Summer 8-1-2015

Interaction and the Art of User-Centered Digital Musical Instrument Design

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INTERACTION AND THE ART OF USER-CENTERED DIGITAL MUSICAL INSTRUMENT DESIGN

by

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B.F.A., College of Santa Fe, 2003

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Fine Arts

(in Intermedia)

The Graduate School

The University of Maine

August 2015

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INTERACTION AND THE ART OF USER-CENTERED DIGITAL MUSICAL INSTRUMENT DESIGN

By John D. Sullivan

Thesis Advisor: Nathaniel B. Aldrich

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Master of Fine Arts
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This thesis documents the formulation of a research-based practice in multimedia art, technology and digital musical instrument design. The primary goal of my research was to investigate the principles and methodologies involved in the structural design of new interactive digital musical instruments aimed at performance by members of the general public, and to identify ways that the design process could be optimized to increase user adoption of these new instruments. The research was performed over three years and moved between studies at the University of Maine, internships in New York, and specialized research at the Input Devices and Music Interaction Laboratory at McGill University.

My work is presented in two sections. The first covers early studies in user interaction and exploratory works in web and visual design, sound art, installation, and music performance. While not specifically tied to the research topic of user adoption of

digital musical instruments, this work serves as the conceptual and technical background for the dedicated work to follow. The second section is dedicated to focused research on digital musical instrument design through two major projects carried out as a Graduate Research Trainee at McGill University. The first was the design and prototype of the Noisebox, a new digital musical instrument. The purpose of this project was to learn the various stages of instrument design through practical application. A working prototype has been presented and tested, and a second version is currently being built. The second project was a user study that surveyed musicians about digital musical instrument use. It asked questions about background, instrument choice, music styles played, and experiences with and attitudes towards new digital musical instruments.

Based on the results of the two research projects, a model of digital musical instrument design is proposed that adopts a user-centered focus, soliciting user input and feedback throughout the design process from conception to final testing. This approach aims to narrow the gap between conceptual design of new instruments and technologies and the actual musicians who would use them.

DEDICATION

To my parents, who instilled into me the love of learning and music.

ACKNOWLEDGEMENTS

To my supervisor Nate Aldrich, thank you for the guidance you have given me in and out of the classroom that helped transform some vague notions of art, music and technology into an articulated vision and practice. Thanks to Owen Smith, Velma Figgins, and colleagues at the University of Maine and IMRC.

Very special thanks to John and Christine Carney for a lasting friendship, endless tacos, late nights at the lab, and reminding me that art should be fun.

Thank you to ASAP Media Services, Mike Scott, Sam Foster and Tim Baker for giving me a place to learn, grow, and make mistakes. Extended thanks to the UMaine New Media Dept., NMD Europe, Ryan and Francesca at CuteCircuit, and Don Foresta,

Thank you to the City of New York for inspiration, motivation, opportunity, and much needed distractions: Hans, Carol, and Daniel Belquer at Harvestworks, and especially Joel Chadabe and New Music World.

To Montréal, McGill and IDMIL – Marcelo Wanderley, Jera, Ivan, Ian, Johnty, Marlon, Carolina: Thank you for a great first year, and here's to a few more!

Finally, the most important thanks of all goes to my family: Mom, Dad, Rachel, Sarah, Keith, Shannon and Erin. None of this would have been possible without a lifetime of encouragement, love and support.

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LIST OF ABBREVIATIONS

DMI	Digital Musical Instrument
EDM	Electronic Dance Music
EMF	Electronic Music Foundation
GUI	Graphical User Interface
HCI	Human Computer Interaction
IDMIL	Input Devices & Music Interaction Laboratory (McGill University)
IRCAM	Institut de Recherche et Coordination Acoustique/Musique
IMRCC	Innovative Media Research & Commercialization Center (Maine)
IMU	Inertial Measurement Unit
MIDI	Musical Instrument Digital Interface
NIME	New Interfaces for Musical Expression
PCA	Principle Component Analysis
SNA	Social Network Analysis
TIEM	Taxonomy of realtime Interfaces for Electronic Music Performance
UCD	User-Centered Design
UDP	User Datagram Protocol
UX	User Experience

CHAPTER 1: INTRODUCTION

This thesis documents the development of a research-based praxis in art, music and technology, and highlights dedicated projects in the field of digital musical instrument (DMI) design. The goal of the work presented here is to investigate the principles and methodologies involved in the structural design of new interactive DMIs aimed at performance by members of the general public, and to identify ways that the design process can be optimized to increase user adoption of these new instruments. Towards the accomplishment of this goal, I draw upon my personal experience as a musician and multimedia artist and upon data distilled from questionnaires circulated among practicing musicians.

The research presented here originates from a preliminary observation: Despite a robust and growing field of engineers, designers, hobbyists and do-it-yourselfers, and a prevalence of new musical instruments and controllers being made in both research and commercial sectors, relatively few new *truly innovative* devices are actually adopted into more widespread use by music communities [1]. The reasons for this are complex and difficult to quantify, as there are a number of factors that contribute to this condition. Some are issues of technology and user interaction, while others may be purely historical,

cultural and sociological. Through my work I aim to shed light on this and to clearly define areas for continued research to address these issues.

This thesis recounts various creative and research-based projects that gave me the basis of knowledge necessary to address user adoption of DMIs from an interdisciplinary point of view. Sound art and multimedia works provided a technical foundation for instrument design and applied knowledge of human-computer interaction (HCI), while allowing me to explore new experimental forms of creative expression. My live music performance experience and a general user experience evaluation provide different views, examining the aesthetics of live performance, choice of instruments, and the impact of social, cultural and environmental factors in the use and adoption of new technology.

1.1 Thesis Overview

This thesis is composed in three parts that highlight the two distinct yet overlapping sections of my MFA studies. Chapter 2 describes work from my two years at the University of Maine and at the Innovative Media Research and Commercialization (IMRC) Center[1]. It traces a path of open exploration across several different mediums and contexts, and provides a conceptual background for the work that follows.

