Dialogue of Strings

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Contents

Introduction

In this thesis, I will describe how a musical concept evolved into an idea to create a new instrument. I will also detail the development of this instrument and the discoveries I made during the prototyping and manufacturing process.

In my early years of composing electronic music, I was fascinated by the techniques and sound masses used by composers such as Iannis Xenakis and Krysztof Penderecki in their compositions. Inspired by their approach, I embarked on my own explorations, integrating sound masses into my own musical works. However, I soon encountered a significant challenge when it came to translating these techniques into live performances. Due to practical constraints, it proved extremely difficult for me to assemble a sufficient number of musicians required to bring my compositions to life on stage. As a result, I found myself confined to working with recorded materials, unable to fully realize the intricate layers of sound masses I was imagining for a live setting. Moreover, I wished for greater artistic freedom, desiring the ability to improvise and interact with the sound masses in real-time, rather than being confined to the limitations of composing on paper or software alone.

To solve these challenges, I came up with the idea of creating a string instrument that could play sound masses while also ensuring it could be effectively played by a single musician. The instrument would enable the player to create rich and intricate sonic landscapes, incorporating dense sonorities and intricate textural layers during live performances, while also providing greater freedom for improvisation with these elements.

Throughout the stages of prototyping and manufacturing, I encountered various challenges that required overcoming. However, amidst these obstacles, I also made valuable discoveries that played a crucial role in refining the instrument and enhancing its overall effectiveness.

In the upcoming chapters, I will delve into the details of my vision, musical ideas and compositions that I needed to bring it to life. I will explain my process of researching and prototyping the instrument, the discoveries I made along the way, and the systems and devices that I developed for it.
Additionally, I will discuss the interface of the instrument and provide insights into how these processes influenced and transformed my initial concepts and perspectives on composition and performance.

1. The Birth of an instrument: From Composition to Invention

In 2020, I composed an eight-channel fixed media piece titled "Synthetic Groans." During this time, I was particularly interested in the textures and sound masses that Xenakis used in his pieces, such as "Metastasis". Inspired by "Metastasis," I endeavored to create similar textures using synthesizers, violins, and electric bass guitar. In certain sections of the composition, I incorporated random envelope generators to govern the dynamics of multiple layers of synthesized sounds, while employing sequencers to control the pitches. These sequencers were set to very high speeds, resulting in complex pitch modulations. The textures and timbres employed in these segments were predetermined, while the notes and pitches themselves were either improvised or occurred by chance. Subsequently, I engaged in improvisation over the recorded sounds, utilizing instruments such as the violin, voice, or bass guitar to evoke a sense of call and response.

Sound Example 1 Synthetic Groans

In the context of this composition, my approach closely relates to Bryan Simms' claims about indeterminacy in music: "Any part of a musical work is indeterminate if it is chosen by chance, or if its performance is not precisely specified. The former case is called 'indeterminacy of composition'; the latter is called 'indeterminacy of performance'."

Working on this piece gave me more ideas on how to use sound masses and indeterminate approach to composition. The process inspired further experimentation in my subsequent pieces and etudes, allowing me to delve deeper into the possibilities offered by these concepts.

During the course of these experiments, I incorporated a device known as an "E-bow" into my creative process. This tool proved to be a game-changer, especially when employed with my bass guitar, as it facilitated the production of immersive and intricate drone sounds that greatly influenced my subsequent works.

One of the musical concepts I had in mind was to create a specific sound mass comprising multiple layers of continuous sound, each occupying a different spatial location. Each layer would commence from the same initial pitch and gradually deviate from it through glissando gestures. This intentional divergence would produce a phase-cancelling effect across various points in space and time. An illustrative instance of a graphical score designed for this concept is presented below. This etude can be performed by any ensemble comprising instruments capable of generating sustained sound and executing glissando techniques. Examples include groups of violins, electric guitars played with an E-bow, or synthesisers.

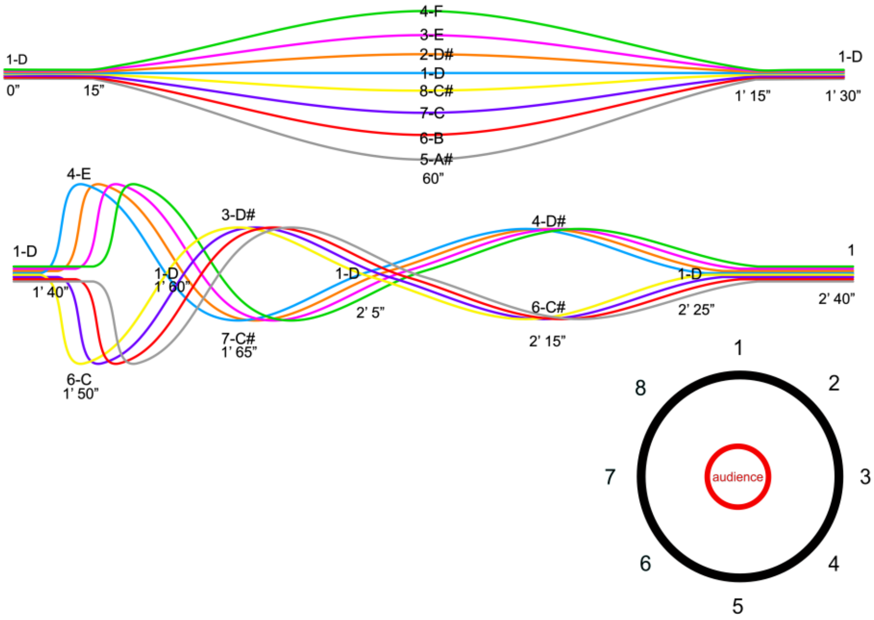

Figure 1

In *Figure 1* each line indicated by different colours, represent layers. The numbers refer to movement of each layer in space. The circle diagram in the right corner shows the points in space. Initially, all the layers start with the same initial pitch, in this case D. Subsequently, then the pitch of each layer gradually moves according to the graphs and written timings.

In a later adaption to this etude, I used the computer software IanniX software to make a digital graphical score and automate the events. With IanniX I could generate OSC messages from each line, and send that to a MAX MSP patch I created. Each line of the graphical score was mapped to an oscillator and controlled its frequency parameter. This provided me with better control and precision over various parameters such as speed and spatialisation.

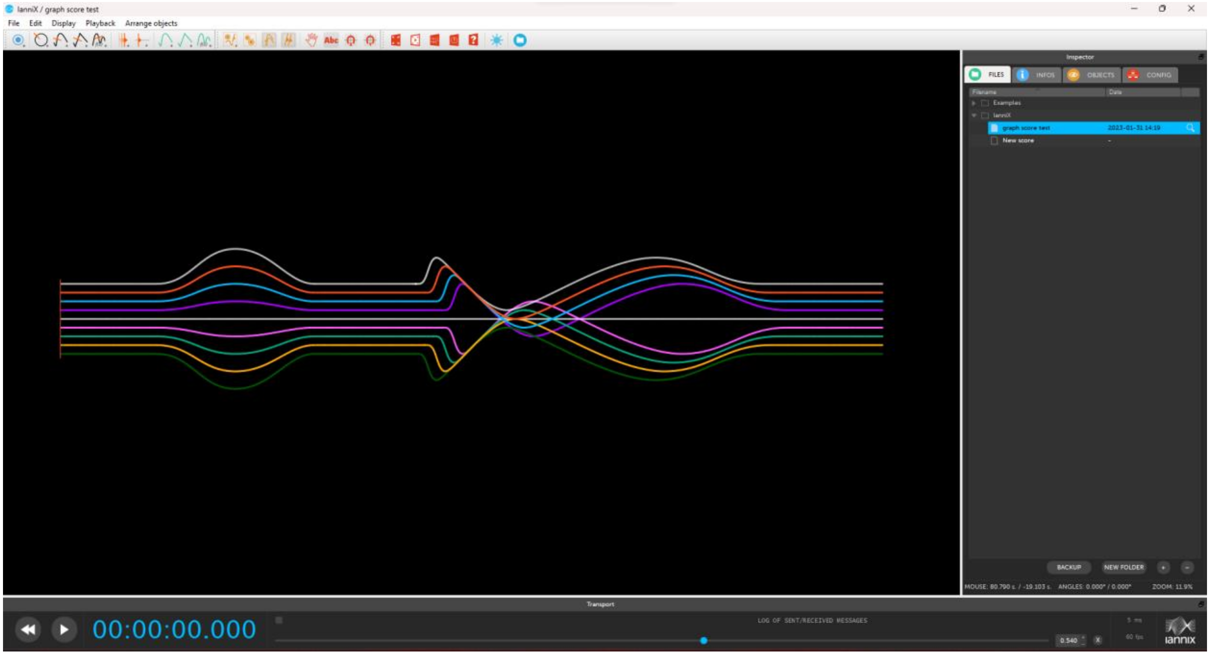

Figure 2 Graphical score in IanniX software

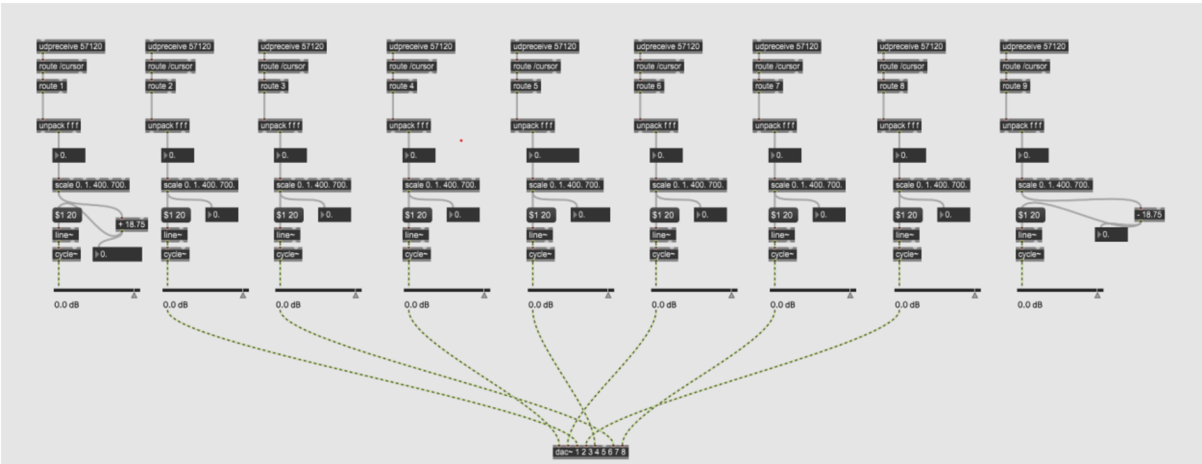

Figure 3

I used this same technique in various different pieces in diverse contexts to evoke a feeling of tension or suspension. Another instance can be found in the song "Substitution" by my band Frikam, where I applied the same technique using the violin. This resulted in a heightened sense of suspension and tension during the transition between two sections.

