröster, G. (n.d.). Audio-Haptic modalities in Musical Interfaces. https://data.snf.ch/grants/grant/150107.
15) Peled, A. (2023). *Phantom limb*. https://www.amospeled.net/phantom-limb
16) *Project: Music not impossible*. Not Impossible Labs. (2018). https://www.notimpossi-ble.com/projects/music-not-impossible
17) *Seaboard Rise 2*. ROLI. (n.d.). https://roli.com/products/seaboard/rise2
18) *Soundplane*. Madrona Labs. https://madronalabs.com/soundplane
19) Stinson, L. (2017, April 3). Electric vehicles are dangerously quiet. Here's what they could sound like. *WIRED*. https://www.wired.com/2017/04/evs-dangerously-quiet-he-res-sound-like/
20) *The warehouse: The place where house music got it's name*. The Music Origins Pro-ject. (2019, June 18). https://musicorigins.org/item/the-warehouse-the-place-where-house-music-got-its-name/
21) *What is an audio feature?* Meyda. (n.d.). https://meyda.js.org/audio-features.html

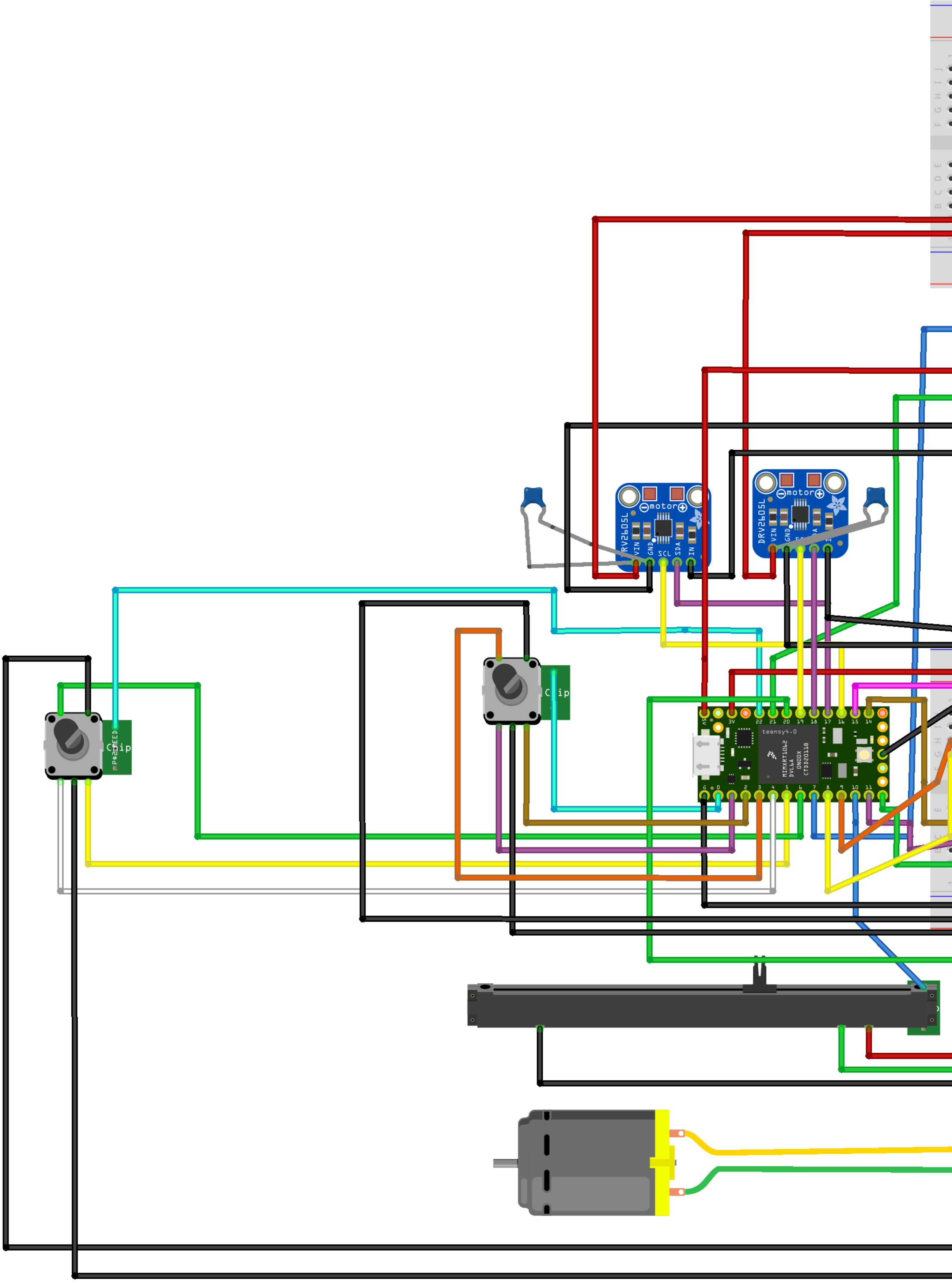
22) *What is SUBPAC?* SUBPAC. (2022, July 3). https://subpac.com/what-is-the-subpac/
23) *Who We Are.* (n.d) https://www.midi.org/about
24) *Wizard of oz prototyping: What it is, how & why it's done*. UX 4Sight. (2023, January) https://ux4sight.com/blog/wizard-of-oz-prototyping

