Enhancing Music Interfaces with Soft Materials

by

Diego Yañez-Laguna

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ABSTRACT

Despite the growing popularity of digital music instruments (DMIs) and relevant technological advances, accessibility and expressive potential remain significant challenges for musical interface designers. These issues stem from generic input-output mappings, sensor limitations, and a lack of physical connection between musicians and instruments. This thesis examines the benefits of incorporating soft materials into musical interfaces and why DMIs should be designed with musician-instrument relationships as a priority in order to enhance intuitiveness and expressiveness. This work culminates with design and analysis of a prototype that explores the potential of a foam user interface. Featuring pressure sensors embedded within foam blocks, the prototype encourages tactile interaction and gives the user nuanced control over various musical parameters. The modular design of the foam blocks allows for versatile configurations, enabling users to control multiple parameters simultaneously with simple, but responsive gestures.

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1. INTRODUCTION

The past twenty years have seen rapid advancements in digital music technology and the birth of the research field NIME (New Interfaces for Musical Expression). Although the field continues to grow quickly, around 100 papers are published each year through NIME, digital music instruments (DMIs) are far from reaching their full potential and issues inherent to DMIs, such as latency, sensor accuracy, and lack of physical feedback, continue to be a challenge for instrument designers. Furthermore, accessibility is a large issue as many DMIs are either not widely available or are complex to learn and use. DMIs that are commercially available tend to have standardized or generic interfaces which lead to weak relationships between user interaction and musical output, as a limited set of user interface elements are used to represent and control the infinite landscape of sound. This thesis analyzes various tangible user interfaces and how they can improve DMIs, both in terms of intuitiveness and expressiveness. Specifically, the affordances of a squishable tangible interface are explored through the design of a prototype musical controller. The prototype is mainly made with foam blocks and utilizes capacitive and pressure sensing to measure the foam's deformation. The thesis concludes by demonstrating several configurations of the prototype and discussing potential further applications of squishable tangible interfaces.

2. BACKGROUND

Overview of Digital Music Instruments Field

Musical interface design is a diverse field that currently contains perspectives from various fields, including human-computer interaction, music, interactive art, dance, and accessibility design. Each field has its own priorities and ways of defining DMIs or NIMEs, but for clarity this thesis will call them digital music instruments (DMIs) and use the following definition: “A control surface or gestural controller, which drives the musical parameter of a sound synthesizer in real time. It can be separated in three parts: (a) the input or gestural control; (b) the output or sound synthesis; and (c) the mapping strategies between input and output” (Medeiros, 2014). While each of these three subparts is constantly evolving with new technologies, this definition can generally be applied to most DMIs. This thesis is most interested in analyzing and exploring new possibilities in the two subparts of input control and mapping strategies. Currently, input control takes advantage of sensor technologies, which “enable virtually any kind of physical expression to be detected and tracked” (Paradiso, 2002). Current mapping strategies have been heavily influenced by the introduction of MIDI (Musical Instrument Digital Interface), which has become the industry standard for communication protocol between interfaces and outputs. It is common to use a PC to process MIDI data sent from a controller. The use of PC/MIDI and advances in sensor technologies allow for “any kind of gesture to be software mapped onto essentially any musical response” (Paradiso, 2002). While this is exciting for DMI designers, it also poses several new problems and while innovations are rapidly being made, the field is still relatively young and it is unclear which directions will eventually succeed. Defining success is also an issue as Paradiso notes that “the vocabulary in this field is likewise in its infancy – there’s still no common set of standards with which to evaluate designs, and as goals are so varied in different applications, it’s unclear whether this can ever be effectively accomplished”. Additionally, Medeiros (2014) points out that “it is hard to find artifacts that have been widely or convincingly adopted by musicians. In fact, there are very few NIME virtuosi or professional musicians who adopted them as their main musical instrument.” There is clearly a lack of a framework for designing successful DMIs and this is validated by the absence of widespread adoption, with only a few new DMIs being widely adopted in the past twenty years, such as the DJ controller. These open problems are the main motivation for this thesis, which will have two goals: (1) identify specific DMI design issues and examine current strategies and methods being used to solve them; (2) explore the potential of integrating soft materials into tangible music interfaces. The reasons for choosing to explore soft materials, will be further explained in the following sections.

Why Mapping Freedom is a Problem

The infinite freedom of being able to map any input to any output creates an arbitrary relationship between the two and this has led to issues that are not always fully considered when designing DMIs. “In acoustic instruments, the excitation of notes and the sound generation are intrinsically linked” (Medeiros, 2014) while in DMIs excitation and generation are dissociated. The loss of an intrinsic link between the two means that by default, there is no longer any natural feedback or response from the instrument and these elements must be recreated. The main responses useful in musical instruments are visual feedback, haptic feedback, and auditory feedback. For example, piano keys have a physical weight that allows performers to control how much force they use when pressing keys, therefore influencing the volume and timbre of the piano notes. Not all natural responses are necessarily useful for performing music. When learning to play guitar, it is typical for the player’s fingers to hurt and develop calluses from the metal strings. Also, sliding your hand across the guitar neck can produce a screeching sound that is not necessarily intended by the musician. However, having natural response to a musician’s input is a big advantage because this allows acoustic instruments to translate even miniscule inputs into unique sonic output. DMIs face the challenge of having to recreate these translations through digital mapping and currently there is “no established method or tool to guide the NIME designer to define how interfaces gestures should be adequately mapped into sound variables” (Medeiros, 2014).

