Interactive Multimedia Devices: An Exploration Relating to Disability and Performance

by

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ABSTRACT

The importance of interactive electronic devices in the twenty-first century is a quickly expanding one, and the field of music technology is not exempt from this. Most traditional acoustic instruments pose challenges for individuals lacking fine motor skills, coordination, or grip strength. The author has responded to this issue as they experience it by developing a programmable interactive instrument system using a Mugic Motion System hardware, which includes a gyroscopic sensor, and Max/MSP, a visual programming environment which allows for customizable musical engagement for a variety of user types and requirements. This thesis explores the potential of interactive electronic devices to revolutionize the field of music as well as their potential in larger immersive environments, allowing creativity to reach a wider range of people regardless of physical limitations. The use of interactive sensor devices presents a not yet completely explored path for creating forms of sonic and multimedia interaction to a degree that has not yet become standard within either the musical field nor the emerging field of immersive environments and storytelling. The implications of a more fleshed out sensor-based system extend beyond the sound potential explored within this paper, and could allow interaction with visual aspects and motion based interactive art installations. This technology can also be applied as part of larger interactive systems, such as those found in theme parks and other large interactive attraction spaces. The author offers a novel approach to the democratization of music by leveraging the potential of interactive electronic devices for a population traditionally overlooked in music.

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And lastly to my mother, Christine Lloyd. I miss you. I hope you would be proud of me and what I've accomplished. I love you.

TABLE OF CONTENTS

APPENDIX Page

LIST OF IMAGES

CHAPTER ONE

INTRODUCTION

People don't really think about how their lives would change if they became disabled. Most musicians don't consider how they would adapt if they became unable to play their instrument of choice. Performers know how to manage repetitive use injuries such as tendonitis, carpal tunnel, and bursitis. As a field of study, music and the larger performing arts often fail to consider what happens if someone becomes permanently unable to perform: whether it be on an instrument, or through dance, live art, or another form of audience-involved creative expression.

My reason for designing this project and paper is rather personal. I have a genetic disorder called Ehlers-Danlos Syndrome (EDS) that affects the collagen produced by my body.[1] Collagen is the most abundant protein in the body, making up a third of the protein in your body and three-quarters of your skin. Collagen is responsible for: structural support to skin, tendons, bones, and ligaments, tissue repair, nerve signaling, joint health, skin elasticity, and other important bodily functions. The collagen my body produces is too stretchy, which leads to almost constant pain and frequent joint, bone, and muscle injuries, among a variety of other effects that don't directly factor into the scope of this project, such as my heart valves slowly failing.

Due to this disorder I am no longer able to play clarinet, the instrument I have been trained to perform on, for more than fifteen to thirty minutes at a time.

[1] Ehlers-Danlos Society, "What Is Eds?," The Ehlers Danlos Society, March 15, 2023, https://www.ehlers-danlos.com/what-is-eds/.

My thumb joint has lost any level of stability when used as the sole bearer of weight, and therefore playing an instrument that is almost entirely supported by the player's thumb is challenging.

Image 1: A picture of my thumb on their right hand, bent backwards past the ninety degree angle thumbs are commonly able to bend to. Picture included as an example of right thumb joint instability. [2]

Since my degree is in composition this does not present a direct challenge to my chosen career field, but rather a challenge to my personal feeling of being able to claim the title of 'musician', and questions about how I fit into the realm of the 'creator' sphere.

[2] Stacia Meconiates. My Own Thumb. Photograph. Personal November 8th, 2023. Personal picture.

How exactly can you describe yourself as a musician when you can't play the instrument you've been trained on for thirteen years? When any instrument you could attempt to learn has an almost guaranteed outcome of leading to physical injury? Even singing for long periods of time can lead to a partial or total collapse of the vocal cords for some people with Ehlers-Danlos Syndrome. Branching into other traditional forms of creativity has been equally lackluster; painting and anything that requires steady hands are out of the question, welding and large scale metal-work become difficult when you struggle to lift more than twenty-five pounds without your shoulder popping out, and dance is laughably out of the question when your rheumatologist has banned you from yoga or any form of stretching. This has been an ongoing self-philosophical issue that has negatively impacted my self-image as well as my compositional output, and as much I decided the best course of action was one that looked into adaptive musical interfaces.

The problem I address in this thesis is that there is almost nothing in terms of accessible instruments designed for adults who have been trained as musicians, but can no longer play their original acoustic instrument. In my Problem and Solution chapter (Chapter 2), I will talk about current interactive musical devices, both those focused for abled and disabled people, and how they informed my personal design decisions. However, the current range for interactive devices focused on accessibility is rather narrow. After discovering this, I set out to create an interactive instrument that I am capable of playing without significant strain on my body.

My criteria for this instrument were the following:

1. Since my finger joints are one of the most affected parts of my body, any instrument that required the continued use of finger motion as a primary method of performance would not be suitable.
2. The instrument must be able to be used in a full performance that reflects the skill of an adult with over a decade of musical training while still also being relatively affordable. This criterion ruled out a large section of accessible instruments that are currently on the market. This criterion is more fully explained later on in this chapter.
3. The instrument had to be rather adaptive in terms of sonic capabilities. If I could previously perform extended techniques on my clarinet that would allow for unconventional note frequencies and timbres, then I expect the same possibilities from my new instrument. This desire led to me realizing early on that Max/MSP would be the most likely software that would be used in some way for this project. As such, the instrument hardware needed to have the ability to communicate with Max or another MIDI-capable software .

With these three guiding criteria in mind, I conducted in-depth research on the variety of options that were available to me. These options will be spoken about in more detail in the next chapter, but I eventually chose the Mugic Motion Device as the primary hardware for this project. With a singular Mugic sensor and Max/MSP I have been able to create a variety of patches that have enabled both myself and others, with a variety of physical ranges, creative trainings, and limitations, to perform with this project.

Before I touch more on the process and findings of my research into current interactive multimedia devices, particularly those that are marketed with a focus on accessibility, I would like to briefly summarize the history of music and disability design that forms the basis of both my recent work and my personal criteria.

Background of Electronic Music Devices

The first electromechanical instrument was conceived of in 1893 by Thaddeus Cahill, who desired a replacement for the orchestra whose sound could be sent across the country via the recently invented telephone.[3] Cahill had an obsession with the concept of mathematical perfection within music, and sought an instrument that allowed for the performer to have peak emotional control over the sound, with minimal mechanical impediment. Named the Telharmonium, it took twelve years to be funded, and was installed in New York City in 1905. The instrument took up an entire building and weighed approximately two hundred tons. Though it was in use for less than a decade due to high operating costs, the Telharmonium directly influenced other twentieth-century instruments that would come after such as the Player Piano, Hammond organ, and Moog synthesizer. Its keyboard-styled interface became the expectation of modern electronic instruments, though the individual tone-wheels needed to create each note quickly became obsolete. This instrument is what inspired the oncoming electronic revolution.

[3] Smithsonian Magazine, “The World's First Synthesizer Was a 200-Ton Behemoth,” Smithsonian.com (Smithsonian Institution, November 16, 2018), https://www.smithsonianmag.com/innovation/worlds-first-synthesizer-was-200-ton-behemoth-180970828/.

Leon Theremin is the inventor of one of the earliest known electronic instruments, which was named eponymously. First prototyped in 1918, the Theremin is not only an electronic instrument, but also a touchless one.[4] The user controls the Theremin by moving their hands near two antennas protruding from a box that the main electronics are housed in. Its sound is rather simple when compared to modern electronic music, but has often been described as ethereal and otherworldly, and was used in quite a few film soundtracks. Though this instrument was not intended specifically for the disabled population, the Theremin is in fact rather disability friendly. The instrument can be easily placed on a table of any height and does not require grip strength to be performed, only control of the hands. Hand tremors can be used as a vibrato effect, and are less noticeable when playing the Theremin when compared to acoustic instruments.