However, given my background in music performance as a string instrument player, I aspired to perform my music live on stage with some parts of improvisation, rather than simply playing a recording of it, but I was limited by the tools and instruments I had at the time. It was simply impossible to improvise a sound mass with a group of musicians. Therefore, I sought a string instrument that could provide the necessities needed to play my musical ideas, necessities such as:

1. Playable by one musician
2. Precise control on pitch
3. Multichannel audio output
4. Producing sustained sounds
5. Capable of making glissandos on each pitch

2. Research and Inspirations

During my search for an instrument that would fulfil the desired requirements just mentioned above, I came across several examples that shared similar concepts. It is intriguing to observe that all of these instruments employ different techniques to generate sustained sounds from strings.

2.1 Hupfeld Phonoliszt Violina

A historical instrument that is very inspiring for me is the Hupfeld Phonoliszt Violina. The Hupfeld Phonoliszt Violina is a self-playing instrument invented in 1907 by Ludwig Hupfeld, a German organization that was the leading manufacturer of automatic pianos between 1892-1930. The instrument is a combination of a player piano and three violins (each with only one active string), which are mounted vertically and played with a rotating circular bow and robotic fingers. The Phonoliszt Violina imitates a human violinist by having steel fingers with wood fingertips covered with thin rubber or leather pads, to simulate the texture of human fingers. A human violinist plays different notes by pressing the string against the violin fretboard to change its speaking length. The mechanism of Hupfeld's invention pushes each violin's one playing string (D, A and E respectively) against a circular horsehair bow giving an accurate reproduction of a violin playing.

Figure 4 Hupfeld Phonoliszt Violina

Figure 5 The circular rotating bow mechanism used in the Hupfeld Phonoliszt Violina is similar to bowing mechanism in Hurdy Gurdy. It consists of a disc that rotates infinitely and excites the string with friction.

2.2 Modern Instrument Inspirations

A contemporary approach to generating sustained sounds from strings involves the use of electro-magnetic feedback. In the course of my research, I encountered several instruments that employed this technique to produce sustained sounds. Among the most notable of these instruments are the "Planet Sustainer," created by Edward Vunderink, the "Lyraei," created by Mihalis Shammas, and the "Magnetophone," created by Aaron Sherwood. The works of these instrument makers served as great inspiration, providing me with a wealth of ideas on how to design my instrument and where to begin.

Figure 6 Planet Sustainer

Figure 7 Lyraei

Figure 8 Magnetophone

The use of an electromagnetic feedback system gives all these instruments the ability of making continuous drone sounds using metal strings. This technique was definitely something I wanted to have on my instrument, becoming, consequently, one of the most essential parts of my research. To successfully implement this technique in my creation, my initial step involved comprehending its underlying mechanics and operation.

2.3 Electromagnetic String Resonator

Using the feed-backing technique to make sustained sound is directly connected to Rock music and the development of electric guitars and amplifiers in 1970’s.

“Rock guitar players discovered that they can actually induce infinite sustain by making the guitar amplifier very loud and moving close to the speakers to force positive feedback, thereby transforming the instrument into an oscillator — one that the player can somehow control.”[1] However, this technique presented significant challenges as it necessitated extremely high volume levels, which can pose risks of hearing damage.

Later on, in the mid-1970's, the E-bow[2] was introduced. This handheld device served as a compact version of the positive feedback system, comprising an input coil connected to a small amplifier (LM386 chip) that supplied a driver coil. With this innovation, musicians could achieve sustained sounds akin to the previous technique but without requiring high amplifier volumes.

Figure 9 E-BOW

The E-bow also contains a toggle switch that allows for switching between two operation modes: "fundamental" and "harmonic". In the fundamental mode, the string is activated based on its fundamental pitch. On the other hand, the harmonic mode reverses the polarity of the driver coil, resulting in the string resonating at a higher pitch, typically a perfect 5th interval above the fundamental frequency.

[1] de Guzman, ‘Infinity Project’.

[2] Heet, STRING INSTRUMENT VIBRATION INITIATOR AND SUSTAINER.

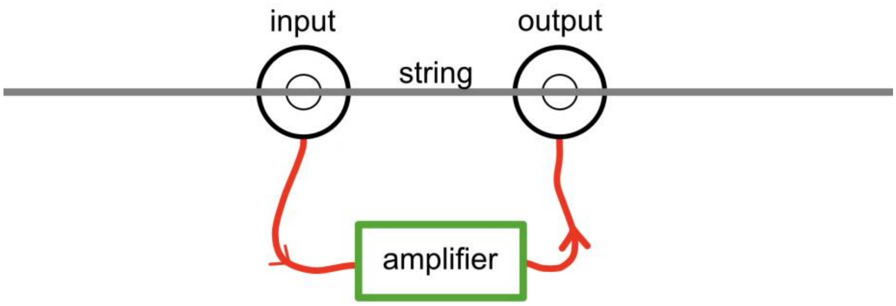

Figure 10

A further upgrade to this system is the "Sustaniac"; A device that uses the same system as the E-bow, but it is installed on the guitar's body, therefore freeing the hand of the player from holding any extra device.

Figure 10 Sustaniac pickup

A more sophisticated implementation of this process involves adding digital signal processing (DSP) to the system. One example of this is the Moog guitar, which uses digital processing to resonate strings. Instead of feeding back the amplified input signal directly to the driver coil, the input first goes to a DSP chip. A pitch detector finds the fundamental frequency, then a signal generator produces a sine wave following the detected pitch. The sine wave then goes to the driver coil and resonates the string. This system is much more accurate than feedback systems and gives more control to the player.


Figure 11 Moog guitar

2.4 Pitch Control

As previously mentioned, in certain compositions and etudes, I incorporated the use of electric guitars and electric bass guitars played with an E-bow. Within these pieces, I utilized the tuning pegs of the instruments to adjust the string tension and facilitate glissando gestures between notes. Nonetheless, a constraint emerged as the player was restricted to manipulating only one tuning peg at a time. This limitation prompted me to devise a new instrument that would overcome this obstacle

The Min-ETune self-tuning system inspired me to find a solution for this problem. This device is an electric guitar auto-tuner installed on the back of the guitar head, and utilizes a small DSP board to detect frequencies and control six motors that internally turn the tuning pegs.

Figure 12 Min-ETune self-tuning system

This device gave me the idea to use motors to turn the tuning pegs. Through my research, I discovered that stepper motors were the most suitable for my application due to their high precision. The advantage of using stepper motors is that they are programmable and highly accurate, that's the reason why they are so commonly used in CNC machines and 3D printers for example.

2.5 Controllers

During my studies at the Institute of Sonology, I had the privilege of encountering the works of numerous inspiring artists, including Michel Waisvisz and Laetitia Sonami.

"The Hands,"[3,4] one of Michel Waisvisz's primary instruments, is a digital musical apparatus that comprises two controllers designed to be affixed to the hands. These controllers are equipped with arrays of keys and sensors that translate the movements of the fingers, hands, and arms into sound. As Waisvisz aptly describes it, this instrument allows one to physically 'touch' sound itself. (In Waisvisz's own words, to 'touch' sound.)

Figure 13 Michel Waisvisz performing his Hands instrument, originally built 1984

Similarly, Laetitia Sonami's "Lady's Glove"[5] is a digital musical controller fashioned in the form of a gloves. This glove is outfitted with buttons, bend sensors, and an accelerometer to capture hand gestures. Sonami employs the data derived from the glove to synthesize and manipulate sounds using MAX MSP patches.

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[3] 'Michel Waisvisz – DIGITAL ART (1960-2000)'.
[4] Magnusson, *Sonic Writing*.
[5] 'Lady's Glove'.

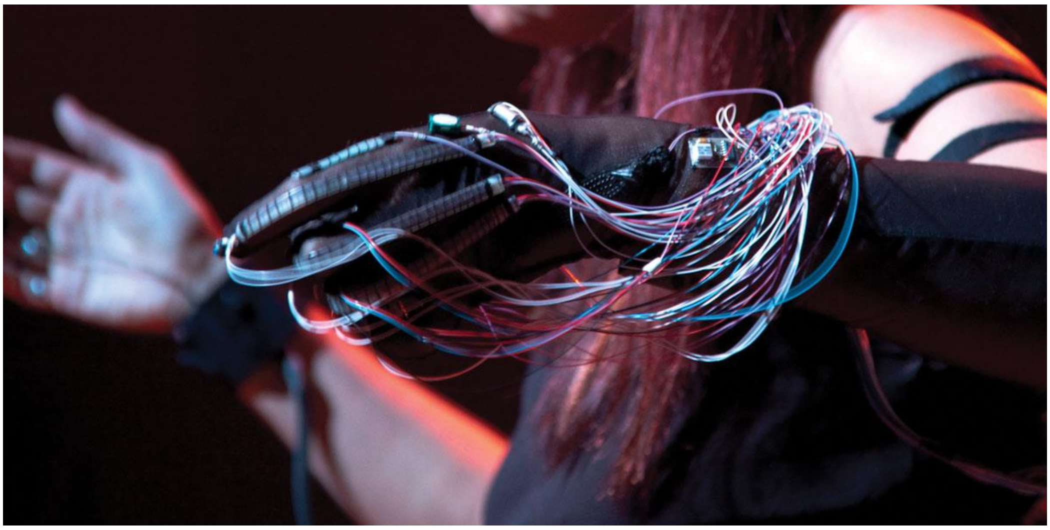

Figure 14 Laetitia Sonami performing with Lady's Glove

Inspired by "The Hands" and "Lady's Glove," I endeavoured to utilize a similar controller to operate my instrument. After conducting research on the internet, I discovered that the only commercially available controller in the form of a glove was a device called "MiMu" gloves.

The MiMu[6] glove was invented by Imogen Heap and the MiMu team. It uses bend sensors and an accelerometer to capture the hand gestures of the user. The sensor data is then wirelessly transmitted to a computer to control musical software.

The use of this controller would have been ideal for me, but unfortunately it was not available at the time of my project due to the global chip shortage. Additionally, this controller is very expensive, making it unaffordable for me as a student. As a result, I made the decision to develop my own controller glove, drawing inspiration from the renowned MiMu gloves.

[6] 'MiMU — Music Through Movement'.

Figure 15 MiMu glove

Having gathered all these ideas during the initial stages of brainstorming and research, the subsequent step involved creating the first prototype that integrated all these components. This allowed me to examine how these ideas functioned collectively.