[1] The Innovative Media Research and Commercialization Center (IMRC) was opened in January 2013, and serves as the home for the Intermedia and New Media departments at the University of Maine. (For more information: http://www.imrccenter.com)

Chapters 3 and 4 document current and ongoing projects carried out as a Graduate Research Trainee at McGill University in the Input Devices and Music Interaction Laboratory (IDMIL) during my final year of research. This work has focused on advanced training in sensor and interface design, research of user-centered methodologies applicable to DMI design, and the administration of a user survey around DMI use in performance. Chapter 5 concludes the main written section of the thesis by connecting the work of the previous chapters, reflecting on successes and failures of past work, and indicating areas for ongoing study and future work.

The final chapter (Chapter 6) contains a portfolio of works I have produced during my time as an MFA student.

1.2 Foundations of Work

One of the defining characteristics of the Intermedia MFA program at the University of Maine is the freedom and flexibility to explore many different areas, mediums, and contexts for creative output. This is exemplified in the diverse catalog of works I have amassed, including interactive web-based applications, audiovisual site-specific installations, hardware and software design, sensor design, and finally musical instrument design.[2] While varied, all of these works have been sound-based or featured

[2] See Chapter 6 for a portfolio of associated works, and Chapter 2 for a description of the research elements of earlier works.

audio in some form, and all utilize user interaction through advanced environmental and tactile sensors. Collectively they have led to my current research topic dedicated to user-centered design of new digital musical instruments and interfaces.

1.2.1 User Interaction Design

The creation of responsive systems has been a primary motivating force in my practice. Beyond the purely technical utility of creating useful and engaging things – websites, musical instruments, and artworks – the theme of interactivity between audience and artist, audience and work, and humans and machines has been a fundamental aspect of everything that I have explored throughout the MFA program.

All of my work has been designed to be attractive as well as functional and responsive. Websites have been designed to go beyond utility as basic content delivery systems to give the user a unique aesthetic experience that they could control. Sound installations varied their behaviors through audience participation using computer vision, motion tracking, and environmental sensing. The digital musical instruments that I have designed have evoked some of the direct tangible playability of their analog relatives, allowing skilled musicians and novices alike to pick one up and to begin making music through direct interaction.

My research and experimentation with various sensing technologies has yielded systems that can translate gestures, movement, and manipulation of objects into digital

signals that can be used to control sound synthesis, audio signal processing, and visual events. The process of analog-to-digital conversion (and conversely digital-to-analog reconversion, that translates digital information and algorithmic instructions back into tangible form again – audible sound, or visual images, for example) becomes a fundamental concept and key focus in the work covered here. When any physical or environmental property can be measured and used as a variable for digital control, the work becomes truly inter-medial.

However, the freedom to utilize any input source to control anything else is both an asset and a liability. On one hand, it allows designers to build nearly anything that can be imagined. On the other, without implicit design limitations (as with acoustic instrument design or oil painting, where the properties of the respective materials dictate certain constraints on what or how an artist or designer can use them), one must carefully construct the parameters around which a work or interaction is created, or risk building an incoherent mess. Alas, this is often a troublesome area for advanced technology in the fine arts, and one that is problematic in the pursuit of better DMIs for music performance. This has led to my vested interest in user interaction, recognizing that truly successful design must temper technology with a true understanding of the needs and desires of the end user, whether that person is a performer, audience participant, or website visitor.

1.2.2 Rethinking Music Performance and Audio Signal Processing

A majority of my work has been sound-based, from music performance to multimedia pieces that also featured visual elements. Though my background as a trained musician and performer provides an obvious rationale for this, I am also interested in working with sound and music in ways that challenge more traditional music performance aesthetics.

The typical contemporary mode of experiencing live music represents a static performer/spectator dynamic. Not unlike an exhibition in a visual arts gallery, the audience is separated from the performer(s) and music is delivered in a closed, one-way direction: Musicians play and the audience listens. However, historically and globally, music has been a more communal activity that is shared, interactive, and inclusive. In this spirit, I have been inspired to explore systems that utilize environmental sensing and unique physical control structures that allow visitors and audience members to directly participate in music making activities.

Similarly, my interest in sound design and audio signal processing has also moved away from more traditional modes of music production. As a musician, my performance practice developed from playing bass and guitar in bands to employing a multi-instrumental setup using a computer, software instruments, samplers, keyboards and multiple controllers. As I worked more with digital signal processing, I began

programming sounds for more experimental contexts well suited for the interactive systems I was designing. I built a variety of digital synthesizers using frequency modulation (FM) and granular synthesis techniques with interfaces ranging from large walk-through motion-activated installations to tablet and homemade hand-held instruments and controllers.

Despite much of my work being rooted in experimental practice and design, I am a musician first and foremost, and I believe this perspective provides an important context for all other considerations. Music (and indeed all art-making) is a deeply personal and expressive field, and it takes more than technical wizardry to imbue a work with aesthetic value or meaning. While the forms with which I work may be experimental, fundamental musical sensibilities remain and the notion of a work as an art form should not be ignored.

These fundamental preoccupations – user interaction design, music performance and signal processing, and musical sensibility - are also at the root of DMI design. The allure of this field is the true interdisciplinary approach that it requires: engineering and computer science for the technical facility to build complex digital hardware and software systems and a creative music- and arts-based perspective to give the technology an appropriate musical context. This last piece is one of great importance, and serves as the foundation of my research today.

1.3 Current Practice

New digital musical instruments and interfaces are popular in certain areas: experimental, avant-garde and computer music, certain adventurous strains of electronic dance music (EDM), and multimedia performance, to name a few. In popular and mainstream music however, this is most often not the case. While some areas like sound engineering, recording, and digital synthesis have embraced new technologies and tools, new DMIs and interfaces have been slow to gain acceptance in popular-music circles. Despite the reputation of many styles to be progressive and to push boundaries, these new tools are often are ignored in favor of familiar and long-established devices and technologies.