Electronic instruments and music progressed throughout the twentieth century, playing a large role in film scores starting in the 1950s and onwards. Electronic music was eventually to become its own genre by the end of the first half of the twentieth century. Another notable electronic instrument is the Hammond Organ, first created in 1934 by Laurens Hammond.[5] Hammond's instrument would go on to be one of the most commercially successful electronic organs, and became a staple in musical performances ranging from Church Gospel to Hard Bop. The Hammond Organ used tone-wheel oscillators until the 1970s[6], though much smaller ones than the Telharmonium. The Hammond Organ is still sold today by Suzuki Music Corp, and remains popular with churches.

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[4] Lemelson MIT Program, "Leon Theremin," Lemelson, accessed February 28, 2023, https://lemelson.mit.edu/resources/leon-theremin.
[5] Hammond, "The Hammond Story," Hammond Organ, accessed February 28, 2023, https://hammondorganco.com/the-hammond-story.
[6]Faragher, Scott (2011). The Hammond Organ: An introduction to the instrument and the players who made it famous. Hal Leonard Corporation. ISBN 978-1-4584-0287-5.

Another groundbreaking electronic instrument was the Moog Synthesizer, first invented in 1964 by Bob Moog.[7] Moog's synthesizer took similar oscillator technology that powered the Telharmonium, but was able to reduce its size and expand sonic possibilities. The relative portability of the Moog Synthesizer, when compared with similar electronic instruments of its time, allowed it to become widely adopted for new music programs. The Minimoog, introduced in 1970, was quickly taken up by rock and jazz performers such as The Beatles, The Grateful Dead, Frank Zappa, and Sun Ra.[8]

Image 2: A picture of the original Moog Synthesizer with Bob Moog and composer-performer Herb Deutsch.[9]

[7] Moog, "The Early Years Of The Moog Synthesizer," Moogmusic.com, accessed February 28, 2023, https://www.moogmusic.com/news/early-years-moog-synthesizer.
[8] BBC NEWS | Entertainment | Music | Obituary: Dr Robert Moog. news.bbc.co.uk/2/hi/entertainment/4696651.stm.
[9] Author Unknown. Herb Deutsch and Bob Moog at Hofstra University. Photograph. Herb Deutsch March 5, 2023. https://www.herbdeutsch.com/wp-content/uploads/2022/01/Bob-and-Herb-university.jpg.

Moving ahead to 1988 we encounter the first electromyogram (EMG) controlled instrument, known as the *BioMuse.* Created by Hugh Lusted and Benjamin Knapp, the *BioMuse* works by taking the EMG signals from a performer's muscle contractions and using that data to control various sonic parameters.[10] With the *BioMuse*, human electric signals generated through physical movement are utilized to generate Musical Instrument Digital Interface (MIDI) data and trigger various musical events.[11] This allows for not only an instrument that does not require physical contact (outside of the sensor armband receiving the EMG data via contact with the performer's arm), but an instrument that can also be used to create rich sonorities with relatively little physical movement. The BioMuse system was further developed to be used by people with disabilities[12], though the project seems to have been inactive for over a decade, as the associated company website lists no further updates to the project after 1992.[13]

As can be seen, the history of electronic music has developed over the last century and evolved, from building-sized synthesizers to sensor-based Digital Musical Instruments (DMIs) that can be worn and utilized by a variety of performers. Pamela Z is a live-performance composer and multimedia artist that often utilizes sensor-based DMIs and other unique musical tools for live composition. My *Mugic & Motion*, the thesis

[10] Hugh S. Lusted and R. Benjamin Knapp, "Biomuse: Musical Performance Generated by Human Bioelectric Signals," The Journal of the Acoustical Society of America 84, no. S1 (1988): pp. 1-2, https://doi.org/10.1121/1.2025994.
[11] Marco Donnarumma, "Principles, Challenges and Future Directions of Physiological Computing for the Physical Performance of Digital Musical Instruments," in Conference on Interdisciplinary Musicology (Conference on Interdisciplinary Musicology, 2014), pp. 2-2, https://www.academia.edu/14251174/Principles_Challenges_and_Future_Directions_of_Physiological_Computing_for_the_Physical_Performance_of_Digital_Musical_Instruments?email_work_card=title.
[12] Lusted, Hugh S., et al. "Musical Performance by the Handicapped Generated From Bioelectric Signals." Journal of the Acoustical Society of America, vol. 87, no. S1, Acoustical Society of America, May 1990, p. S41. https://doi.org/10.1121/1.2028212.
[13] BioControl Systems. www.biocontrol.com/producthistory.html.

project created in conjunction with this paper, is inspired by and builds off Pamela Z's *BodySynth*. *BodySynth* is a wearable instrument that further developed the EMG sensor work pioneered by the *BioMuse* creators.[14] Her instrument system also interfaces with Max/MSP for further musical expression control. While my instrument does not utilize EMG sensors, it does work off of sensors interfacing with the Max/MSP software, in my case a nine-axis gyro sensor that sends movement data to a Max Project that live-processes the movement data into pitches, controls the glissando effect, and operates other musical events and effects, dependent on the patches loaded for the individual performance.

Domestication in Regards to Disability Access

My field of academic study revolves around media and sonic arts, and as such I knew little on the academic writings regarding disability design when I started this project. One of the most useful standardized terms I came across during my foray into this study was the concept of *domestication*, which I first read about in *Ability or Disability – Design for Whom?*, a paper that analyzes the Danish healthcare system in regards to long-term disabilities, and how the country's laws regarding home modification of disabilities could be improved.[15] The paper uses the term domestication to describe the process of the disabled person adapting the assistive technology into their homes and lives. An example given within the paper is a disabled woman named Sophie,

[14] Pamela Z, "The BodySynth," The bodysynth(tm), accessed November 6, 2022, http://www.pamelaz.com/bodysynth.html.
[15] Søsser Brodersen and Hanne Lindegaard, "Ability or Disability – Design for Whom?," Scandinavian Journal of Disability Research 16, no. 3 (April 2013): pp. 267-279, https://doi.org/10.1080/15017419.2013.803499.

whose house was remodeled by the Danish government due to her Multiple Sclerosis (MS). Certain aspects of the house adaptation were well received by Sophie, such as a new bedroom on the ground floor that contains remote controlled windows and a sliding door that Sophie could open herself. This part of the redesign fit Sophie's personal perspective of her disability and needs, so it was domesticated well into her life. However, Sophie expressed displeasure with her new bathroom, as she finds it too large for her current needs. The space acts as a reminder to Sophie that at some point she will require a level of personal hygiene care that the larger bathroom will necessitate. In this instance, Sophie mentions that while the architect for her remodel listened to her in regards to assistive technology within her new bedroom, in the bathroom she was overruled regarding the size, with her future care needs being explicitly mentioned by the architect. Sophie's new bathroom fails the domestication criteria, as Sophie associates it with a negative future outcome of her disability.

This paper inspired me to focus on user design and appeal for my work, both for this project and in regards to future ones. Any instrument I designed needed to not feel like an 'instrument for a disabled person' to me if I was to fully domesticate it into my life and performance practice. The concept of domestication led to my second criteria: this instrument had to reflect the fact that my performance ability has not suffered, even though I can no longer perform on my original instrument of clarinet. I did not want the physical hardware I chose to be the 'traditional' medical device colors of white, off tan, or black, nor did I want the device to feel like it was a medical device in any way. For my case, domestication of my instrument meant that not only would it be an instrument system that worked for me, but that it was an instrument system that could work for anyone, regardless of their level of mobility. The current band is a rather vivid shade of turquoise, which most certainly does not feel medical, and is easily integrated into the performer's outfit.