3. The First Prototype (Sustain Puppeteer)

The initial prototype of the instrument was developed as a proof of concept. The purpose of this prototype was to test the feasibility of the idea by integrating all its components together. Although my initial idea for the instrument was to have at least eight strings, I decided to simplify it for prototyping purposes and start with only two strings. Based on my initial concept, the main components of the instrument are as follows:

1. Feedback/String resonator system
2. Stepper motors for string tension control
3. Electromagnetic pickups for audio output
4. Controller glove

The initial prototype concept is depicted in the following image, which shows the juxtaposition of all components.

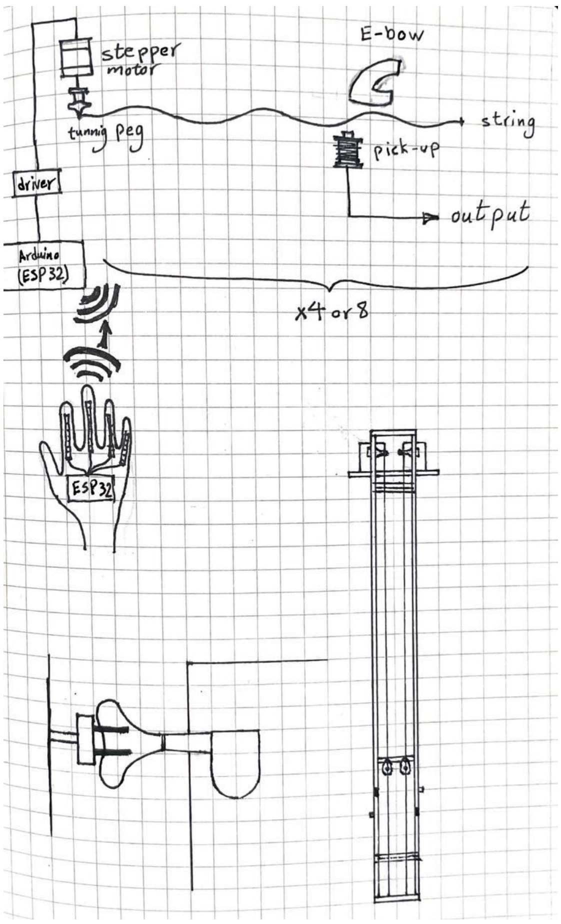

Figure 16 first concept designs of Sustain Puppeteer

3.1 Feedback/String resonator system

In the previous chapter, I discussed different string resonator systems. The simplest and most primitive version of these systems is the E-bow. After conducting some research on the internet, I found a few electronic circuits that are based on the original design of the E-bow. This circuit contains two coils and an LM386 amplifier as the heart of the circuit. The input gain of the amplifier is set to maximum in order to pick up even the slightest vibration of the string.

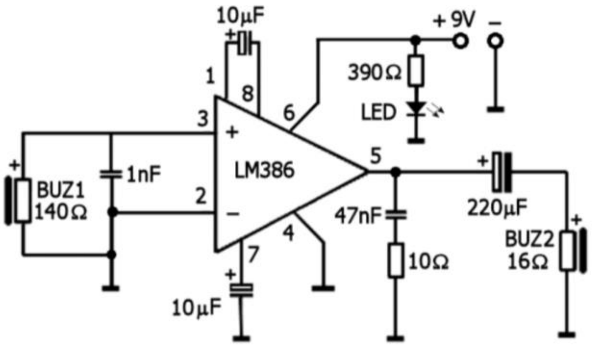

Figure 17 E-BOW circuit

This circuit is primarily designed to be compact (and small) compact and small are almost the same thing enough to fit into a handheld enclosure. However, this simplicity comes at a cost. The circuit is very inefficient and noisy. For prototyping purposes, I used this design to understand how it works in the bigger picture.

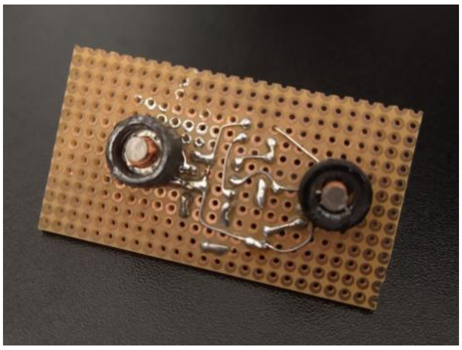

Figure 18

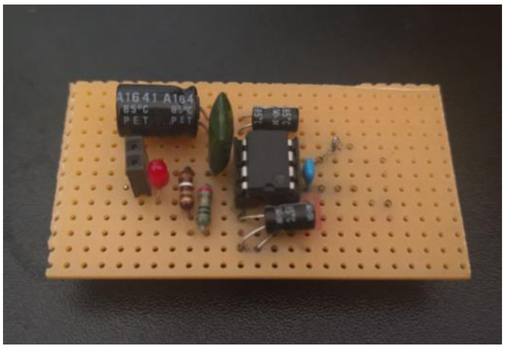

Figure 19

In a later adaption of my own E-bow, I designed a two-channel board for the circuit, taking a different approach by separating the coils from the circuit board. Instead, I implemented mini-TS jack connectors to connect the coils to the circuit board. This system made it easier to adjust the placement of the coils. Additionally, each channel featured a polarity switch for the output coils. Similar to the functionality of the original E-bow, toggling the switch would cause the string to resonate at a higher harmonic, typically a perfect 5th or an octave above the string's fundamental tuning.

Figure 20 Amplifier module

Figure 21 Input and Output coils

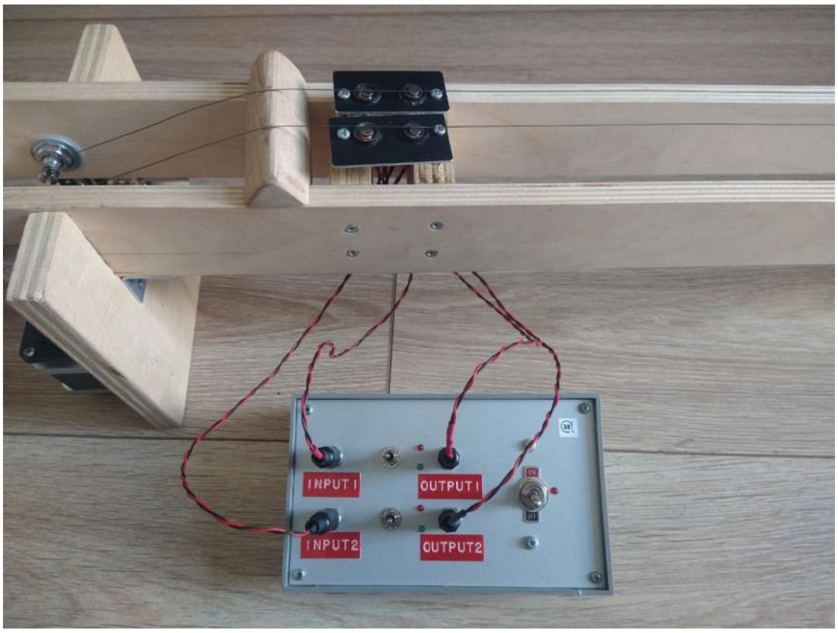

Figure 22

3.2 Stepper Motors for String Tension Control

As previously mentioned, the decision was made to employ to control the tention of the strings. To connect the stepper motors to the tuning pegs, I built a mount that couples the motor shafts to the tuning pegs and used dampers to isolate the vibrations of the motors from the system.

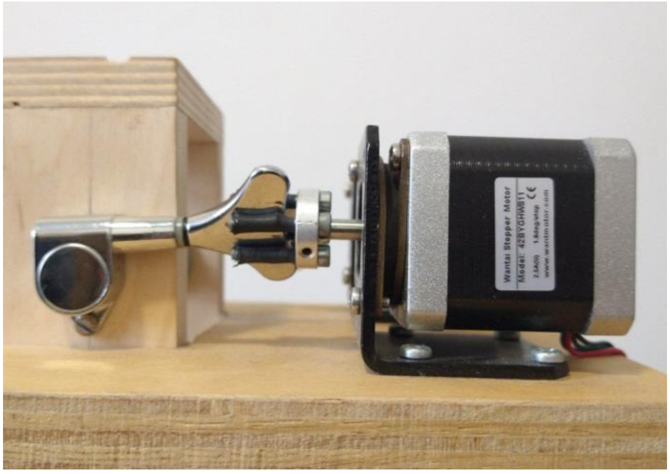

Figure 23 "NEMA 17" stepper motors coupled with tuning pegs

To control the motors with a microcontroller, I utilized stepper motor drivers. This allowed me to have control over the direction, speed, and acceleration of the motors.

Figure 24 stepper motor driver breakout box

3.3 Electromagnetic Pickups

To enable multichannel audio output, the instrument requires a pickup for each string. Commercially available pickups designed for a single string were not found during the prototype building phase. As a result, custom pickups were designed and built.

The pickups consist of an Alnico magnet in the core, 42 American gauge enamel copper wire, and wooden frames on top and bottom to hold the structure together. Typically, professional pickups are wound using high-speed pickup winders equipped with turn counters. However, these devices are often expensive and not easily available. To wind the pickups for this first prototype, I improvised a method by attaching the frame to a drill and manually winding the wire around the magnet by rotating the drill. This process is challenging due to the thinness of the copper wire, which is thinner than human hair and can easily break during winding. Additionally, because there is no counter in this process, achieving precise impedance in the pickup was not possible.

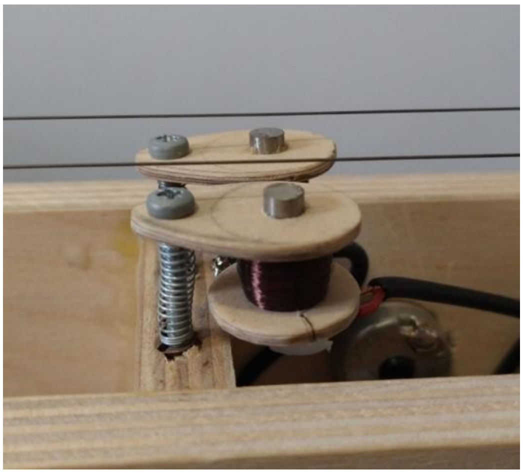

Figure 25 Hand-made single core pickups

3.4 Controller Glove (First Prototype)

The initial concept for playing the instrument was to control it with hand gestures, similar to the theremin. The MiMu gloves controller could provide a wide range of possibilities and control over various parameters with hand gestures. However, due to their high cost and unavailability at the time, I endeavoured to create my own controller inspired by the MiMu gloves that would offer similar capabilities.

The concept was to control the movement of each motor by bending fingers. To test this idea, a simple prototype was created, incorporating a flex sensor attached to the finger. The flex sensor transmitted data to an Arduino, which in turn controlled the stepper motor based on the degree of finger bending. The program parameters were adjusted to customize the speed and range of movement.