Sensor Limitations

Another challenge in translating user inputs is having to consider the limitations of sensor technologies. Sensors typically measure a single variable, such as force, resistivity, temperature, proximity, light, etc., and have varying degrees of accuracy and reliability. Because of this, sensors do not paint a full picture of whatever you are measuring and a DMI designer needs to decide how much to trust the sensor or how to balance utilizing too little or too much data. In order to pick up more nuances from a user's input, a sensor can be made more sensitive, but this can lead to the sensor's data becoming too noisy and meaningless. A common way of using sensors is to use them as binary encoders. For example, a capacitive sensor can be used to detect if it is being touched or not very reliably as the interference of noise becomes negligible when only differentiating between touching and not touching. This example has effective use cases because the capacitive sensor can now act the same as a tactile button, while taking up less space, since capacitive sensors can be flat. However, by turning sensors into binary or even discrete encoders, they do not take full advantage of the sensor's capabilities and simplify user inputs. Medeiros (2014) categorizes sensor limitations into three categories:

- real-time (latency and jitter)
- precision (information can be incorrectly translated in the analog to digital conversion)
- information richness (important data may be ignored by sensors)

Additionally, some sensors are sensitive to things like temperature or dust contamination, which can cause them to wear out and become unreliable. This thesis will not be focused on improving sensing technologies, but it is important to keep their limitations and mind and consider their effects in translating user inputs when defining mappings.

Generic Musician-Instrument Relationships

The introduction of MIDI has allowed new types of interfaces to become widely available and commercially successful. Having the common language of MIDI allows a variety of interfaces to communicate with each other, such as keyboards, synths, and drum pads. This is useful for musicians that utilize multiple MIDI instruments since they can connect these different instruments together and also benefit from the familiarity of a shared user interface language. Over the years, the design of commercial DMIs has been standardized in order to appeal to a wider range of customers. Common features include buttons, knobs, pads, and sliders. Additionally, commercial DMIs borrow elements from existing acoustic instruments, most commonly the layout of piano keys, which has become the default way of playing notes on most DMIs. Another widely popular instrument that takes both digital analog forms is the modular synth, which doesn’t typically use MIDI, but also shares much of the same design elements of MIDI interfaces. This standardization of interface design allows commercial DMIs to include a wide variety of features and functions and this is a large selling point. “What might be seen as a limitation of MIDI – its lack of a signature built-in sound – is framed as an advantage of versatility (play any sound you can imagine)” (McPherson, 2019). However, in prioritizing flexibility these instruments have sacrificed usability. The Traktor Kontrol S4 MK3 is a DJ Controller (Fig. 2.1) released in 2018 that shows the extreme number of functions that get packed into commercial DMIs. In a YouTube video describing the product’s features, it is shown that a single button can perform at least 6 different functions depending on the mode and settings of the controller. The controller has a customizable layout with around 100 different input elements, many of which can also take on different functionalities. Obviously, this is a high-end controller being designed for experienced DJs and the designers are not prioritizing accessibility for novices. However, in prioritizing versatility there is still a negative impact on the interaction experience. These types of controllers often use arbitrary indicators and feedback to show users which mode is active or what the function of a certain element is. The indicators are usually visual and a variable such as color, blinking speed, or text is modified to differentiate between functions. These indicators do the bare minimum of communicating a change or specific state, but contain no other intuitive meaning and it is up to the musician to learn the relationship between indicators and functions.

Figure 2.1 Native Instruments Traktor Kontrol S4 MK3 4-channel DJ Controller. Complete 4-deck USB DJ Control Surface, Audio Interface, and Software System for Mac and PC

The generic qualities of commercial DMI design along with the mapping problem previously discussed, create a large disconnect between the musician’s intentions and musical output. In acoustic instruments each musical intention is naturally tied to a specific gesture or action. For example, a drummer will strike a cymbal harder to make it louder, a guitarist will use palm-muting to change the length and timbre of a note, and a violinist will move their finger back and forth on the string to create vibrato. Each of these musical choices uses a unique gesture, but in the DMI world they are indistinguishable. Turning a knob changes the volume of the digital cymbal, turning a knob changes the envelope response of the digital guitar note, and turning a knob increases or decreases the amount of vibrato applied to the digital violin note. This generic quality of interaction makes it harder for DMIs to be expressive and for a meaningful musician-instrument relationship to be formed. This issue is especially problematic for people with disabilities, whose needs are underrepresented in the current DMI design framework. McMillan's (2023) research on designing accessible musical instruments (AMIs) shows how current frameworks focus on end-goals and technological solutions and argues that musician-instrument relationships should be considered at an earlier stage so that the specific needs of more users can be addressed. Overall, modern commercial DMIs are extremely powerful in terms of functionality and versatility, but have elements of black-box design that create high barriers to entry in addition to limiting their expressive capabilities.

3. LITERATURE REVIEW

Potential Strategies and Measures of Success

As previously discussed, DMIs can be analyzed from a wide range of perspectives and through the lens of various stakeholders. Manufacturers may value reliability and versatility, while audiences care more about feeling engaged in a DMI performance, which can be achieved through exciting interactions or visuals. However, '"there is no doubt that the most important stakeholder in the process of designing and building a DMI is the performer. Unless the instrument can successfully translate their musical intent into sound in a reliable way it fundamentally fails as an instrument" (O'Modhrain, 2011). This thesis evaluates DMIs through the lens of a performer, focusing specifically on the mapping strategies and any added elements that enrich the musician-instrument relationship.

