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The Co-Evolution of Humanity and Technology

On Consciousness, Symbiosis, and Mediated Techno-Sensorial Experiences

by

McLean J. Macionis

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Supervisory Committee

Ajay Kapur

Mentor

Jordan Hochenbaum

Committee Member

Michael Leisz

Committee Member

"Admirable and amazing are all things of which we do not know the causes…"

-Francesco de Vieri

Abstract

This thesis represents an exploration of the relationship between humanity, technology, consciousness, and nature. In particular, this research addresses the question regarding how modern technology, which includes software and hardware, might better assist humanity in 'becoming.' This term describes a process in which an individual achieves greater self-awareness, mindfulness, and inner peace, which leads to improved self-esteem, personal growth, and mind-body wellness. The majority of this document describes three projects, created over a period of two years, that utilize unique combinations of technology in order to produce multimedia and multisensory experiences. These experiences engage the human senses in abstract and unfamiliar ways in order to encourage audiences to reconsider the proximity of the self to technology. The projects are organized in the document as follows: Chapter 3 introduces Sansa, an extended thumb piano that invites users to control the instrument with more than just their fingers; Chapter 4 presents a mixed-media installation titled *Where Is The Quiet?* that immerses visitors in an atmosphere of stillness and serenity; Chapter 5 describes an interactive exhibition called *z3R0* in which participants use their thoughts to simultaneously alter digital art and their physiological state. The cumulative findings produced by each of these projects reveals that it is possible to use technology to serve humanitarian needs in ways that promote self-discovery, awareness, and interconnectivity. Most importantly though, this research opens the door to further exploration regarding how humanity and technology might co-evolve in ways that enhance life on Earth.

Acknowledgments

I am tremendously grateful for the people in my life that have supported my personal and artistic endeavors over the last two years. Each one of them encouraged me to dream big, enjoy the journey, and find a balance between pursuing my professional goals and taking care of myself.

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Finally, I want to thank my community. To my friends at CalArts, each one of you is a role model for me. Thank you for bravely expressing yourself, exploring your edges, and witnessing my personal growth. To the wellness community, you are my anchor. Thank you for encouraging me to stay open. You gave me with a light to see through the dark.

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Chapter 1

Introduction

Human beings are constantly becoming. That is, each individual, regardless of whether or not they are aware of this process, is discovering what it means to be human and, consequently, living the fullest life possible at any given moment in time. This notion of 'fullness' with regards to life is arbitrary. While society generally recognizes a singular definition of this term that is circumscribed by certain images of success such as financial security and material wealth, this definition and its associated conditions are far from ubiquitous. Rather, what might be considered a ubiquitous human condition is that each individual is a moment away from self-discovery. Typically, self-discovery happens in two distinct manners: first, as a sudden and momentary burst of understanding that often concerns one or more aspects of the self, including identity and existence; and second, as the gradual accumulation of knowledge that is most often characterized by the word 'wisdom.' Neither manner is superior to the other. It is only important to acknowledge the universal nature of self-discovery as it relates to human life on Earth.

An essential element of becoming is consciousness. This term, which is loosely synonymous with 'awareness,' is seldom discussed without debate. In fact, there is little agreement amongst thinkers regarding the exact origin and meaning of consciousness. Some even deny its existence altogether.[1] This collective disagreement is summed into a singular statement by philosopher David Chalmers in his essay titled "Facing Up to the Problem of Consciousness." In this essay, he explains that "there is nothing that we know more intimately than conscious experience, but there is nothing that is harder to explain." (Chalmers 1995) Despite how little is known about consciousness, there is no shortage of working definitions. In

[1] Daniel Dennett, among others.

the same essay, Chalmers describes the basis by which a system might be considered conscious. He states:

> Sometimes a system is said to be conscious of some information when it has the ability to react on the basis of that information or, more strongly, when it attends to that information or when it can integrate that information and exploit it in the sophisticated control of behavior. (Chalmers 1995)

To further simplify this idea, Chalmers compares the experience of consciousness to a state of wakefulness. He points out that “all it means for a system to be awake is for it to be able to use this information in directing behavior in an appropriate way.” (Chalmers 1995) From the previous passages, it is clear that consciousness according to Chalmers, in a basic sense, is organized around the ability to perceive information and make decisions based on the content of this information. What is unclear, however, is the nature of ‘information’ and how it relates to consciousness.

The information that Chalmers is describing forms the basis of human experience. Every individual receives information by way of the senses i.e. touch, sight, smell, hearing, and taste. Once they are aware of this information, it immediately forms a single stream of sensory data that is then used to construct an interpretation of the present experience. Prior to the advent of technology, hereby referring to the collection of objects, tools, systems, and institutions that increasingly define how human beings live, express, communicate, and interact with each other, the process of constructing an interpretation was quite simple.[2] For example, a person felt the warmth of the sun on their skin, heard a storm in the distance, or smelled food cooking over a fire. The sound of an aircraft engine only existed in the imagination of a few twentieth century engineers and pocket-sized intercontinental communication devices were inconceivable. Modern technology is therefore disrupting the most fundamental aspects of human life by generating new pathways between objects, mediums, and people by way of intangible networks and extraordinary sensory information. In other words, technology is revolutionizing how human beings live, which ultimately impacts how they become.

[2] The following experiences are not necessarily simple. Rather, they are built upon millennia of living close to the land and are therefore easily absorbed by our innate primal instincts and intuition.

Humanity is in a symbiotic relationship with technology. Without technology, humanity would almost certainly perish. Without humanity, technology would cease to exist. The implication of this relationship is that both sides are co-evolving. This particular idea is explored at length in Kevin Kelly's book titled *What Technology Wants*. Kelly begins the book by describing the 'technium,' a term that represents "culture, art, social institutions, and intellectual creations" in addition to "software, law, and philosophical concepts." (Kelly 2010) He then explains that mutualism, which arises out of codependence, is readily apparent in the relationship between humanity and the technium. "We are coevolving with our technology," he says to the reader, "and so we have become deeply dependent on it." The consequence of this dependency is both opportunity and risk. On the one hand, Kelly argues that the technium affords each individual with "a chance to excel at the unique mixture of talents [that] he or she was born with, a chance to encounter new ideas and new minds…, and a chance to create something his or her own." On the other hand, he explains that "certain aspects of the technium are detrimental to the human self because they defuse our identity" and "harm nature." Despite the potential for harm, Kelly urges readers to invest in the technium:

> Our mission as humans is not only to discover our fullest selves in the technium for others, and to find full contentment, but to expand the possibilities for others. Greater technology will selfishly unleash our talents but it will also unselfishly unleash others: our children, and all children to come. (Kelly 2010)

The process of self-discovery that Kelly is describing in this passage is analogous to the process of becoming that was introduced at the beginning of this chapter. This is a crucial observation as it reveals that technology supports human evolution in ways that promote awareness.

The particular ways in which technology communicates information to the human senses is an active topic of exploration amongst artists. In fact, museums and art institutions have staged entire exhibitions dedicated to this topic. One such exhibition, called *Sensorium*, premiered at the MIT List Visual Arts Center in Cambridge, Massachusetts in 2006 and 2007. Coinciding with the exhibition's debut was a book release with the same title. In the book's opening pages, editor Caroline A. Jones states that *Sensorium* offers "encounters with and reflections on embodied experience in an ever more technological world." (Jones 2006) She continues by explaining that the "authors and artists variously engage embodied technology and the technologized body, investigating how technology changes our understanding of the senses." The remainder of the book includes essays on the theoretical and practical basis of the featured artworks. These essays stimulate the reader to consider the manner in which technology mediates their conscious experiences by engaging the human senses in increasingly abstract and unfamiliar ways. Audiovisual artist Ryoji Ikeda utilizes technology in this way. His work, which is discussed in *Sensorium*, "assaults the body, stimulating many of the senses at once, and transcends, or rather rejects, linguistic or image-based interpretation." (Jones 2006) In the absence of familiarity and faced with technological encounters that directly address the body and consciousness, a renegotiation between the self and technology is inevitable. This point is further developed in a quote by media theorist and performance artist Allucquére Rosanne Stone. She declares that:

> [This is] the adventure that is our [humanity's] future, as we immerse ourselves ever more deeply in our own technologies; as the boundaries between our technologies and ourselves continue to implode; as we inexorably become creatures that we cannot even now imagine. (Jones 2006)

In no other space is the process, or rather the reevaluation, of self-discovery and becoming more apparent than in *Sensorium*. In this exhibition, artists explored the edges of sensorial art mediated by an ever more complex array of technology. The consequence of this exploration is human experiences that transcend syntactical representations of meaning and instead disseminate information that communicates directly to human consciousness by way of the senses. This is technology that brings humanity closer to its fullest expression as characterized by an increase in awareness, reflection, and self-realization. Poet Mark Doty, in an essay on Samuel Galison's installation titled *Television Horses*, articulates this attitude clearly through an inquiry. He asks, "what would be the consequences, if our artifice turned out to be a means of opening the doors of perception?" (Jones 2006)

This inquiry inspired the projects that are presented in this thesis. In an era of unprecedented hyperconnectivity, individuals and groups that facilitate human self-discovery must consider technological space, including physical and digital space, as a valid environment for these types of experiences to unfold. To presume that these moments of awareness only manifest in nature is inadequate under the present circumstances. Instead, this thesis argues, in light of the unique multisensory experiences that are imaginable through networks of communicating technologies, that mediated techno-sensorial experiences might serve human becoming like never before.

The remainder of this document is organized as follows. Chapter 2 provides a brief historical overview of the 1960s countercultural revolution and lists several artists whose work directly influenced the projects that are presented in this thesis. Chapter 3 introduces Sansa, a hyper-instrument that uses machine learning and a series of sensors to extend its functionality far beyond its original design. Chapter 4 describes an immersive mixed-media installation called *Where Is The Quiet?* that enhances individual, communal, and environmental awareness through systems of complex technologies. Chapter 5 presents an artistic application of the Muse 2 brain-sensing headband, called *z3R0*. Chapter 6 offers concluding remarks and describes the premise of future work in this field.

Chapter 2

Related Work

This chapter serves as a review of the artists that influenced the projects that are presented in this thesis. These individuals and groups, many of whom produced multimedia and multisensory experiences, inspired several decades of art-making and pushed the boundaries of experimental performance practices. In order to better understand the context in which these artists emerged, this chapter begins with a brief historical overview of the 1960s countercultural revolution (2.1). The content of this overview is by no means exhaustive. Instead, it focuses on the San Francisco Tape Music Center (SFTMC), an organization that revolutionized the sonic arts (2.2). Section 2.3 through 2.7 name additional key artists and summarize their work. Finally, section 2.8 expounds on the contributions of each of these artists to the contents of this thesis.

2.1 Experimental Art and Performance Practices During the 1960s

The 1960s are often characterized by creativity, hippie culture, drug use, and the emergence of the avant-garde. In New York City, artists such as Yoko Ono, shown in Figure 2.1, The Velvet Underground, and Andy Warhol participated in the first downtown art scene by staging exorbitant and unpredictable events.[3] In South America, populous folk movements such as La Nueva Canción and Tropicália revolutionized the prevailing political and cultural climate through music and organized masses.[4] In San Francisco, the counterculture flourished as hordes

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[3] For narratives that recall this period of time, see Richard Hell's book *Massive Pissed Love*.

[4] For more information, see Caetano Veloso's book *Tropical Truth: A Story of Music and Revolution in Brazil* and J. Patrice McSherry's book *Chilean New Song: The Political Power of Music, 1960s – 1973*.

of artists and hippies congregated in districts such as Haight-Ashbury in order to celebrate new social norms.

Despite their geographic differences, the artists who were involved in these movements shared the same fundamental artistic vision. That is, a growing fascination with experimentation and the amalgamation of what were typically considered distinct artistic disciplines. No longer constrained by the boundaries of normative art-making and traditional schools of thought, these artists created cross-disciplinary works by collaborating and organizing communal events. For example, the New York avant-garde artist collective known as Fluxus planned curated interdisciplinary events called Happenings in which the relationship between the audience and performer was skewed. (Higgins 2002) At the same time on the West Coast, the San Francisco Tape Music Center organized concerts and festivals in partnership with the city's diverse artistic community using revolutionary technologies for sound-making (discussed in 2.2). (Goebel and Rockwell 2008)

Figure 2.1 – Yoko Ono performing *Cut Piece*. Ono was an acclaimed member of Fluxus

These communities are significant in part because they disrupted traditional art norms, for example the tendency to confine artistic experiences to museums, galleries, and concert halls. Fluxus and the Tape Music Center, however, presented their works in unconventional spaces resulting in unique encounters.[5] Their unwillingness to assimilate into long-established artistic norms points to a denial of a singular definition or standard with regards to art. Indeed, these groups set an important precedent; innovative artistic experiences are born at the borders that separate disciplines, and even in the most mundane moments of time. The next section explores this notion further through a close examination of the SFTMC and their body of work.

2.2 The San Francisco Tape Music Center[6]

During the 1960s, San Francisco developed a reputation as one of the leading cities in the worldwide countercultural revolution. Amongst the city's residential demographic were hippies and other freethinkers, a large LGBTQ population, and artists from multiple creative backgrounds. These communities were distinct but hardly independent. In fact, individuals often identified with several of these communities, and it was common for the larger communities to work together in order to advance their shared projects and interests.[7] Amongst the most important examples of this communal cooperation are the cross-disciplinary collaborations that took place between the city's artistic organizations, including the San Francisco Actor's Workshop, Ann Halprin's Dancer's Workshop, and the San Francisco Mime Troupe, among others. These collaborations produced new methods of art-making and unique multisensory experiences that, over time, lead to groundbreaking developments in the field of art and technology. One such group at the forefront of these developments was the San Francisco Tape Music Center.