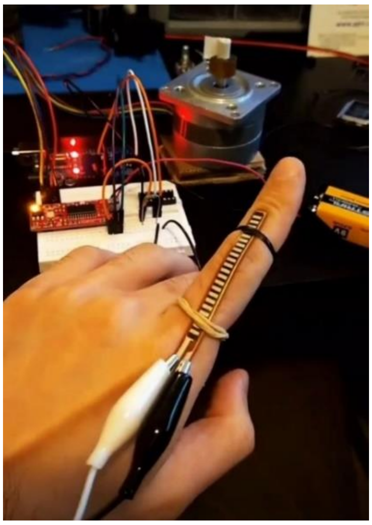

Figure 26

Another step to make this system more comfortable to use for the player, was to make a wireless connection between the glove and the motor. To achieve this, I replaced the Arduino with an ESP32 development board. Utilizing the ESP-NOW protocol, I established a wireless connection between two ESP32 boards: one acting as the transmitter on the glove to transmit the flex sensor data, and the other as the receiver to receive the data and control the motor accordingly.

For the initial prototype of the controller glove, I attached four flex sensors and an ESP32 board to a glove. However, due to extensive research on other aspects of the instrument, I postponed the full development of the glove to the second prototype.

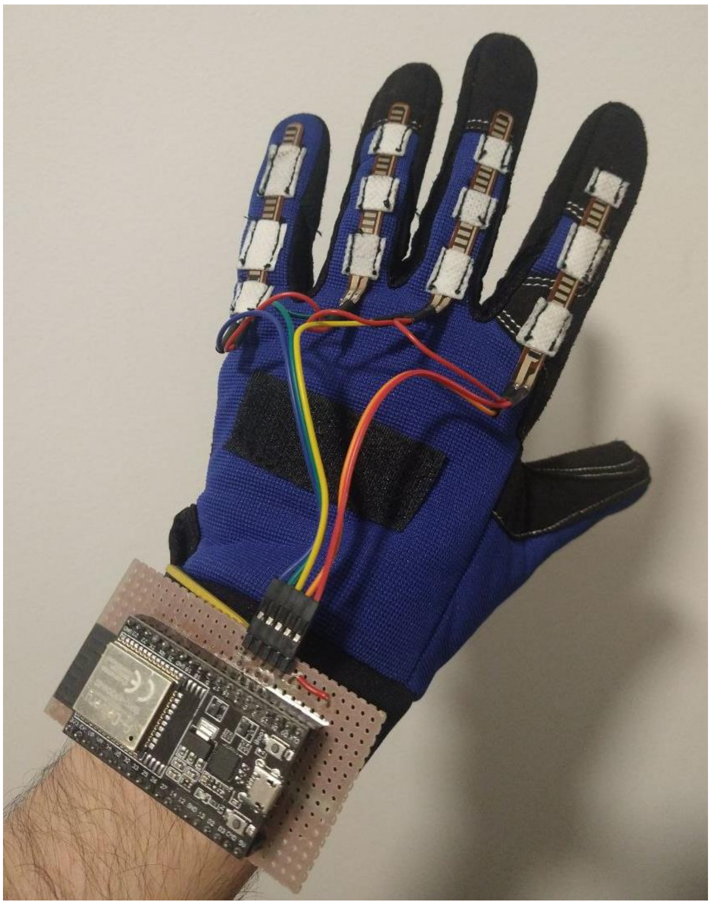

Figure 27 First prototype of the Controller Glove

4. Everything coming together

To integrate all the components into the instrument, I constructed a simple wooden frame and equipped it with two strings, two stepper motors, two E-bows, and two pickups.

Figure 28 Sustain Puppeteer

Due to the initial intention of using the prototype (which I fondly named the "Sustain Puppeteer") as sound installation, the controller glove was not utilised. Instead, the motors were programmed to continuously move to different positions with different speeds. This resulted in an improvised-like behaviour where the strings' tuning changes unpredictably.

The prototype functioned as intended by producing the sustained string sound and altering its tuning. However, during the testing phase of this prototype, a significant discovery was made that had a profound impact on the future of this project; cross feedback behaviour of the strings.

4.1 Cross Feedback

The amplifier module provided me with the opportunity to experiment with novel combinations of connections between the coils and the amplifiers. By switching the output coils of the feedback system, a cross-connection between the strings was established, allowing them to be coupled together. As a result, the resonance of the first string was transmitted to the second string and vice versa.

This created a complex feedback loop between two strings resulting in new harmonics being formed. In addition, the increment of polarity switches to this system further increased its complexity.

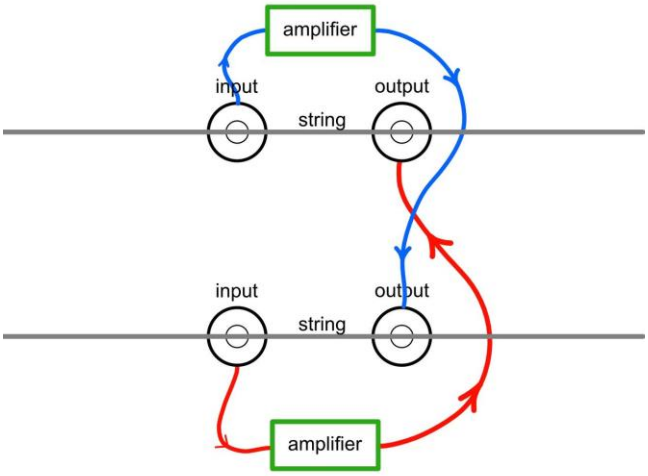

Figure 29 Cross-feedback connections

The system became even more complex when the stepper motors changed the tension of the strings to different tunings. Upon powering the instrument on, unpredictable melodic motifs are unavoidably generated by the combination of its strings' natural harmonics, cross-feedback system, and motor movement.

Video Example, Sustain Puppeteer

As priorly mentioned, the cross-feedback behavior, and consequently, the entire use the instrument in this manner was not an idea I initially considered in the original concept. However, this valuable discovery became one of the most fundamental concepts for the instrument's future development, once it gave me an abundance of new ideas on how to use it and perform with it.

5. Sonic exploration with Sustain Puppeteer

During my second year of study, I presented the Sustain Puppeteer instrument at an exhibition for the 'Sound Installation' course of the Sonology degree. At this event, the instrument was situated in the center of a big room divided into three distinct sections as illustrated in the following image:

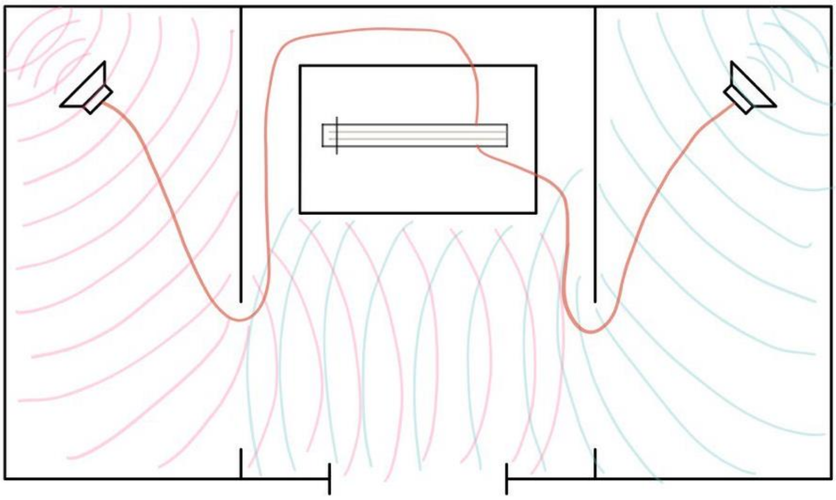

Figure 30

The output of each string in the instrument was connected to a designated speaker, which were positioned in the left and right rooms and oriented towards the walls.

The arrangement of sounds within the space incorporated the acoustics of the environment and transformed the entire area into a part of the installation. While the audience could observe the instrument working in the central section, they heard the reflected sound coming from the adjacent rooms.

In a nutshell, the installation presented a blend of harmonic sounds and melodic motifs of the Sustained Puppeteer with the spatialization and acoustics of the space. This created a captivating experience that encouraged people to spend extended periods of time appreciating the work.

On other occasions, I incorporated the Sustain Puppeteer into my live performances. During these performances, the Sustain Puppeteer functioned as an additional "improvising musician". I accompanied it with another one of my self-made instruments, the Misfit Box, various synthesizers, and sometimes even my own live vocal improvisations. In some parts of the performance, I listened to what Sustain Puppeteer was playing and I tried to respond to it by creating sounds that had a similar morphology. This created a sense of dialogue between me and the Sustain Puppeteer, as if we were two distinct entities exchanging ideas and responding to one another.

Figure 31 Misfit-Box

This method relates to my initial approach to composing with indeterminacy; in which structure, textures, sound qualities, and instruments are predetermined, but the pitches, frequencies, and dynamics were left to choose by the Sustain Puppeteer.

In situations like these, where the instrument improvises and composes on its own, new 'gray' areas emerge between the roles of the instrument maker, composer, and the instrument itself. The instrument is no longer just an inanimate tool for the composer or musician but can become a creator in its own right. Following this line of thought, it is relevant to say that the instrument maker also plays a role in creative compositional processes by making technical and artistic choices during the creation of the instrument.

In 2022, I had the privilege of collaborating with Farzaneh Nouri. During this collaboration, Nouri employed *Énacteur*, an AI system she developed while studying at the Sonology Institute. Énacteur is capable of improvising freely based on audio input and its training. It works by sampling and processing the giving audio, synthesizing new sounds, and spatializing the output. During our rehearsal sessions we trained Énacteur with samples from the Sustain Puppeteer. After several sessions, Énacteur was able to accompany the Sustain Puppeteer by processing and generating new sounds and panning them in an 8-channel speaker setup. The result of this collaboration was a live performance at a Sonology discussion concert in October 2022. As with my previous performances, I utilized the Sustain Puppeteer and the Misfit Box. However, this time, a copy of my audio output was fed to Énacteur. Drawing from its training, Énacteur listened to both me and the Sustain Puppeteer and responded accordingly. At times, our roles were reversed; I listened to Énacteur and attempted to react to its generated output. This created a dynamic and engaging dialogue between myself, the Sustain Puppeteer, and Énacteur.

Sound Example 2 Sonology Discussion Concert

These performances provided an opportunity to explore and comprehend the capabilities and limitations of Sustain Puppeteer.
Initially developed as a basic proof of concept, the Sustain Puppeteer lacks stability and is not user-friendly.

A significant constraint of Sustain Puppeteer is that the majority of its components are affixed to the wooden frame and lack mobility. The ability to reposition components and modify settings could facilitate more precise experimentation with strings. For example, relocating the coils to various positions near different nodes of the strings could substantially impact the sound and actuated harmonics.

In conclusion, my experiences with the initial conception of the instrument led to its transformation. This necessitated the development of an additional prototype with enhanced experimental capabilities and fewer constraints.