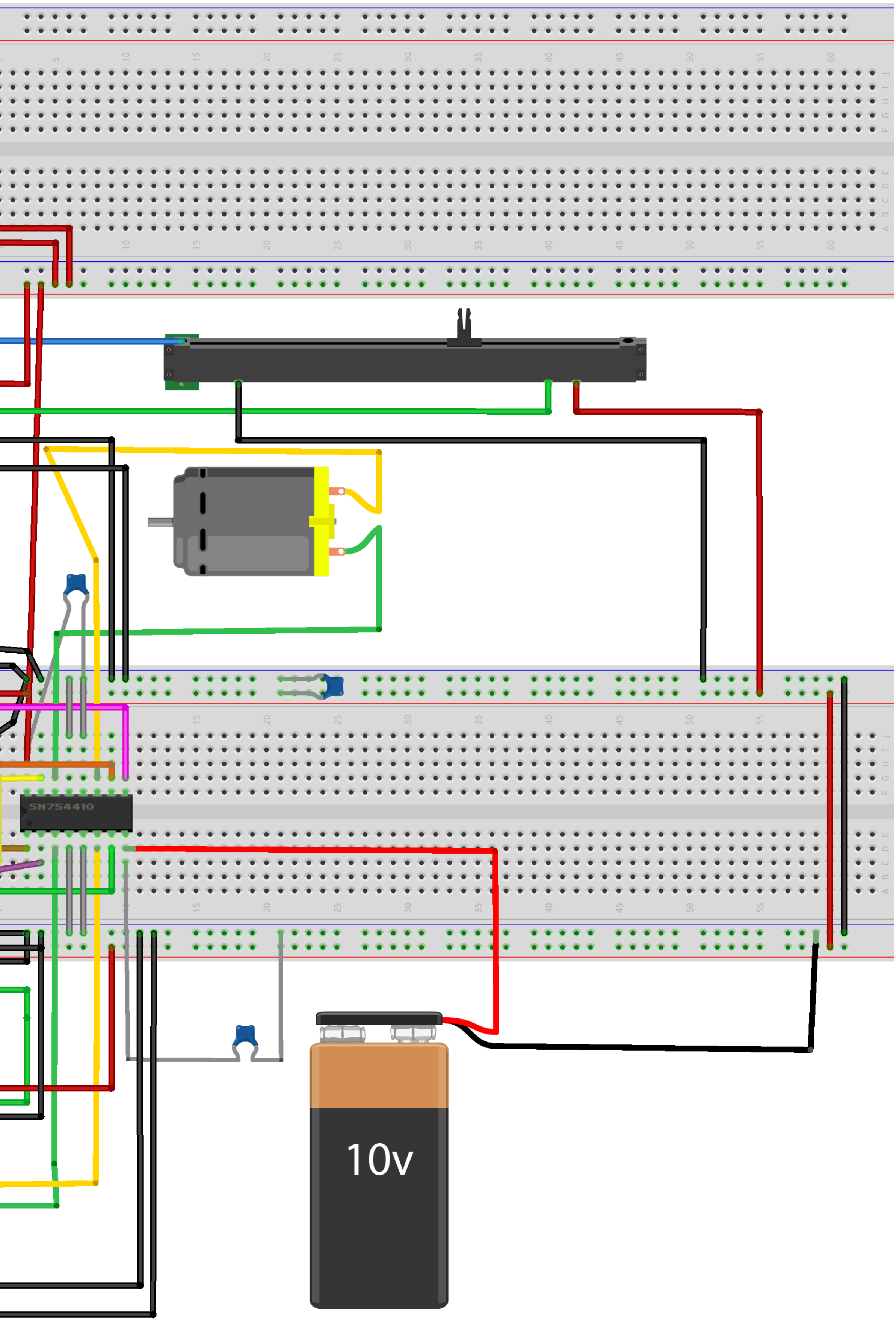
Appendix








motor
DRV2605L
VIN
GND
SCL
SDA
IN
motor
DRV2605L
teensy4.0
Chip
Chip


SN754410
10v

```
#include "MIDIUSB.h"
#include <Wire.h>
#include "Adafruit_DRV2605.h"
#include <Encoder.h>
#include <FastTouch.h>

#include "GUI_Communication.h"

Adafruit_DRV2605 drv1;  // First DRV2605 object
Adafruit_DRV2605 drv2;  // Second DRV2605 object

// configure I2C Bus on Teensy
int pin_SCL1 = 16;
int pin_SDA1 = 17;
int pin_SDA0 = 18;
int pin_SCL0 = 19;


unsigned long timeMs;

// fader 1
#define potPin_1 A6  // reading pot values
#define enA_1 A0     // PWM
//touch pin on digital 10 (needs to be declared in the function )
#define in1_1 11  // was 8
#define in2_1 12  //was 9


int touchFaderMIDI_1 = 0;
int lastTouchFaderMIDI_1 = 0;


int lastFader1 = 0;

// fader 2
#define potPin_2 A7  // reading pot value
#define enA_2 A1
//touch pin on digital 7 (needs to be declared in the function )
#define in1_2 8  // was 11
#define in2_2 9  // was 12

int touchFaderMIDI_2 = 0;
int lastTouchFaderMIDI_2 = 0;


int lastFader2 = 0;


// -----knob 1-----
Encoder myEnc_1(2, 1);  // encoder A + B
//touch pin on digital 0 (edited in code!)