One method for analyzing DMIs is Jorda's (2004) framework of three diversity classes: Macro, Mid, and Micro. DMIs can support each class to varying degrees.

Diversity Class	Definition	Example of High Diversity	Example of Low Diversity
Macro diversity	Stylistic diversity, ability to be used in a wide range of musical contexts	Acoustic Guitar	Double Bass
Mid diversity	How different two performances played with the instrument can be	Trumpet	Snare drum
Micro diversity	How different two performances *of the same piece* played with the instrument can be. How well it can pick up nuances in input	Violin	Keyboard

Figure 3.1 Diversity classes further explained (Jorda, 2004)

Interesting cases in this framework include the guitar, which Jorda describes as the perfect “desert island” instrument due to it having both high (used in many genres) and low (has developed very genre-specific repertoire, such as flamenco) macro diversity.

Jorda (2004) also introduces the idea of “non-linearity.” He describes how “in acoustic instruments, mappings are often multidimensional and slightly non-linear. Blowing harder on many wind instruments not only affects dynamics but also influences pitch, and it is in this control correlations and difficulties where may lay, in fact, the expressiveness for many acoustic instruments.” These complex relationships between various parameters can be learned and mastered by performers and creates a large potential for expressiveness. Contrarily, DMI parameters are typically unlinked or only directly related to one or two other parameters. One can imagine how acoustic instruments provide a multi-dimensional space for expressive exploration while DMIs only provide single or two-dimensional spaces.

MacMillan (2023) analyzes instrument-musician relationships in order to design better instruments for disabled musicians. They suggest that more adaptability should be incorporated into the design framework to allow each musician to have a more unique and personal relationship with the instrument. They then identify key elements for creating an intimate relationship, some of which he believes are missing from current DMI design frameworks. Most relevant to this thesis are:

- Ensure an intuitive, natural, and predictable response from the instrument that can generate a visceral connection and symbiotic relationship.
- Design for a low entry level so that a musician can start playing the instrument with relative ease while offering the opportunity to progress and develop those skills to a high ceiling for more complex performances.
- Create “functional transparency” by linking the psychological and the physical connection(s) and responses
- Utilize conceptual metaphors to inform design decisions when mapping interface elements to function and assessing how abstract sound concepts might be associated with physical interactions

The importance of conceptual metaphors is also discussed by Wilkie (2009), who states that when applied to music interaction, it should “facilitate the development of innovative and intuitive interaction designs for both novices and experts alike.” Finally, Medeiros (2014) states that it is unclear which measures of success are most useful, but suggest the following categories: ergonomics, sound quality, visual feedback, fine-grained gesture control, embodied relationship, ease of use, efficiency, and learning curve.

Analysis of Relevant DMIs

In order to have a more concrete discussion of potential advances in DMI design, this thesis dives deeper into the DMI subset of tangible user interfaces. While most DMIs have some physical component, tangible user interfaces use physical objects and interactions as the main method of communication between musician and instrument, as opposed to interfaces that also rely on visual communication or gestural sensing which does not involve tactile interaction. This will allow for a narrower focus on fewer variables, such as tactile feedback, material properties, and shape.

The first example that fits this category is *FabricKeyboard* by Irmandy Wickasono (2017). *FabricKeyboard* is made of multi-layer fabric sensors that detect touch, proximity, electric field, pressure, and stretch. The result is a controller that combines both the discrete controls of a keyboard and various continuous controls from the embedded fabric sensors. The keyboard is able to react to a range of user inputs, including touch, non-contact proximity, stretching in different directions, twisting, and lifting. They explored various mapping strategies, such as stretching to pitch bend, proximity to amplitude modulation, and pressure to note velocity. Some of these actions are linked which leads to unique results, such as twisting the keyboard which results in multiple keys being activated due to touching each other along with various degrees of stretch being applied to multiple keys. While the mapping is still somewhat arbitrary, simple actions like twisting show the potential of the controller as it is able to approximate the complex relationships of parameters seen in acoustic instruments.

Another relevant example is the research done by Bakker (2012), which introduced a people-centered, iterative approach to the design of tangible learning systems with embodied metaphor-based mappings. This approach was then applied to the design of MoSo Tangibles. They identified embodied metaphor schemas (listed below) and created prototypes to explore the mapping between the input design space and metaphorically linked output responses. They chose and validated these mappings based on user testing with kids.

Metaphor Type	**Tangible Artifact**	**Musical Mapping**
Slow - Fast (speed of movement)	Shaker - shaking object up and down Rotator - rotating a plate	Tempo: Slow - Fast
Low - High (location)	Stick - pointing it up or down	Pitch: Low - High
Near - Far (distance between two points)	Puller - pulling two connected handles away from each other	Pitch: Low - High
Quiet - Wild (energy or force of movement)	Squeezer - squeezing wooden parts together	Volume: Soft - Loud

Figure 3.2 Key insights about embodied metaphors (Bakker, 2012)

These metaphor schemas are similar to ones presented by Wilkie (2009), who identifies common patterns in human experience, such as “more is up”, “down is low”, or relationships such as object-container and source-path-goal. This meta-language is then leveraged to create intuitive user interfaces which are able to effectively communicate with users without being overly complex or busy.