6. Second Prototype: Misfit-Harp

The goals for building the second prototype, named Misfit-Harp, were to remove the constraints mentioned earlier and expand the instrument's overall capabilities. I accomplished this by increasing the number of strings in the instrument, building a more user-friendly and stable interface, and experimenting with a modular build.

The concept of modularity was key for the design of the Misfit-Harp. On a personal note, in 2021, I had the opportunity to join the team of technicians responsible for constructing the new Voltage Control studio at the Sonology Institute. My involvement in wiring the studio, assembling racks and modules, and connecting all components proved to be an invaluable experience. Through this experience, I learned that a modular design greatly facilitates experimentation and fine-tuning of settings. This allows for a wider range of combinations with fewer constraints. This experience influenced my decision to incorporate modularity into the design of the Misfit-Harp. By doing so, I was able to create an instrument that offers greater flexibility, and versatility in its use.

When discussing modularity, one idea I found particularly valuable was presented by inventor Martin Molin. He discussed the "Modules and Interfaces"[7] design framework of his Marble Machine Instrument. This approach aims to reduce complexity by breaking it down into smaller, more manageable parts. Molin frequently employs this approach in his design process and defines a module and an interface as follows:

Module definition: Distinct subassembly that can be easily added, removed or replaced in a larger system.

Interface definition: A point where two modules meet and interact.

Based on this, a primary objective in the development of my instrument's second iteration was to establish a modular framework that facilitates the repositioning of system components and the integration of additional modules.

Moreover, the incorporation of additional strings expands the potential for cross-feedback connections between them. Consequently, an interface capable of generating these connections was deemed necessary. This function can be accomplished through the utilization of a matrix mixer.

[7] 'Wintergatan'.

6.1 Modular framework

In an effort to reduce complexity and improve manageability, I chose to apply the Modules and Interfaces design framework to the design process. This involved converting components such as pickups, string resonator coils, stepper motors, and tuning pegs into distinct modules. To integrate these smaller parts into a comprehensive system, a larger framework was necessary for mounting the components.

Following my research, I found that the most advantageous approach to constructing a modular framework was through the employment of 3030 aluminum extrusion. This specific variety of aluminum extrusion is typically utilized in the manufacture of industrial equipment such as CNC machines. Its design features railings on each side, enabling the effortless installation of attachments and expansions.

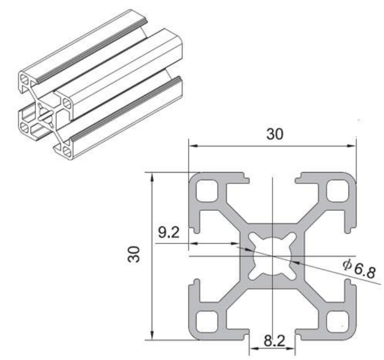

Figure 32 3030 Aluminium extrusion

Figure 33 Main frame of the Misfit-Harp

In order to attach the components to the aluminum extrusion, specialized mounts were designed and constructed for each individual component. These mounts were designed to enable their relocation and installation at any point along the aluminum extrusion, with the capability for fine-tuning their positioning in multiple directions. This design facilitated the placement of the coils at any desired location and distance relative to the strings, and even permitted the adjustment of the strings’ length. This versatility provided lots of possibilities for experimentation.

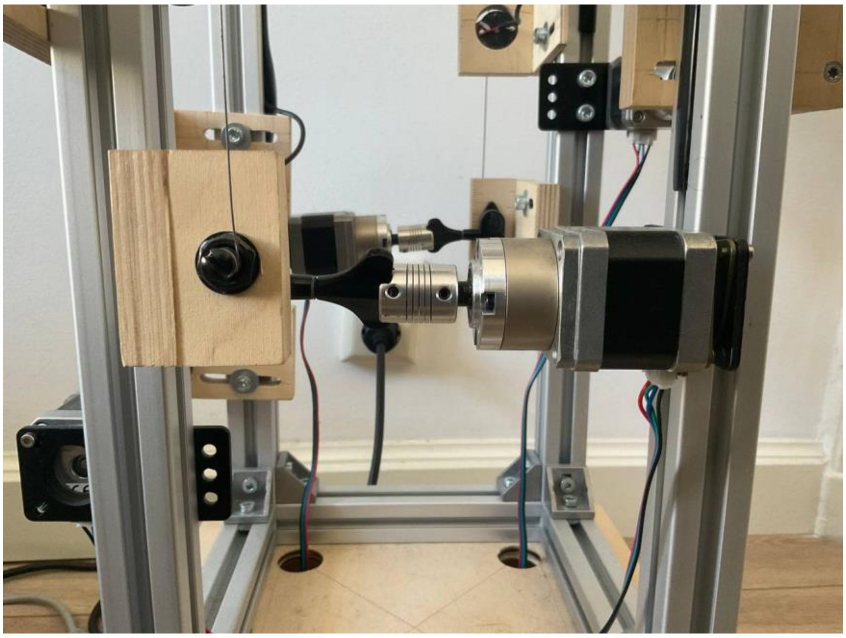

Figure 34 Stepper motor with gearbox attached to the tuning peg

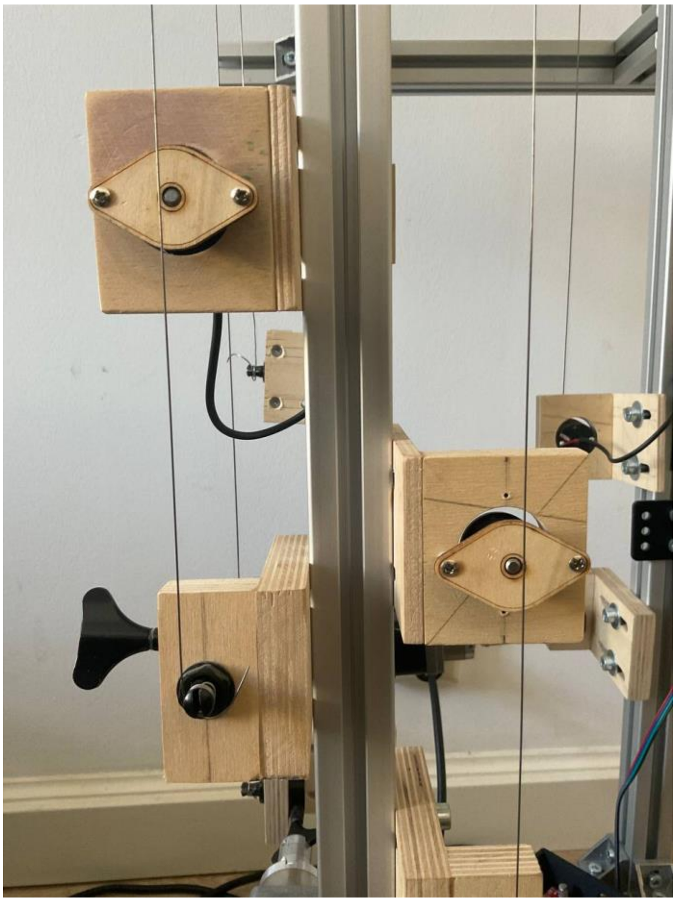

Figure 35 Input pickups on modular frame

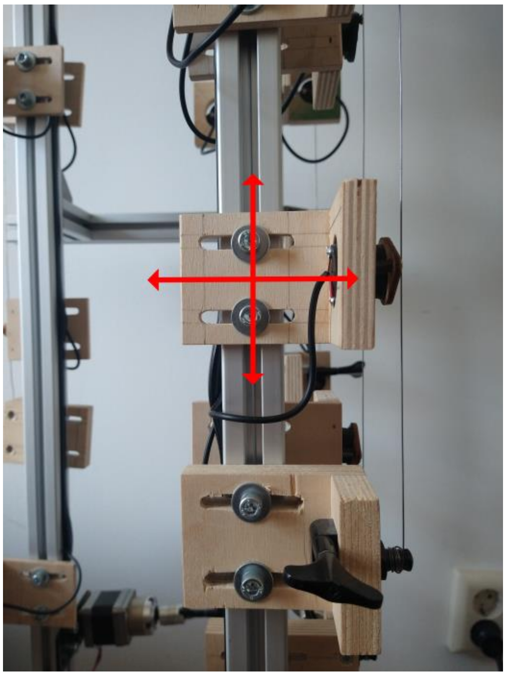

Figure 36 Movement directions of the modules

The implementation of a modular system introduced a concept where each string could be divided into two segments using a wheel. The length of each segment could be adjusted independently through the modular system, allowing for the establishment of a fixed ratio between the segments. This ratio corresponded to a fixed musical interval between the two segments. This development expanded the range of possibilities for experimentation with string tunings and the exploration of harmonics, as any alteration in the tuning of one segment, which was part of the same string, would correspondingly change the tuning of the other segment. This breakthrough expanded the range of possibilities for experimentation with string tunings and the exploration of harmonics.

Figure 37 Rotatable wheel dividing the string in two segments

6.2 Upgraded Coils

One issue encountered during the development of the first prototype was the proximity of the coils to the strings. The coils had to be positioned very close to the strings in order to actuate them. However, this occasionally resulted in the strings coming into contact with the coils while vibrating, producing an undesirable buzzing noise.

Several factors played a role in this issue, including:

1. Impedance of the output coils
2. Strength of the output coil magnets
3. Circuitry of the amplifier

These factors collectively contributed to the problem, making it essential to address each one in order to resolve the buzzing noise and ensure better performance for the second prototype, the Misfit-Harp.

Upon conducting research on the E-bow circuit, it was determined that the LM386 amplifier utilized in the circuit operates at maximum efficiency when the output impedance is 8 ohms. Despite extensive online searching, no commercially available coils with the desired specifications could be located. As a result, I decided to explore methods for creating custom coils.

My research on pickup winding methods led to the discovery of a DIY guide by Chris Monck[8] for constructing a pickup winding machine with a counter. The machine was built according to his instructions. It features a high-speed motor for winding the wire and a low-speed motor for creating various patterns. A proximity sensor counts each revolution of the high-speed motor, allowing for the creation of coils with relatively accurate measurements.

[8] 'EGuitar Plans'.