#define ENCODER_SWITCH_PIN_1 3  // button pin

int lastKnob = 0;
int lastKnob1 = 0;
long oldPosition = -999;
bool hasError = 0;
unsigned long MIDI_encoder_button_1 = 0;
unsigned long lastMIDI_encoder_button_1 = 0;
```

```
// Detents function
int absPos = 0;


// ------knob 2--------
Encoder myEnc_2(5, 4);
//touch on digital 22
#define ENCODER_SWITCH_PIN_2 6  // button pin
int lastKnob2 = 0;
int oldPosition2 = -999;
unsigned long MIDI_encoder_button_2 = 0;
unsigned long lastMIDI_encoder_button_2 = 0;

// Detents function
int absPos2 = 0;

//-------- GUI Communication ---------
//fader 1
unsigned long setFader_1 = 0;

unsigned long setNumDetents_1 = 2;
//fader 2
unsigned long setFader_2 = 0;
unsigned long setNumDetents_2 = 2;
//knob 1
unsigned long setKnob_1 = 0;
unsigned long setKnobNumRevo_1 = 1;

//knob 2
unsigned long setKnob_2 = 0;
unsigned long setKnobNumRevo_2 = 1;

// LRA
uint8_t effect = 4;

// touch
int touchKnob_1 = 0;
int touchKnob_2 = 0;

int touchFader_1 = 0;
int touchFader_2 = 0;


unsigned long samplePeriod = 1700;  // controls the rate of the loop exacution


void setup() {
  Serial.begin(115200);
  // Teensy
  analogWriteFrequency(A0, 20000);
  analogWriteFrequency(A1, 20000);

  Wire.begin();   // Initialize the first I2C bus
  Wire1.begin();  // Initialize the second I2C bus

  Wire.setSDA(pin_SDA0);
  Wire.setSCL(pin_SCL0);

```

```
  Wire1.setSDA(pin_SDA1);
  Wire1.setSCL(pin_SCL1);


  drv1.begin(&Wire);   // Initialize the first DRV2605 object with the first I2C bus
  drv2.begin(&Wire1);  // Initialize the second DRV2605 object with the second I2C bus
  drv1.useLRA();
  drv2.useLRA();
  drv1.selectLibrary(6);
  drv2.selectLibrary(6);

  drv1.setMode(DRV2605_MODE_INTTRIG);
  drv2.setMode(DRV2605_MODE_INTTRIG);

  // set the effect to play
  drv1.setWaveform(0, 0);  // play effect
  drv1.setWaveform(1, 0);  // end waveform
  drv2.setWaveform(0, 0);  // play effect
  drv2.setWaveform(1, 0);  // end waveform

  // play the effect!
  drv1.go();
  drv2.go();

  pinMode(potPin_1, INPUT);
  //pinMode(enA_1, OUTPUT);
  pinMode(in1_1, OUTPUT);
  pinMode(in2_1, OUTPUT);

  pinMode(potPin_2, INPUT);
  // pinMode(enA_2, OUTPUT);
  pinMode(in1_2, OUTPUT);
  pinMode(in2_2, OUTPUT);

  //knob 1 button
  pinMode(ENCODER_SWITCH_PIN_1, INPUT_PULLUP);

  //knob 2 button
  pinMode(ENCODER_SWITCH_PIN_2, INPUT_PULLUP);
}

void controlChange(byte channel, byte control, byte value) {
  midiEventPacket_t event = { 0x0B, 0xB0 | channel, control, value };
  MidiUSB.sendMIDI(event);
}
unsigned long delta = 0;

void loop() {


  // touchKnob 1
  touchKnob_1 = fastTouchRead(0);   // touch knob on pin digital 0
  touchKnob_2 = fastTouchRead(22);  // touch knob on pin digital 22

  // ------touchFaders-----
  //fader 1
  touchFader_1 = fastTouchRead(10);  // touch fader on pin digital


```

```
// MIDI touch
if (touchFader_1 >= 47) {

  touchFaderMIDI_1 = 127;
} else {
  touchFaderMIDI_1 = 0;
}

if (touchFaderMIDI_1 != lastTouchFaderMIDI_1) {

  controlChange(0, 7, touchFaderMIDI_1);
  MidiUSB.flush();
  lastTouchFaderMIDI_1 = touchFaderMIDI_1;
}


// fader 2
touchFader_2 = fastTouchRead(7);  // touch fader on pin digital


// MIDI touch
if (touchFader_2 >= 47) {

  touchFaderMIDI_2 = 127;
} else {
  touchFaderMIDI_2 = 0;
}

if (touchFaderMIDI_2 != lastTouchFaderMIDI_2) {
  controlChange(0, 8, touchFaderMIDI_2);
  MidiUSB.flush();
  lastTouchFaderMIDI_2 = touchFaderMIDI_2;
}

//time
timeMs = millis();

// ---------MIDI FADERS---------
//Fader 1 MIDI
int fader1 = analogRead(potPin_1);
int MIDIPot1 = map(fader1, 0, 1023, 0, 127);

if (MIDIPot1 != lastFader1) {

  controlChange(0, 0, MIDIPot1);
  MidiUSB.flush();
  lastFader1 = MIDIPot1;
}

//Fader 2 MIDI
int fader2 = analogRead(potPin_2);
int MIDIPot2 = map(fader2, 0, 1023, 0, 127);
if (MIDIPot2 != lastFader2) {

  controlChange(0, 1, MIDIPot2);
  MidiUSB.flush();
  lastFader2 = MIDIPot2;
}

```

```

  // ---------MIDI KNOB----------
  //knob 1 MIDI