Relevant Personal Work

Sequencer Clock is a beat sequencer that mimics a clock in order to challenge typical electronic music standards. One of the ways it does this is by not conforming to the typical beat grid, which quantizes notes to specific rhythms and sounds very robotic and unnatural. Instead notes/beats (physically represented by magnets) are placed on a grid-less disk which is an intuitive way to represent the looping nature of a sequencer and allows notes to be placed imperfectly to create more natural sounding rhythms. The sequencer has a very minimalist interface, but invites the user to play with the magnets and discover how moving them around affects the sound. Aside from the radial position, which defines the moment that the beat will be played, there is also a mapping of the radial distance from the center of the sequencer to the magnet. This is mapped to a certain property of the beat, such as volume or pitch, depending on the mode.

Figure 3.3 *Sequencer Clock, by the author*

Since each magnet is only mapped to two parameters at a time (radial position: when it is played, distance from center: volume/pitch), it is easy for users to figure out how they are affecting the musical output. However, since both parameters are based on position it creates an unintentional link between the two. Since the surface has now markings or detents, it is hard to move a magnet in only one axis. For example, when attempting to make a note quieter the corresponding magnet must be moved closer to the center, but this can unintentionally shift the radial position and cause an unintuitive musical outcome, since the rhythmic feel will be affected. Generally, playing louder or softer on an acoustic instrument will not change the rhythmic quality. Even when it does that rhythmic change is applied consistently, such as a drum player playing softer as well as playing slightly behind the beat. This consistent change is hard to mimic on *Sequencer Clock* as the unintentional shifts will not be consistent.

Tangible Sampling focuses on the production technique of sampling. Sampling is when you take existing sections of music or any audio recordings and rework them to create new music. This can include modifying the sample through methods such as pitch-shifting, time-stretching, and reversing. New rhythms can be created by chopping up a sample into smaller sections and playing them in different orders. The sampling process usually requires expensive equipment and extensive knowledge of how to use it. This project seeks to create a more physically/visually intuitive representation of sampling by using objects that can be freely played with and modified to mimic how samples are modified in the digital world. Sampling is a powerful way of introducing people to music production because you already start off with something that sounds “good” and you get to focus on reinterpreting those pieces into something new and you are encouraged to continually play around with it.

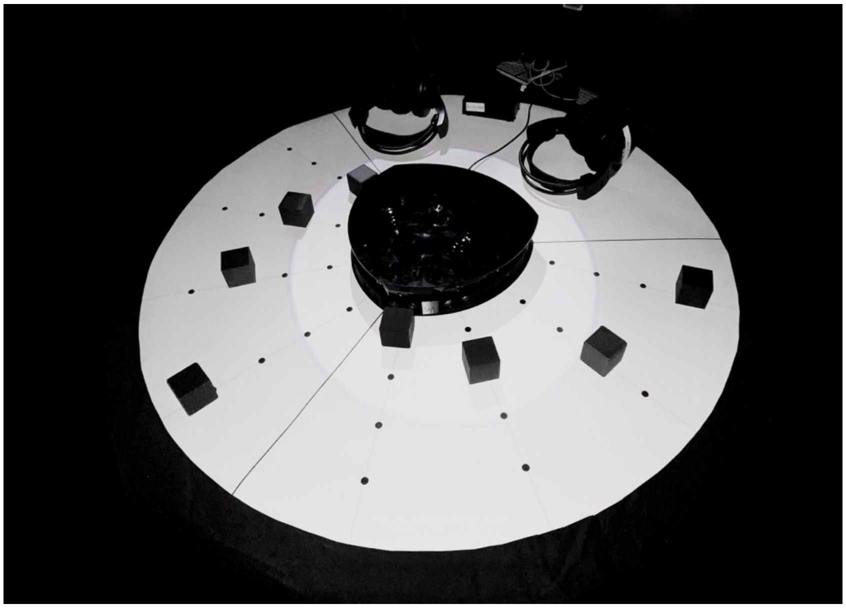

Figure 3.4 *Tangible Sampling, by the author*

Similar to *Sequencer Clock*, *Tangible Sampling* is constantly looping to allows users to focus on playing with the blocks. The interface is even simpler, relative to *Sequencer Clock*, as dots represent discrete points where the blocks can be placed. Both of these projects are successful in being accessible to new users as the interactions are simple and the looping nature of both automates much of the music being produced. However, both projects lack expressivity and responsiveness. They are good at visually representing what is going on, but lack the ability to fully translate nuances from user input. For example, some users attempted to stack blocks or rotate them before realizing that did not have any effect. Additionally, there is a lack of physical connection since the objects users are playing with are purely symbolic and do not respond to any forces being exerted directly onto them. Another way to think about it is how much energy is being transferred between input and output. For example, depending on how much energy you put into playing a drum, its volume and timbre will greatly change. *Sequencer Clock* and *Tangible Sampling* are both indifferent to the energy or force being put into them as they are mainly visual and symbolic representations. Most DMIs lack this type of energy transfer and creating more of a perceived physical connection could greatly enhance them.

Application to Soft Tangible Interfaces

In order to further explore and test out DMI design strategies, this thesis designs a prototype in the following section. *FabricKeyboard* (2017) showcases how soft materials, such as textiles, can provide rich tactile interaction with a wide range of output variables. There is already a lot of research being done on smart textiles and wearable computers and as more advances are made with sensing technologies, smart soft materials have the potential to enhance musical interfaces by providing rich tactile interaction. I chose to use foam as the main material for the prototype interface in order to explore new possibilities for soft user interfaces.

The following section will describe the design process of the prototype and how the learnings of the literature review were used to inform design choices.