The last fifty years have seen major technological advances in musical instrument design, sound synthesis, and music production tools [2]. One need only look as far as a modern day rock concert to see the pervasiveness of technology in music performance: fully digital sound engineering capable of routing and mixing hundreds of channels of audio, analog and digital processors to shape and tweak every facet of the performers' sound, wireless monitoring systems, massive fully-automated and digitally-controlled lighting design, and more. When it comes to the actual performer, we can see three different applications of technology: a) a musician may use advanced technology to process their main instrument's output with the use of analog and digital audio effects,

samplers, sequencers, signal conditioning, etc., b) a musician may use well-established, older even vintage pieces of technology that have made their way into the canon of popular music over decades of use, or c) an adventurous musician may use software-based instruments and control them with external MIDI[3] controllers. While performers may be using new technology, they rely heavily on familiar and well-established performance conventions: dependence on well-known instrument forms and shapes, and exclusive use of traditional interfaces such as piano keyboards, knobs, faders, foot-switches, and buttons. Despite the overwhelming variety of innovative and engaging tools at musicians' disposal, for the most part they stick with what is familiar.

While many of the guiding principles of DMI design have tended towards technical and quantitative methods of organization, experimentation and evaluation, other research areas have long cited the need for more qualitative and participatory methods, merging design with social sciences and bringing users into the design process [3]. My current research is founded on the hypothesis that similar processes can be applied to DMI design that would make new instruments more enticing for musicians of all styles to experiment with and use. Ultimately, I hope to show that the reluctance of many musicians to engage with new technology can be assuaged by refining the design cycle with more formalized user-centered processes that put the performer first.

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[3] MIDI (Musical Instrument Digital Interface) was designed as an industry-standard protocol that enabled devices made by different manufacturers to connect with each other.

User-centered design (UCD) describes the processes in which end users are involved with all aspects of the design cycle. Coined by design innovator Donald Norman in the 1980's, it is a broad term that outlines a high-level philosophy and various methodologies that emphasize the importance of the user in human-computer and human-machine interactions [4]. User-centered design of DMIs has gained some traction. A look at the NIME Conference Proceedings from 2001 – 2014 shows over 100 papers with keywords relating to user experience and evaluation[4]. However, these publications show little consensus on guidelines and methodologies to be used. In order for UCD to truly be useful across the field, researchers and designers must adopt a consistent set of standards that can be applied and repeated across many different projects.

Chapters 3 and 4 document research on user-centered design of digital musical instruments across two projects, culminating in a proposed model of the design process:

1) Chapter 3 describes a project to design and prototype a new musical instrument called the Noisebox. Through the process of building the instrument, several areas of DMI design are surveyed and considered, including gestural control and sensor design, mapping strategies, and user evaluation.

[4] Taken from the NIME proceedings database: https://github.com/NIME-conference/NIME-bibliography

2) Chapter 4 describes a user survey that I administered to better understand how different factors influence new technology adoption and use in music performance. The survey was delivered to musicians from a variety of musical styles and backgrounds, and included questions about performance practice, instrument choice, training, musical genre, and experiences and familiarity with new DMIs and interfaces.

These works are in progress and will continue beyond the writing of this thesis. Already, based on lessons learned from the Noisebox project, and information gained from the user survey, I have been able to propose a simple model for a user-centered approach to DMI design.

CHAPTER 2: BACKGROUND AND EARLY WORK

Before joining the Intermedia MFA program, I was a full-time musician and freelance web designer. In 2003, I completed my Bachelor of Fine Arts degree at the College of Santa Fe in Contemporary Music Performance and Composition. The program emphasized experimental and avant-garde music performance and production, and I studied composition, improvisation and music theory. During this time, I was heavily involved with free jazz and structured improvisation ensembles. However, upon graduation, my passion for improvised and unstructured music performance had waned, and I ultimately made my living as a rock musician. For nearly 10 years, I played in a variety of popular styles: rock, alternative, folk, reggae and indie. I achieved a small amount of success as a bass and keyboard player, and was fortunate enough to tour in the United States and internationally several times with different groups, and record several albums.

As a professional musician, I also found myself handling managerial and promotional duties for several of the groups I worked with. While much of the work was tedious, producing fliers and visual/web content was always enjoyable and provided a secondary creative outlet, marking my first works in media other than music. In 2011, looking to establish a more permanent practice in the visual arts, I enrolled in graphic and digital

design courses at Southern Maine Community College and began teaching myself web design. This marked a pivotal point in my artistic career for several reasons. For the first time, I began to understand the power of computers and coding as artistic tools and the flexibility of a digital environment to work between different mediums and to combine them in different ways. While none of this was particularly groundbreaking in the art world, it was new to my musician-brain. It also signaled the beginnings of my preoccupation with interaction design and sensor technologies.

The beauty of digital media - and perhaps its main criticism - is that data is reduced to a common numerical format. While purists and sentimentalists may cry foul at the digitization of analog signals, the fact of the matter is that today, with 24-bit, 96kHz audio sampling rates and beyond (and similar high resolutions available in moving image, photography and other sampled media), the fidelity of digital sampling outperforms what the human body can detect. Leaving the vinyl vs. compact disc vs. MP3 debate aside, which goes beyond questions of audio quality to areas of aesthetics, cultural relevance and beyond, it is safe to say that digital media does an excellent job of quantifying the world around us - visually, aurally, physiologically, and beyond.

Through digital sampling, with the right sensors one can convert nearly all known properties in the physical world (audible sound, movement, gesture, material properties, etc.) into digital information, which can be used as an input source for literally any

computational process. This is well-documented with DMIs, where controls and sound production are not necessarily bound by physical dependencies [5]. Instead, user controls are converted to digital signals that are mapped to sound producing variables. (This process is explained in depth in Chapter 3). Digital sampling can be applied to other media as well, and is a particularly enticing concept when moving into areas of interdisciplinary and multimedia work. We can sample any aspect of the physical world and apply that data to a computational process that can be output as another form entirely, or choose to combine processes and inputs and outputs to formulate new mediums of expression and interaction. The notion of using sound to control video output, movement to synthesize sound, or even geographical data to modulate other control structures[5], is extremely powerful. When anything can be reduced to a common data type, technology becomes the bridge through which we can reimagine and reexamine the world around us. This powerful concept was the beginning of my entrance into the world of interdisciplinary work in which I produced music, multimedia works, and audiovisual installations.

2.1 Music Performance

When I entered the Intermedia program in 2012, I was a part of 12 different musical projects. I was fortunate to have established myself as a bass player, keyboardist and

[5] This was employed in the installation *Unconquered Earth* (Section 6.10).

multi-instrumentalist in reasonably high demand, and was afforded the luxury of taking my pick of projects that I was interested in. During the first year of the program, I maintained my regular performance schedule while attending university full time.