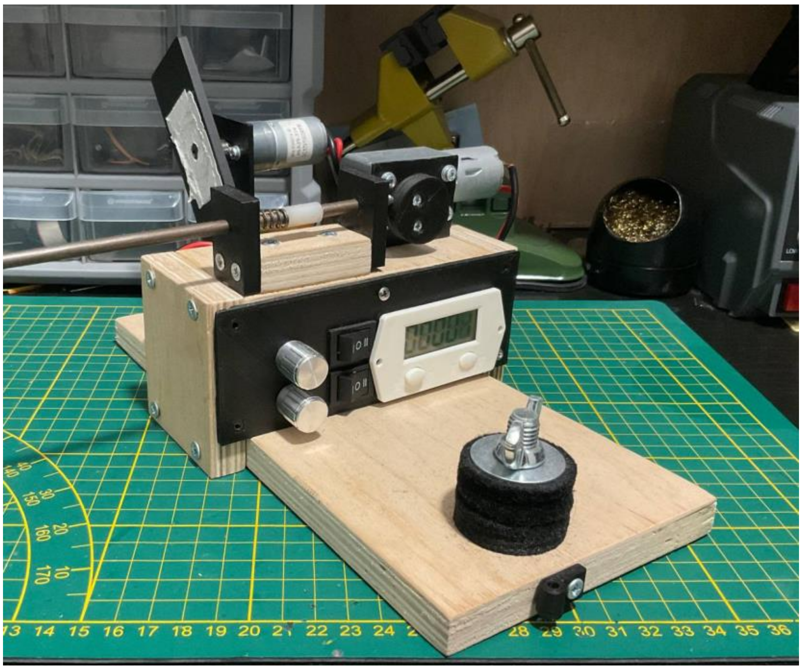

Figure 38 Hand-made pickup winder

Once the coil frames were designed and constructed, I employed the pickup winding machine to create coils with a precise impedance of 8 ohms. To amplify the coil power, I integrated Alnico magnets into the design. As a result, these coils exhibited exceptional performance, allowing them to actuate the strings with increased power and over a greater distance.

Figure 39 Hand-made 8 ohm coil with fibre frame and Alnico magnet core

Figure 40 Output coils installed on the modular frame

6.3 Main structure

With all components fully assembled, this new version of the instrument comprised four strings, four stepper motors, eight pickups, and eight actuator coils. Utilizing the previously mentioned wheels that divide each string into two segments, the final configuration resulted in a total of eight strings.

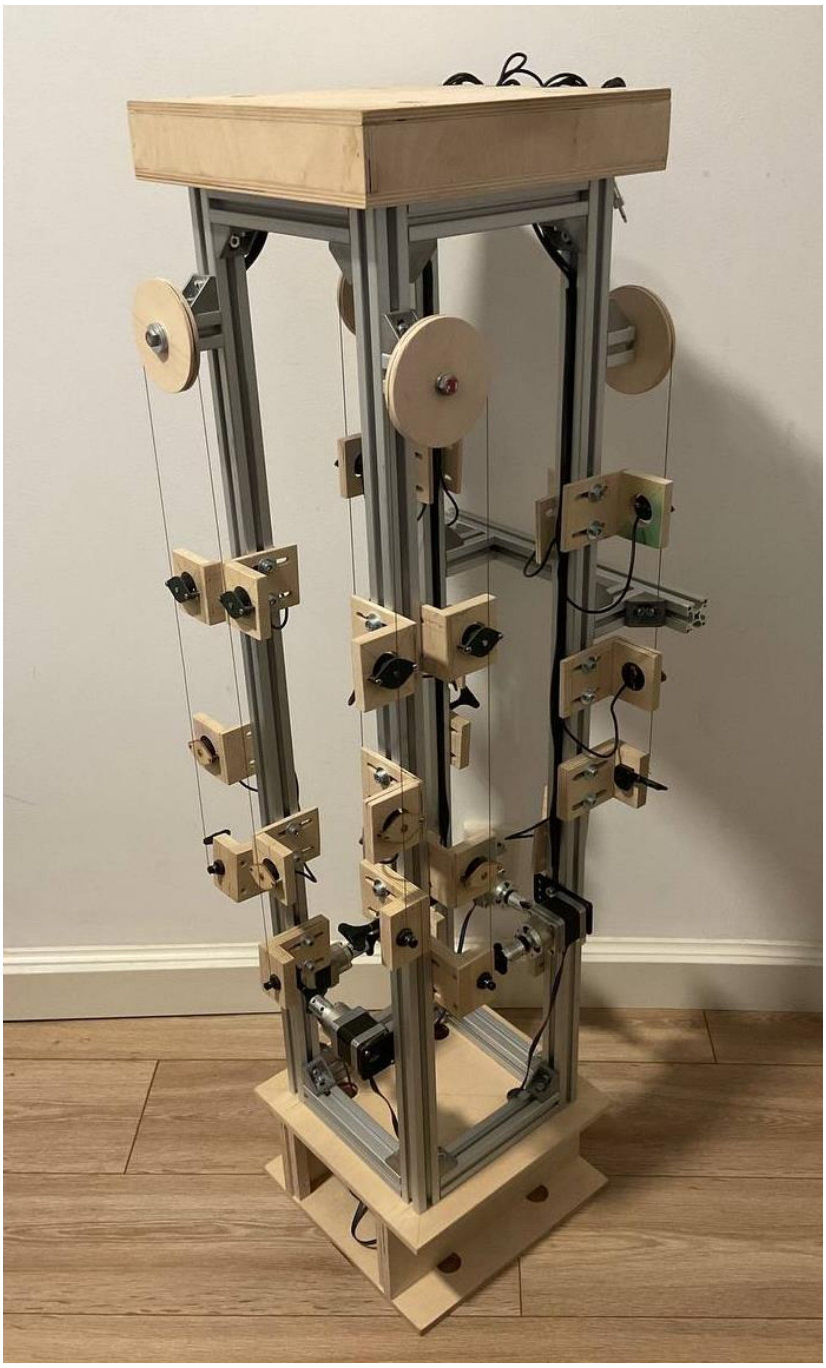

Figure 41

The circuitry of the instrument is divided into two distinct sections: one for audio and one for the motors. In order to prevent any interference and maintain the integrity of the audio signals, the audio circuitry is completely isolated from that of the motors. To house the electronic components and cables, two wooden boxes were constructed for the top and bottom portions of the structure. The top box contains the audio components, while the bottom box houses the stepper motor drivers. By utilizing the gap within the aluminum extrusions, it was possible to conceal and protect all cables by routing them through the space in-between.

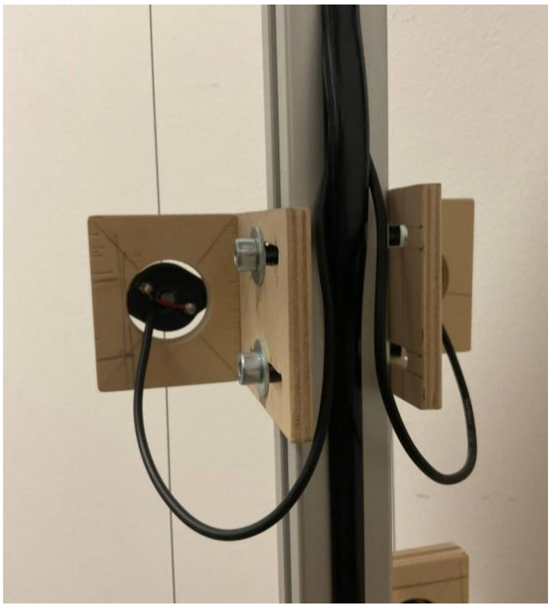

Figure 42 Cables routed through the aluminium extrusion

6.4 Matrix Interface

One technical concept that was explored in this prototype to simplify its design was the reduction of the number of coils on the instrument. Instead of having separate pickups for the audio output and the string resonator system, the idea was to use a single input pickup and split the signal into two branches: one for the audio output and the other for the resonator system. This technique is made possible through the use of a matrix mixer, which can serve as an interface between all modules and establish a network of connections between them. The diagram below illustrates this concept.

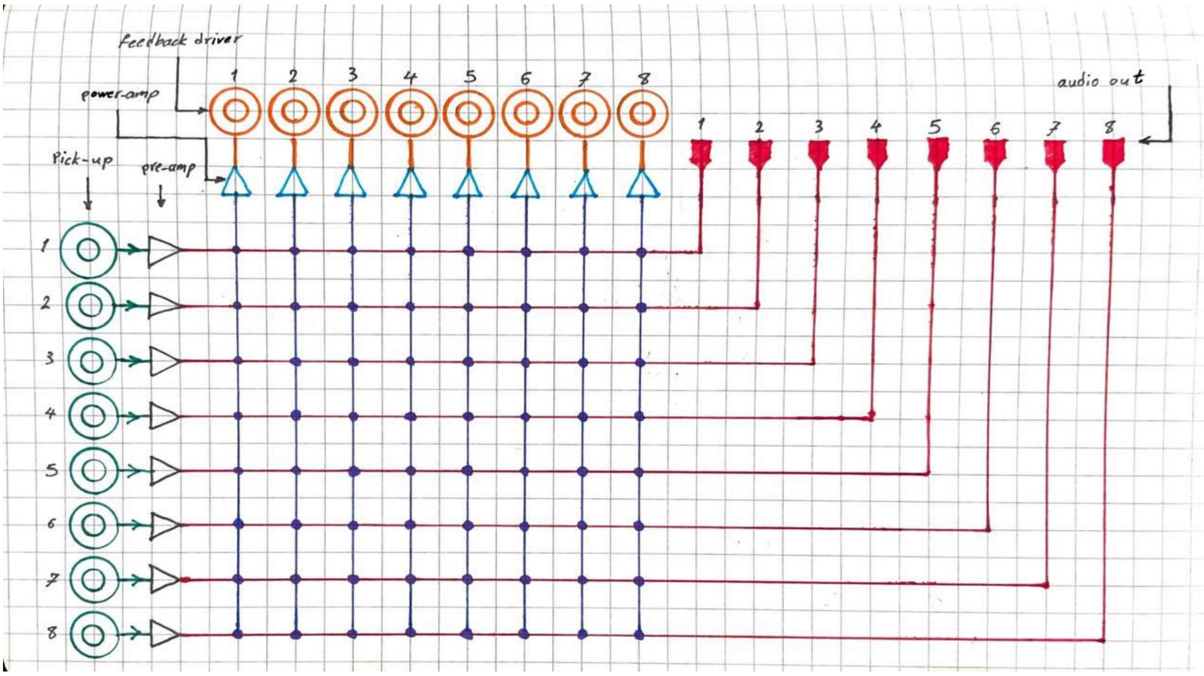

Figure 43 Initial concept diagram of the matrix mixer

After conducting research on commercially available matrix mixers and consulting with several teachers, I discovered that my electronics teacher, Lex van den Broek, had designed a matrix mixer as part of his research project. Named the Voltage Controlled Signal Patch Generator (VC-SPG)[9], this mixer was precisely what was needed for the instrument.

[9] van den Broek, 'CompLex (VC-SPG) An OpenSoundControl (OSC) and Voltage Controlled Signal Path Generator'.

In his research paper, Van den Broek describes the VC-SPG as "an audio-matrix with 16 inputs and 16 outputs that can be fully configured, controlled and programmed with Open Sound Control (OSC) and that can be synced and triggered with external analogue signals."