The SFTMC was founded in 1961 by Ramon Sender and Morton Subotnick. Sender, then a composition student at the San Francisco Conservatory of Music, had noticed that there was "an immediate need for a studio for the production of sounds by electronic means and for a concert hall in which to present programs of an experimental nature." (Goebel and Rockwell 2008) In response to this need, Sender created a tape recording studio in the attic of the music

[5] In particular, the SFTMC hosted concerts in city streets, basements, and living rooms.
[6] The following section contains passages from an essay that I wrote for Evyind Kang's fall 2018 "Experimental Pop" class. The material is reused due to its relevance to the topic at hand.
[7] For example, Pauline Oliveros was a member of both the SFTMC and the LGBTQ population.

conservatory along with a series of concerts called "Sonics," which were co-organized by future Tape Music Center member Pauline Oliveros. The first of these concerts was successful and proved "that elegant music could be created using limited technical resources." Following the last of the Sonics concerts in 1962, the group moved to a new location on Jones Street in San Francisco and adopted their Tape Music Center identity. Figure 2.2 shows several of the long-standing members of the SFTMC.

Figure 2.2 – From left, Bill Maginnis, Tony Martin, Ramon Sender, Morton Subotnik, and Pauline Oliveros

Unfortunately, the SFTMC's time on Jones Street was short lived. A house fire during the summer of 1963 leveled the Tape Music Center's home and forced them to relocate to 321 Divisadero Street, shown in Figure 2.3. Despite this misfortune, the new space was better suited for studio work and contained two small auditoriums for holding concerts. Over several seasons, the Tape Music Center presented collaborative, multisensory, and interdisciplinary performances of an experimental nature. One such work, Ramon Sender's *Desert Ambulance* (1964), utilized a score composed of aural instructions sent to the performers via headphones, and "painted 16mm film" by visual artist Tony Martin. (Goebel and Rockwell 2008) Other works, while less collaborative, made "powerful statement[s] about nineteenth-century musical culture and specifically women's role in society," such as Pauline Oliveros' *Bye Bye Butterfly* (1965).[8]

[8] A recording of *Bye Bye Butterfly* is available here: https://www.youtube.com/watch?v=DMCTxkFwLHw

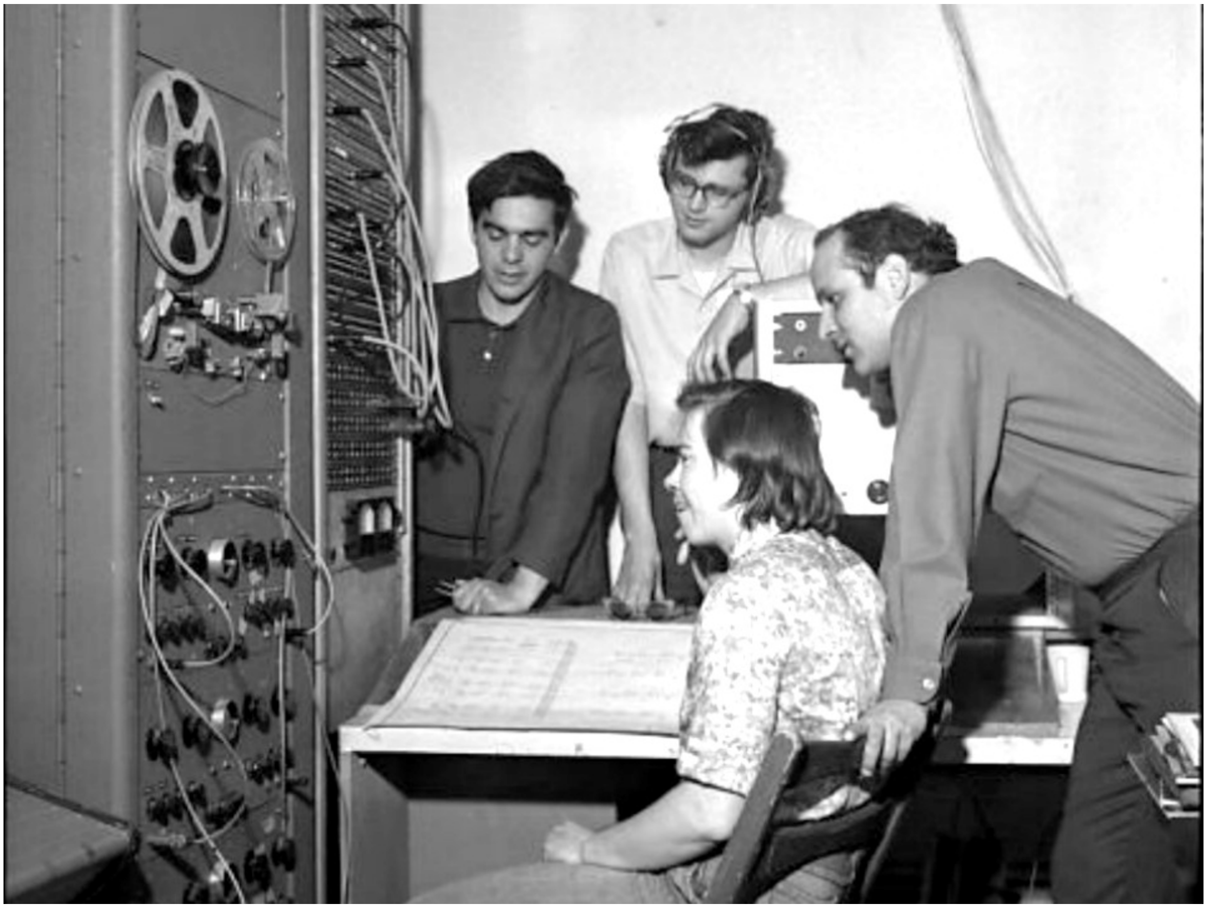

Figure 2.3 – Members of the SFTMC in their studio on Divisadero Street

The SFTMC was adept at isolating itself from the prevailing social climate. One way that they accomplished this was by remaining independent from major academic and corporate institutions. Sender articulated this ambition by saying:

> We have felt that somewhere there should be a place where the composer can find brought together all the necessities of his art in an atmosphere conducive to his developing his own personal utterance free from the pull and tug of stylistic schools and from the competitive scramble that typifies much of the musical activity of today. (Goebel and Rockwell 2008)

Even as other electronic music studios were emerging in the U.S. and Europe, characterized by partnerships with colleges and universities, the Tape Music Center "resisted institutionalization." Instead, they chose "a high degree of independence and self-sufficiency." (Goebel and Rockwell

2008) To this end, Sender and the other members of the organization sought out new ways to present their work.

Perhaps the most successful of these performances was *City Scale* (1963). This experiential event brought audience members on a physical journey through San Francisco in order to view several real-time art displays. These displays included: a "car ballet;" a performance by trombone player Stuart Dempster in a tunnel; a "woman in her bathrobe singing Debussy" from a building window; and dancers performing in "a broken-down vehicle." As a whole, the event played with the edge "between order and chaos" whereas "the viewers… [would] look more carefully at everything and try to figure out if a particular event was staged or just happening." (Goebel and Rockwell 2008) The nature of these performances is suggestive of the Happenings by Fluxus. Both Fluxus and the SFTMC shared a disdain for traditional artistic institutions, a position that was also reflected in each organization's art practices.

One of the most important artistic conventions that the SFTMC created was the notion of "music as studio art." This phrase, coined by Morton Subotnick, describes an approach to composing in which the composition also encapsulates the performance. According to Subotnick, he invented this concept while working with the Actor's Workshop in San Francisco on a production of *King Lear*. "It was really the work with *King Lear*," he explained in an interview, "that made me understand that I could combine my performing ability with my composing and put together a new concept, which I called 'music as studio art.'" (Goebel and Rockwell 2008) This concept eventually inspired Subotnick to team up with Don Buchla, an engineer living in San Francisco, for the purpose of devising a revolutionary new instrument.

Near the end of 1964, they created the Buchla 100 Series Modular Electronic Music System, shown in Figure 2.4. The Buchla, as this instrument was abbreviated, is a modular synthesizer that allowed users to program sounds on-the-fly using patch cables, voltage-controlled oscillators and filters, step-sequencers, and other hardware electronics. However, the most striking feature of this machine is its lack of a black and white keyboard. Instead, the Buchla Box includes a "touch-controlled voltage source, with individual A and B control outputs per touch-sensitive area (pad) and… [a] pressure-sensitive C control output that could control amplitude [and] frequency." (Beyler 2003) This feature breaks the "standardized link to the traditional tonal scale" resulting in "greater freedom for the synthesist but also more difficult integration with other music and musicians." The instrument's complexity resulted in poor commercial viability after its initial release. However, it radically changed the long-standing relationship between musician and sound object; users were required to rely solely on the Buchla's unfamiliar interface to generate musical forms, arrangements, and soundscapes.

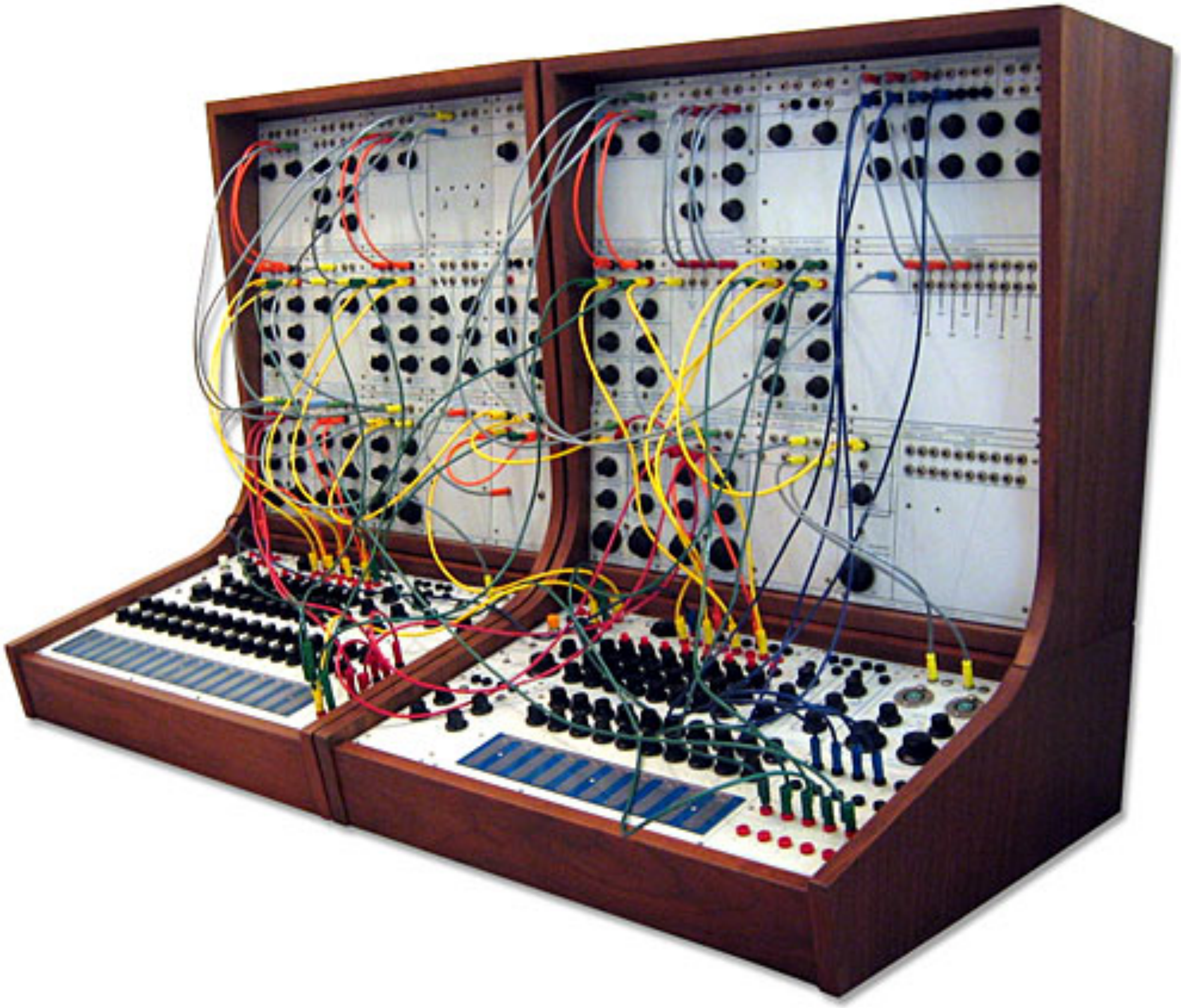

Figure 2.4 – The Buchla 100 Series Modular Electronic Music System

The SFTMC's achievements in the area of experimental art practices resulted in worldwide recognition and set an example for forthcoming generations of artists, composers, technologists, and even entire music scenes. For example, both the Buchla and Subotnick's notion of "music as studio art" presented artists with a new way of conceiving unique sonic experiences in the studio and on stage. Recording artists such as Kaitlyn Aurelia Smith, shown in Figure 2.5, and LCD Soundsystem, shown in Figure 2.6, have taken advantage of this methodology by blending synthesized tones with elements from popular music. These hybrid tracks are then manipulated in real-time during performances using modular synthesizers. The Tape Music Center's use of interdisciplinary performances, immersive experiences, and new art venues also set a powerful precedent for artists that continues to this day. It is now common to experience art in non-traditional venues, such as city streets, alleys, and parks, among others. Furthermore, art events are often multidimensional, meaning that they include several layers of media and interactivity. One artist that has earned acclaim for producing multidimensional art is Björk, shown in Figure 2.7. Her work regularly combines fashion, visual art, set design, sound, and technology. She has also pursued new means of sharing music through phone applications, virtual reality experiences, and the invention of new instruments for musical expression.[9, 10, 11]

Figure 2.5 – Kaitlyn Aurelia Smith

[9] https://itunes.apple.com/us/app/bj%C3%B6rk-biophilia/id434122935?mt=8
[10] https://www.latimes.com/entertainment/arts/la-et-cm-bjork-digital-20170518-htmlstory.html
[11] https://www.vice.com/en_us/article/eza747/a-guide-to-bj%C3%B6rks-custom-ibiophiliai-instruments

Figure 2.6 – LCD Soundsystem

Figure 2.7 – Björk

Even though artists and researchers are charting the course for emerging technologies such as virtual reality and machine learning, the Tape Music Center's inventions and achievements are as relevant now as they were in the past. The nature of globalization, the creation of vast online knowledge bases, and the rise of hyperconnectivity means that artistic works are more often the culmination of ideas from multiple sources. In other words, collaboration and the proliferation of multidimensional work are the norm within art forms. The

Tape Music Center is not the only entity with this legacy. In fact, many of the Tape Music Center's peers, as well as their contemporaries, have produced multisensory experiences that explore the edges of artistic expression. The remainder of this section lists several of these artists and introduces their work.