Much of my work was as a sideman and session musician, filling the roles for other artists' music. But two projects stood out during this time that exemplified the direction that my musical performance practice was going: Sea Level and Post Provost.

Sea Level[6] is the moniker of a live electronica/trip-hop project by musician Dan Capaldi. After working together on other projects, we joined forces to realize his complex arrangements both in the studio and during live performance. In a configuration that was typical for me at the time, I played a setup that was comprised of a Nord Electro 3 digital keyboard, Moog Li'l Phatty analog synthesizer, a laptop running Ableton Live digital audio performance software controlled by multiple MIDI controllers, and electric and upright bass. A typical performance would feature me singing and switching between several instruments, playing many simultaneously. Through it was undoubtedly the most demanding performance situation I played in, it was also the most exhilarating, and served to pique my interest in expanded music performance practice and instrumentation. It was also the beginning of my foray into new digital musical instrument design. As my digital setup grew and our arrangements became more

[6] Sea Level: https://sealevel.bandcamp.com/

complex, I moved towards finer control of sound synthesis and sequencing, building my own sounds and complex control structures that went beyond the out-of-the-box applications of most of my equipment.

Post Provost[7] was a large indie-folk band comprised of several multi-instrumentalists. Fronted by singer/songwriter David Gagne, the group had just completed a new album, *Ancient Open Allegory Oratorio*. Though the songs were relatively simple folk tunes, the versatility of the group was exceptional. With several members switching between multiple instruments, we were able to produce a dynamic variety of music. For my work as a performer, it exemplified my own creative exploratory process, where I alternated between electric and upright bass, piano and keyboards, glockenspiel and vocals.

Toward the close of my first year in the Intermedia program, I made the decision to take a hiatus from music performance to concentrate fully on my studies in multimedia and digital design. In April 2013, at the University of Maine's new IMRC Center, I performed what would be my last concert with Post Provost. The following month, we returned to the IMRC Center audio recording facilities to record several new songs.

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[7] Post Provost: https://www.reverbnation.com/postprovost

2.2 Web

My interest in graphic and visual design, combined with the practical necessity of managing my bands' media and online visibility, led me to the field of web design. Largely self-taught, I learned how to write HTML and CSS and began to build simple websites. At this time, the newest web specifications[8] had just been introduced but were not yet the industry standards. But as I learned the basics, I realized the powerful potential of the new technology. New HTML tags allow for direct embedding of rich media content like audio and video, and the increasing power of JavaScript libraries has changed the World Wide Web into a rich interactive environment.

Out of my interest in web design and development, I began studying user experience design and human-computer interaction. Though first drawn to these fields in a strictly web and GUI (graphical user interface) context, it was soon apparent that these concepts are applicable across all facets of hardware and software design. It was my work with web technologies that got me started in this direction of research.

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[8] HTML5 was introduced as the official HTML standard in October 2014, while CSS3 has been standardized over time since 2012. (For more information: http://www.wc3.org/standards)

2.2.1 Interactive Web

One of my first finished works for the MFA was a simple web application entitled *Strangers* (2012). With little knowledge and experience about what it meant to actually make an *interactive* work, I wanted to explore the web as a medium that went beyond just graphics and information, and make something that a visitor could fully engage with to have an embodied experience. Conceptually, it was a retelling of a trip I had taken to Ireland through images, sounds and words. The project was conceived as a means of experimenting with multimedia and web-based documentary techniques. For two weeks, I travelled around Ireland with my partner, collecting audio and photo footage everywhere we went.

The piece was a single-page website constructed from a selection of twenty-three full-screen images taken from the trip that the user could scroll down through, or click a button to allow the images to advance by themselves. Keywords were displayed on several slides that triggered audio clips. The audio was constructed from the field recordings of the trip, edited, manipulated and reconstructed into short vignettes to encapsulate some of the intangible emotional depth of the experience.

Technically, it was a rudimentary execution of a dynamic, media-rich HTML5 site, and it served as my training ground for learning to program interactivity with JavaScript and jQuery. Behind the scenes, it incorporated programming techniques to

allow full-screen, high-resolution images and high quality audio files to load asynchronously[9] while utilizing the graphical user interface library *jQueryUI*[10] and other libraries to create an uncluttered, simple interface. Smooth navigation and optional automatic scrolling kept the focus on the audio and visual content.

This piece also marked my first work with user evaluation in the creative process, which is one of the most crucial elements of user-centered design. During the creation of the project, I solicited peers and classmates to evaluate the site on several different aspects, from technical achievement (does it work?) to aesthetic appeal (how does it make you feel?) They were able to test the site at two different points and give valuable feedback about their experiences, which helped to guide the project. After using the site, users were given a short questionnaire to fill out, followed by a round table discussion of their experiences and suggestions for improvement.

2.2.2 New Music World

In the summer of 2013, I moved to New York City for an internship with Joel Chadabe. A well-known and respected figure in the world of contemporary music, Chadabe is a composer, educator and author. His book *Electronic Sound: The Past and*

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[9] Instead of delivering all page elements on the initial page load, only the first images and audio files would load, and the rest of the page content would load and fill in as the user navigated through the site. This facilitated short load times and a smoother user experience.
[10] jQuery UI: http://jQueryUI.com

Promise of Electronic Music [2] is a seminal text on the development of electronic and computer music in the second half of the 20th century [6].

At the time of my arrival, he had decided to divide his Electronic Music Foundation into three affiliated entities: New Music World[11], Intelligent Arts[12], and Ear to the Earth[13]. My internship consisted of building new websites for each. The websites themselves were relatively standard, lacking the interaction and aesthetic beauty that works like Strangers strove for. However, through the design of the three sites (which stretched beyond the summer into an ongoing engagement that continues today), I was able to refine my skills and continue to build a fluency in the field of web design and development.

My move to New York and introduction to Joel Chadabe reignited my latent interest in new and experimental music, and crystallized my desire to pursue research in music technology. The primary project that we worked on was New Music World, an online resource for new music events, releases, publications and ideas. Through the experience of building the online presence, I became familiar with the rich community of artists, practitioners, researchers and supporters of a wide variety of music and multimedia works. Chadabe and I discussed the history and current state of new music and music

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[11] New Music World: http://newmusicworld.org
[12] Intelligent Arts: http://intelligentarts.net
[13] Ear to the Earth: http://eartotheearth.org

technology at length, and, after this experience, I decided to pursue full time research in the field.