  int encoder_button_1 = digitalRead(ENCODER_SWITCH_PIN_1);

  if (encoder_button_1 == LOW) {
    MIDI_encoder_button_1 = 127;
  } else {
    MIDI_encoder_button_1 = 0;
  }

  if (MIDI_encoder_button_1 != lastMIDI_encoder_button_1) {

    controlChange(0, 5, MIDI_encoder_button_1);
    MidiUSB.flush();
    lastMIDI_encoder_button_1 = MIDI_encoder_button_1;
  }

  //knob 2 MIDI
  int encoder_button_2 = digitalRead(ENCODER_SWITCH_PIN_2);
  if (encoder_button_2 == LOW) {
    MIDI_encoder_button_2 = 127;
  } else {
    MIDI_encoder_button_2 = 0;
  }

  if (MIDI_encoder_button_2 != lastMIDI_encoder_button_2) {

    controlChange(0, 6, MIDI_encoder_button_2);
    MidiUSB.flush();
    lastMIDI_encoder_button_2 = MIDI_encoder_button_2;
  }

  //HAPTIC BEHVIOUR SETTINGS FROM GUI
  if (Serial.available()) {
    int incomingByte = Serial.read();  // Read the incoming byte and store it in a variable

    int valueSerial = Serial.parseInt();

    if (incomingByte == Fader1BehavHeader) {
      setFader_1 = valueSerial;
    } else if (incomingByte == Fader2BehavHeader) {
      setFader_2 = valueSerial;
    } else if (incomingByte == Knob1BehavHeader) {
      setKnob_1 = valueSerial;
    } else if (incomingByte == Knob2BehavHeader) {
      setKnob_2 = valueSerial;
    } else if (incomingByte == Knob1RevoHeader) {
      setKnobNumRevo_1 = valueSerial;
    } else if (incomingByte == Knob2RevoHeader) {
      setKnobNumRevo_2 = valueSerial;
    } else if (incomingByte == Fader1NumDetentsHeader) {
      setNumDetents_1 = valueSerial;
    } else if (incomingByte == Fader2NumDetentsHeader) {
      setNumDetents_2 = valueSerial;
    }
  }

```

```
  // Fader 1 function calling based on serial
  switch (setFader_1) {
    case 0:
      digitalWrite(in1_1, LOW);
      digitalWrite(in2_1, LOW);
      digitalWrite(enA_1, LOW);
      break;
    case 1:
      Detents_Fader_1();
      break;
    case 2:
      Resistance_1();
      break;
    case 3:
      Rubberband_1();
      break;
    case 4:
      Centre_1();
      break;
    default:
      // do nothing
      break;
  }
  // Fader 2 function calling based on serial
  switch (setFader_2) {
    case 0:
      digitalWrite(in1_2, LOW);
      digitalWrite(in2_2, LOW);
      digitalWrite(enA_2, LOW);
      break;
    case 1:
      Detents_Fader_2();
      break;
    case 2:
      Resistance_2();
      break;
    case 3:
      Rubberband_2();  // doesn't exist yet
      break;
    case 4:
      Centre_2();  // doesn't exist yet
      break;
    default:
      // do nothing
      break;
  }


  // Knob 1 function calling based on serial
  switch (setKnob_1) {
    case 1:
      Intensity_1();
      break;
    case 2:
      Detents_1();
      break;
    default:
      // do nothing
      break;
```

```
  }

  // Knob 2 function calling based on serial
  switch (setKnob_2) {
    case 1:
      Intensity_2();
      break;
    case 2:
      Detents_2();
      break;
    default:
      // do nothing
      break;
  }

  // call the different behaviours from the script. Not to be used together with the GUI
  //--knobs--
  Intensity_1();
  Intensity_2();
  Detents_1();
  Detents_2();
  //--faders--
  Detents_Fader_1();
  Detents_Fader_2();
  Rubberband_1();
  Rubberband_2();
  Centre_1();
  Centre_2();
  Resistance_1();
  Resistance_2();



  delaySamplePeriod();
}


// controls the rate of loop execution based on the variable "samplePeriod"
void delaySamplePeriod() {
  static unsigned long lastTime = 0;
  if (micros() - lastTime > samplePeriod) {
    // Serial.println("1202 alarm");
    lastTime = micros();
  } else {
    while (micros() - lastTime < samplePeriod) {
      //wait
      yield();
    }
    lastTime += samplePeriod;
  }
}
///-------------knobs--------------
//knob 1
void Intensity_1() {

  static long previTime = timeMs;
  long newPosition = myEnc_1.read();

  // see if knob has been moved
```

```
  if (newPosition != oldPosition) {
    hasError = 0;

    // is knob in valid range?