4. METHODOLOGY / DESIGN PROCESS

Problem and Proposed Solution

This thesis has identified the following issues with DMI design:

- Generic Mappings - The connection between a user input and related output is often arbitrary or unintuitive
- Sensor Limitations - overly discrete data is misses input nuances, while noisy or imprecise data is not controllable enough
- Lack of Physical Connection - Contributes to generic nature of mappings and lack of feedback when interacting with sensors

These are broad problems that cannot fully be solved in this thesis, but instead it uses the design of a prototype to explore the potential solution of using a soft interface made of foam. This is in order to gain more understanding of the potential uses of foam in the context of musical interfaces, since it has not been widely explored yet. The following design framework will further describe the process and goals of the prototype.

Initial Decisions: Foam and Compression

Due to the short time-frame of this thesis, initial decisions were made quickly to allow time for exploring a specific solution more in depth. It was decided early on to use sensors that measured pressure or force in some manner to address the lack of perceived energy transfer in DMIs. Pressure sensing naturally suggested two common musical interactions, hitting (commonly found in percussion instruments or guitar slapping techniques) and squeezing (bagpipes, accordion, talking drum) which was eventually chosen. Hitting interactions tend to be methods for generating sound, while squeezing interactions are more versatile and can also be used to modify other parameters, such as the pitch of the talking drum, which is determined by the tension of the cords that are squeezed between the drummer's arm and body. Foam then seemed like a good material to receive compressive types of interaction. It is soft enough to be easily deformed, but dense enough to still provide good tactile feedback and resistance.

Material Tests

Next, material tests were performed to explore different properties of foam in order to find interesting design affordances. While the exact method of pressure sensing was not determined at this point, it was assumed that the level of sensing would be pretty simple, since the sensing technology is not the focus of the thesis.

The final design uses modular foam cubes with an edge length of 2.5 inches. Smaller sizes were not effective since they did not provide enough range of compression. Larger sizes were potentially misleading as they provided many degrees of compression, not all of which could be measured. The final size allowed for a decent range of compression while also being small enough that multiple blocks can be assembled together and still be controlled by a single hand. A cube shape was chosen since anything more complex could make the intended use more ambiguous. A cylinder could also work, especially since the compression is only being measured in one direction, but the cube shape made it easier to assemble the modular blocks together. A memory foam was chosen over other types, since it provided a more consistent, linear force resistance while not requiring excessive effort to compress it.

Several interactions were tried out along with methods for sensing them. Capacitive sensing seemed promising at first, since a capacitive surface on one end of the foam block could detect hand proximity when pressing from the other side. However, the range was too small and was not able to detect proximity at more than a couple inches. Ultimately, the most effective sensor was a pressure sensor that was made using conductive foam (explained in detail in the following section) which was able to reliably detect a large range of compression in a single axis. Twisting and bending interactions seemed promising, but no effective sensing mechanisms were able to be found due to the short time-frame for prototyping. A more complex squeezing interaction was able to be detected by using two pressure sensors that measure compression in two perpendicular axes. However, the size of sensors made it hard to fit it inside the foam block along with providing unwanted physical feedback when squeezing the block. Additionally, compression from one axis would often bleed into the other sensor’s readings.

Final Prototype: Pressure Sensor

The pressure sensor is actually measuring the voltage between two capacitive strips that are connected by a conductive piece of anti-static foam. As the conductive foam initially has a high resistance, but as it is compressed the resistance lowers and a higher voltage is measured between the capacitive strips. The sensor is composed of three layers, as shown in Fig. **, and fits into a 1.5-inch by 1.5-inch square area. The bottom layer has the two capacitive strips, with a small gap in between them and each soldered to a wire. Next is the thin square of conductive foam and sitting on top of the foam is a thin 3D-printed square used to equally distribute the compressive force that will later be applied by the larger memory foam cube. The sensor is fit into a square 3D-printed enclosure which also has a hole to pass the wires through. Finally, the enclosure is glued to the bottom face of a memory foam cube. The memory foam cube works well as an interactive object due to its larger scale and large compression range (2.5 inches can compress to 0.25 inches). This larger foam cube is able to transfer the compression force onto the small square which then compresses the conductive foam and produces a voltage value that represents pressure variations.