After returning to the University of Maine for the academic year, I returned to New York the following summer where I continued working with Chadabe. In addition to the knowledge that he imparted to me, I was also introduced to several other musicians and educators, which ultimately put me on the path to spending my final year in the MFA program as a visiting researcher in McGill University's Music Technology program.

2.3 Multimedia Works

As mentioned at the beginning of the chapter, an exceptional aspect of the Intermedia program at the University of Maine is its flexibility and the potential for students to explore a wide variety of different subjects, mediums, and processes. As a musician and web designer interested in user interaction and music technology, I was captivated by the notion of combining several of these areas into single works. Audiovisual installation was a natural draw, and during my time in the MFA, I produced four large installation works.

Most were developed in collaboration with other artists. Perhaps a concession to the band dynamic in music performance, I have always enjoyed collaborative work and have found that two or more people working together can often create work that exceeds the sum of its parts.

2.3.1 Installation Design

My first major installation work was *fourSQUARE: Death by Pop Song* (2013). A collaboration with Sally Levi, this piece explored themes of youthful emotion and social interaction in the schoolyard. The work reconstructed an urban playground complete with a fully playable game of four square as an indoor site-specific installation. Four square is a ball game where a ball is tapped back and forth among up to four players with the objective of keeping the ball in play. Computer vision tracked the visitors in the space and movement of the ball. The movements controlled an evolving spatialized soundscape that adapted to the activity in the room, from lonely isolation to joyful exuberance, depending on the number of people visiting and gameplay occurring at any given moment.

The technical aspects of motion tracking, interaction, and spatialized audio output were developed in Max/MSP, a visual programming language for music and multimedia design. Movement in the room was captured by an infrared camera suspended overhead. The camera feed was converted into a motion map in Max and activity was analyzed for location and frequency of occurrence. Based on these variables, two simultaneous audio processes were controlled. First, an ambient soundscape responded to visitors by matching their locations and movements with a collage of background sounds spatialized through the room. For example, if a single visitor entered and moved to one corner they

would be greeted with the sounds of muted whispers nearby, while the laughter of children could be heard from the far corner. Alone, the visitor could approach the other side, only to have the laughter fade and the whispers return. On the other hand, when several people were present, the whispers disappeared and the soundscape morphed into the sounds of a crowded playground at recess. The second audio process occurred when visitors began to engage with one another. Based on their positions and interaction with the four square game, clips of pop songs would play from various locations, selected to specifically match the "mood" of the players based on activity in the room, number of people, and vigor of the game. A single person playing alone on the court might be greeted by a chorus of "Crazy" sung by Patsy Cline ("Crazy... crazy for feeling so lonely..."), while a spirited game could trigger anything from Prince's "1999" to Black Eyed Peas' "I Gotta Feeling".

While the technical challenges of the piece were both demanding and rewarding, one of the more rewarding aspects of the piece for artist and audience alike was the integration of a tangible physical environment. It gave the technology a context and reason to exist.

2.3.2 Sensor Design

In the spring of 2014, along with collaborator John Carney, I presented another installation piece called *High Striker!*. We were both interested in creating a hybrid

digital multimedia and physical installation, and our union represented a good mix of hardware and software design with physical sculpture and installation work. The piece was modeled after the classic carnival game of High Striker, where participants test their strength and accuracy by hitting a target that propels a heavy lug up a cable towards a bell at the top. Our version was a fully playable video version for up to seven people at a time. We crafted wooden mallets and pedestals equipped with self-designed force sensors that detected strike velocity. In play, the velocity data was captured via Arduino and sent to Max, where a video was selected and played back, according to the strength of the blow.

The video output was designed for projection onto a large bay window that fills the exterior wall of the Fernald Adaptive Presentation Space at the University of Maine. The window is made up of several vertical panels. For our piece, each panel contained the output for one of the pedestals. When the target was struck a selected video would play forward according to the recorded velocity, then recoil back to its initial position. If the maximum force was achieved (equivalent to ringing the bell in the carnival version), the full video sequence would play through to the finish. Each strike also triggered audio effects, and, with all stations in play, the piece in action evoked the manic energy of a carnival midway, with a collage of visual and audio output combining with the sights and sounds of several players taking part.

This piece was especially significant because of the unique sensors that we designed and built for it. Unbeknownst to us at the beginning of the project, there are no inexpensive sensors on the market that can accurately measure the velocity of a sharp and heavy strike. We began prototyping several different versions to try to find a solution. One early prototype involved a homemade capacitive sensor made out of semi-conductive foam sandwiched between two wired copper plates. Our hypothesis was that, if we could find the correct density and thickness for the sandwiched material, we measure the signal at the point of the material's greatest compression against a control signal and use the depth of variation for our measurement. But after testing several versions, we were unable to arrive at any workable solution. The main issue we experienced was that of *hysteresis*. After a strike, the sandwiched material never returned to its initial mass, making the output wildly inaccurate.

After further brainstorming and experimentation, I arrived at a low-tech but workable solution. We had done several tests with piezoelectric sensors but found them far too fragile and inaccurate to yield an accurate variable analog input signal[14]. As the act of hitting a target with a large mallet generates a huge amount of force, to the naked eye the problem seemed to be one of scale: how could we translate a large force into something small enough to be measured by a small inexpensive sensor? The answer

[14] An analog input signal can read a variable range of values, whereas a digital signal only reads on or off.

seemed to be that we could convert the energy of the blow into some intermediate stage that could be more easily measured by the resources we had at our disposal. After testing a spring mechanism without success, I thought to try a rubber bouncy ball suspended on a rubber band over a piezo sensor. Despite its crude materials this system actually worked very well (Figure 2.1).