    if (newPosition < 0) {
      // went below valid range
      hasError = 1;
      newPosition = 0;
      myEnc_1.write(-1);
    } else if (newPosition > (96.0 * setKnobNumRevo_1)) {
      // went over the allowed limit
      hasError = 1;
      newPosition = (96 * setKnobNumRevo_1);
      myEnc_1.write((96 * setKnobNumRevo_1) + 1);
    }
    oldPosition = newPosition;
  }
  // constrain and map knob position to a usable range
  // int constrainVal = constrain(newPosition, 0, 96);
  int midiVal = map(newPosition, 0, 96 * setKnobNumRevo_1, 0, 127);

  // apply a logarithmic interpolation to the value
  int intervalPulse = map(midiVal, 0, 127, 0, 100);  // the interval time between pulses
  float intervalPulseDec = intervalPulse / 100.0;
  float logIntervalPulse = pow(intervalPulseDec, 0.333);
  float logPulse = map(logIntervalPulse, 0.0, 1.0, 400.0, 80.0);


  if (touchKnob_1 >= 30) {
    if ((timeMs - previTime) > (logPulse)) {

      // play intensity haptic
      drv1.setWaveform(0, effect);  // play effect
      drv1.setWaveform(1, 0);       // end waveform
      drv1.go();

      previTime = timeMs;
    } else if (hasError) {
      // play error haptic
      drv1.setWaveform(0, 50);  // play effect
      drv1.setWaveform(1, 0);   // end waveform
      drv1.go();
    }
  }

  // send out the current value over MIDI
  if (midiVal != lastKnob) {
    controlChange(0, 2, midiVal);
    MidiUSB.flush();
    lastKnob = midiVal;
  }
}

//knob 2
void Intensity_2() {
  static long previTime = timeMs;
  long newPosition = myEnc_2.read();
  // see if knob has been moved
  if (newPosition != oldPosition) {
```

```
    hasError = 0;

    // is knob in valid range?
    if (newPosition < 0) {
      // went below valid range
      hasError = 1;
      newPosition = 0;
      myEnc_2.write(-1);
    } else if (newPosition > (96.0 * setKnobNumRevo_2)) {
      // went over the allowed limit
      hasError = 1;
      newPosition = (96 * setKnobNumRevo_2);
      myEnc_2.write((96 * setKnobNumRevo_2) + 1);
    }
    oldPosition = newPosition;
  }
  // constrain and map knob position to a usable range
  // int constrainVal = constrain(newPosition, 0, 96);
  int midiVal = map(newPosition, 0, 96 * setKnobNumRevo_2, 0, 127);

  // apply a logarithmic interpolation to the value
  int intervalPulse = map(midiVal, 0, 127, 0, 100);  // the interval time between pulses
  float intervalPulseDec = intervalPulse / 100.0;
  float logIntervalPulse = pow(intervalPulseDec, 0.333);