Though this seems like a concept that would be rather simple to implement within interactive media, I quickly found multiple articles describing incidents where immersive and interactive installations were not able to work for all people. In 2019 the Museum of Modern Art (MoMA) closed during the summer for a renovation project and staff training on increasing disability access.[16] An exhibit by Olafur Eliasson that commented on perspectives and the human body was inaccessible to wheelchair users due to a walkway being too narrow.[17] The Tate Modern museum in London had no solution to this issue, and the wheelchair user in question was completely unable to interact with the piece. This irony should not be lost when we are speaking about a work that is meant to create conversation around the human body and how it's perceived.

Though captivating, Yayoi Kusama's *Infinity Rooms* are inaccessible to me personally on multiple levels. They are almost impossible to navigate in a power chair, something I often require when going to events or on outings that involve long periods of standing. The lighting used in *YOU WHO ARE GETTING OBLITERATED IN THE*

[16] Claire Voon, "How Museums Are Increasing Accessibility for Visitors with Disabilities," Artsy (Artsy, October 14, 2019), https://www.artsy.net/article/artsy-editorial-museums-finally-accessibility-visitors-disabilities-seriously.
[17] Jim Richardson, "Access Issues at Tate Modern Olafur Eliasson Installation Provoke Anger," MuseumNext (MuseumNext, October 30, 2021), https://www.museumnext.com/article/access-issues-at-tate-modern-olafur-eliasson-installation-provoke-anger/.

DANCING SWARM OF FIREFLIES, currently on exhibit at the Phoenix Art Museum as of November 2023,[18] is obliterating, but of my ability to see. The blue light LEDs used in the installation scatters across the blue light coating on my glasses, creating spikes of light across my field of vision. When I went into the exhibit my fiancee had to guide me though, as I could not navigate the installation or exit on my own due to the visual impairment.

Though there may be statements by multinationals on their desire to be inclusive, we are not yet in a place where the majority of interactive and immersive experiences are accessible to all people. When we focus on music performance and that sphere, the currently accessible experiences lessen even further. As a musician and multimedia artist I look forward to helping change this current reality. However, there are few musical instruments and music related devices that are disability friendly at this time. These are discussed in the next chapter.

[18] "You Who Are Getting Obliterated in the Dancing Swarm of Fireflies (Tú Que Estás Siendo Obliterado Por Una Multitud De Luciérnagas Danzantes)," Phoenix Art Museum (Phoenix Art Museum, August 20, 2022), https://phxart.org/arts/you-who-are-getting-obliterated-in-the-dancing-swarm-of-fireflies-tu-que-estas-siendo-obliterado-por-una-multitud-de-luciernagas-danzantes/.

CHAPTER TWO

PROBLEM AND SOLUTION

The Problem

Due to a genetic condition that impacts the way my body produces collagen, it is no longer practical nor comfortable for me to perform on the acoustic instruments I have training on. Since I do not want to give up musical performance, I decided to investigate the possibilities and current options of electronic musical devices and digital musical instruments that would allow for a sufficient level of complexity in performance. The main roadblock that I have discovered throughout my research into interactive musical devices and systems is that while there is a body of work on creating interactive sound devices and systems for medical rehabilitation and elite physical training,[19] less research and development seems to have been done in regards to creating interactive musical instruments for trained musicians who are no longer able to perform on their original instrument. A paper co-authored by Dr. Paine had a fixation on disability-focused musical instruments and improvisation,[20] but this research was again done with the emphasis on music therapy for non-musicians, as opposed to the non-therapeutic performance aspect that I am interested in. Though the results were intriguing, the results were deemed not significant for flour out of the five participants.[21]

[19] Nina Schaffert et al., "A Review on the Relationship between Sound and Movement in Sports and Rehabilitation," Frontiers in Psychology 10 (December 2019), https://doi.org/10.3389/fpsyg.2019.00244.
[20] Paine, Garth. "A Dynamic Sonification Device in Creative Music Therapy." Asu, May 2014, www.academia.edu/6315619/A_Dynamic_Sonification_Device_in_Creative_Music_Therapy.
[21] Ibid., 10.

This fact is rather confusing to me, as studies have been conducted in regards to university-level performance majors and found an average rate of injury of 8.3% when looking at all instrument families.[22] This does not factor in long-term injuries acquired from repetitive use by older musicians, or the impact of aging on performance ability. I personally know multiple practicing musicians at various levels who have some sort of repetitive-stress injury that they or their doctors consider at least partially caused by their instrument performance. To see almost no adaptations for a field that causes some level of injury to over 8% of the students learning it at a collegiate level seems like a missed opportunity.

As someone who can no longer hold a clarinet or saxophone for more than ten to fifteen minutes without joint pain this was a rather frustrating discovery, to realize that little research seems to have been done in regards to trained musicians who are no longer able to perform in a traditional manner. The few instruments I did find that had either been designed to some degree with disabilities in mind, or could be used to aid disabled people in some way, did not fully meet the requirements I have for my own work. However, their various methodologies were interesting enough to influence the thought process around my end result, so I will include an overview of a few currently existing technologies that are either adaptable for some section of the disabled population, or were specifically created with at least some section of the disabled population as the primary market of impact. Their various drawbacks and any aspects I found worthwhile to consider will also be mentioned. The musical systems I have chosen to talk about in this

[22] Cayea, Danelle, and Ralph Manchester. "Instrument-specific Rates of Upper-extremity Injuries in Music Students." Medical Problems of Performing Artists, vol. 13, no. 1, Mar. 1998, pp. 19–25. JSTOR, https://doi.org/10.2307/45440745.

section are the Subpac, the Soundbeam, the Skoog, the Eyeharp, and the MiMU.It should be stated that each system I will talk about is not a bad system. Each one has specific solutions that may fit their targeted audience well, but may not be useful as a long-term solution for trained musicians looking for an accessible instrument or interface device.

Partial Solutions

There are a few devices, such as the Subpac, that may be useful for the Deaf and Hard of Hearing (HoH) communities, but are not directly involved in sonic creation and do not aid in performance in regards to mobility. This type of device is a wearable sonic feedback system that allows the user to feel vibrations from a bass speaker via haptic feedback, and hear the sounds being transmitted via bone conduction.[23] While bone conduction is a viable way for some Deaf and HoH people to experience sound and is used in select models of hearing aids,[24] the Subpac does not specifically allow for musical creation, only for an enhanced musical listening experience. However, the haptic feedback element is an aspect of acoustic instruments that is often overlooked when designing digital instruments and interfaces, so it is important to highlight the potential in utilizing haptic feedback for performance benefit. I can confidently say that the subtle tactile feedback a performer gets from the vibration of their instrument is a sensation that is important for expressive flair. The physical sensations an instrument gives to the performer, such as the feeling of reed vibration against the lips or tongue of a woodwind

[23] Subpac, "What Is SUBPAC?," SUBPAC (Subpac, July 3, 2022), https://subpac.com/what-is-the-subpac/.

[24] "Bone Conduction Hearing Devices | Hearing Implants," National Deaf Children's Society (NDCS), accessed March 23, 2023, https://www.ndcs.org.uk/information-and-support/childhood-deafness/hearing-aids-and-implants/hearing-implants/bone-conduction-hearing-devices/.

player, provides information about articulation and is used by the performer to create timbral changes, even if the performer does not fully realize that they utilize this vibrational feedback. As I am able to expand my work, creating a mild vibrational feedback when the performer has reached the minimum or maximum range of the device would aid in user domestication of the interactive device.