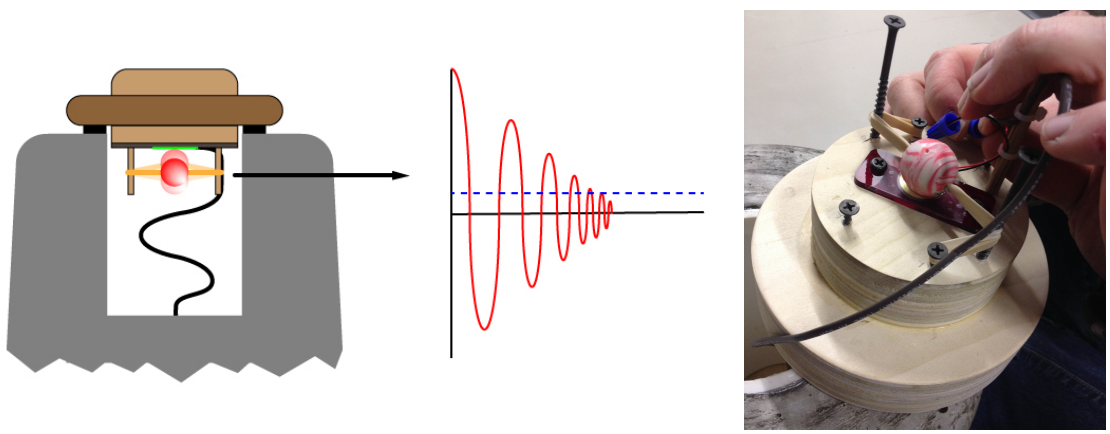

Figure 2.1 Diagram and prototype of *High Striker!* sensors.
Energy of a strike impact is transferred to a suspended rubber ball that bounces off a piezo sensor. The number of bounces above a set threshold determines the force.

In its finished form, the sensor was attached to the underside of the trigger "button". The trigger was mounted on top of a hollow concrete pedestal. On the underside of the trigger, a piezo sensor was attached to a flat panel, below which a bouncy ball was suspended on a rubber band. The trigger was seated on hard rubber blocks on top of the concrete pedestal, so a firm strike would compress the trigger but only slightly. When struck, the energy of the blow would travel down to the plate and rubber ball, which

would then bounce off the piezo several times, depending on the force of the strike. The number of bounces above a predetermined threshold gave an accurate measurement of the force and accuracy of the strike.

This project honed my skills in electronics and circuit design, an area that I had previously dabbled with but never fully explored. It extended my range with interaction design by giving me new tools with which to build even more interactive systems. It was through this project that I also became interested in building hardware, which again steered me towards digital musical instrument design.

2.3.3 Audio Synthesis and Installation

In 2013, I put together a hybrid installation/presentation entitled *From Pythagoras to La Monte: An Interactive Analysis of Harmony as Time*. The piece presented research on connections between traditional notions of harmony and tonal structure and modern and experimental forms of music and sound art. Using a similar configuration as *fourSQUARE*, a large space was converted into an interactive synthesizer through which visitors could explore musical concepts of pitch and interval relationships, tuning systems, and timbre.

Conceptually, I was interested in documenting my research around harmony and tonality through a comparison of Pythagoras' music theorems and the drone music of contemporary composer and sound artist La Monte Young. I chose Pythagoras and La

Monte Young as musical bookends to explore how pitch relationships (intervals), tuning and timbre are directly related, and how these relationships inform our perception of traditional harmonic structure and contemporary new music forms.

The piece was set up as a lecture in a sound installation environment. Three sections covered unison pitches (including explanation of phasing, sine tones and separation of unisons into multiple distinguishable frequencies), intervals and tuning systems, and timbre and the overtone series. Each section was comprised of a short lecture followed by activation of a sound 'mode' for the installation, in which the audience could navigate the space to experience different aspects of the topic (Figure 2.2).

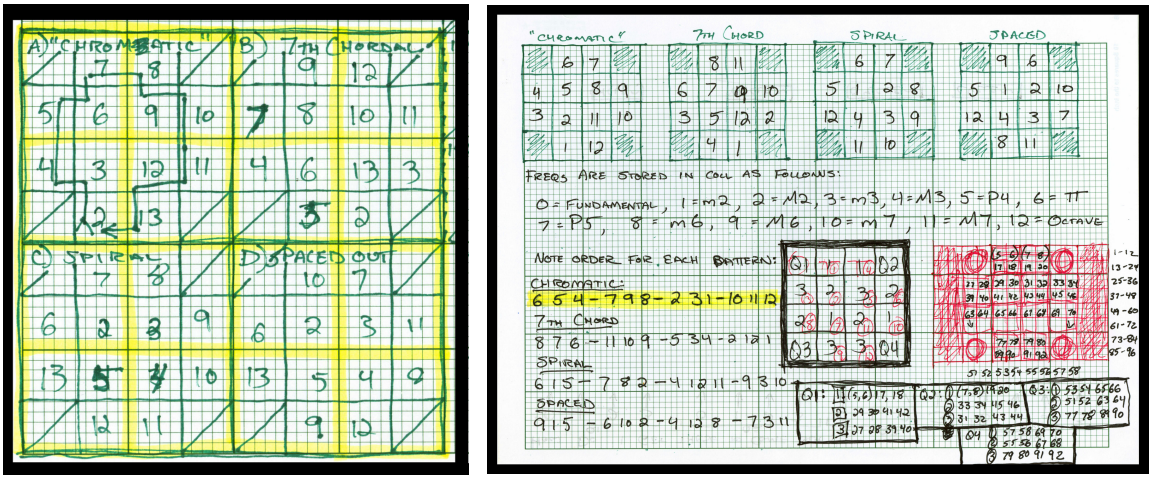

Figure 2.2 Sketches of synthesis mappings for *From Pythagoras to La Monte.* Using an overhead camera, visitors were tracked across a grid, where movement through different 'zones' was mapped to audio variables. Thus the entire space functioned as a playable walk-through synthesizer.

Starting with unison sine tones, the piece explored the audible effects of two or more frequencies slowly falling out of unison. At first, phase cancellation is heard, where loudness of the tones, which were audible together as one, begins to oscillate as the sine waves fall out of sync with each other and alternately cancel and reinforce one another. As the pitches separate further apart the oscillations become audible in a rhythmic pattern, called *beating*, while still recognizable as a single pitch. As the separation of pitches increases, eventually the frequencies audibly separate into separate recognizable tones, bearing some intervallic relationship with one another.