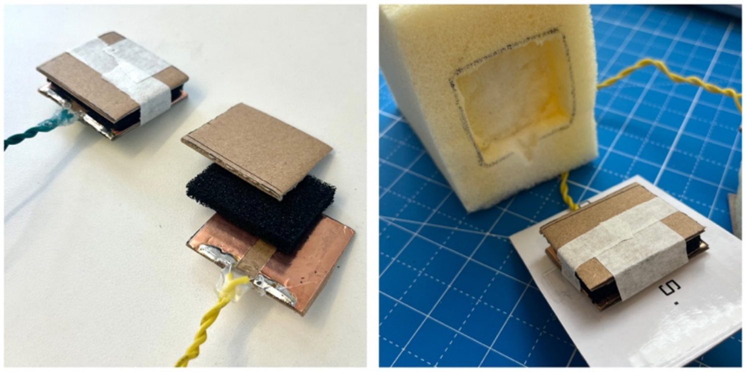

Figure 4.1 First version of pressure sensor, using cardboard housing

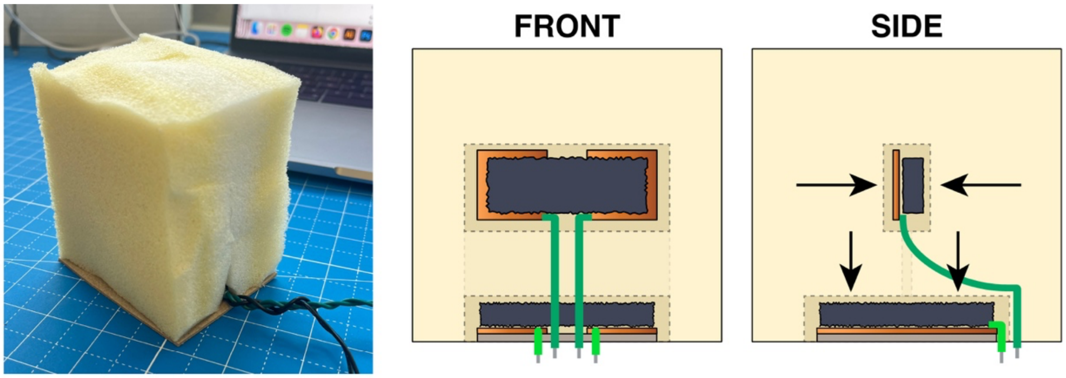

Figure 4.2 Foam block with two embedded pressure sensors, allowing for 2-axis squeeze sensing as opposed to 1-axis compression sensing

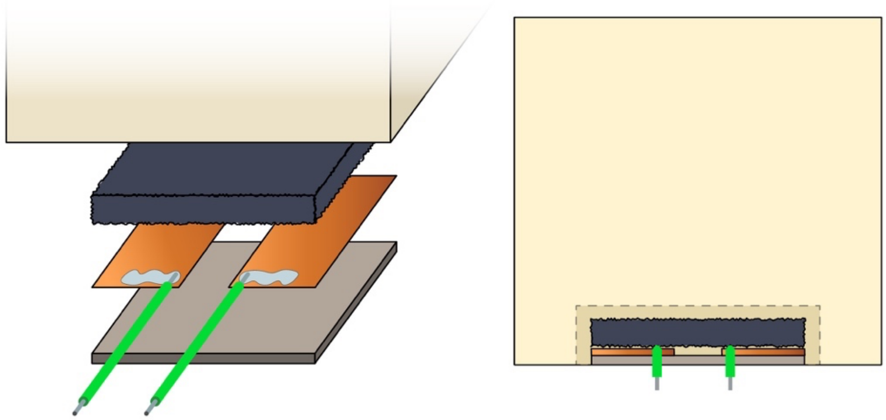

Figure 4.3 Final version of pressure sensor, 3D-printed housing shown in Figure 4.4

Final Prototype: Modular Block

The final version of the block includes a 3D-printed base, which the capacitive strips are directly taped onto. Wires are passed through the hole in the base, soldered to the strips, and hot glued to provide mechanical support. The wires are connected to an ESP32 running Arduino, which reads the analog voltage value at a rapid rate and sends the data to a python script through serial. The python script processes the sensor data by normalizing it and scaling it. Currently, the values are being linearly scaled, but in the future it would be useful to use a non-linear mapping due the pressure sensor being a lot more sensitive near full compression. Once values are properly scaled, they are passed into a PureData patch which then routes them to the corresponding parameter mappings or triggers notes.