The Soundbeam is a touch-free ultrasonic sensor system designed specifically for individuals with profound disabilities and music therapists.[25] It can have up to four ultrasonic sensors communicating to its system. The Soundbeam system has a wide variety of pre-created 'soundsets' that can be modified by the user, or programmed by a therapist to be used during session work. The touchless technology is very intriguing and seems to be a well crafted setup for those with severe physical limitations. The website mentions that the Soundbeam system is most commonly used for individuals with severe learning disabilities, as well as adults with a memory loss related disease, such as Dementia or Alzheimer's.[26] Though the focus of my project is on those with less severe physical limitations, this system seems to be a wonderful tool for those with more severe physical restrictions. The Soundbeam system showcases one of the barriers I continued to run into; many of the best designed interface instruments are not designed for a performance level but rather a therapeutic one. In addition, the Soundbeam system seems to be difficult to procure outside of the United Kingdom, and at the time of writing this

[25] "What Is Soundbeam," Soundbeam (Soundbeam), accessed March 23, 2023, https://www.soundbeam.co.uk/what-is-soundbeam-1.
[26] "How Is Soundbeam Used," Soundbeam (Soundbeam), accessed March 23, 2023, https://www.soundbeam.co.uk/how-is-soundbeam-used.

would cost about $3,100 USD before factoring in shipping costs. The living co-founder seems to have recently passed, so it is unsure how long the project will continue.

The next interface I want to discuss, the Skoog, is the result of a 2006 research project spearheaded by Dr. David Skulina and Dr. Ben Schögler of the University of Edinburgh in England.[27] The goal of their work was to create an instrument that was specifically designed for children with disabilities, with a particular focus on autism and involving music as a form of exploratory play therapy.

Image 3: A picture of the Skoog, with bluetooth and battery symbols visual on the lower left side.[28]

[27] "About," SkoogMusic (Skoog, January 14, 2020), https://skoogmusic.com/about-2/#1470320958783-5694e999-201d.
[28] Apple. Skoog Side View. Photograph. Apple March 14, 2023. https://store.storeimages.cdn-apple.com/4982/as-images.apple.com/is/HJAV2_AV1?wid=1144&hei=1144&fmt=jpeg&qlt=95&.v=1599760462000

Skoog is capable of connecting to GarageBand and can be used for rudimentary live performance, but the client base being focused towards children limits the overall possibilities for my target group of adults with mild to moderate physical disabilities. With the main way to perform with the Skoog being gripping, pinching, and rubbing, the system requires a level of fine motor skills and grip strength that my target demographic may not possess. However, the set up and ease of use factors are important aspects that I have attempted to replicate in my own works, as the users are more likely to continue using and engaging with interactive devices that they find easiest to domesticate into their own lives.

The EyeHarp is an eye tracking instrument that seems well engineered for people with severe physical disabilities, such as those with quadriplegia or little to no controlled movement of their upper limbs. It was designed by Zacharias Vamvakousis after a musician friend of his was involved in a car accident, leading Vamvakousis to also realize that there are almost no accessible musical instruments for adults with physical disabilities. The EyeHarp project seeks to be as accessible and easy to use as possible, which is demonstrated by the EyeHarp team offering a free version of the software.[29] EyeHarp's software can also function as a MIDI controller, allowing for the musician to send the MIDI data out to external Virtual Studio Technology (VST) objects. [30] This allows the user to send the MIDI to Max/MSP or other musical software programs for further personalization of sounds and effects triggered. The only major downside I find

[29] "What Is EyeHarp," EyeHarp (EyeHarp, November 2, 2020), https://eyeharp.org/about/.
[30] "FAQ," EyeHarp (EyeHarp, January 29, 2022), https://eyeharp.org/faq/.

with this is that during the initial download of the EyeHarp software the user will also need to download Visual C++ Redistributables, though after speaking with people who use eye tracking software these will likely already be installed on the user's computer. This may still present a barrier to newly disabled and less technology savvy users who may feel overwhelmed with the initial software setup. My own solution also requires the user to download Max/MSP software, which can be considered a drawback. This project does not meet my own personal needs, but is a project I have shared with members of my community that have spinal cord injuries, cerebral palsy, and other severe limitations to their mobility. After they had the time to download and try out the software, they informed me that it overall works very well with their eye-tracking hardware, and they enjoyed using it. This DMI is a strong contender for trained musicians with more severe limitations.

The last device that drew my attention was the MiMU, a set of gloves designed by Imogen Heap.[31] Through flex sensors located within each glove finger, a gyroscope used for orientation sensing, and a Wi-Fi transmitter mounted on the wrist of the glove, the MiMU allows a performer to control sound and effects through movement.[32] The last digits of each finger of the glove are removed, allowing for more traditional instruments to be played at the same time. Though it has not been sold since 2021 due to a chip shortage, the website set up to sell these gloves will allow you to add your name to a waitlist for a new design they say will release sometime in 2024. From what I can find, the price for a set of the MiMU gloves were approximately $3,188 USD last time they

[31] "Music Through Movement," MiMU, accessed March 23, 2023, https://www.mimugloves.com/mimu-story/.
[32] "Mimu Gloves," MiMU, accessed March 23, 2023, https://www.mimugloves.com/gloves/.

were sold, and with the technical lifespan being listed as only two years the cost feels difficult to justify.[33] Since the gloves mainly collect data from finger movement this device is less than ideal for someone like myself who lacks fine motor skills and finger dexterity. However, the idea behind the MiMU gloves, creating sound manipulation through physical movement, strongly influenced my overall design, though at a more accessible form and price point.

My Solution

While each of these musical interface systems provide their own unique strengths, I ended up choosing the Mugic Motion System for my hardware. The Mugic Motion System is a hardware device and small downloadable suite of Max/MSP patches created by Mari Kimura and Liubo Borissov that primarily utilizes live data captured by a nine axis gyroscopic sensor.[34] The Mugic hardware is small enough to easily be attached to a limb without any serious issue, is capable of communicating data in real-time over Wi-Fi built into the device, and has a few Max/MSP patches as well as a desktop app designed by Mari Kimura that allow new Mugic users to quickly set up and begin creating their own with the device.[35] As far as I have been able to tell, Kimura did not originally design Mugic to be used as an assistive musical interface device. However, it ended up being the best hardware setup for my price point and want of easy personalization and user customizable control. The capability of Mugic to be easily set up through Max/MSP, as

33 "Music Through Movement," MiMU, accessed March 23, 2023, https://www.mimugloves.com/repairs/.
34 Mari Kimura, "Mugic Sensor," Mugic (Mari Kimura), accessed March 23, 2023, http://www.marikimura.com/mugic-sensor.html.
35 Mari Kimura, "Mugic® FAQ," MUGIC®, accessed March 23, 2023, https://mugicmotion.com/faq.

well as the starter patches available through the Mugic site, made learning how to set up the device and direct the data to control specific objects and parameters in Max overall quite easy. The ability to set a minimum and maximum range within the Mugic Starter project allowed for the project to be customized for a specific user's range of motion. The fact that it is able to connect so well with Max allows for musical expression and performance to only be limited by one's ability and familiarity with the Max/MSP software.

To showcase the ease-of-use and flexibility of the Mugic system, as well as get it into the hands of accessibility-focused users, I have created custom programs in Max/MSP for multiple events and performers. The most notable cases so far have been the Change the World event held at Arizona State University in March 2023 [36], as well as creating a custom patch for dancer Valkyrie Yao who utilized it for the Saguaro Sounds concert on March 16th 2023, and designing a non-musician style patch that will be utilized for a demonstration and audience-participation opportunity in conjunction with Phoenix Forge on December 1st 2023. With the Mugic device being so compact, I was able to fabricate an adjustable armband that the Mugic can be inserted into for general demonstration and use.