2.3 Hans Haacke

Hans Haacke is a German artist that, throughout his decades-long career in the international art scene, is recognized for his acute observations and radicalism. On the latter subject, Haacke criticized the predominant artistic institutions of the twentieth century for how they commodified art and suppressed artistic expression. In the artist's own words:

> In order to gain some insight into the forces that elevate certain products to the level of 'works of art' it is helpful – among other investigations – to look into the economic and political underpinnings of the institutions, individuals and groups who share in the control of cultural power. (Grasskamp 2004)

He continues by stating that a "galleries' promotional resources should be used without hesitation for a critique of the dominant system of beliefs while employing the very mechanisms of that system." This dissatisfaction with art culture and the resulting institutions are visible in works such as *MoMA Poll* (1970), shown in Figure 2.8.

In addition to institutional critique, Haacke was fascinated with real-time organic systems, and ultimately designed several pieces that exploited them. These pieces, which are perhaps best described "in terms of the physical energy they harnessed or consumed," focused primarily on natural processes such as growth, interactivity, and indeterminacy. (Grasskamp 2004) For example, *Rain Tower* (1962) created an "event container" made up of acrylic structures that let "water run through the holes in its subdividing floors." The resulting work was not only visually compelling but also it presented an "operative structure" based on environmental processes. Other works such as *Blue Sail* (1964), shown in Figure 2.9, *Grass Cube* (1967), and *To The Population* (1998) reference nature through their use of motion and energy.

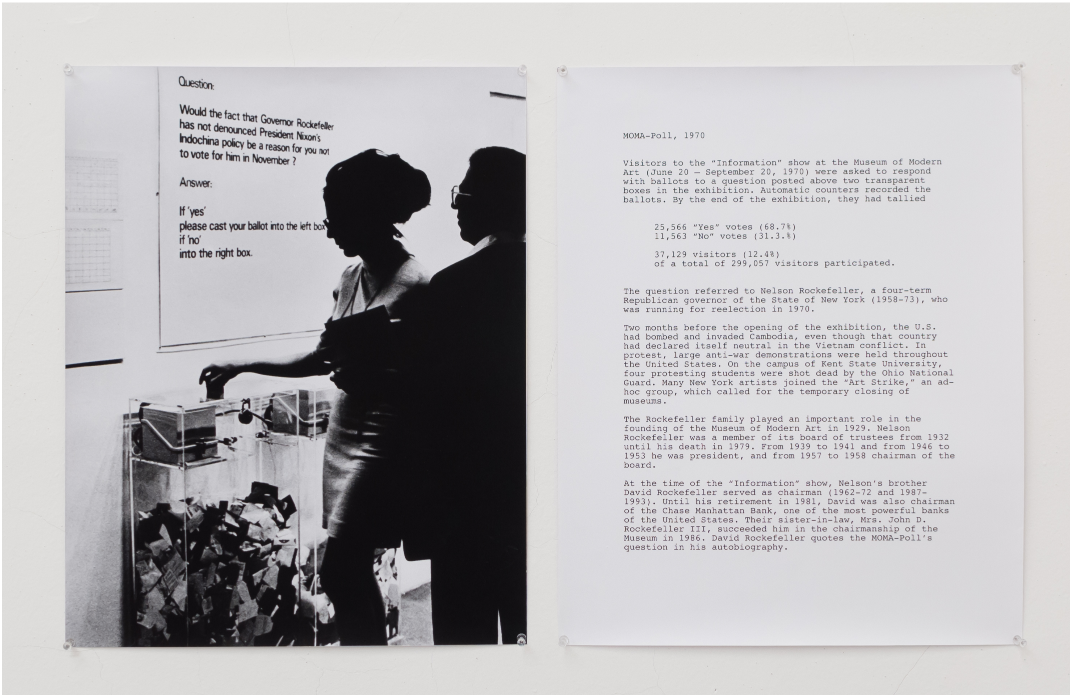

Figure 2.8 – *MoMA Poll* (1970) by Hans Haacke

Figure 2.9 – *Blue Sail* (1964) by Hans Haacke

2.4 Céleste Boursier-Mougenot

Céleste Boursier-Mougenot is a French contemporary artist with roots in theater and music. His artistic output is primarily installation-based and many of these projects involve live animal or plant subjects. The use of these subjects illustrates his "romantic fascination with natural life and mechanical objects, and his confounding of these two opposing forces through interactive installation[s]." (Gelsomini 2016) He expands upon this notion in an interview with The Seen journal in 2016, stating that his "work is meant to unfold as an encounter, be it the encounter of a vacuum cleaner with a harmonica, that of a drum set with cherry pits falling from the sky, or that of the viewer with a compelling situation." One of his most striking works is titled *clinamen v.3* (2012), shown in Figure 2.10. In this piece, porcelain bowls travel through a pool of water "producing a percussive soundscape of unexpected musicality." (SFMOMA 2017) Another work titled *from here to ear v.19* (2015), shown in Figure 2.11, involved the introduction of seventy zebra finches into a museum gallery that had been prepared with acoustic and electric instruments. In this encounter, "the finches replace[d] the artist as composer of the piece," creating an indeterminate sound world based on their chance landings. (Gelsomini 2016)

Figure 2.10 – *clinamen v.3* (2012) by Céleste Boursier-Mougenot

Figure 2.11 – *from here to ear* (2015) by Céleste Boursier-Mougenot

2.5 Olafur Eliasson

Olafur Eliasson is a contemporary Icelandic-Danish artist known for producing sculptures and installations. Not only do his works reference nature or natural processes but also they incorporate natural elements directly into the works. For example, *Inhale, Exhale* (2018), shown in Figure 2.13, involves several sheets of transparent colored glass layered together and mounted onto driftwood retrieved from the Icelandic shore. In 2018, Eliasson produced a large installation that was on display at the Marciano Art Foundation in Los Angeles, California. This piece, titled *Reality Projector* (2018), involved a moving projector shining a light through several transparent colored sheets of acrylic. The interaction between the light and the acrylic produced a moving landscape of colored shapes akin to the slow motion of clouds in the sky. A musical score, composed by Icelandic musician Jónsi using "noises generated by the process of building a piano from component parts," accompanied the visual experience. (Knight 2018) In a review of the work, journalist Christopher Knight described the work as "a languid, sometimes portentous composition," noting that "the sequence of scraping, clanging, creaking, gonging sounds [was] as aurally prismatic as the colors [were] visually." Figure 2.12 shows the installation at the exhibition space in Los Angeles.

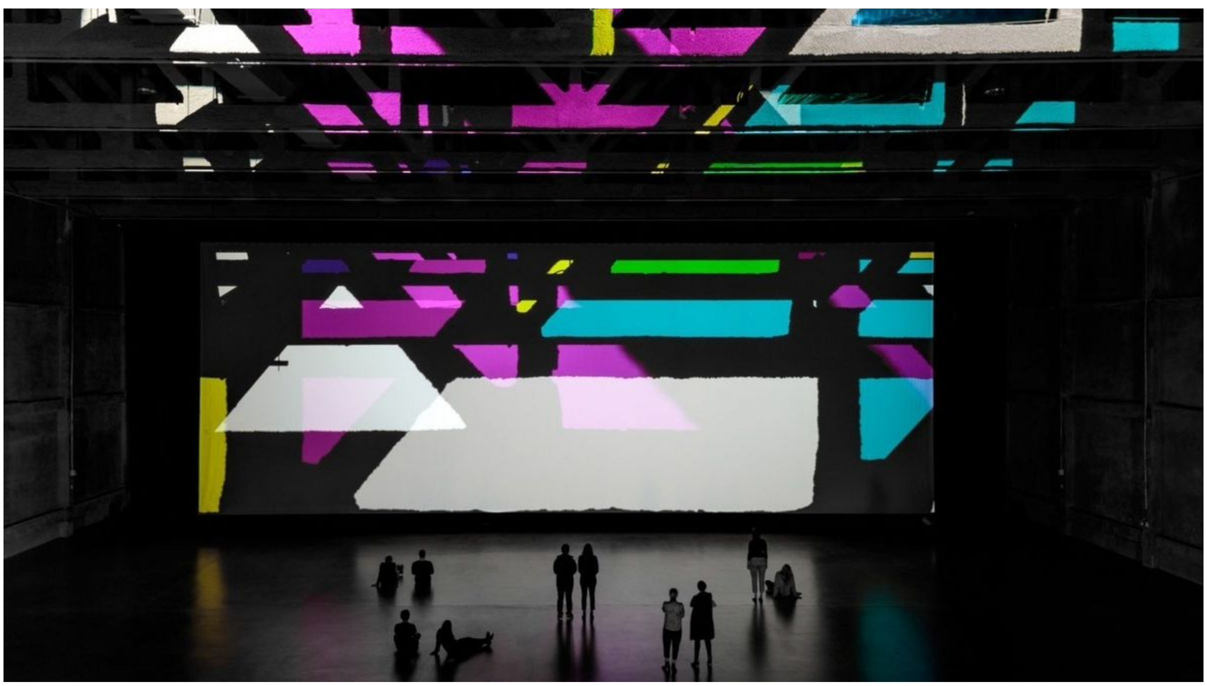

Figure 2.12 – *Reality Projector* (2018) by Olafur Eliasson

Figure 2.13 – *Inhale, Exhale* (2018) by Olafur Eliasson

2.6 Pipilotti Rist

Pipilotti Rist is a video artist and installation designer from Switzerland. At the heart of her work is a deep fascination with color, nature, technology, and feminism. In particular, many of her installations involve "transformative experiences" where the audience is exposed to "fluid and hypnotic imagery often focusing on the convergence of nature and technology." (Pipilotti Rist 2019) In a New York Times article about her life and artistry, she was quoted as saying "the whole question of how to put art into regular life is what interests me the most." (Kennedy 2009) To this end, her work excels at "bringing the world right up to your nose… but doing so while inviting you to relax [and] stretch out." One of Rist's most famous works, titled *Pixel Forest* (2016), is a video installation that places viewers in the middle of an immersive experience. Audience members sit on large meditation cushions on a carpeted floor in a gallery space while watching a film that is projected onto two perpendicular walls all the while surrounded by hanging LED lights. Figure 2.14 shows a specific iteration of this piece. Other installations of this nature include *Worry Will Vanish* (2015) and *Gravity Be My Friend* (2007).

Figure 2.14 – *Pixel Forest* (2016) by Pipilotti Rist

2.7 Bruce Conner

Bruce Conner was an American artist who is famous for his artistic phases, which span multiple disciplines including film, sculpture, assemblage, drawing, painting, and photography, among others. During each of these phases, the artist explored a different medium and then "pushed [it] to the breaking point" before finally abandoning it for something else. (Hatch 2016) Despite the drastic differences between these mediums, Conner's work "consistently [pointed] inward, toward an unreachable center, even as it [opened] out toward the public sphere." This direction is evident in many of his felt-tip pen works such as *Untitled* (1965), shown in Figure 2.15, and *Mandala* (1966). In his book titled *Searching for Bruce Conner*, author Kevin Hatch comments on these drawings saying that they "attempt to illuminate the very forces of energy and mutability coursing through the universe of sense experience." This interest in the energetic forces of the universe is also visible in Conner's photographic works, particularly *Sound of Two Hand Angel* (1974), shown in Figure 2.16. Indeed, this work reflects his "long-standing fascination with light shining through various surfaces whether in art, as when particles of dust would sparkle on black film leader during projection, or in nature, as in the filtering of sunlight through leaves." (Hatch 2016) Other well-known works by the artist include *Black Dahlia* (1960) and *Crossroads* (1976).

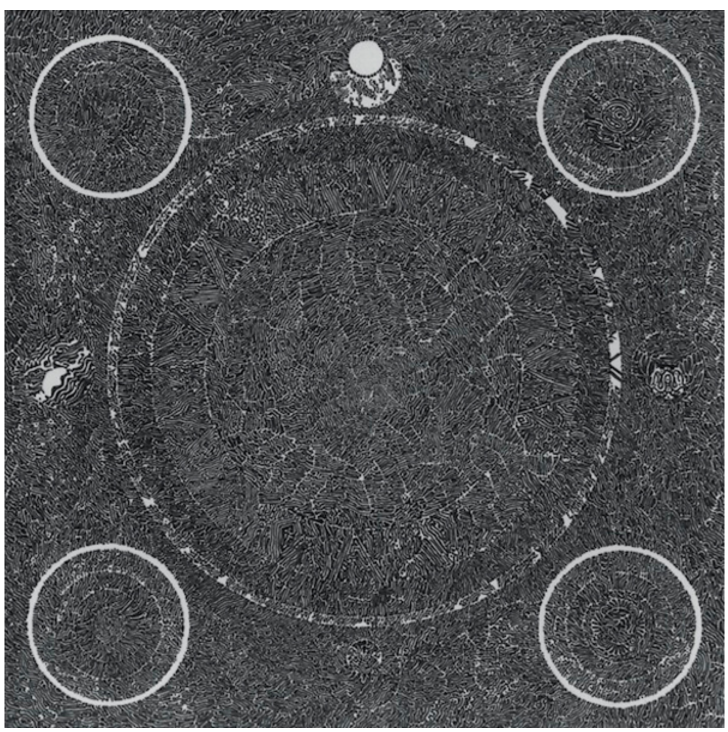

Figure 2.15 – *Untitled* (1965) by Bruce Conner

Figure 2.16 – An exhibition in The Museum of Modern Art with several of Bruce Conner's photographic works, including *Sound of Two Hand Angel* (1974)

2.8 Summary

Each of the aforementioned artists significantly inspired the projects presented in this thesis. In moving forward to the project reports, it is worth recalling the technical and conceptual elements that are underlying these artistic works. Technically, these works exhibit multidisciplinary tendencies, drawing on a combination of old and new technologies in order to generate meaning and stimulate a dialogue about the subject matter. Furthermore, they address the audience from several different sensory angles in order to cause a visceral reaction to the work. Conceptually, they explore the boundaries between art, technology, consciousness, nature, and spirituality. For example, Boursier-Mougenot's *clinamen v.3*, Rist's *Pixel Forest*, Eliasson's *Reality Projector*, Conner's *Mandala*, and Haacke's *Blue Sail* evoke meditative states of consciousness. These pieces evoke meditative states of consciousness, which are characterized by the absence of distracting thoughts and the experience of physiological tranquility. Both the conceptual and technical basis of these works deeply impacted the following projects.