Figure 44 Signal Path Generator PCB designed by Lex van den Broek

The VC-SPG is designed to be highly versatile and can be configured in a variety of ways. It can be controlled and programmed through a MAX-MSP patch specifically created for this purpose by Lex Van den Broek.

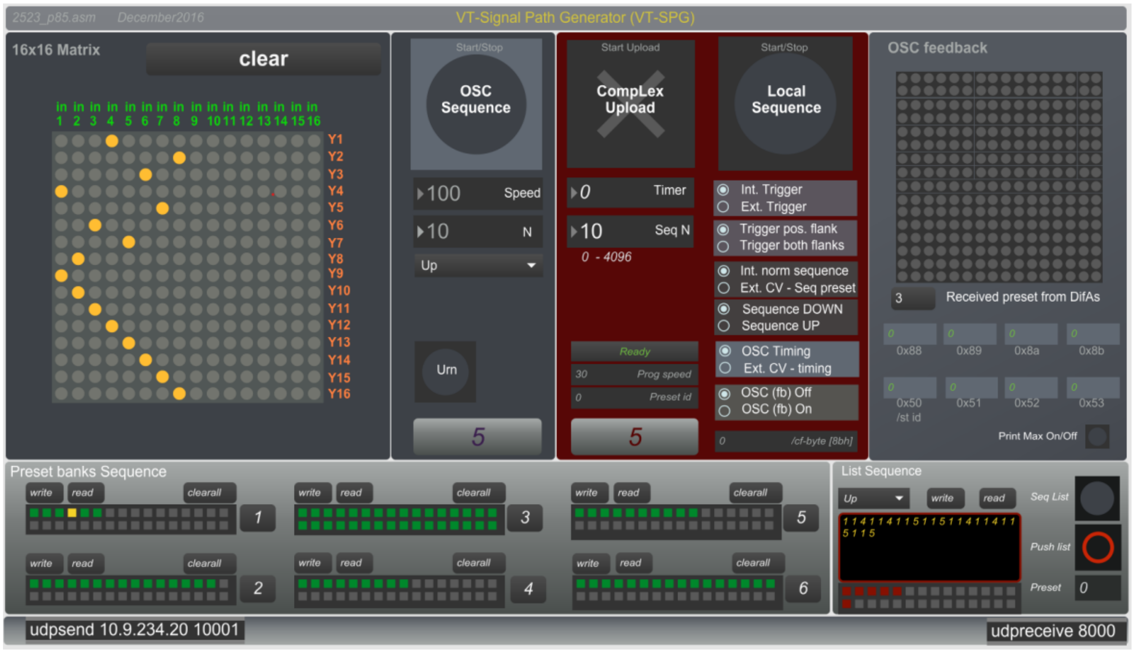

Figure 45 MAX MSP patch to control the Signal Patch Generator. User can make connections between the 16 Inputs and 16 Outputs by selecting dots in the matrix array.

A custom enclosure was designed and constructed to house all of the electronics and circuitry of the VC-SPG, as well as the electronics for the feedback system. The diagram below illustrates the internal electronic connections of the device.

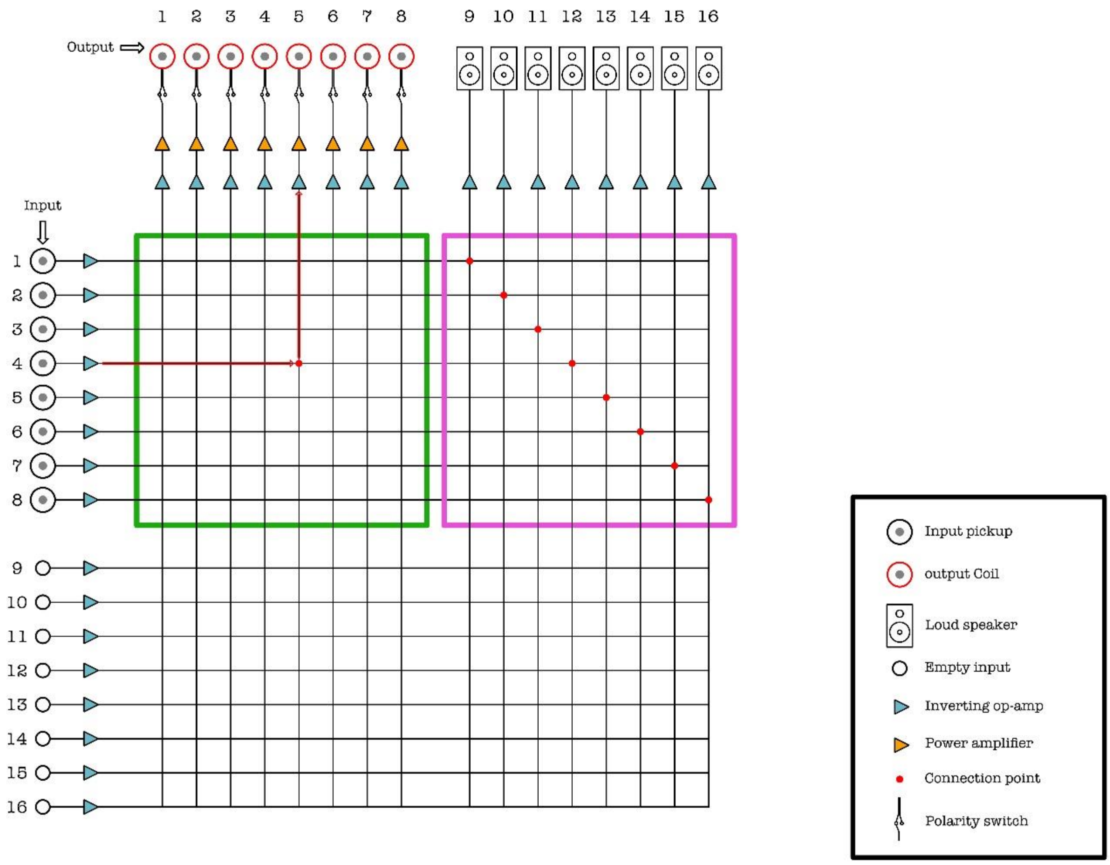

Figure 46 Diagram of connections

By utilizing the VC-SPG as the control center of the instrument, it is possible to create a series of presets to connect inputs and outputs. The VC-SPG can also function as a sequencer, cycling through the defined presets at a programmed speed and order. This capability enables the coupling of different strings to create diverse feedback connections.

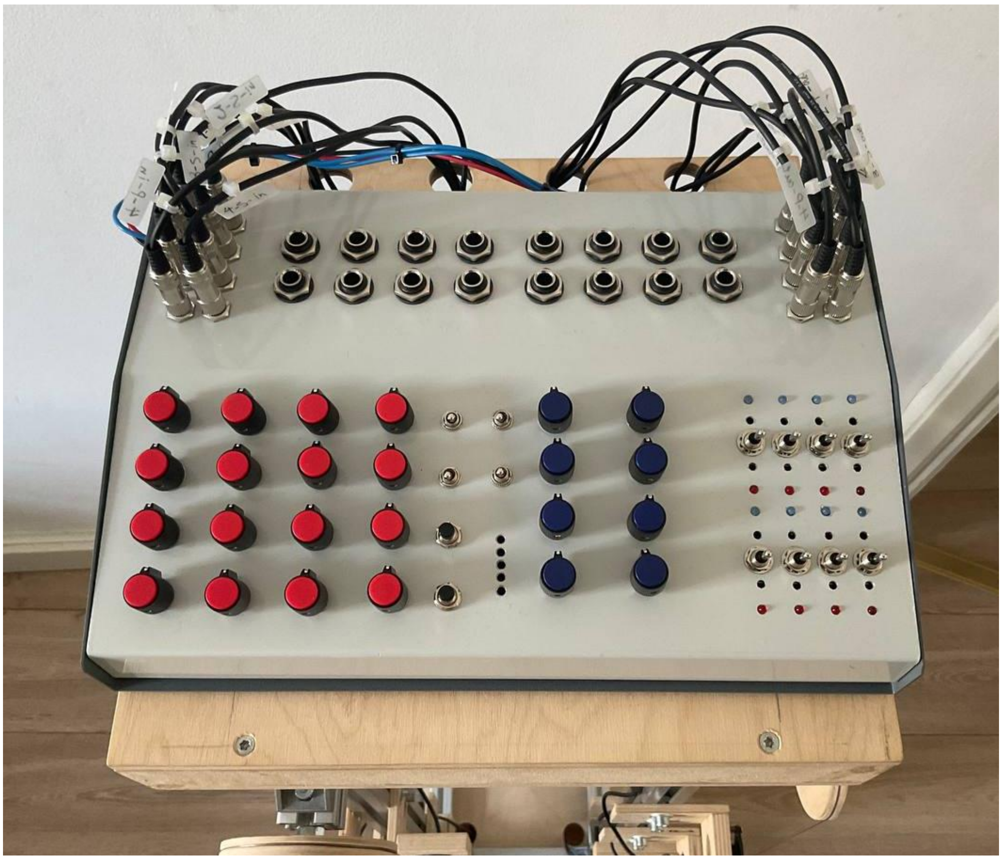

Figure 47 Matrix mixer enclosure. The knobs adjust the input gain of each channel

During the writing of this thesis, work is still ongoing to improve the design of the feedback system circuitry with the aim of enhancing audio quality and efficiency. The LM386 amplifier used in the circuit is an inexpensive and relatively weak option. Research is currently being conducted to identify more powerful amplifiers that offer superior audio quality and are still compact enough to be used in a small configuration.

6.5 Controller glove - second prototype

Development of the controller glove continued with the creation of a battery-powered circuit based on the ESP32 microcontroller. This circuit was housed within a 3D-printed enclosure that fit onto the wrist portion of the glove. By utilizing the ESP32 microcontroller and the ESP-NOW protocol, a wireless connection was established between the glove and the stepper motors.

The glove operates the motors through a mapping system in which each finger corresponds to a specific motor. When the fingers are bent, the motors rotate to increase the tension of the strings. Conversely, when the fingers are unbent, the tension of the strings is decreased. The range and precision of the motors can be calibrated through adjustments in the code.