[36] "Change the World," Change the World (Educational Outreach and Student Services), accessed March 23, 2023, https://eoss.asu.edu/change-the-world.

Image 4: A picture of the Mugic sensor being held in the armband created by the author.[37]

The patch designed for my dance performer will be fully explored in the next section (Chapter 3). The full code of the patch I created for the Saguaro Sounds Contemporary Concert that took place on March 16th 2023 may be found in Appendix B.

[37] Stacia Meconiates. Mugic&Motion armband. Photograph. Personal March 16, 2023. Personal picture.

CHAPTER THREE

TECHNICAL BREAKDOWN OF MAX/MSP PATCHES

Overview of Saguaro Sounds Patch

This chapter of my thesis will review a few of the Max/MSP patches I wrote to be utilized alongside the Mugic hardware and software that already exist. For the purposes of keeping this somewhat concise, I've chosen to walk through how the patch I specifically created for Valkyrie Yao functions, as well as provide an example of a filtering effect that utilizes the live-processed movement data for a more VST and effects focused user. However, the demo patch I created for the Change the World event on March 15th is similar to the patch created for Valkyrie, the main changes being scaling for the X and Y axes to account for the more limited range of motion my demo partners had. I have provided an image of the patch I created for the contemporary concert below.

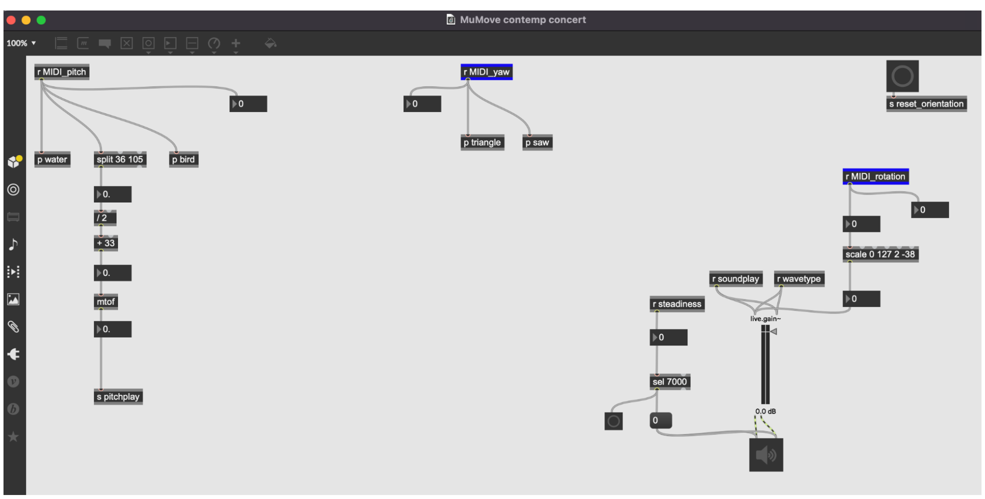

Image 5: An image of the full MaxMSP patch used by Valkyrie during the Saguaro Sounds concert.

The *rMIDI_yaw*, *rMIDI_pitch*, and *rMIDI_rotation* objects are taking data from the X, Y, and rotation axes and separating the data into sections via the *split* object. In this case, the term ‘yaw’ refers to movement that is leftwards or rightwards; ‘pitch’ refers to movement that is upwards and downwards, as opposed to the more traditional musical definition. All of the axes’ data is scaled from Quaternions to Euler (QtE) ranges (-30 to 30 for pitch and yaw, -90 to 90 for rotation) into MIDI format (0 to 127 for all axes). Pitch provides data on the Y axis, yaw provides the X axis data, and rotation provides data from the large limb rotational movement.. The *r steadiness* object is taking information from the X axis about stability and relaying milliseconds of no change in data. This patch uses seven seconds of no movement detected to end the patch and the performance-at-large, but of course the steadiness data is in no way required to be used in this fashion. In the top right of the patch there is a button linked to an *s reset_orientation* object, that sends a bang to the connected Mugic Starter project designed by Mari Kimura and Teerath Majumder. This bang resets the neutral position of the hardware device to where the performer’s current limb location is, providing a neutral point of reference for operations completed within the patch.

First let us discuss the notes and pre-recorded sounds generated or triggered by the current patch. Sound generation is done via live data in the form of integers received from the *rMIDI_pitch* object. The note generation is performed by a *split* object that takes integers between 36 and 105, then divides it by two so that each note is triggered by two integers (eg. 36 and 37 will both output an integer of 18 after being divided due to Max’s rounding logic.) We then add 33 to bump the output up into the standard range of human hearing, and then an *mtf* object converts the new MIDI integer into a frequency that can then be fed into the two waveform objects being controlled by the via the s pitchplay object.

For the 0-35 and 106-127 ranges, each range triggers a different pre-recorded sound chosen by Valkyrie for her performance. The subpatch shown below is specifically of the code created to trigger the bird sound file and send it back to the main patch, but the water sound file subpatch functions in the same way as this one. Both of these subpatches trigger sound files from the extremities of the pitch range; with the bird sound file being triggered to play when the performer is at the top of their pitch range (106-127), and water sounds play when the performer activates the bottom of the pitch range (0-35).

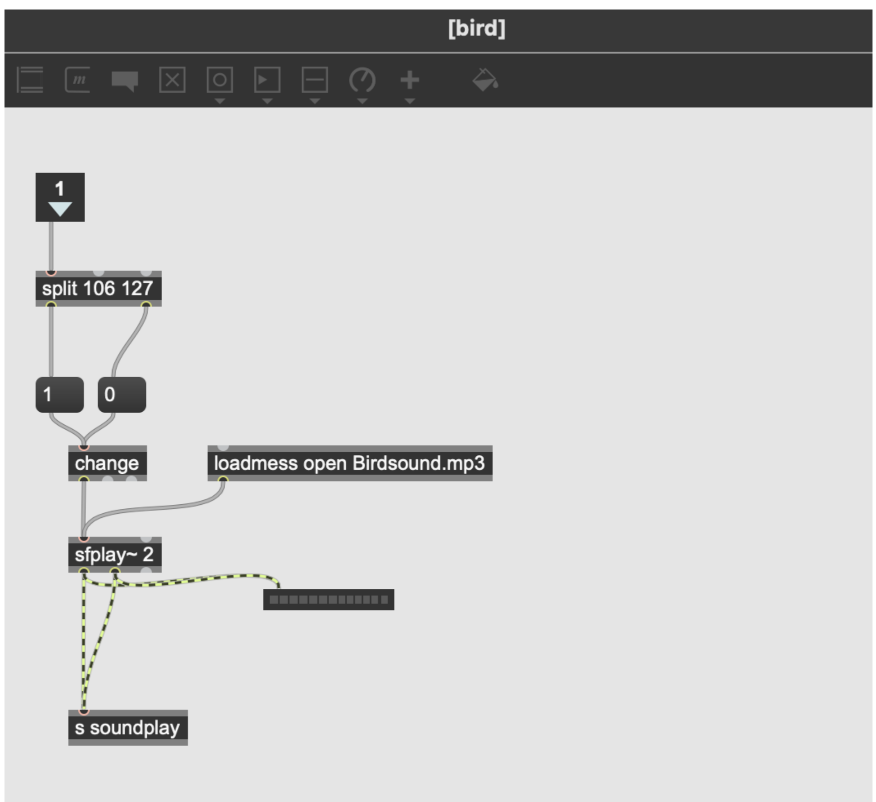

Image 6: The subpatcher labeled p bird in the main patch.