Chapter 3

Sansa[12]

Sansa is an extended sansula; a hyper-instrument that is similar in design and functionality to a kalimba or thumb piano. At the heart of this interface is a series of sensors that is used to augment the tone and expand the performance capabilities of the instrument. The sensor data is further exploited using the machine learning program Wekinator, which gives users the ability to interact and perform with the instrument using several different modes of operation (3.4). In this way, Sansa is capable of both solo acoustic performances as well as complex productions that require interactions between multiple technological mediums. Sansa expands the current community of hyper-instruments by demonstrating the ways that hardware and software can extend an acoustic instrument's functionality and playability in a live performance or studio setting.

3.1 Introduction

The sansula is a modern adaptation of the kalimba, a type of thumb piano that originates from southern Africa.[13] The instrument consists of metal tines that are mounted to a wooden block. The block is then attached to a hollow resonating membrane. There are two features that make the sansula an attractive choice for music technologists seeking to develop hyper-instruments. First, the instrument's simple interface makes it easy to pick up and play. This means that users of all musical backgrounds are able to explore the instrument with little to no prior experience using it. Second, the instrument's hollow frame is an ideal location for sensors and microcontrollers.

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[12] The following chapter is published in the 2018 Proceedings of the International Conference on New Interfaces for Musical Expression (NIME).

[13] https://www.hokema.de/en/products/sansula/

3.2 Related Work

Several related works involving extended thumb pianos inspired the design and development of Sansa. The first is *Kalimba Mocante* (2016) by Meng Qi; the second is *Ember* (2013) by Colin Honigman et al.; the third is *El-Lamellophone* (2014) by Shawn Trail et al.; and the fourth is *Kalimbo* (2017) by Rob Blazey. (Meng Qi 2019; Honigman, Walton, and Kapur 2013; Trail et al. 2014; Blazey 2017) These interfaces use real-time data streams from microcontrollers and sensors to expand the capabilities of homemade kalimbas.

Sansa is also motivated by a number of works within the field of machine learning, audio and gesture recognition, and multimodal analysis. Jordan Hochenbaum et al. used these techniques within the context of drum stroke computing and musical pedagogy. (Hochenbaum and Kapur 2013) Alongside Matt Wright, they also used these techniques to classify and distinguish between the playing styles of multiple musicians. (Hochenbaum, Kapur, and Wright 2010) Similarly, Parag Chordia et al., Kameron Christopher et al., Arne Eigenfeldt et al., Alex Tindale et al., and Manj Benning et al. relied on machine learning and multimodal analysis to recognize musical sounds and gestures for the purpose of enhancing musical performances. (Chordia and Rae 2008; Christopher et al. 2013; Eigenfeldt and Kapur 2008; A. Tindale, Kapur, and Fujinaga 2004; A. R. Tindale et al. 2005; Kapur, Benning, and Tzanetakis 2004)

Sansa draws on these examples and expands current research by showing that acoustic instruments are capable of uses far beyond their original design or functionality. In some cases, users might not need to play these instruments at all. Instead, they might rely on a series of vocalization and gesture recognition technologies in order to generate sound. Sansa builds on this notion; it utilizes machine learning and demonstrates how this technology is applicable to live performances.

3.3 System Architecture

3.3.1 Instrument Design

The instrument itself is a Sansula Elektra.[14] It contains a 3.5mm mini-jack, a piezo transducer and a condenser microphone, all of which are used to amplify the instrument's acoustic signal. In order to power the amplifier, and subsequently pass audio to a digital audio workstation

[14] https://www.kalimbamagic.com/shop/hokema-kalimbas/hokema-sansula-elektra

(DAW), it is necessary to connect the instrument to an audio interface with phantom power. Figure 3.1 and Figure 3.2 show the instrument's body including the built-in hardware.

3.3.2 Microcontrollers and Sensors

Sansa contains a Teensy microcontroller, an XBee wireless data transmitter, a battery, and a series of sensors. In particular, it includes a three-axis accelerometer and two force-sensitive resistors (FSR). The hardware components are located within the frame of the instrument and configured according to the diagram in Figure 3.3. There are several reasons for this design configuration. First, the sansula frame contains a hollow cavity which is suitable for housing small electronics. Second, installing the hardware within the frame of the instrument removes it from the user's line of sight, therefore limiting distractions during use. Finally, the frame provides an accessible location for applying pressure to the FSRs. While Sansa is in operation, the sensors generate a data stream based on the user's interactions with the instrument. The data is then transmitted wirelessly via the onboard XBee to a computer. ChucK, a music-oriented programming language, is used to parse and distribute the data to different applications.[15]

3.3.3 Machine Learning

Sansa provides users with precise control over compositional form and the arrangement of sound and music in real-time through its application of machine learning. This is accomplished using Wekinator, a machine learning program developed by Rebecca Fiebrink.[16] Wekinator is free and open-source and allows individuals to build interactive systems with supervised learning algorithms. A number of different algorithms are included with the software including AdaBoost, dynamic time warping (DTW), decision tree, and nearest neighbor.

Networking between Sansa and Wekinator is achieved using Open Sound Control (OSC).[17] First, Sansa sends the sensor data as a continuous stream of OSC messages from ChucK to Wekinator. These messages are then used to tell Wekinator to alter its behavior based on the chosen learning algorithm and training data. Next, Wekinator's Input Helper filters the data using averages, buffers, and other mathematical expressions. Sansa uses Wekinator's machine learning algorithms to great effect; they cue new musical sections, process audio, add or remove instruments from an arrangement, and drive a performance forward.

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[15] http://chuck.cs.princeton.edu/
[16] http://www.wekinator.org/
[17] http://opensoundcontrol.org/

Figure 3.1 – Front view of Sansa

Figure 3.2 – Rear view of Sansa

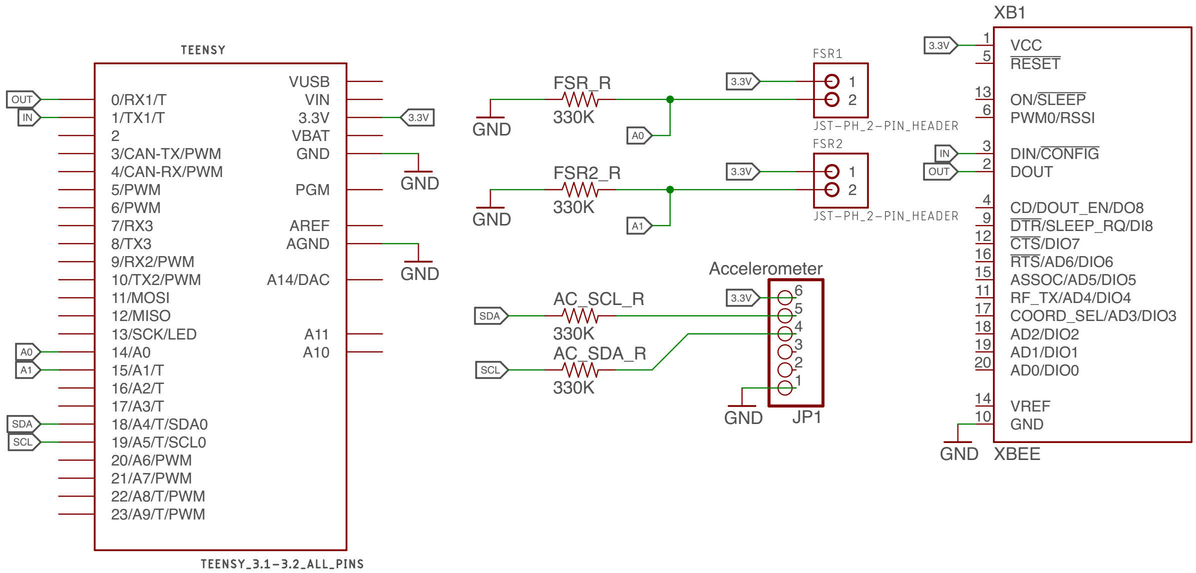

Figure 3.3 – An Eagle schematic outlining Sansa's electrical components

3.4 Operation

Sansa draws on its unique configuration of hardware and software to realize new ways of playing the sansula. This section describes five experimental live performance modes and several example applications of the data. The modes are organized as follows: conductor (3.4.1), advanced filtering unit (3.4.2), audio processor (3.4.3), drummer (3.4.4) and visualizer (3.4.5). The last section emphasizes Sansa's acoustic functionality (3.4.6). A diagram of the signal flow and example applications are shown in Figure 3.4.

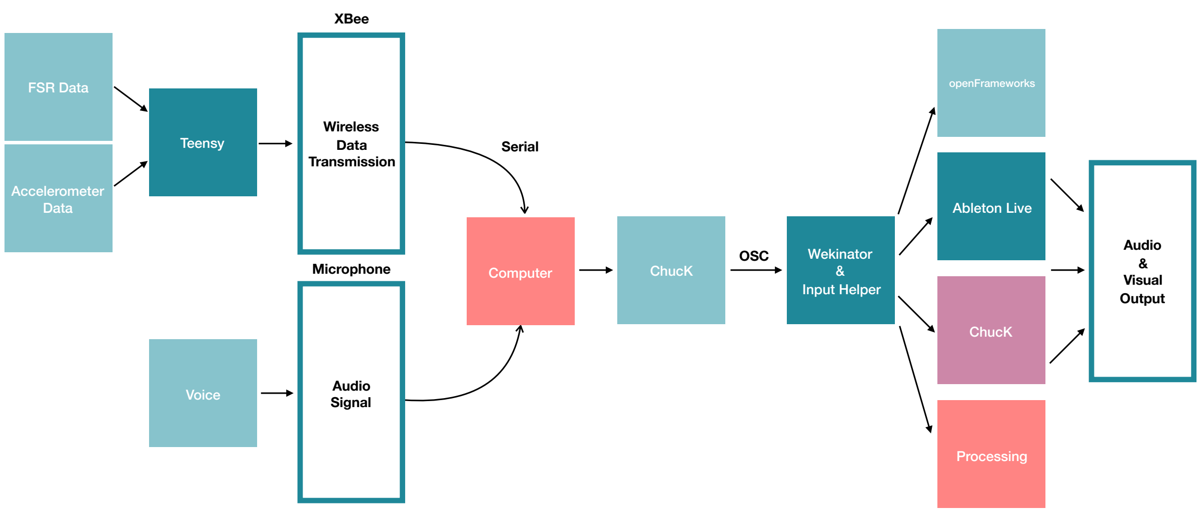

Figure 3.4 – Signal flow diagram

3.4.1 Conductor

Sansa is capable of organizing and conducting an entire ensemble of instruments by way of sensor mapping. Under one configuration, the sensor data triggers scenes in Ableton Live.[18] Tilting the instrument to the left or right moves the arrangement forward or backward; tilting the instrument to the front or back starts or stops playback. The FSR sensors apply effects to the stereo mix or individual tracks.

The conductor mode is also useful for score following. By using specialized gestures and Wekinator's dynamic time warping algorithm, Sansa is able to move through a score and shift between user modes. Figure 3.5 shows how a performer might move through a score using simple gestures and one possible score.

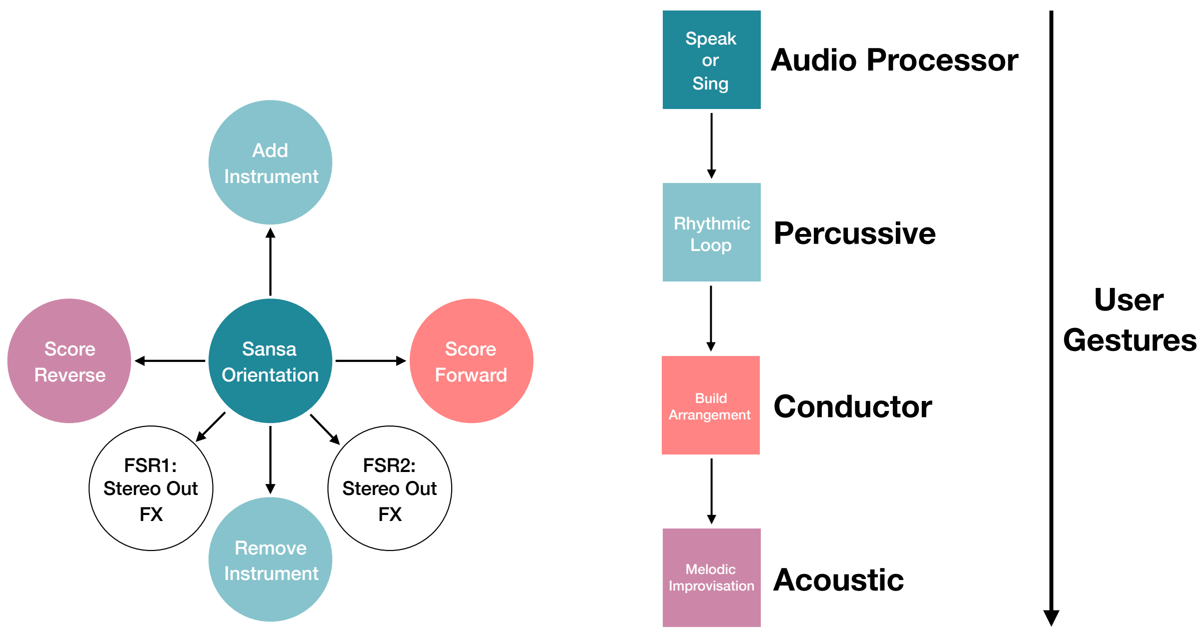

Figure 3.5 – Sansa's conductor mode mapping (right) and a potential score (left)

3.4.2 Advanced Filtering Unit

The advanced filtering mode of operation uses the sensor data to shape external audio. In this mode, the user is not required to play the instrument at all. Instead, their gestures shape the sound with a series of filters. Wekinator's Input Helper is especially useful in this mode as it allows the user to apply algorithmic formulas to the raw data before mapping the values to parameters in programs such as Ableton Live or Reaktor.[19]

[18] https://www.ableton.com/en/live/
[19] https://www.native-instruments.com/en/products/komplete/synths/reaktor-6/

3.4.3 Audio Processor

Sansa's internal microphone is able to capture the audio from external sources when placed near the source. This feature is especially useful for capturing vocal sounds or audio from other acoustic instruments. One application of this mode involves the user speaking or singing into the microphone in order to take advantage of any filtering or processing that is already taking place. Another application involves using Wekinator's DTW system and an audio feature extractor for timbre or speech recognition.