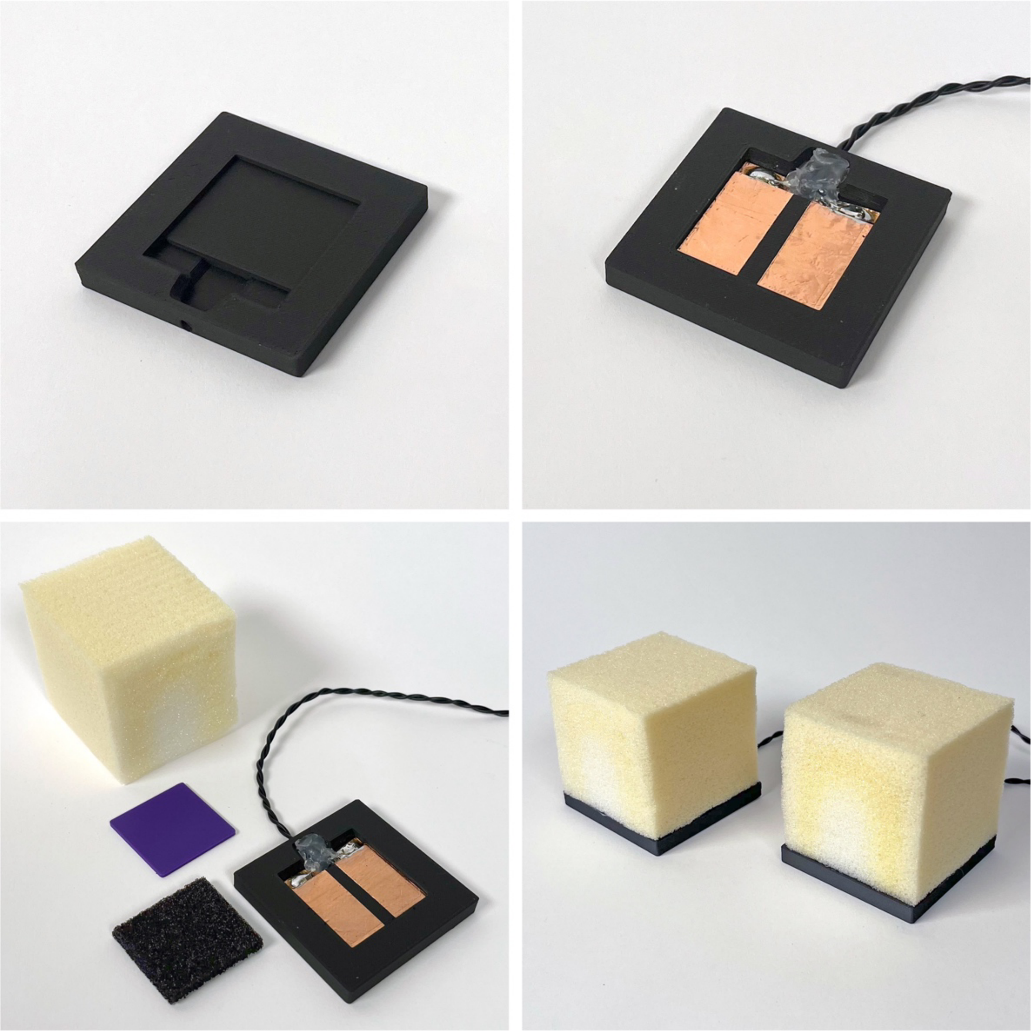

Figure 4.4 Assembling a foam block module

Final Prototype: Configurations

The shape of the blocks allows them to be placed together in different configurations to create new types of interactions at different scales. Fig. ** shows several possibilities with just four blocks. Each configuration adds new degrees of freedom, while maintaining a single interaction. A singular module is essentially a large slider that is controlled by the vertical compression of the block. While this provides an interesting way of controlling a single parameter, the real potential of this prototype is achieved by combining multiple blocks. By placing two blocks together, a single hand can now control two parameters with one motion. With each block that is added, more nuances are able to be picked up from input actions and each sensor will react slightly differently since the organic shape of a hand will not apply even pressure across all foam blocks. In these configurations the interface can mimic the highly responsive and intrinsically linked properties of acoustic instruments.

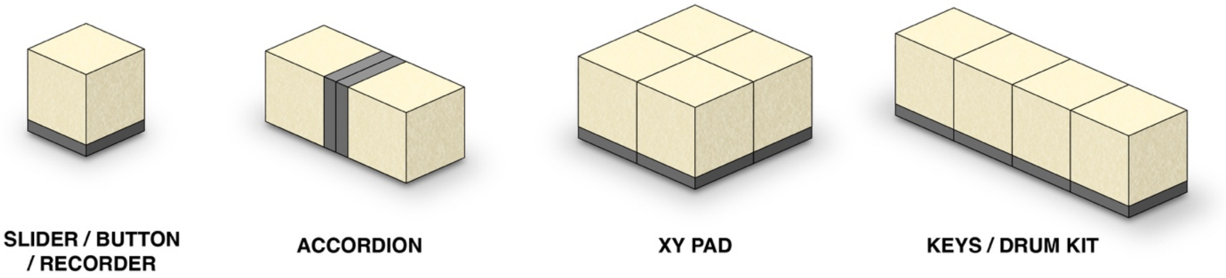

Figure 4.5 Some of the possible configurations using up to four blocks

The XY Pad configuration of four blocks in a square can be treated as a single block that can detect presses in four directions and anywhere in between by combining the four different sensor values. A potential application of this is DJ Mixing. The example in Fig. ** two sensors are mapped to the amount of Reverb and Distortion being applied, while the other two sensors are inversely mapped to the volume of Low and High Frequencies (higher pressure value lowers the volume). Setting up two of these configurations would allow you to mix tracks by suppressing frequencies from each one or completely muting one while the other plays. This can all be done with a single hand pressing down on each set of blocks. In contrast, the usual methods DJs use for mixing between two tracks involves multiple knobs and faders, which must all be interacted with individually.