As we can see from the image of the bird subpatcher on the previous page, I used another *split* object here, this time with the left and right outlets feeding into messages sending 1 and 0 respectively. These messages trigger the start and stop of the sound file. Both messages go through a *change* object, which prevents the patch from retriggering the sound file playback while the performer is moving within the specified range. Both the *change* and the *loadmess* objects are going into the left inlet of an *sfplay~ 2*, which is what plays the preloaded sound file, in this case the *Birdsound.mp3* file, with the 2 denoting that two outputs are needed, creating stereo sound. The *sfplay~* object then has two objects attached to its leftmost outlet, an *s soundplay* object that sends the sound file to the *live.gain~*, and a *meter~* object that is useful for troubleshooting if the sound file does not play for any reason.

Next, let's talk about the different waveforms generated by the yaw data taken from movement along the X axis. In this version of the patch there are only two waveforms that are utilized, triangle and sawtooth, as Valkyrie found the square wave object too "buzzy" for her to wish to utilize that particular signal type in her performance. As can be seen this subpatch also utilizes a *split* object as its method of data processing and sorting. This *split* also feeds into two messages with 1 and 0 to trigger the event, but this event is the opening of a *gate~* object as opposed to the *sfplay~* used in sound file playback. The *gate* has not only the message values feeding into via a toggle, but also a *ramptime* attribute that mitigates the popping effect that otherwise occurs if there is no *ramptime* or other smoothing object feeding into the gate object when opened.

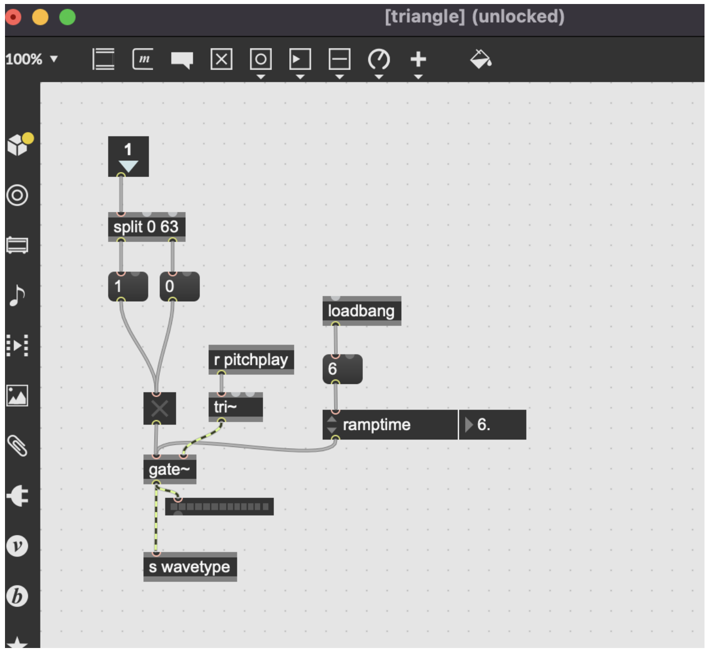

Image 7: An image of the subpatch labeled p triangle.

The *loadbang* and message that feed into the left inlet of the *ramptime* object simply reset the *ramptime* to six every time the patch is opened. We have a *tri~* object feeding into the right inlet of the *gate~* object, with an *r pitchplay* receiving frequency data from the previously mentioned note generation path. Similar again to the p bird subpatch, the *gate~* object feeds out into an outlet to send the data out of the subpatch. This send, labeled *s wavetype*, sends the frequency into a *live.gain~* object in the main patch. The subpatch for the sawtooth generation functions in the same way as the p triangle patch.

Leaving the sound generation, let us briefly touch upon the volume control that the performer has via the *r MIDI_rotation* object. Volume in Max is read in decibels instead of MIDI, but the software is able to convert them without a direct conversion object. The *r MIDI_rotation* object is able to feed its output directly into a *scale* object, which in this instance is scaling the movement data between 0 to 127 that it's receiving into a more manageable 2 to -38, which then feeds into the *live.gain~* object. The decibel values -38 to 2 were chosen so that at the minimum volume the sounds were just barely audible, while the maximum volume creates a feeling of overwhelming sound in the audience. This positive decibel value is limited via the design of the human body; a person of average to limited mobility is much less likely to hold the uncomfortable position of their arm rotated outwards to such an extreme degree for long periods of time when compared to the easier task of rotating one's arm inwards. This limits the amount of time a performer spends in the positive decibel value; leaving it only to be used in moments of the extreme and to create the feeling of overwhelming sonic arrival. I personally exceed this outward rotation, but Valkyrie is not hypermobile and as such found holding the maximum awkward. This is why the MIDI value of zero correlates to the decibel value of two in her patch; the opportunity for overwhelming sound is there, but it is highly unlikely that it will be utilized for any period of time over that of a few seconds. My own personal performance patch has a scaling that is more compatible with my personal range of motion.

The last patch path I'd like to discuss in this patch is the *r steadiness* object. As mentioned earlier in this chapter, this object is monitoring for any change in the integers sent from the X axis and sending out the milliseconds that no change data has been received. In this little pathway, a *sel 7000* object is used to denote that after 7,000 milliseconds (7 seconds) the signal pathway will send a *bang* output. This *sel* object is connected to a 0 message, which then leads directly into the *ezdac~* speaker object. Sending a zero to the *ezdac~* shuts it off, stopping all sound. For this patch it signaled the end of the performance.

Overview of Ring Drone Patch

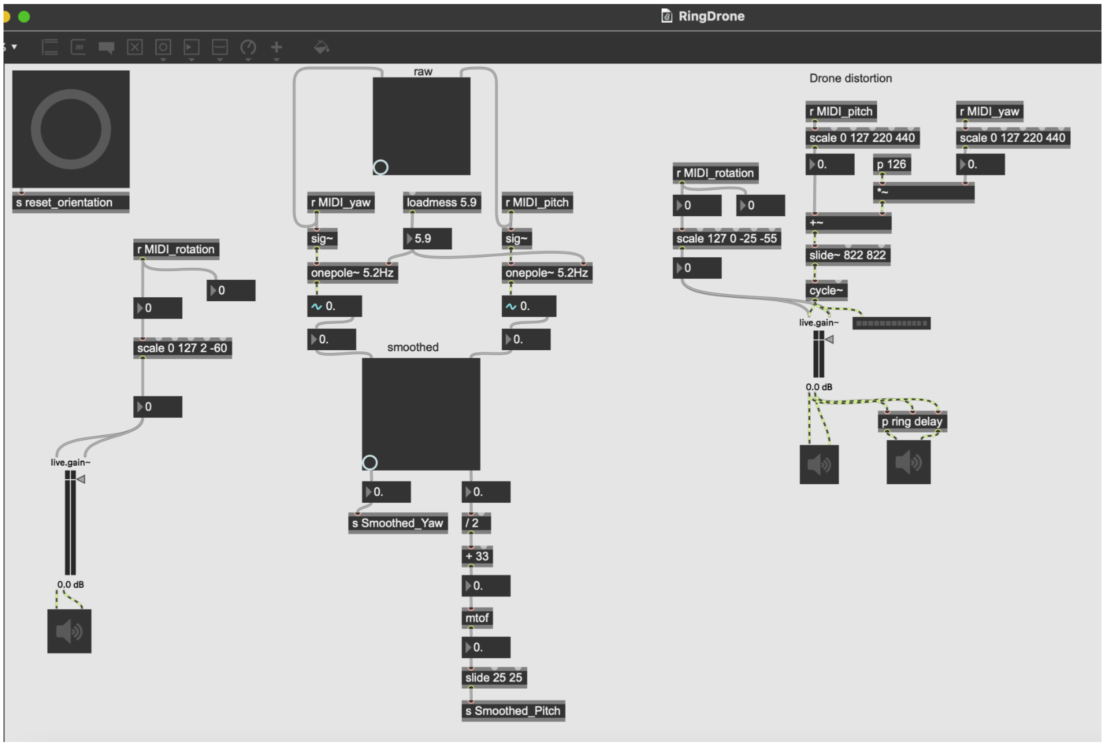

Image 8: An image of the full Ring Drone effects patch created in Max/MSP to be used with the Mugic hardware.