3.4.4 Drummer

Any user is able to rhythmically play the instrument's membrane. Sansa's internal microphone naturally amplifies such interactions. This mode is especially useful within the context of loop-based live performances. In this context, a performer records multiple layers of sound sequentially in order to create a complex melodic, harmonic, or rhythmic track. By sending percussive audio from Sansa to a looping device, such as a loop pedal or Ableton Live's *Looper* plugin, the performer is able to record and overdub in real-time thereby generating a rhythmic foundation to improvise over.

3.4.5 Visualizer

In addition to the aforementioned musical applications, Sansa's sensor data is capable of driving visualizations. Many visual programming languages, such as Processing, openFrameworks, and TouchDesigner, accept OSC messages.[20, 21, 22] This means that creating audio-reactive or gesture-reactive visualizers is as simple as sending messages between ChucK or Wekinator and the target visual programming environment. Musical performances take on more complexity and depth when combined with additional sensory information. Sansa is capable of driving both auditory and visual elements with ease.

3.4.6 Acoustic

It is worth emphasizing that Sansa is capable of purely acoustic performances. No modifications to the instrument were made that impede on the user's ability to explore the instrument without the use of the hardware.

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[20] https://processing.org/
[21] https://openframeworks.cc/
[22] https://www.derivative.ca/

3.5 Challenges and Limitations

Several challenges emerged during Sansa's development phase. First, mounting electronics within the frame of the instrument dampened the overall sound and shortened the decay of each note. One possible solution for restoring the original timbre of the instrument involves mounting the electronics away from the wooden resonator in some capacity. However, this would require new paneling for the back of the instrument, which might cause further tonal changes in addition to difficulties holding the instrument.

Another challenging aspect of this project was handling accelerometer data spikes. These data spikes are due in part to the accelerometer's location directly on the wooden resonator. Every note pluck vibrates the membrane, thus momentarily jostling the electronics. This resulted in unwanted sounds and changes to the arrangement. A combination of data averaging and a gentle playing style helped to minimize the effect of the data spikes, but some presence still remains.

Finally, striking the instrument while using the drummer mode (3.4.4) occasionally caused the internal microphone to malfunction resulting in loud amplified buzzing. Reinforcing the connection between the microphone and the mini-jack is necessary in order to resolve this issue.

3.6 Conclusion

Sansa is a powerful instrument that is capable of both simple and complex performances involving multiple technological mediums. Machine learning further extends the functionality of this instrument by providing users with a wider range of possible interactions. In this way, Sansa offers a peak at the sansula's future while simultaneously honoring the instrument's past.

Future work on Sansa will focus on two distinct areas of improvement. The first is minimizing the impact of the hardware on the overall sound and playability of the instrument. The most obvious means of accomplishing this is to substitute large microcontrollers for smaller ones, effectively reducing the mass of the hardware on the resonator. Another way to reduce the impact of the hardware on the instrument is to create a dedicated panel for the electronics that is isolated from the resonator. However, this runs the risk of impairing playability if the panel interferes with the user's grip on the instrument.

The second area of improvement involves Sansa's software and hardware system. A greater understanding of the audio and control capabilities related to latency, distortion, and connectivity is needed to better understand the instrument. Initial testing showed that Wekinator's DTW and nearest neighbor algorithms were the most well-suited for the instrument's intended design. However, more analysis of Wekinator's machine learning models is needed in order to optimize the instrument.

Future iterations of this project might also involve adding capacitive touch capabilities to the metal tines. This would allow users to generate MIDI or OSC messages by touching the tines. The benefit of this modification is that it creates a one-to-one relationship between playing a note and a resulting output.

Chapter 4

Where Is The Quiet?[23]

Where Is The Quiet? is a mixed-media installation that utilizes immersive experience design, mechatronics, and machine learning in order to enhance wellness and increase connectivity to the natural world. Individuals interact with the installation by wearing a brainwave interface that measures the strength of alpha waves. The interface then transmits the data to a computer, which uses it in order to determine the individual's overall state of relaxation. As the individual achieves higher states of relaxation, mechatronic instruments respond and provide feedback. This feedback not only encourages self-awareness but also it motivates the individual to relax further. Visitors without the headset experience the installation by watching a film and listening to an original musical score. Through the novel arrangement of technologies, *Where Is The Quiet?* demonstrates that mediated technological experiences are capable of evoking meditative states of consciousness, facilitating individual and group connectivity, and bringing attention to the natural world. As such, this installation opens the door to future research regarding the possibility of immersive experiences supporting humanitarian needs.

4.1 Introduction

One of the pitfalls of living in the twenty-first century, a time defined by the rise of technology and hyperconnectivity, is that there is a shortage of quiet spaces. That is, spaces that are free of distractions. Highway billboards lure eyes towards commercial displays. Phones and computers constantly advertise to users. Social media demands attention and activity. *Where Is The Quiet?* (*WITQ*), an immersive mixed-media installation, is intended as a meaningful escape from these distractions.

[23] The following chapter is published in the 2019 Proceedings of the International Conference on New Interfaces for Musical Expression.

This installation invites participants to consider the notion of quiet places, both internal and external, as it relates to the individual, the community, and the surrounding world. As such, the primary goal of this experience is twofold: first, to evaluate the potential for technology to improve individual and communal wellness; and second, to increase connectivity to the natural world. A single individual interacts with the installation by using a brain-computer interface (BCI) that measures relaxation as determined by the strength of alpha waves in the brain. Visitors without the interface listen to the soundtrack and watch the accompanying film, which includes footage of landscapes that are found in California, The Adirondack Park, and Vermont.[24] The use of environmental footage is deliberate; it suggests that it is possible to experience the natural quiet of nature through technology.

The installation was exhibited on October 29, 2018 in the WaveCave gallery at California Institute of the Arts (CalArts) for one week.[25] It was composed of film, musical score, brain interface, mechatronic singing bowls, carpet, and meditation cushions. The film and musical score are available online on Vimeo and Soundcloud.[26, 27]

4.2 Related Work

WITQ was motivated by several works in the areas of biofeedback, mechatronics, machine learning, and immersive experience design. With regards to biofeedback, Yoichi Nagashima's exploration of biosensors within the context of interactive performances served as a primer on exploiting this type of data for artistic purposes. (Nagashima 2003) Another influential work was Tomohiro Tokunaga and Michael J. Lyons' experiments using brain signals to alter sound and visuals in real-time. (Tokunaga and Lyons 2013) Javier Jaimovich was also involved in two notable projects that used biosignals for research and artistic purposes. (Jaimovich 2016; Jaimovich et al. 2012) Finally, Ryan McGee, et al. produced an audio-visual installation that changed form based on data from the cardiovascular system. (Mcgee, Fan, and Ali 2011)

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[24] I would like to take a moment to acknowledge the land and the indigenous peoples that occupy or occupied these places.
[25] http://wavecave.calarts.edu/
[26] https://vimeo.com/299370692
[27] https://soundcloud.com/mjmmusique/sets/where-is-the-quiet

Two papers inspired the installation's solenoid-based instrument system. First, a team of artists and researchers at University of Victoria in British Columbia wrote about solenoid implementations for musical expression with a specific focus on robotic drumming. (Kapur et al. 2007) This paper was especially useful for its discussion on how to handle certain issues that arise while using solenoids within a musical context such as timing and reducing mechanical noise. Second, A. Blokkum Flø and H. Wilmers' paper on their sound installation *Doppelgänger* described a methodology for designing networks of solenoid-based sound objects. (A. B. Flø and Wilmers 2015)

In the area of machine learning, research in gesture recognition was helpful in devising the installation's interactive system. One such paper by Baptiste Caramiaux and Atau Tanaka presented several implementations of classification and regression models within the context of musical performance and interface design. (Caramiaux and Tanaka 2013) Another paper by Margaret Schedel, et al. described how a band used machine learning during live performances. (Schedel, Perry, and Fiebrink 2011) Furthermore, Cornelius Poepel, et al. introduced a neural network system for tracking singing gestures to afford non-vocalists the experience of singing without actually vocalizing. (Poepel et al. 2014)

Many papers published in the NIME community on interactive installations were helpful in designing *WITQ*'s user experience.[28] Brennon Bortz, et al. produced a public installation called *Luminous Kite Lanterns* that responded to participants' movement. (Bortz et al. 2013) Benjamin Knichel, et al. also produced a public installation that invited users to engage with sound objects within a space. (Knichel, Reckter, and Kiefer 2015) Another installation by Anthony T. Marasco scraped critiques of musical compositions from the web and used the content of these reviews as the basis for sound modification. (Marasco 2018) Lastly, Georg Hajdu, et al. described how installation art within hospitals might improve patient recovery time and well-being. (Hajdu et al. 2017)

Finally, several artistic works outside of academia motivated the design and functionality of this installation: Olafur Eliasson's *Reality Projector* (2018), Céleste Boursier-Mougenot's *clinamen v.3* (2012-ongoing), Pipilotti Rist's *Worry Will Vanish* (2016), Fidelia O. Lam's *LMNSCNCE* (2017-2018), and the Gamelatron.[29, 30, 31]

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[28] NIME refers to the International Conference on New Interfaces for Musical Expression.
[29] https://fidelialam.com/lmnscnce
[30] http://gamelatron.com/

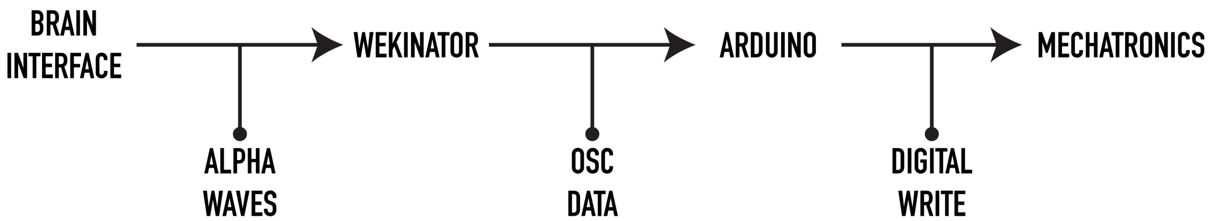

Figure 4.1 – Flow of data throughout the installation

4.3 System Architecture

The WaveCave gallery includes several features that made implementing the installation's spatial design possible: a square shape with four walls measuring approximately 18 ft. across, two hanging projectors, four speakers located inside a ceiling grid, and a control room containing a computer and an audio mixer.

To prepare the space for the installation, the projectors were arranged in such a way that their images were directed towards two perpendicular walls with the corner acting as a point of symmetry. A seating area, designated by a carpet and several meditation cushions, was subsequently placed in the center of the room. It was intended that the participants sit in the seating area so that their field of vision was consumed by the projected images thereby creating an immersive visual experience.

Adding to the immersive quality were two spatialized audio components. First, an original musical score was played through each of the four speakers located in the ceiling. Second, three self-playing singing bowls controlled by a series of devices and sensors were placed surrounding the seating area. Figure 4.1 shows the flow of media and data information throughout the installation. Figure 4.2 and Figure 4.3 show the assembled space during two different moments of the film.[32]

[31] Many of these pieces are discussed in Chapter 2.
[32] The film is divided into three sections: *Water*, *Air*, and *Earth*.