With the basic demonstration of unison tones covered, the work continued with a review of intervallic relationships and tuning systems. Pythagoras was one of the first to provide a mathematical relationship between pure intervals and the organization of pitches into 12 subdivisions, thus providing a scientific rationale to an audible phenomenon [7]. However, there have been many variations on the 12-tone scale as Pythagoras' ratio-based system revealed. The piece demonstrated several tuning systems and microtonal intervallic structures and the mathematical and audible differences of each. Here, the work of La Monte Young was considered in detail, with his creative use of prime numbers and other complex calculations for significant intervals and tuning systems [8].

Finally the piece turned to a demonstration of timbre. Using the unison tones, beating and separating of frequencies, and interval explanations as the basis for

explaining harmonic and non-harmonic overtones, the piece explained the basis of simple additive and frequency modulation (FM) synthesis.

Aesthetically, the piece may have been overambitious. It attempted to combine several disparate ideas into a single piece: cultural and historical aspects of music theory, audio signal processing and sound design, interactive sound installation and academic lecture. In hindsight, the hybrid educational presentation/artistic work format was difficult to assemble, and the considerations for both aspects didn't fully mesh together. As a further critique, the audio synthesis design was never quite perfected, nor was the piece adequately user tested before its exhibition. As a result, while functional, it was underwhelming as both a pedagogical aid and a piece of sound art.

However, as a part of ongoing experimental research, the experience gained from this project was invaluable. The piece continued my training in interface design, from the production of a responsive environment to the construction of a tablet based wireless controller (Figure 2.3). It explored new methods of audience participation and interaction. Additionally, it explored digital sound synthesis, and marked the beginnings of my own work in this field. It was during this time that I first met Joel Chadabe and subsequently focused my research specifically on music technology.

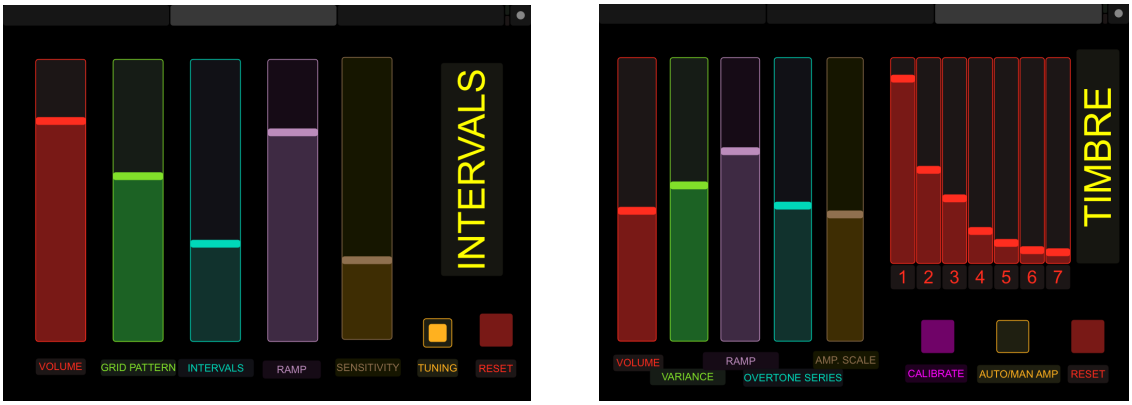

Figure 2.3 Screenshots of tablet interface for *From Pythagoras to La Monte.* The tablet interface allowed for wireless control of all parameters of the audio synthesis, and progression through the several different modes of operation.

2.4 Bridging Art and Technology through Interaction

Throughout my artistic development, finding the right balance between art and technology has been a continued challenge and a sustained learning curve. Pieces like *fourSQUARE* and *High Striker!* blended the two well and created compelling work, while others like *From Pythagoras to La Monte* struggled to combine them into a coherent form. The synthesis of these two worlds continues to be a fundamental part of my practice as an artist, designer and researcher. As an artist, I get inspiration from technology: the challenge of building something that hasn't been built before, reimagining something classical with new tools, or building digital versions of analog artifacts. On the other hand, as a technologist, I draw heavily on my artistic sensibilities to explore new uses and interpretations of technical tools and knowledge, and to extend hardware and software beyond strictly utilitarian use to things that can capture a user

or visitor's imagination and temper function with aesthetic value. This interdisciplinary approach can be seen in my frequent collaborations with other artists, the variety of mediums and topical matter of my own work, and my arrival into full time music technology research.

Early in my MFA career, I read a speech by composer and electronic musician Herbert Brün, delivered to UNESCO in 1970. Entitled *Technology and the Composer*, one quote in particular has been an inspiration and reference point for my own work and progress as an artist, engineer and researcher:

> *I imagine a building in which the arts are met by technology and the sciences on their common ground. They all investigate, stipulate, create, and exploit systems. They are all faced with the puzzles and the functions of structure. And their aims and results complement one another because of their difference. While the sciences observe or stipulate systems which are to be analogous to an existent truth or reality, and while technology stipulates and creates systems that are to function in an existent truth or reality, the arts stipulate and create systems which are analogous to an existence desired to become true or real* [9].

2.4.1 Transition into Music Technology Research

For the third and final year of my MFA studies, I was awarded the University of Maine's Chase Distinguished Research Assistantship to complete my studies as a

Graduate Research Trainee at the Input Devices and Music Interaction Laboratory (IDMIL) at McGill University in Montreal. The laboratory performs research in the areas of human-computer interaction, sensor development, and the design of musical instruments and interfaces for musical expression.

At IDMIL I have been working on two research projects. The first project, described in the following chapter, was the design and prototype of a new digital instrument. I was new to DMI design when I arrived at McGill, and this project served as a survey and introduction to the field in a learn-by-doing practice-based research project that produced a working instrument prototype and plans for a new revised version. The second project, discussed in Chapter 4, was a user study of musicians intended to identify trends around new instrument adoption and usage. Together, these two projects have shaped the topic of my current and ongoing work.

CHAPTER 3: DESIGNING A NEW DMI

Figure 3.1 An early prototype of the Noisebox.