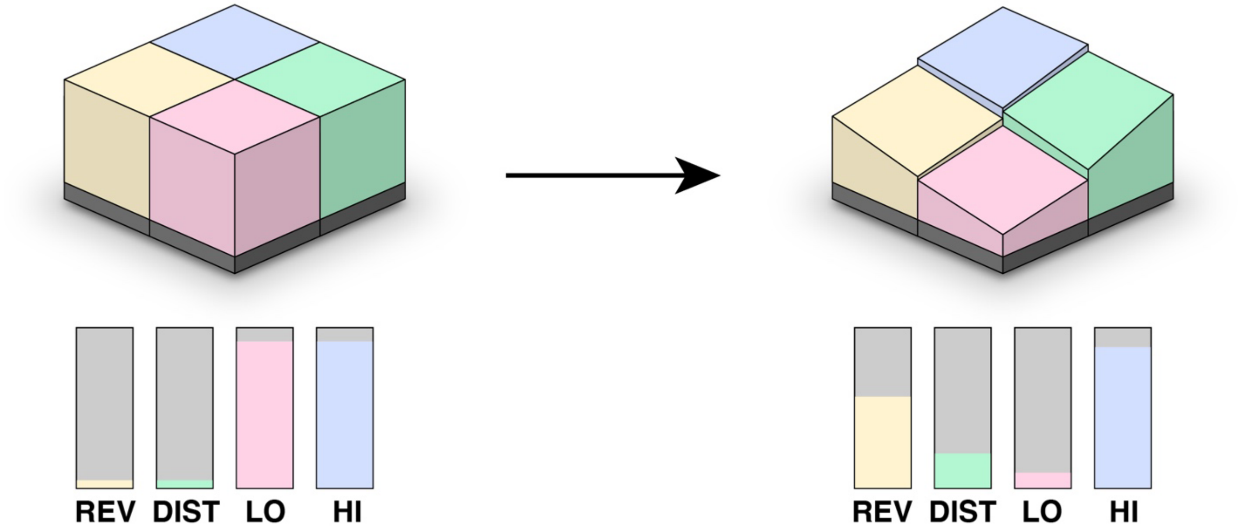

Figure 4.6 Mappings for an XY Pad configuration that are affecting a track that is playing. Default states are at either minimum or maximum value. In this example a hand is pushing all four blocks at the same time, but pushing mostly towards the red block and slightly towards the yellow block. This results in lowering the volume of low frequencies, adding reverb, and adding a slight amount of distortion.

Another interesting configuration comes from connecting two blocks by placing their bottom faces together, shown in Fig. 4.5, as the accordion configuration. Instead of compressing the block against a surface, the user is now compressing two blocks against each other. Blocks can continue to be added to each side to create asymmetrical forces.

Since the blocks produce a consistent range of values, they naturally work as parameter controls. However, they can also be used as sound generators in several ways. The most basic mode being a force-sensitive piano key that plays a note with its velocity mapped to the pressure value. Similarly, it could be used as a simple drum knit that plays different drum sounds depending on the pressure value.

An interesting application is playing back samples, since it incorporates a conceptual metaphor specific to foam. Although maybe more applicable to a sponge, one can still imagine the recording process as the foam block soaking up sound. Naturally, to playback that sound, it must be squeezed out. This can be further enhanced by time-stretching the recorded sample depending on how slow or fast the block is squeezed. Furthermore, since the foam naturally returns to its uncompressed state, this can be translated as the sample being soaked in again or being played backwards. By repeatedly compressing and releasing the block, it is now able to mimic DJ scratching.

Final Prototype: Limitations

To take full advantage of the reconfigurability, new mappings must be made in each configuration. This requires extra interaction that can be burdensome to the user and slow down music-making, if setting up mappings is a process they are not familiar with. Potential solutions are having presets with pre-made mappings or just having a specific block for every possible type of mapping, although producing that many blocks would be costly and eventually become overwhelming for the user to keep all of them organized.

As a note trigger, the blocks are limited in how fast they can play since there is a slight delay between the compression required to trigger a note and the return to its original state. Because of this, the block's input has to be debounced so that a single press does not cause multiple triggers. However, since the decompression is not immediate, a relatively high debounce time is required which limits how fast you can play.

Demonstration of Prototype

This link includes videos of the prototype being used to test out different functions and in a short performance.

5. DISCUSSION & CONCLUSION

Analysis

The prototype developed in this thesis could still undergo much development and benefit from user testing, which ended up being out of the scope of the thesis. It would be interesting to conduct testing with users that have varying degrees of musical experience. This would test the adaptability of the foam interface when being used in different contexts. Can it be easily picked up by a non-musician? Going back to Jorda's (2004) concept of diversity: does it have enough micro-diversity to be a useful method of expression for a professional musician? Each of the configurations can still be explored more deeply and potentially improved with the inclusion of other types of foam interactions that were not able to be explored through the current prototype, such as bending, twisting, varying levels of stiffness, and shape variations. Additionally, the prototype was focused on designing interesting tactile interactions, but users would likely benefit from having more visual feedback to help them understand mappings and different functions that the blocks can take on in different configuration. However, the use of foam seems to be a promising direction for tangible interfaces as the prototype was able to achieve a variety of interaction possibilities, ranging from simple parameter control to sample manipulation and playback, all with the pressure-sensing cube module.

Potential Further Applications

The evolution of smart textiles provides potential ways of expanding on the ideas explored in this thesis. Wickasono's *FabricKeyboard* (2017) achieves complex interaction by being built with a variety of layers, each of them providing a different type of sensor or useful material property. Similarly, foam interfaces could achieve this level of complexity by integrating other sensors that are compatible with foam deformation, potentially even combining foam and smart fabrics.

While the foam interface provides interesting tactile feedback through its natural resistive force, it would be interesting to develop a foam that can be actuated to physically react in different ways to user input by changing its physical properties, such as stiffness or shape.

Conclusion

This paper demonstrates the potential of a musical interface that is controlled by compressible foam blocks. Using pressure sensors to detect the compressive deformation of foam blocks, the prototype is able to accurately detect varying levels of compression from user interaction. The sensor data can be processed quickly enough to control and trigger various musical parameters in real time. The modular design of the blocks allows for freedom of configuration which allows users to control various parameters at once with simple interactions. Additionally, the tangible nature of the blocks adds another layer of feedback while performing, as performers can feel the correlation between applied force and sonic output.

Overall, this work addresses the larger challenges of mapping user interactions to musical output in digital music controllers and effectively using sensor data to create responsive and expressive controllers. Foam, along with other soft materials, provide unique material properties that can be taken advantage of and there are various combinations of soft materials and sensing methods that can be further explored. Furthermore, the potential applications of the prototype would enable DMI design to move in the direction of designing with musician-instrument relationships as a priority. A larger adoption of soft music interfaces would result in more unique instruments that leverage physical metaphors and intuitive mappings, therefore promoting musical creativity and allowing for more inclusive design.

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SUPPLEMENTARY MATERIAL

Prototype demonstration videos – website link

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