Figure 4.2 – ***Earth***

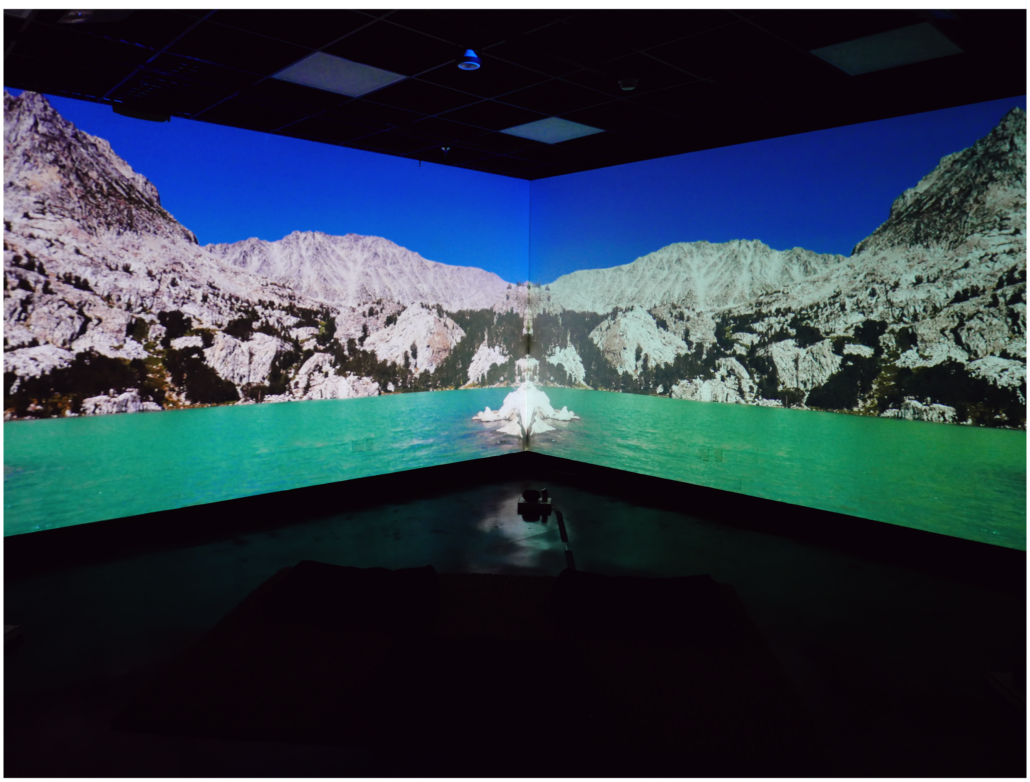

Figure 4.3 – ***Water***

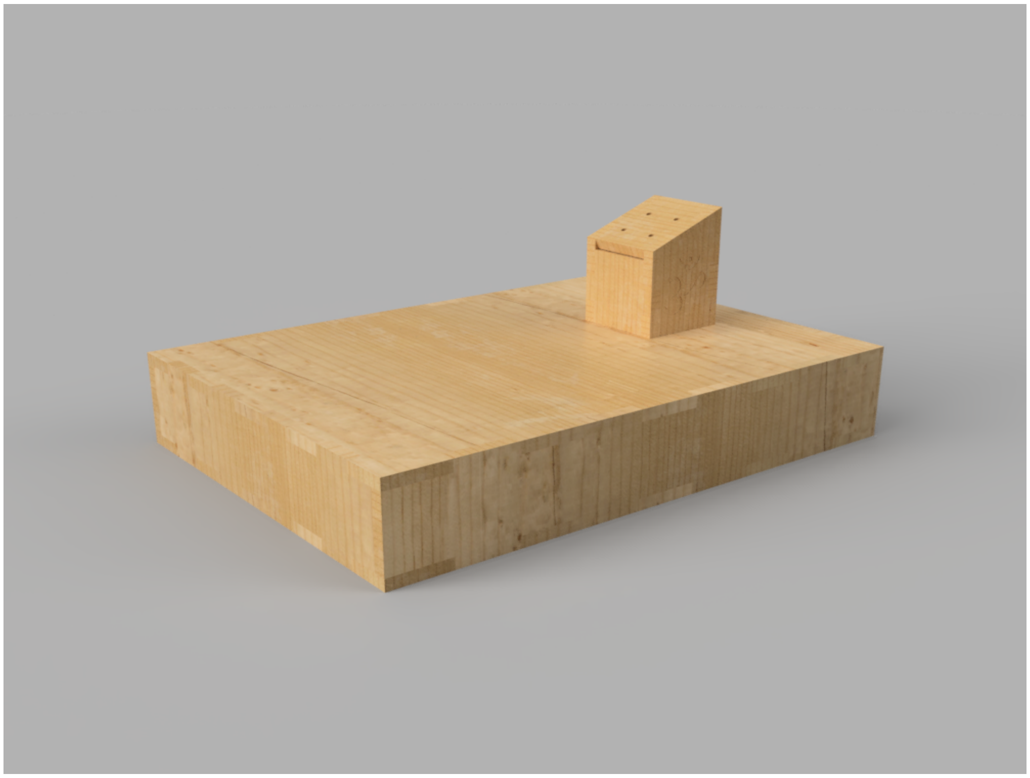

Figure 4.4 – A three-dimensional rendering of the solenoid structure

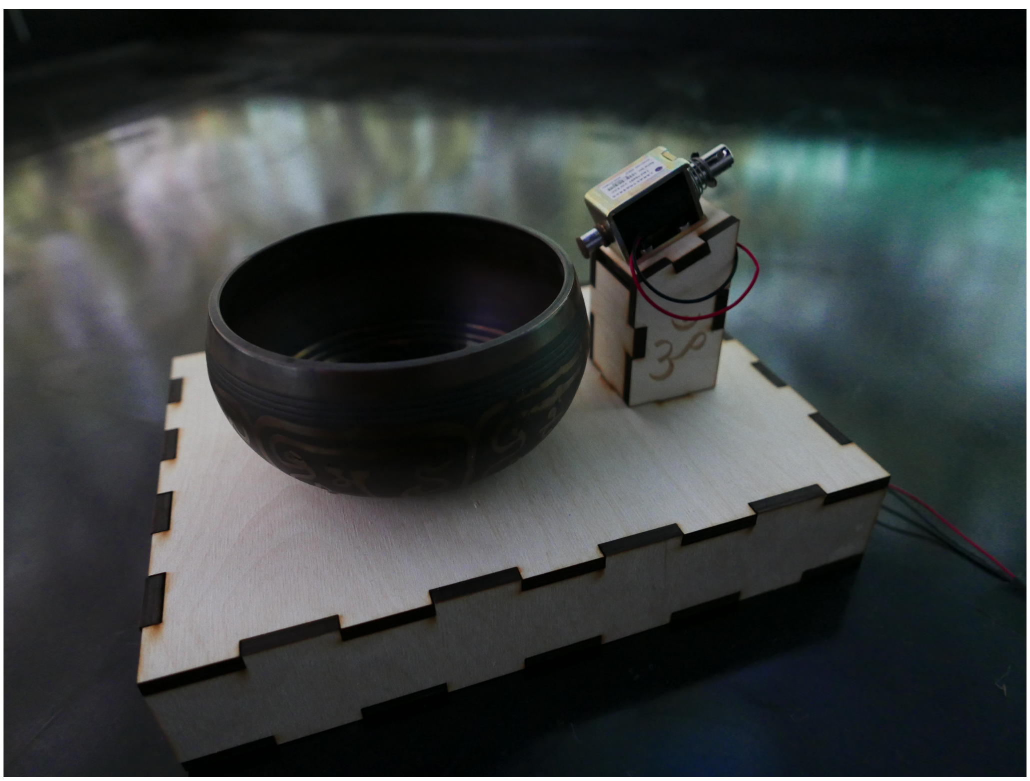

Figure 4.5 – The laser cut solenoid structure

4.4 Operation

4.4.1 Mechatronics

A mechatronic system designed to play three Tibetan singing bowls functioned as the core spatialized audio component of the installation. This system emulated an experience known as a sound bath. In a sound bath, a group of participants lies down in a room and a facilitator plays an assortment of instruments such as gongs, wind chimes, and singing bowls. The diffusion of sound washes over the group and evokes deeper states of consciousness.

However, there are two notable issues with sound baths such as the one previously described. First, facilitators are often localized within a corner of the space. This means that participants are subject to a varying sound experience depending on where they choose to lie down. Second, the number of instruments playing at any given moment in time is limited by the physical capabilities of the facilitator(s). *WITQ*'s mechatronic system addresses these issues by distributing the sound-objects equally throughout the space and assigning the performance to a system capable of supporting multiple instruments simultaneously.

Each singing bowl was placed on top of a custom laser cut plywood structure. A large push-pull 12V solenoid, which was responsible for striking the instrument, was also mounted to the structure. Figure 4.4 shows a three-dimensional rendering of the plywood structure and Figure 4.5 shows the completed instrument.

The system's timing was dictated by the BCI, in this case a Muse brain sensing headband, and an Arduino microcontroller located in the control room.[33, 34] The Muse device includes seven calibrated electroencephalography (EEG) sensors and a gel-free electrode system that record information about the wearer's brain activity in real-time. There are several reasons that this device was chosen for the installation. First, Muse devices are affordable and accessible. Second, they transmit data as OSC messages via Bluetooth, which simplifies the process of connecting this device to other software.[35] Third, they produce an extensive list of data streams including several that concern an individual's sense of calm. Finally, they internally handle noise and supply a reference signal in order to improve the accuracy of the readings. While a review of

[33] https://choosemuse.com/
[34] https://www.arduino.cc/
[35] http://opensoundcontrol.org/introduction-osc

these processes is outside the scope of this paper, further information is available in the manufacturer's documentation.[36]

After the BCI registered a high enough level of alpha waves, which loosely correspond to states of relaxation, the microcontroller triggered a digital-on message to an L298N motor drive controller board. The board then passed the necessary power to the solenoid via a 220V power supply hooked up to a wall outlet. This resulted in the solenoid armature extending outward to meet the surface of the singing bowl. A digital-off message ended the flow of power to the solenoid causing the armature to retract to its resting position. This series of messages was sent to each instrument sequentially with a 15 second interval between each series. The long interval time allowed the sound of each singing bowl to naturally come to silence before the next singing bowl was struck. Figure 4.6 shows a schematic for the mechatronic system.

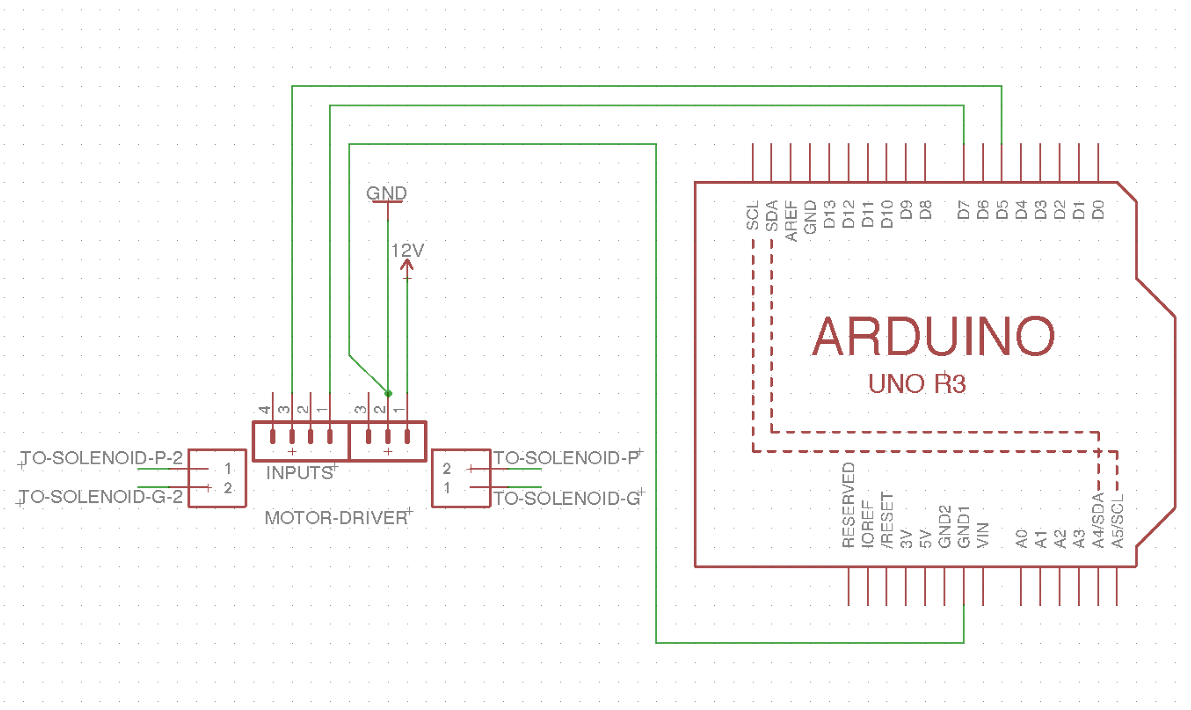

Figure 4.6 – An Eagle schematic outlining *WITQ*'s mechatronic system

4.4.2 Machine Learning

Wekinator, an open-source machine learning program, analyzed, averaged, and interpreted the data from the BCI. The software then provided real-time feedback to the user about their mental state. Muse Monitor, an iOS application, was responsible for forwarding OSC messages to

[36] http://developer.choosemuse.com/tools/available-data

Wekinator from the BCI.[37] Once Wekinator received the messages, the values were averaged using a short time window to smooth the output. By training Wekinator to identify and respond to calm states based on the strength of the user's alpha waves, the installation was able to provide feedback by triggering the singing bowls.

The feedback informed the user of their mental state as reflected by the sensor data. This mechanism was intended to motivate the user to further increase their level of relaxation. Figure 4.7 shows a diagram outlining the installation's feedback loop.

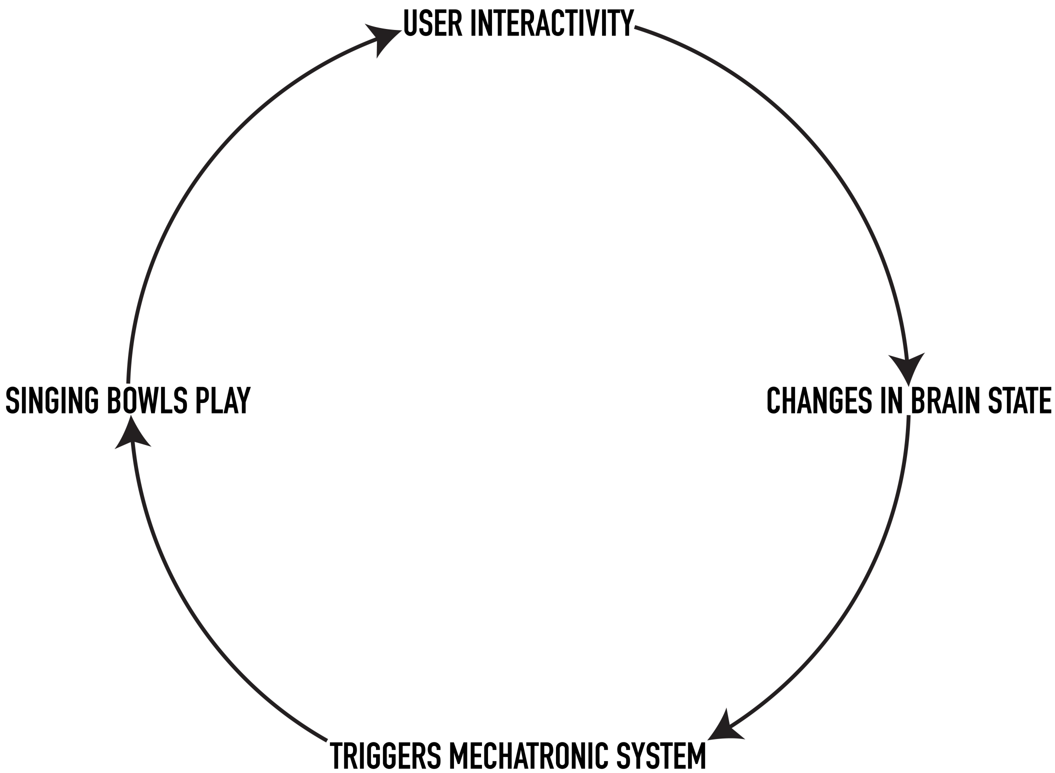

Figure 4.7 – Feedback loop

4.5 Challenges and Limitations

The mechatronic system was the most challenging aspect of implementing this installation. A great deal of time and attention was required to develop a system that produced a particular tonal characteristic with as little mechanical noise as possible. To address this issue, each solenoid was fitted with several thin layers of felt; one at the solenoid's tip and another between the armature and its body. Not only did the fitting reduce the amount of perceptible noise resulting from the solenoid's motion but also it softened the attack of each note.