Figure 48 Second prototype of the controller glove

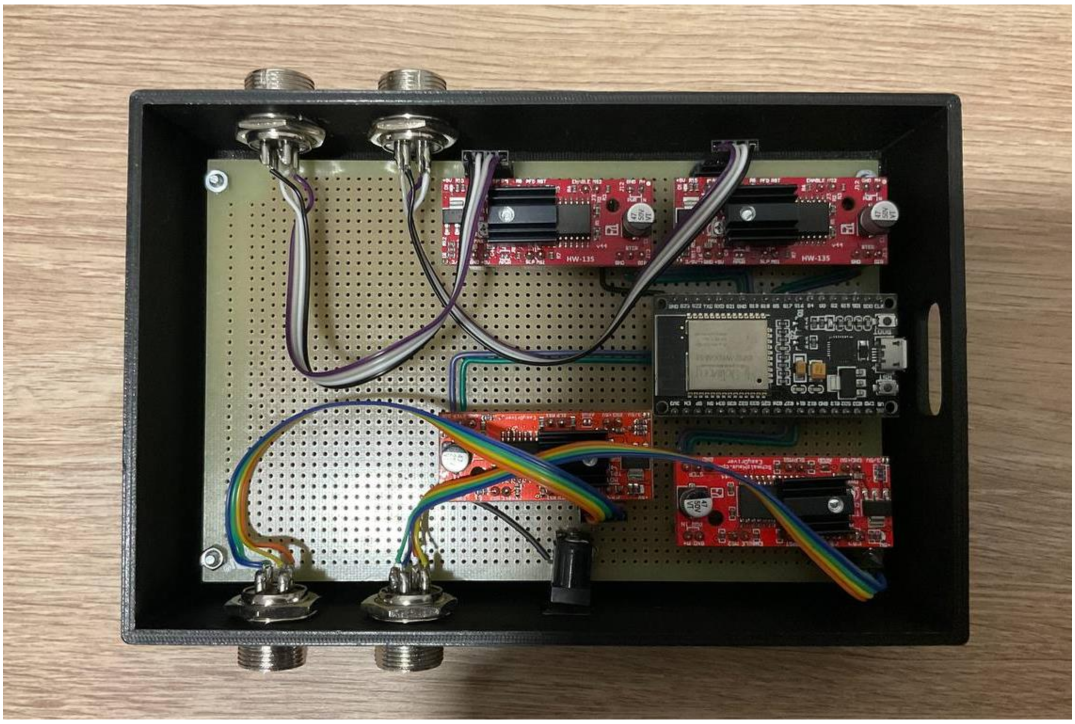

Figure 49 Stepper motor driver breakout box including an ESP32 microcontroller and four stepper motor drivers

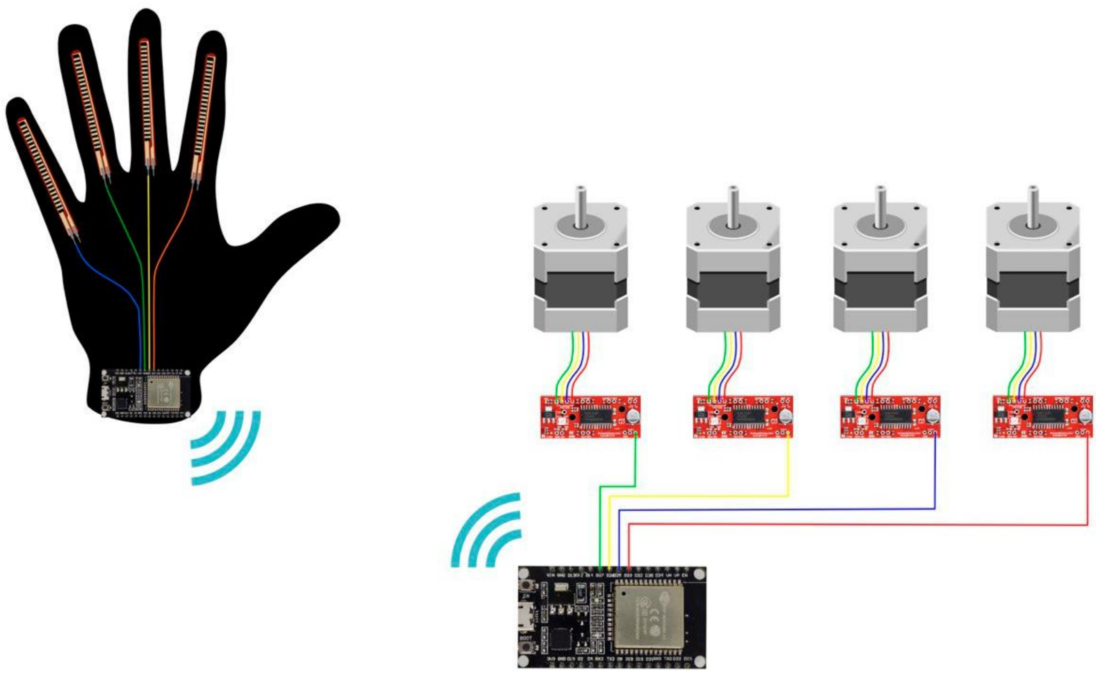

Figure 50 Diagram of motor control connections

6.6 Bringing Misfit Harp to Life: Assembly to Performance

The completion of the Misfit-Harp has successfully enhanced the capabilities of the Sustain Puppeteer and addressed its limitations. The instrument is highly versatile and can be easily adjusted, calibrated, and expanded. The modular system that was designed for this instrument makes it an exceptional tool for experimentation.

Misfit Harp can be utilized in various ways. It can be played manually by a user through the manipulation of the matrix mixer settings and the glove sensors. Alternatively, it can be programmed to play a predetermined composition by providing it with preset instructions to follow. Additionally, it can be configured to improvise independently in a manner similar to the Sustain Puppeteer.

Playing Misfit-Harp with the controller glove is an experience that I have not experienced before with any other instruments. the feeling of having a wireless connection to the instrument feels a bit similar to playing Theremin, but because Misfit-Harp is polyphonic and its sound is spatialized in eight channel system, playing it feels much more immersive. by setting the instrument on cross-feedback setting, it can create sounds that are unpredictable, and for the player It feels like an exploration. any small movement of any of the fingers can create a completely new series of harmonic sounds.

The combination of using the controller glove and the cross-feedback setting of the mixer creates a unique sense of interaction and control between the user and the Misfit Harp. The wireless connection to the instrument evokes a sensation akin to playing the Theremin. However, due to the polyphonic nature of the Misfit Harp and its spatialized sound in an eight-channel system, playing it feels significantly more immersive. When the instrument is set to cross-feedback mode, it can produce unpredictable sounds, creating a sense of exploration for the player. Even slight movements of the fingers can generate entirely new series of harmonic sounds. By removing the haptic feedback associated with touching a physical instrument, the controller glove facilitates the establishment of a more profound connection between the player and the sound. Consequently, the sound itself becomes the "Interface".

Figure 51

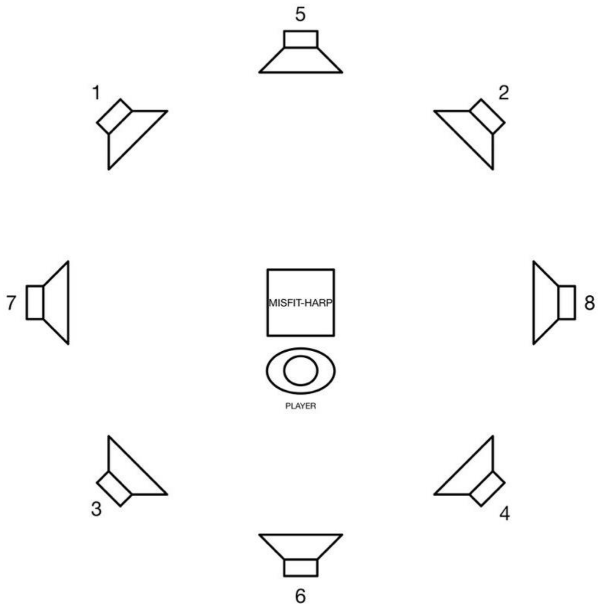

Figure 52 Misfit harp in 8-channel performance setting. The output of each string is routed to a speaker.

7. The Road Ahead: Future Developments for Misfit Harp

Due to the substantial research involved, there are a multitude of unexplored ideas for innovative techniques and methods in harnessing the full potential of the Misfit-Harp. These ideas Include various approaches to programming and performing with the instrument, as well as the addition of new modules that would enhance its functionality.

One such idea is the development of new modules equipped with solenoids to strike and/or pluck the strings, thereby enabling the production of percussive sounds and rhythmic patterns.

Another idea for expanding the capabilities of the Misfit Harp is to utilize the IanniX software to program the instrument. With IanniX, graphical scores can be created for the Misfit Harp allowing for the mapping of instructions to the stepper motors to control string tension and trigger solenoids for striking the strings. IanniX provides a relatively user-friendly interface for programming the instrument, making it more accessible for composers to create compositions for the Misfit Harp.

In conclusion, the Misfit-Harp offers an array of possibilities for expanding its sonic potential. Notably, the instrument can be enriched by feeding an external audio signal through the matrix mixer, causing the strings to resonate and act as a "string reverb", as demonstrated by Nicholas Collins in his "backwards electric guitars."[10]

In his book Handmade Electronic Music, Nicholas Collins explains this technique: "In these instruments, sounds are sent into guitar pickups or coils (scavenged from relays) whose fluctuating electromagnetic fields vibrate the strings of guitars and basses. The strings filter, resonate, and reverberate the original sounds (similar to the effect of shouting into a piano with the sustain pedal depressed) and are picked up, amplified, and further processed through distortion and other typical guitar effects. The filtering is 'played' by fretting and dampening the strings, like a one-handed guitarist."

Through various demonstrations and presentations, it has become evident that the use of the controller glove may not be the preferred method of interaction for all potential users of the Misfit-Harp. Consequently, a fundamental objective for

[10] Collins and Lonergan, *Handmade Electronic Music*.

the instrument is to promote accessibility and openness, inviting other composers and performers to engage with it in their preferred manner. This inclusive approach encourages artistic exploration, empowering individuals to experiment with the Misfit-Harp and unleash their creativity, ultimately pushing the boundaries of musical expression.

8. Conclusion

The journey of researching, designing, and constructing these instruments proved to be a transformative experience that significantly impacted my artistic and professional trajectory. Initially, my goal was to address limitations I encountered while performing my compositions live. However, the project ultimately resulted in the development of entirely new musical and performative concepts. Throughout the course of this endeavor, I acquired a diverse range of skills, including 3D design, carpentry, 3D printing, PCB design, and pickup winding. This project also marked the beginning of my career as an instrument maker and led to my involvement in several subsequent projects focused on designing and constructing new instruments.

The implementation of cross-feedback connections among the strings demonstrated the potential for novel approaches to string utilization. This revealed that strings can function as components within more intricate systems. The systems and devices developed for the Misfit-Harp can be reshaped to accommodate diverse performative requirements.

This project will be further advanced through the refinement of existing components, such as the matrix mixer and controller glove, as well as the introduction of new modules and control mechanisms. Additionally, the project will be furthered through continued composition and performance utilizing the instrument.

One of my primary objectives for the future is to collaborate with other composers, performers, and instrument makers to gain their feedback and insights regarding the Misfit-Harp. My discoveries and developments will be made available to others as open-source documents and tutorials, with the aim of facilitating further advancements by other instrument makers. I am confident that this will also prove beneficial to my own work.

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