I also created an effect-styled patch for personal use that can be used simultaneously alongside other effects patches. The patch above creates a drone sound with a ring-modulation-with-distortion type effect. This patch utilizes second-order logic via the data-smoothing done with the *onepole~* operator. The *onepole~* object is a type of filter that uses a standard difference equation of $y(n) = a_{0} x(n) + b_{1} y(n-1)$, where $b_{1} = 1 - a_{0}$[38]. The *onepole~* object takes the left input of the signal you want filtered, in the case of this patch the raw movement data of the X and Y axes, and the right input of the cutoff frequency in hertz. The filter in this patch has been adjusted to a

[38] Cycling 74. "Onepole~ Reference - Max 8 Documentation." Max v8.5 Documentation, docs.cycling74.com/max8/refpages/onepole~.

cutoff that I personally feel strikes a satisfying balance that provides an output that is still reactive to the user's live movement, without suffering from jankiness or latency. This smoothing creates an end result that is more pleasing for further manipulation of other signal paths.

The smoothed signals are then sent to the subpatch named *ring*, a picture of which is visible on the next page. Each smoothed data stream is used in two separate delay effects in a *tapin~* object with a max delay of 1000 milliseconds and a scaling that converts the 0-127 integers into 0-1000, and a *tapin~* with a delay and corresponding scaling of 2500 millisecond maximum delay. This creates polyphony as well as multiple leaps that happen at different times when changing pitch in performance. The *tapin~* objects are receiving raw movement data from the x and y axes that have been manipulated and scaled in other fashions before being added together and outputted to *cycle~* then *live.gain~* objects. This part of the signal path will be spoken more on later. The 2500 delay lines also add 33 to the scaled integers. Each separate delay line then feeds into a *tapout~* object, and each *tapout~* abject outputs into its own *rampsmooth~*. The *rampsmooth~* linearly smooths the signal being inputted from each of the *tapouts~* across the number of samples specified for each *rampsmooth~* object.

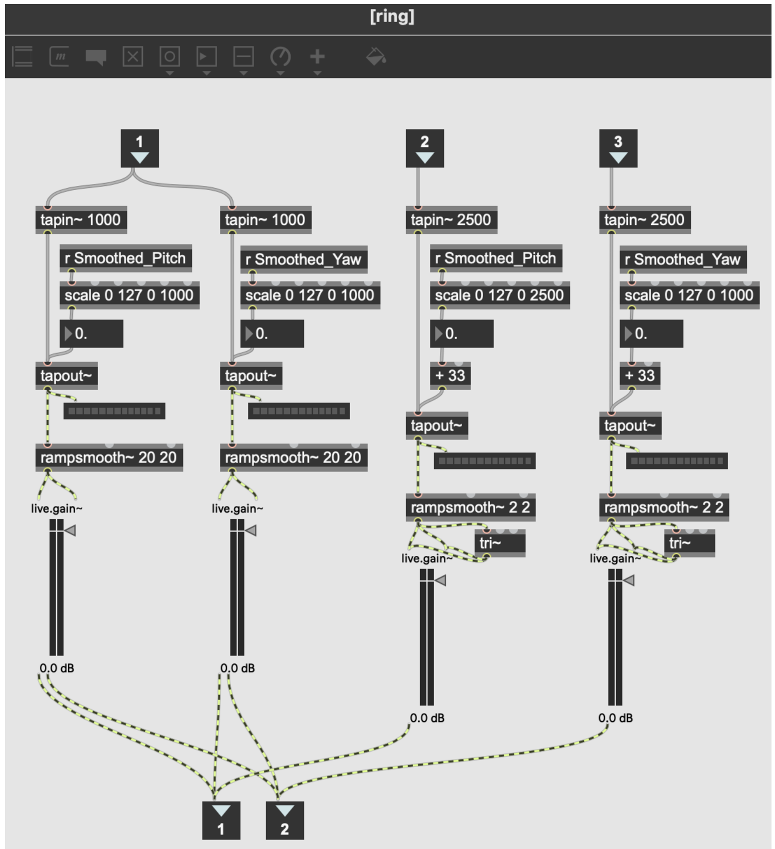

Image 9: An image of the subpatch labeled p ring delay in the main patch.

The last section of this patch I would like to briefly go over is the section in the top right of the main patch that is labeled ‘Drone Distortion’. This contains the subpatch previously broken down, as well as scaling of the raw pitch and yaw data. This is scaled from 0-127 to 220-440, as those integers as frequencies give us C2 to C4 in range. The raw yaw signal is multiplied with a *cycle~ 440* subpatch, and the resultant of that is then added to the raw pitch signal. This combined signal is sent through a *slide~* object set to 822 in both directions, and to another *cycle~* object. This is finally sent through a *live.gain~* with outputs leading to both an *ezdac~* as well as the previously spoken on p ring delay subpatch.

CHAPTER FOUR

CONCLUSIONS

Future Expansion

Though I feel like the current Mugic Motion System hardware allows me and the performers I have worked with so far a good level of musical craftsmanship and control of objects, adding haptic feedback to alert the user when an axis' range limit has been reached would be useful to prevent over-extension by the performer. The patch creator and performer would be able to dial in the scaling of the patch more easily with the inclusion of a tactile sort of feedback, such as vibration. This additional inclusion of a vibration object within the hardware would also grant the performer awareness in live performance when they are at the far end of the detectable motion range without looking at the computer screen.

Having the funds to acquire multiple Mugic hardware devices would allow for more subtle control of various objects within a patch, as opposed to my current setup of having one sensor whose live data is processed into a control of every musical event and object pathway that is coded to be influenced by the real-time processing. This multiple-device design would additionally allow for a set up where the performer can engage more than just one limb for motion control of the patch or project. An example of this would be having five sensors attached to a user, one of each limb and an additional gyroscopic sensor attached to the forehead via a band. The additional Mugic sensors would allow for multiple devices spread across the body to influence a singular aspect of the overall soundscape in a many-to-one mapping, such as having the X axes of both the right and left arms be involved in pitch generation, while a head sensor is solely responsible for triggering the end of a performance by tracking the steadiness of the user's skull. This type of many-to-one mapping via a multi-device structure would also create the opportunity to have more complex Max patches be designed for accessible music creation and performance, as the current setup can become overwhelming at times for the performer to control.

Though I have already been able to introduce a small number of people with physical disabilities to musical performance using my current setup and connections, having the ability to engage with a larger pool of users and be able to provide some level of compensation for their time would give me access to a much wider range of disabled user experiences and feedback data. This expansion of users would also eventually allow for a better idea of what sensor placements work for different levels and types of physical handicaps, as well as give a larger pool of user experience in regards to desires in patch design. So far I have mainly tested this setup of a singular armband with able bodied users, hypermobile people, and paraplegic wheelchair users. Having the funds available to seek out additional interested parties, particularly those with limitations to their upper body movement or less control over the movement of their limbs, would allow me to gather a wider range of data and over time create solutions for those who may not have full and conscious control of their arms, as well as more severely physically disabled potential users.