[37] https://musemonitor.com/

Another enhancement to the mechatronic system optimized its sound and playability. That is, the timing of each digital-on message from the Arduino was adjusted to suit the desired tonal characteristics. For this particular system, 25 milliseconds produced a quick transient followed by a long resonant decay. As a juxtaposition, a slow digital-on message extended the armature excessively, therefore diminishing the decay, while a fast message restrained the arm from reaching the singing bowl at all.

4.6 Conclusion

The feedback from visitors was generally favorable. During two critiques, participants described the space as tranquil and inviting. Additionally, they expressed feeling peaceful upon exiting the experience. In some cases, individuals admitted to spending several hours in the space due to its overall energy, even though the film was on a 15-minute loop. However, several visitors expressed discontent. They explained that the film's cinematographic style, which was almost entirely static with the exception of scene changes, was distressing.

With regards to the BCI and feedback system, most participants found the system easy to use. To better assist visitors, a series of instructions on how to interact with the installation was posted outside the gallery entrance. The instructions described how to use the BCI and how to enjoy the space without the headband. Several users also stated that the feedback from the singing bowls was helpful in deepening their state of relaxation. Others, however, described the opposite effect; the sound and noise from the mechatronic system distracted them.

WITQ is a space for individuals and groups to experience quiet contemplation. To this end, this installation demonstrates that technology is capable of connecting individuals not only to themselves and others but also to the surrounding world. The feedback element of the installation supports the intended experience by encouraging mindfulness.

Human and environmental awareness will remain at the heart of this experience during future iterations. The power of technology as a tool for improving well-being and facilitating group connectivity is a growing area of interest for artists and researchers. Further exploration may yield deeper truths about the human condition and how technology might go about serving humanitarian needs in the future.

Chapter 5
z3R0

z3R0 is an interactive exhibition. During the exhibition, an individual wears a brain interface that monitors their average delta, theta, alpha, beta, and gamma wave levels. These levels are then concatenated in order to determine the individual's overall depth of relaxation and focus. This determination is dictated by a computer, which simultaneously functions as an audiovisual display. The goal of this exhibition is threefold: first, to explore intentional alterations in brain state as a modulation source for interactive art experiences; second, to establish a system in which technology mediates the relationship between consciousness and the desired artistic output; and third, to investigate an application of technology that is intended to strengthen mindfulness skills, improve overall wellness, and facilitate self-discovery.

5.1 Introduction

In 1924, a German psychiatrist named Hans Berger invented a device for recording electrical activity in the brain. This device, known as an electroencephalogram, afforded researchers the opportunity to observe the brain in an unprecedented way as it delineated momentary shifts in consciousness based on changes in brain chemistry. During the remaining century, scientists and researchers expanded Berger's invention. In doing so, they uncovered several streams of brain activity. Now, after decades of analysis, these streams are revealing the hidden relationship between thoughts and physiological states; as individuals change their thoughts, the body responds in kind.

As EEG technology has become more accessible, artists have adopted these devices in order to produce brain-driven experiences. The most distinguished of these artists, such as composers Alvin Lucier and David Rosenboom, used brainwaves and other biosignals to trigger sounds and modulate synthesis parameters in real-time. Recently, the number of artists exploring this technology has increased. This is due in part to the introduction of affordable brain-computer interfaces (BCI) into the general public.

z3R0 draws on the rich history of EEG-driven art to realize this unique audiovisual experience. During the exhibition, participants are instructed to meditate and bring awareness to their body. They are then asked to observe the changes in their body as they interact with the sound and visual elements using only their thoughts. Subtle transformations in these elements of the experience take place concurrently and provide real-time feedback regarding participants' mental states. Holistically, this project seeks to empower individuals by teaching them how to generate change both inside and outside of the body.

5.2 Related Work

Alvin Lucier is recognized as the first person to incorporate EEG into the process of musical expression. His piece titled *Music for Solo Performer* (1965), shown in Figure 5.1, used amplified alpha waves from the brain as a means of triggering percussive instruments.[38] Another pioneer in EEG-driven sound-art is David Rosenboom. His work around "biomusic" and "brainwave music" demonstrated the manner in which human biosignals could generate and modulate synthesized tones. (Rosenboom and Paul 1986) Furthermore, he integrated aspects of "biofeedback" into his performances. This term describes the process of influencing an individual's response to an experience by using their biological state to change the environment, thus motivating further changes as they contemplate and explore this relationship.

In addition to these artists, several papers published in the NIME community on BCI and interactive experience design motivated the particular implementation of *z3R0*. The most influential of these papers is *Enactive Mandala* by Tokunaga and Lyons. (Tokunaga and Lyons 2013) This paper describes a project in which real-time data from EEG sensors was used to alter ambient sound and visual art generated by a computer. Other noteworthy papers include the *BCI-Piano* by Miranda and Brouse, *MoodMixer* by Leslie and Mullen, *Music for Online Performer* by Mullen et al., *Physiopucks* by Mealla et al., *Insight2OSC* by Levicán et al., the real-time BCI performance system by Hamano et al., and *Xmotion* by Le Groux et al. (E. Miranda and Brouse

[38] A live version of *Music for Solo Performer* is available here: https://www.youtube.com/watch?v=bIPU2ynqy2Y

2005; Leslie and Mullen 2011; Mullen, Warp, and Jansch 2011; Mealla et al. 2011; Levican et al. 2017; Hamano et al. 2013; Le Groux et al. 2010)

Research regarding emotional fluctuations amongst audiences and performers during concerts, while outside the scope of this particular project, provided further insight into artistic applications of BCI and body sensors. This chapter acknowledges the work by Miranda, Jaimovich and Knapp, Jaimovich et al., as well as Knapp and Lyon for investigating the relationship between emotional expression, brain activity, and physiological state. (E. R. Miranda 2006; Jaimovich and Knapp 2009; Jaimovich et al. 2012; R. Benjamin Knapp and E. Lyon 2011)

Finally, two papers describing academic and artistic applications of the Muse brain sensing headband dictated the technological direction of *z3R0*.[39] First, Krigolson et al. evaluated whether or not the Muse device is a practical tool in studies involving event-related brain potential. (Krigolson et al. 2017) Second, Kovacevic et al. used these devices to explore neurofeedback during an immersive art installation. (Kovacevic et al. 2015)

The aforementioned artists, researchers, and scientists regard the human brain as a source of knowledge, inspiration, and interactivity. *z3R0* is motivated by the examples put forth by these groups and extends this field of study further by examining how modern BCI and digital art-making technologies enhance individual wellness.

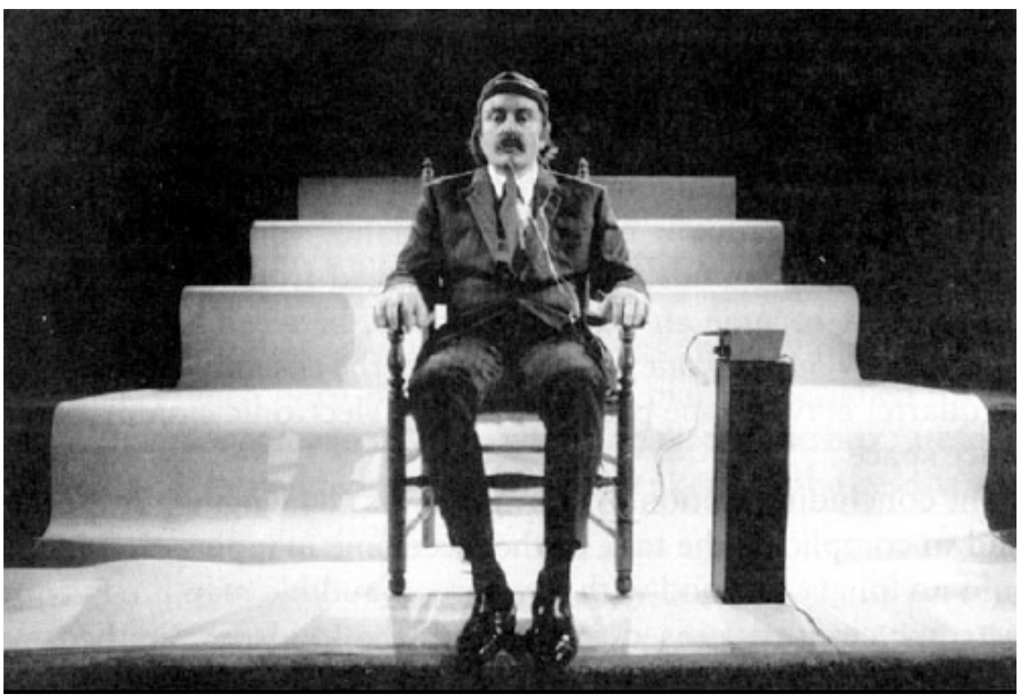

Figure 5.1 – Alvin Lucier performing *Music for Solo Performer* (1965)

[39] https://choosemuse.com/

5.3 System Architecture

5.3.1 A Brief Overview of Brainwaves

Before proceeding to a description of *z3R0*'s system architecture, it is worth naming each of the brainwaves that are pertinent to this project. The following brainwaves are accompanied by a brief description of their characteristics and their corresponding states of being. For more information about this topic, see Muse's summary of brainwaves and Scientific American's article on brain activity.[40, 41]

1. **Delta waves** are the slowest of the brainwaves. These signals have a frequency range of 0.5 - 4 Hz and they are most active during deep sleep.
2. **Theta waves** correspond to states of deep relaxation that often occur during meditation and while dreaming. These signals have a frequency range of 4 - 8 Hz.
3. **Alpha waves** have a frequency range of 8 - 13 Hz and they correspond to physical and mental relaxation.
4. **Beta waves** correspond to states of focus. They have a frequency range of 13 - 32 Hz and they are most active while managing tasks, making decisions, solving problems, and learning new skills.
5. **Gamma waves** are the fastest of the brainwaves. They have a frequency range of 32 - 100 Hz and they correspond to states of peak alertness in which information is processed simultaneously in several areas of the brain.

The strength of each these signals changes from moment to moment based on factors such as level of focus, physiological state, environmental conditions, and time of day, among others. Furthermore, the weight of each signal, when measured against the others, is used by scientists to loosely classify an individual's quality of being i.e. peaceful or distracted. Considering how little is known about human consciousness, this classification is far from accurate. Rather, it approximates quality of being by averaging the overall strength and configuration of brainwaves over time. These averages are at the heart of efforts made by interested parties to design

[40] https://choosemuse.com/blog/a-deep-dive-into-brainwaves-brainwave-frequencies-explained-2/
[41] https://www.scientificamerican.com/article/what-is-the-function-of-t-1997-12-22/

interactive systems that offer users with precise real-time feedback regarding their physical and mental state.

5.3.2 Hardware and Software

z3R0 uses analog and digital technology in order to drive the user experience. First, a Muse 2 brain sensing headband gathers and organizes brainwave data.[42] This device uses seven calibrated EEG sensors and a dry electrode system in order to record information regarding the wearer's brain activity. Next, the information is sent as a series of OSC messages over Bluetooth to an iOS app called Muse Monitor. The app then parses the message data and graphs it in real-time. This graphical representation, shown in Figure 5.2, gives users the opportunity to observe changes in their brain's activity.

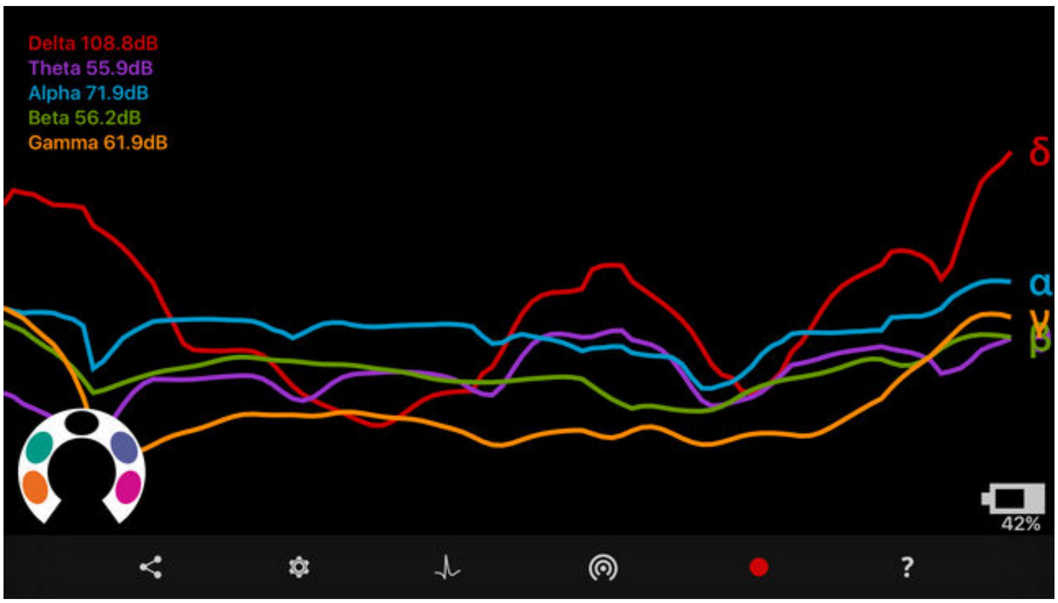

Figure 5.2 – The graphical representation of brainwaves produced by Muse Monitor

Despite its utility, the graph is ordinary and the app lacks a method for incorporating sound into the data representation. It is for these reasons that *z3R0* uses TouchDesigner, a visual programming environment, in order to generate complex data visualizations that include sound. TouchDesigner receives data from Muse Monitor as a stream of OSC messages over Bluetooth. The data is then organized by several native modules that generate a list of available messages and values. Once the software produces this list, the values become functional parameters throughout the entire system.