  float logPulse = map(logIntervalPulse, 0.0, 1.0, 400.0, 80.0);

  if (touchKnob_2 >= 30) {
    if ((timeMs - previTime) > (logPulse)) {

      // play intensity haptic
      drv2.setWaveform(0, effect);  // play effect
      drv2.setWaveform(1, 0);       // end waveform
      drv2.go();

      previTime = timeMs;
    } else if (hasError) {
      // play error haptic
      drv2.setWaveform(0, 50);  // play effect
      drv2.setWaveform(1, 0);   // end waveform
      drv2.go();
    }
  }

  // send out the current value over MIDI
  if (midiVal != lastKnob) {

    controlChange(0, 3, midiVal);
    MidiUSB.flush();
    lastKnob = midiVal;
  }
}

void Detents_1() {
  long newPosition = myEnc_1.read();
  if (newPosition != oldPosition) {
    if (newPosition < 0) {
      // went below valid range
      newPosition = 0;
      myEnc_1.write(0);
```

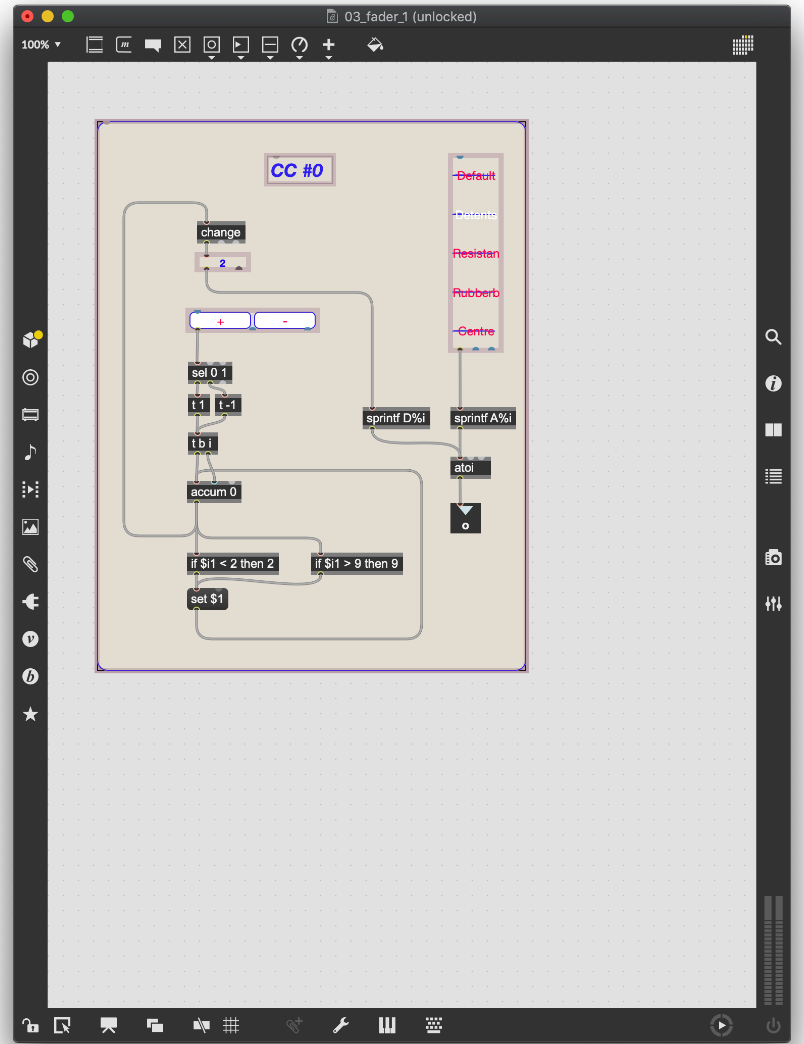
```
    } else if (newPosition > (96.0 * setKnobNumRevo_1)) {
      // went over the allowed limit
      newPosition = (96 * setKnobNumRevo_1);
      myEnc_1.write((96 * setKnobNumRevo_1));
    }
    oldPosition = newPosition;
    absPos = abs(newPosition);
    int midiVal = map(absPos, 0, 96 * setKnobNumRevo_1, 0, 127);
    if (midiVal != lastKnob1) {
      drv1.setWaveform(0, 24);  // play effect
      drv1.setWaveform(1, 0);   // end waveform
      drv1.go();
      //MIDI out
      controlChange(0, 2, midiVal);
      MidiUSB.flush();
      lastKnob1 = midiVal;
    }
  }
}

void Detents_2() {
  long newPosition = myEnc_2.read();
  if (newPosition != oldPosition2) {
    if (newPosition < 0) {
      // went below valid range
      newPosition = 0;
      myEnc_2.write(0);
    } else if (newPosition > (96.0 * setKnobNumRevo_2)) {
      // went over the allowed limit
      newPosition = (96 * setKnobNumRevo_2);
      myEnc_2.write((96 * setKnobNumRevo_2));
    }
    oldPosition2 = newPosition;
    absPos2 = abs(newPosition);
    int midiVal = map(absPos2, 0, 96 * setKnobNumRevo_2, 0, 127);
    if (midiVal != lastKnob2) {
      drv2.setWaveform(0, 24);  // play effect
      drv2.setWaveform(1, 0);   // end waveform
      drv2.go();
      //MIDI out
      controlChange(0, 3, midiVal);
      MidiUSB.flush();
      lastKnob2 = midiVal;
    }
  }
}

///------------faders-------------
void Detents_Fader_1() {
  int val = analogRead(potPin_1);

  int interval = (1015 - 8) / (setNumDetents_1 - 1);  // calculate the interval between points

  for (int i = 0; i < setNumDetents_1; i++) {
    int point = 8 + i * interval;