Potential Impacts

The impact of multimedia technology that utilizes sensor-based interfaces on the disabled demographic of people is far larger than I initially expected. When demonstrating my thesis project to the general population, I had multiple people come up and share stories about ways they could see this technology personally impacting them as well as their loved ones. At ASU's Change the World event on March 15th, the mother of a child with cerebral palsy spoke with me about how her daughter had always wanted to play cello, and how they had a cello sitting unused in their house after finding no way to adequately adapt the instrument to their daughter's physical needs, or find a teacher willing to work with her physical limitations. I was able to re-scale the demo patch created for the event on the fly so that daughter was able to get a full range of sounds from the Mugic controlled Max patch I had created for the Change the World event.

The impact of this project has been far beyond my original goals. While the initial endpoint was simply to create an instrument that I could play without causing further pain and joint damage to myself, the project has since expanded into working with and meeting a variety of different people within the disability community who can benefit from this to some degree. One of the largest unexpected impacts that has come out of this is the potential to work with a visual artist with malformed hands. This future collaboration will branch this work into Max/MSP's Jitter function, and hopefully expand the tools this artist has to create and manipulate visual media. Another opportunity that has come out of this project is an interview with Jen Sparks, a filmmaker creating a documentary about EDS: the difficulties in diagnosing, building a medical team, and less often spoken of impacts on the body, as well as the impact on the lives of people diagnosed with the condition and their loved ones. We have already sat down for an interview and discussion around adaptable equipment, and she plans to document an event December 1st at the Phoenix Forge makerspace where I will be speaking on accessible multimedia and allowing the audience to participate in using the Mugic Motion System hardware alongside a few patches I have created for the event.

Beyond the obvious and previously mentioned impacts to the disability community and myself, this line of multimedia technology has a variety of potential uses across multiple fields of study, a major one being Augmented Reality and Virtual Reality (AR/VR) applications. A probable use of a further developed gyroscopic multimedia technology would be an upgrade to the currently used handheld controller style of most VR technology and applications. If gyro and feedback technology was integrated into a smartwatch style controller, then a limb controlled, less restrictive form of controller could be used as opposed to the more common full hand models. On the next page is an image of the Quest 2 controllers, which are current-technology full-hand VR controllers. One can only imagine how an elderly person or adult with severe developmental disabilities would react to being handed this style of controllers. I would expect poor domestication outcomes of these controllers in these group. With AR/VR technologies being explored for potential therapeutic applications, particularly in regards to rehabilitation after physical injury or stroke as well as dementia and memory care, the ease-of-use regarding controllers should be more closely examined for these functions.

Image 10: An image of the Quest 2 controllers.[39]

My suggested wearable controller model would allow for better movement control by older people who may be lacking in fine motor skills. Multiple studies on aging-related illnesses and memory care have shown VR applications to be positively impactful on a variety of quality of life measurements among the elderly,[40] so creating a simplified controller system for this population would be a clear benefit over the current generation of AR/VR controller technology. As the body loses mobility and reaction times due to aging, creating a system that is simplistic, and does not rely on fine motor skills and quick reflexes, will allow these emerging technologies to better suit the aging population.

[39] Meta. Quest 2 controllers. Photograph. Meta date unknown.. https://scontent.fphx1-2.fna.fbcdn.net/v/t39.8562-6/297845323_529323015640173_7685372163631784020_n.jpg?_nc_cat=105&ccb=1-7&_nc_sid=6825c5&_nc_ohc=SMQuP4tZb3oAX8CX5OK&_nc_ht=scontent.fphx1-2.fna&oh=00_AfCBQ9UuDafnXbv3BgUaSU1EKGKhAzdTcLut2UslKbQb1g&oe=6421B4AC

[40] Lora Appel et al., “Virtual Reality to Promote Wellbeing in Persons with Dementia: A Scoping Review,” Journal of Rehabilitation and Assistive Technologies Engineering 8 (2021): p. 205566832110539, https://doi.org/10.1177/20556683211053952.

Another field that would be positively impacted through adoption of gyroscopic multimedia technology in some way would be the themed entertainment and immersive attraction industries. As more themed amusement parks shift into a 21st century model of innovation and focus on more personalized guest experiences, wearable park devices are becoming more common. These devices store information such as your park ticket, add-ons such as skip the line or 'fast lane' upgrades, dining reservations, and other personalized park information. Newer generation models have also recently introduced the ability to interact with certain park statues and characters.[41] This technology could be taken further and lead into pre-ride line interactions. Currently, attraction lines that offer interactive elements offer them mainly in a fixed point of contact; the point of interaction is unable to adapt to the user who may be attempting to interact with the experience. If sensor-based interface technology was designed and integrated into these wearable park devices, they could easily be used for greater engagement in interactive immersive experiences.

A hypothetical example that I would like to propose is a 25 year-old guest who is using a power chair while at an imaginary theme park we'll term 'AttractionLand'. AttractionLand has a wearable park device, which our hypothetical guest is wearing, as well as interactive points of contact in the ride queue. Our hypothetical guest is unable to fully engage with the pre-ride interactive elements due to the interaction point being placed above the average seated height of a wheelchair user, resulting in a diminished experience for the hypothetical guest in question. A solution that involves the gyroscopic

[41] "MagicBand+," Disneyworld.disney.go.com (Walt Disney Company), accessed March 23, 2023, https://disneyworld.disney.go.com/guest-services/magicband-plus/.

technology used in my thesis project would be in the utilization of guests' minimum, maximum, and average range of motion data in the x, y, and z axes. This movement data could be communicated to the interactive element in question, which should not be too large of a challenge as data communication in regards to motion and acceleration data already occurs in some of these interactive elements and devices that utilize motion activation.[42] Attraction designers and engineers would be able to retrofit existing participatory attractions, and design future ones, with the ability for interaction points to be adaptable to the individual guest's personalized range-of-motion data that is collected through their park devices. This type of application would have massively positive effects in regards to opening up areas of accessibility and interaction that past guests may have missed out on.

To conclude, the ability to create multimedia interfaces and digital musical instruments that are accessible is currently available. However, it is not being explored to its full potential as an option for trained musicians and other creatives who are no longer able to pursue their original instrument or other method of creative expression due to injury or disability. My project and paper work show that it is possible to create a DMI that is relatively inexpensive, user friendly, customizable, and fully accessible. The current cost for a monthly subscription of Max/MSP is currently $9.99 USD a month, with a full license $399. [43] Adding a microcontroller to this setup could be done rather

[42] "Disney Fab 50 Character Collection," Disneyworld.disney.go.com (Walt Disney Company), accessed March 23, 2023, https://disneyworld.disney.go.com/attractions/magic-kingdom/fab-50-character-collection/.
[43] Max | Shop | Cycling '74. cycling74.com/shop/max.

cheaply, with Electrosmith's *DaisySeed* controller being able to run Max patches.[44] As we create a more open and diverse society, it will only become more important to explore how we can utilize sensor based interactions as a bridge towards a more equal future.

[44] "Daisy Seed — Electro-Smith." Electro-Smith, www.electro-smith.com/daisy/daisy.

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APPENDIX A

MARI KIMURA'S "MUGIC_STARTER" MAXMSP PROJECT

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APPENDIX B

MY “MUGIC & MOTION” MAXMSP PATCH USED IN SAGUARO SOUNDS CONTEMPORARY CONCERT

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-----------end_max5_patcher-----------
</code></pre>

APPENDIX C

MY “RINGDRONE” MAX/MSP PATCH

<pre><code>
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-----------end_max5_patcher-----------
</code></pre>