[42] https://choosemuse.com/muse-2/

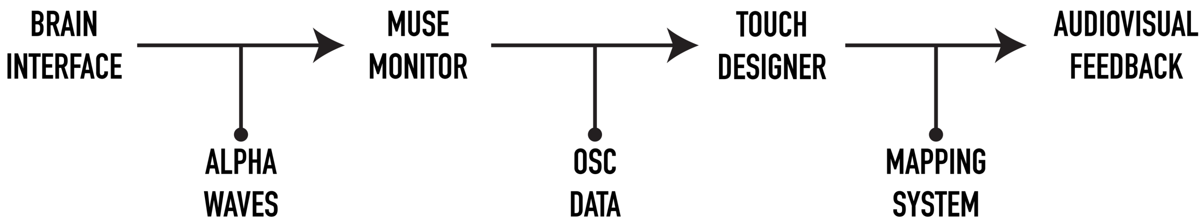

Figure 5.3 – The flow of data throughout *z3R0*

5.4 Operation

5.4.1 Experience Design

Muse's free mobile application possesses several exercises for improving meditation skills. The 'mind meditation,' which utilizes all of the available EEG sensors, gives users real-time feedback regarding their brain activity and quality of being. The feedback consists of changes in the dynamic quality of the soundscape, which each user hears via headphones or the speaker in their phone. An increase in loudness means that the user is distracted. The opposite holds true for states of relaxation.

z3R0's feedback structure is based on this application and it makes use of available research on brainwaves and their associated meanings in its design. This structure is intended to meet two specific goals: first, to give participants the opportunity to observe changes in their brain activity by way of sight and sound; and second, to induce mental and physical tranquility. The latter goal is realized by encouraging users to change their thought patterns in response to the multisensory cues that are produced by the visualizer.

To further reinforce the feedback structure, *z3R0* is organized like a game. A distracted user will hear noise and notice shapes that behave chaotically, shown in Figure 5.4. However, as the user achieves a higher level of relaxation, this behavior will subside, and the shapes will organize into a recognizable form. This form of feedback is shown in Figure 5.5. Additionally, the noise will transform into an ambient drone. The choice to organize the experience in this way is deliberate; it encourages users to actively engage their thoughts in order to alter the audiovisual elements.

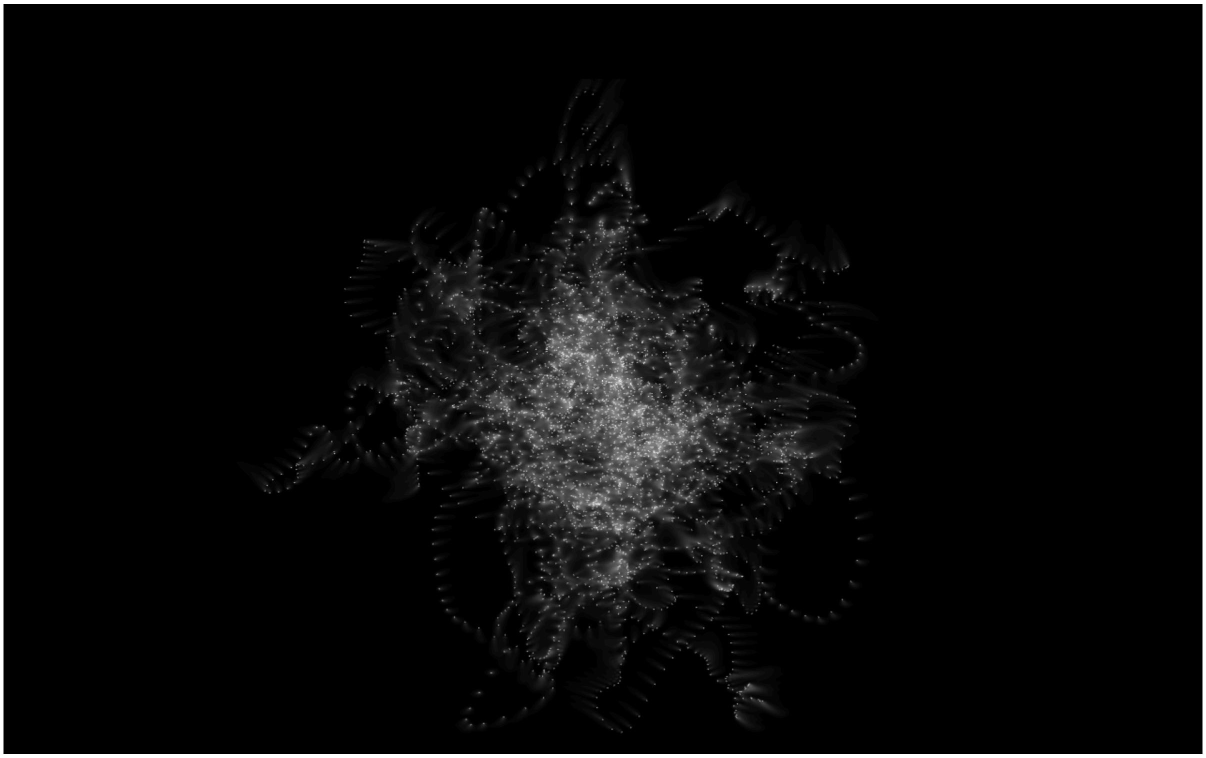

Figure 5.4 – The visualizer indicating a distracted state

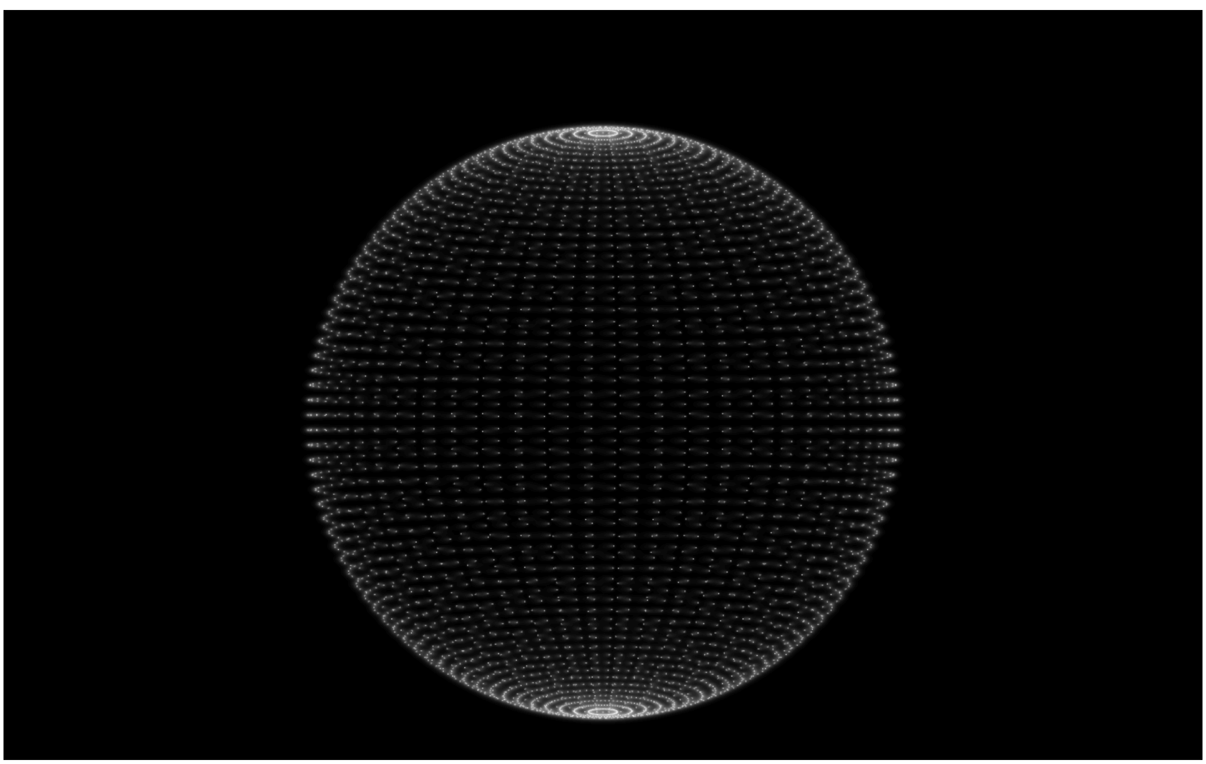

Figure 5.5 – The visualizer indicating a calm state

Research shows that mindfulness exercises such as meditation increase the strength of alpha waves in the brain. (Herrmann 2019) In light of this research, *z3R0* primarily uses this signal's strength in order to drive the interactive experience. Muse Monitor simplifies the process of accessing alpha wave data by broadcasting an individual stream of OSC messages that contain the corresponding values. The app also generates a data stream called 'mellow,' which is based on alpha wave data and affected by increased relaxation. This information forms the basis of TouchDesigner's real-time visualizations and sonifications.

The feedback system is by no means a precise reflection of quality of being. Rather, this system assumes quality of being based on the strength and accuracy of the signal over time.

5.4.2 Interactivity & User Feedback

z3R0 was presented at the CalArts Expo on May 9, 2019.[43] The exhibition was located in the front entrance of the school and consisted of a small table and chair, a Muse 2 brain sensing headband, a laptop running TouchDesigner, and a pair of over-ear headphones.

Visitors were instructed to sit in the chair and face the laptop. Next, they were offered an antibacterial wipe to clean their forehead and thereby improve the EEG recording. They were then fitted with the Muse sensor and the headphones. An example of the sensor fitting is shown in Figure 5.6. After establishing a connection between the headband and Muse Monitor, the user's brainwave values were sent to the laptop. The user was then instructed to observe the screen and respond to the feedback by modifying their thoughts.

While challenging at first, users were eventually able to produce calm states as reflected by the feedback system. However, these moments were short-lived; most users spent a majority of the time in between distracted and calm states. When asked about the experience afterward, many users stated that they noticed moderate changes in their mood and level of focus. Other users expressed enjoyment around the game aspect of the experience. In particular, they enjoyed the challenge of producing a calm state and maintaining it. The most common reaction to the experience was curiosity.

It is impossible to know exactly how much noise was present in the sensor readings during the exhibition. This project assumes that the data was inaccurate at times and that the inaccuracy affected the user experience. However, observation suggests that the system functioned according to its intended use for most of the day.

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[43] https://expo.calarts.edu/2019/

5.5 Challenges and Limitations

One of the greatest limiting factors with the Muse 2 headband is the battery. The battery provides up to five hours of continuous use before it needs to charge. Therefore, a single headband was inadequate for the scope of the exhibition. In light of this limitation, two Muse headbands were acquired prior to the event. This allowed for one to charge while the other was in use. It is worth noting that both headbands were tested prior to the event and the results were compared in order to identify any performance differences. The tests showed that both units functioned virtually the same under near-identical circumstances.

Another challenge with implementing *z3R0* was the space itself. CalArts' front entrance experiences high foot traffic during the CalArts Expo. The flow of visitors through the space was both distracting and a source of noise. This situation might have inhibited users' ability to relax during the experience. Furthermore, the outside light from the entrance made seeing the laptop screen difficult during certain parts of the day.

Figure 5.6 – The Muse headband in use during testing

5.6 Conclusion

Overall, *z3R0* achieved its principle goals and produced a strong foundation on which to build subsequent iterations. These iterations will include several new features. First, it will support multiple users with several BCI. Second, it will incorporate a way to calibrate the feedback system in order to yield more accurate measurements. Finally, it will integrate a memory system in order to hold a record of each user's brainwave measurements.

Chapter 6

Conclusion

This thesis presents several projects that address the relationship between humanity, technology, consciousness, and nature. Chapter 2 established the context of the work through an overview of the 1960s countercultural revolution and several relevant artists. Chapter 3 introduced a new interface for musical expression that uses hardware and software to generate novel forms of interactivity. Chapter 4 described a mixed-media installation that immersed visitors in a techno-sensorial experience in which nearly all aspects of the environment are mediated by technology. Finally, Chapter 5 outlined a participatory exhibition in which individuals attempt to change their thoughts in order interact with digital art on a laptop computer. Underlying each of these projects is the theory that technology is capable of serving human beings in the process of becoming. That is, the process of enhancing self-awareness, mindfulness, and connectivity to other individuals and the surrounding world.

The initial findings of this thesis suggest that mediated technological experiences are able to elicit a greater sense of awareness from visitors, if only for a moment. Indeed, an analysis of the user responses to each of the aforementioned projects reveals that most participants successfully observed a positive transformation in their quality of being both during and after the encounter. This observation implies that they experienced a certain degree of clarity that made it possible for them to reflect upon their own mental, emotional, and physiological state. In the absence of a formal user survey, these findings and their resulting implications are predominantly speculative. Still, it seems viable that multisensory and multimedia experiences realized using unique combinations of technology might produce altered states of consciousness and facilitate self-discovery.

Future work in this field will continue to explore the relationship between both objects and experiences, such as the ones previously described, and human consciousness. This will require several modifications to the research and artistic development process. First, an extensive study of consciousness, especially as it relates to technology, is necessary in order to strengthen the theoretical foundation of the artwork. This is already an active area of interest amongst philosophers, computer scientists, health practitioners, and artists.[44] In fact, such studies are becoming increasingly important as virtual reality and augmented reality grow in popularity and accessibility. New technologies such as these skew the boundary between natural sensory experiences and phenomenal experiences that transcend substantive human events. As such, these technologies are suitable tools for addressing complex questions such as those that focus on the relationship between technology and the self.

Additionally, future work will require a resolute system for collecting user feedback. This is especially important given the inherent subjectivity of the matter. An adequate system might involve surveys that instruct users to reflect on the nature of their experience and disclose their personal feelings in response to an encounter. These responses would then be compiled into a database and examined for commonalities. In doing so, they might reveal meaningful information about how these experiences cause particular reactions, thus motivating future implementations.

In an era of unprecedented technological ubiquity, in which even the most isolated communities are subject to exposure, human beings are facing a radically different notion of evolution. This process is happening quickly, the repercussions are widespread, and the stakes are higher than ever before. Humanity is in a symbiotic relationship with technology, therefore, the forces that affect one side certainly affect the other. Taking into account the present circumstances, individuals must make a conscious effort to adopt new technologies in ways that facilitate personal growth and establish an interconnected global community in harmony with nature. Artists wield a particular power within this dynamic. Art induces awareness by alerting the mind to new possibilities and perspectives by way of sensory information. Naturally, it follows that artistic experiences such as those described throughout this thesis might unlock technology's capacity to guide the process of becoming in healthy and mindful ways. Time will affirm or deny whether or not this is a legitimate possibility. Until then, human beings must continue to put themselves in technology's way and observe the forces of interaction that are changing the world.

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[44] One such individual is Jaron Lanier, author of several books including *Dawn of the New Everything*.

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