    if (i == setNumDetents_1 - 1) point = 1015;

    int lowerBound = point - interval / 2;
    int upperBound = point + interval / 2;
```

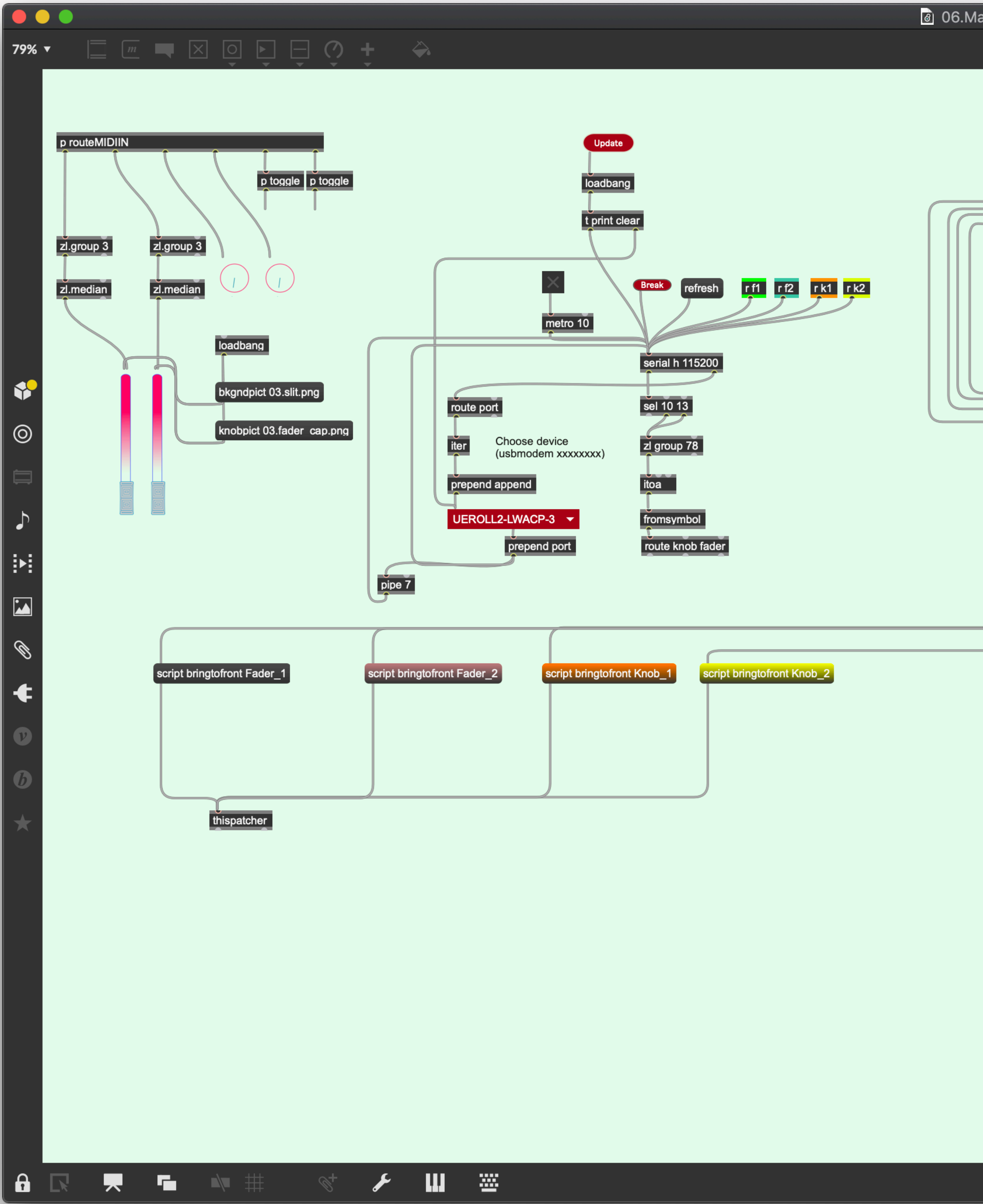
```

    if (val >= lowerBound && val < upperBound) {
      int midPoint = (lowerBound + upperBound) / 2;  // calculate the midpoint of the interval

      if (val > midPoint + 6) {
        digitalWrite(in1_1, LOW);
        digitalWrite(in2_1, HIGH);

        analogWrite(enA_1, map(abs(val - midPoint), 0, interval / 2, 165, 192));  // P regulat
      } else if (val < midPoint - 6) {
        digitalWrite(in1_1, HIGH);
        digitalWrite(in2_1, LOW);

        analogWrite(enA_1, map(abs(val - midPoint), 0, interval / 2, 150, 192));  // P regulat
      } else {
        analogWrite(enA_1, LOW);
      }
    }
  }
}


void Detents_Fader_2() {
  int val = analogRead(potPin_2);
  // Serial.println(val);
  int interval = (1015 - 8) / (setNumDetents_2 - 1);

  for (int i = 0; i < setNumDetents_2; i++) {
    int point = 8 + i * interval;
    if (i == setNumDetents_2 - 1) point = 1015;

    int lowerBound = point - interval / 2;
    int upperBound = point + interval / 2;

    if (val >= lowerBound && val < upperBound) {
      int midPoint = (lowerBound + upperBound) / 2;

      if (val > midPoint + 6) {
        digitalWrite(in1_2, LOW);
        digitalWrite(in2_2, HIGH);

        analogWrite(enA_2, map(abs(val - midPoint), 0, interval / 2, 160, 185));
      } else if (val < midPoint - 6) {
        digitalWrite(in1_2, HIGH);
        digitalWrite(in2_2, LOW);

        analogWrite(enA_2, map(abs(val - midPoint), 0, interval / 2, 160, 185));
      } else {
        analogWrite(enA_2, LOW);
      }
    }
  }
}

// ---------- resistance (not snapping back)-----
// fader 1

void Resistance_1() {
  int val = analogRead(potPin_1);
```

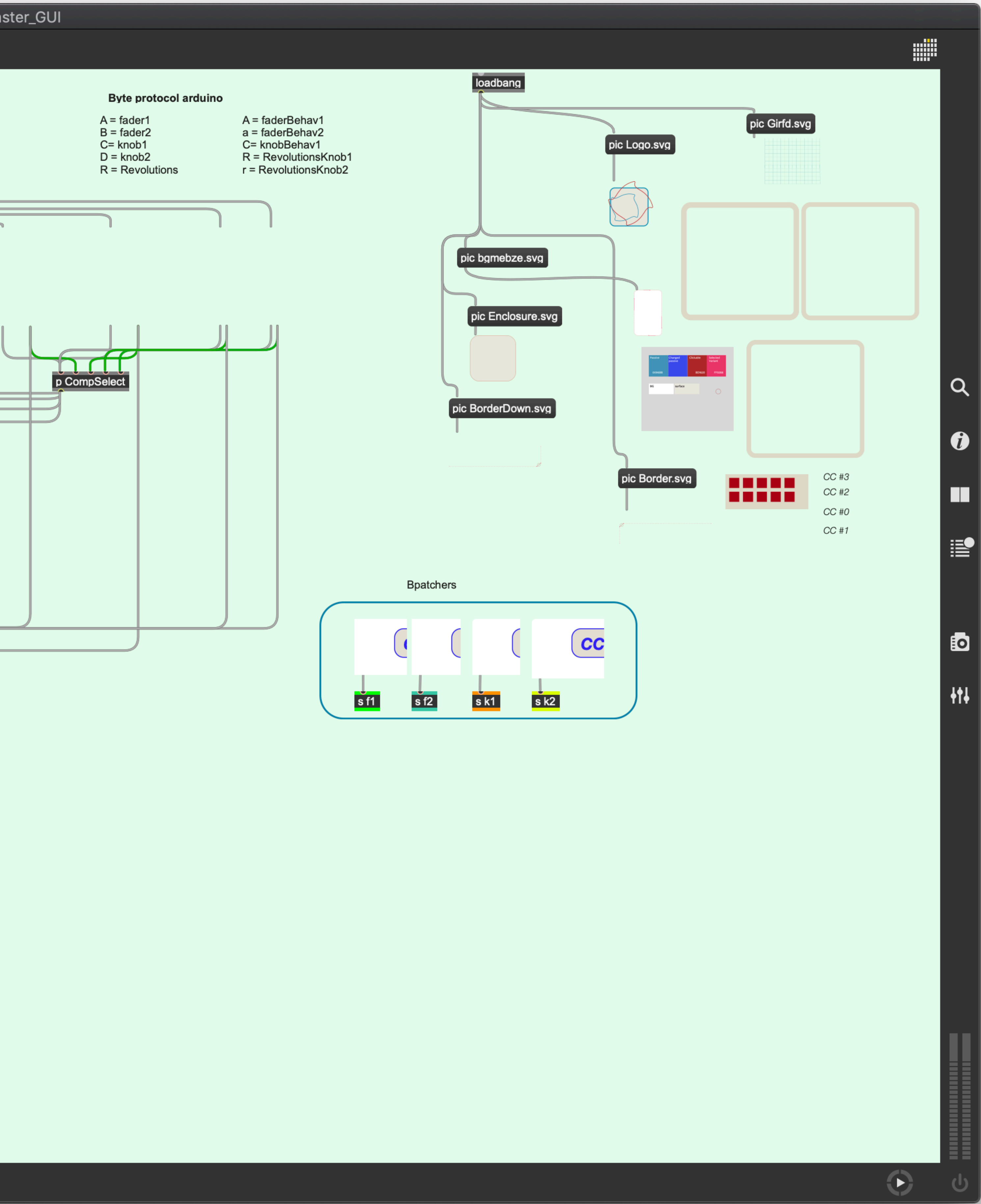
```

  if (val > 25) {
    digitalWrite(in1_1, LOW);
    digitalWrite(in2_1, HIGH);
    analogWrite(enA_1, map(val, 10, 1024, 160, 255));

    if (touchFader_1 <= 60) {
      analogWrite(enA_1, LOW);
    }
  }
}


void Resistance_2() {
  int val = analogRead(potPin_2);


  if (val > 25) {
    digitalWrite(in1_2, LOW);
    digitalWrite(in2_2, HIGH);
    analogWrite(enA_2, map(val, 10, 1024, 160, 255));

    if (touchFader_2 <= 60) {
      analogWrite(enA_2, LOW);
    }
  }
}

void Rubberband_1() {
  int val = analogRead(potPin_1);
  if (val > 25) {
    digitalWrite(in1_1, LOW);
    digitalWrite(in2_1, HIGH);
    analogWrite(enA_1, map(val, 10, 1024, 185, 255));
  } else {

    analogWrite(enA_1, LOW);
  }
}

void Rubberband_2() {
  int val = analogRead(potPin_2);
  if (val > 25) {
    digitalWrite(in1_2, LOW);
    digitalWrite(in2_2, HIGH);
    analogWrite(enA_2, map(val, 10, 1024, 185, 255));
  } else {

    analogWrite(enA_2, LOW);
  }
}

void Centre_1() {
  int val = analogRead(potPin_1);
  if (val > 520) {  // middle point upper range
    digitalWrite(in1_1, LOW);
    digitalWrite(in2_1, HIGH);
    analogWrite(enA_1, map(val, 520, 1024, 165, 215));
  } else if (val < 502) {  // middle point lower range
```

```
    digitalWrite(in1_1, HIGH);
    digitalWrite(in2_1, LOW);
    analogWrite(enA_1, map(val, 502, 0, 165, 215));
  } else {
    analogWrite(enA_1, LOW);
  }
}

void Centre_2() {
  int val = analogRead(potPin_2);
  if (val > 520) {  // middle point upper range
    digitalWrite(in1_2, LOW);
    digitalWrite(in2_2, HIGH);
    analogWrite(enA_2, map(val, 520, 1024, 165, 215));
  } else if (val < 502) {  // middle point lower range
    digitalWrite(in1_2, HIGH);
    digitalWrite(in2_2, LOW);
    analogWrite(enA_2, map(val, 502, 0, 165, 215));
  } else {
    analogWrite(enA_2, LOW);
  }
}
```

```
#define Fader1BehavHeader 'A'
#define Fader2BehavHeader 'a'

#define Fader1NumDetentsHeader 'D'
#define Fader2NumDetentsHeader 'd'

#define Knob1BehavHeader 'C'
#define Knob2BehavHeader 'c'

#define Knob1RevoHeader 'R'
#define Knob2RevoHeader 'r'

#define Fader1NumDetentsHeader 'D'
#define Fader2NumDetentsHeader 'd'
```


03_fader_1 (unlocked)
100%
CC #0
change
2
+
-
sel 0 1
t 1
t -1
t b i
accum 0
if $i1 < 2 then 2
if $i1 > 9 then 9
set $1
sprintf D%i
sprintf A%i
atoi
Default
Resistan
Rubberb
Centre


06.Ma
79%
p routeMIDIIN
p toggle
p toggle
Update
loadbang
t print clear
zl.group 3
zl.group 3
zl.median
zl.median
Break
refresh
r f1
r f2
r k1
r k2
metro 10
loadbang
serial h 115200
bkgndpict 03.slit.png
knobpict 03.fader_cap.png
route port
sel 10 13
iter
Choose device
(usbmodem xxxxxxxx)
zl group 78
prepend append
itoa
UEROLL2-LWACP-3
fromsymbol
prepend port
route knob fader
pipe 7
script bringtofront Fader_1
script bringtofront Fader_2
script bringtofront Knob_1
script bringtofront Knob_2
thispatcher


ster_GUI
Byte protocol arduino
A = fader1
B = fader2
C= knob1
D = knob2
R = Revolutions
A = faderBehav1
a = faderBehav2
C= knobBehav1
R = RevolutionsKnob1
r = RevolutionsKnob2
loadbang
pic Girfd.svg
pic Logo.svg
pic bgmebze.svg
pic Enclosure.svg
pic BorderDown.svg
pic Border.svg
p CompSelect
CC #3
CC #2
CC #0
CC #1
Bpatchers
cc
s f1
s f2
s k1
s k2