This section documents the initial prototyping of a new digital musical instrument. Specifically, it focuses on the design of the interface, and contextualizes the project through some of the existing research in the field of gestural control of new musical instruments [10] [11]. The project began with a concept for a stand-alone hand-held polyphonic synthesizer called the Noisebox (Figure 3.1). Several key concepts and strategies were explored and implemented during its development, including: analysis and application of gesture in musical performance, choice of sensors and sensor conditioning, appropriate mapping strategies, and evaluation of user experience. The outcome yielded a functional prototype that fulfilled the initial goal of the project to

design and build a working instrument from start to finish. The stage documented here represents the first phase of a longer project. Future phases will conduct user tests to measure the success of the instrument based on performer feedback and refine the design through multiple iterations, leading to a finished instrument.

3.1 Overview

This project began as a way to apply fundamental concepts of designing input devices for new musical instruments directly to practice. A new instrument called the Noisebox[15] was conceived and built to test the capabilities of the Raspberry Pi as a platform for low cost, embeddable processors for digital musical instruments (DMIs). The design attempted to embody some of the characteristics of analog instruments, most importantly reuniting controls and sound production together into one discrete unit (Figure 3.2). This feature marks a reversal of a primary characteristic of DMIs, where the lack of acoustical coupling of physical control and sound production has allowed for complete separation of these two systems [12] [5]. Other strategies included the removal of external wires and connections to auxiliary components, and a focus on simple, learnable controls. The Noisebox is intended to be easily held and manipulated in the hands of a performer.

[15] Video demonstration: http://vimeo.com/113886990

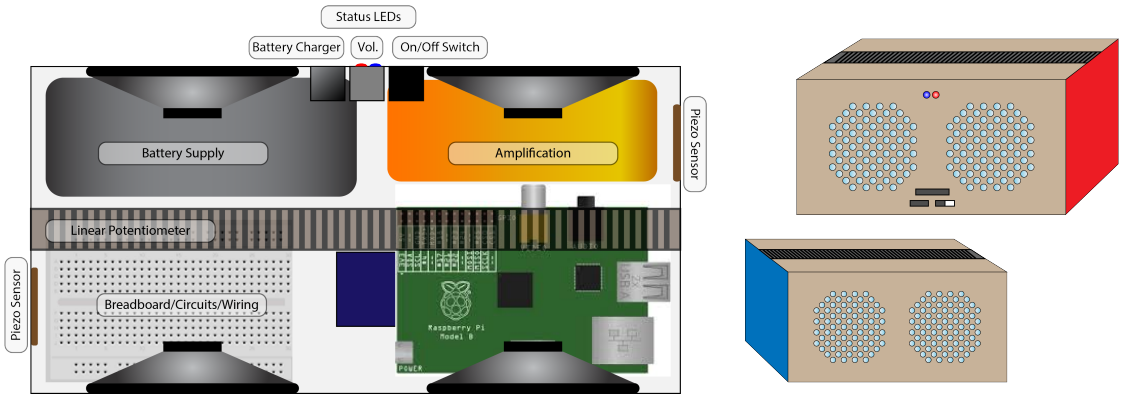

Figure 3.2 Illustrations of first Noisebox design.

3.2 Designing the Noisebox

The process of designing and building the instrument spanned four sections. First, a summary study of gesture was used to plan a basic control system that would be inherently intuitive and playable for a performer. Then, sensors and sensing strategies were chosen and implemented. A polyphonic FM synthesizer was programmed in the visual programming language Pure Data[16]. Finally, a software mapping system was devised to connect the performer's gestures to sound production. Figure 3.3 shows an early diagram of the instrument's data flow, from gesture capture to mapping to sound output.

[16] This section focuses specifically on the design of the interface, and sound synthesis is not covered here in depth.

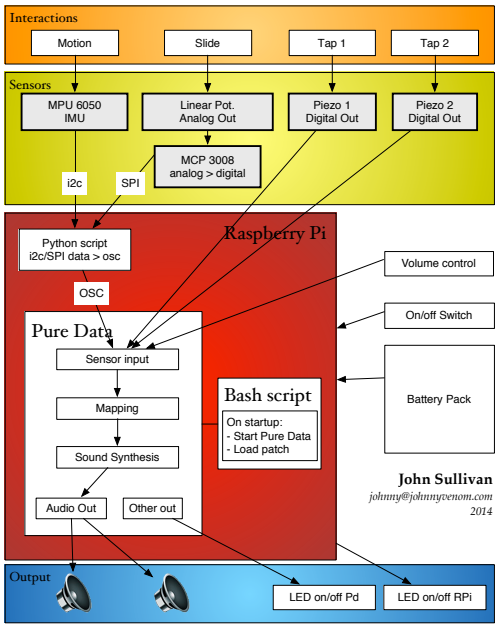

Figure 3.3 An early diagram of Noisebox data flow.

3.2.1 Gesture Selection

When considering how a performer might interact with the proposed instrument, priority was given to creating a set of controls that would be simple and intuitive. Direct gesture acquisition was chosen over indirect or physiological methods, as this offered the most straightforward connection between performer and instrument [10]. Studies have shown that a tight coupling between performer and instrument is a key factor in achieving musical expression [12]. This relationship is linked to the perception of expressiveness by both performer and audience [13] [14]. Inspiration was drawn from the

relationship between a skilled performer and acoustic instrument, in which the instrument has been described as an extension of the musician's body [15].

Claude Cadoz [11], François Delalande [16] and Sophia Dahl et al. [17] offer similar classifications of levels of gesture, from functional (sound-producing) to symbolic (non-sound-producing). Using Delalande's classification, the primary mode of gesture for the Noisebox is "effective", using handed gestures of tapping and sliding across a specially designated surface. Another class of control is available, which can be classified as an "accompanying" gesture. This is achieved through manipulation and orientation of the instrument through physical space. The effective gestures of tapping and sliding to control sound parameters closely mimic controls of many traditional analog instruments. Movement of the instrument in physical space is also common with traditional instruments; however, the production or modulation of sound is uncommon. With the Noisebox, these gestures add a wide array of sound parameters that the performer can control. This demonstrates the use of "effective", or "ancillary" gestures that can be used to extend musical control beyond the normal capabilities of a traditional acoustic instrument [18].

3.2.2 Sensors and Signal Acquisition

With the methods and types of gestures established, the next step was to select the appropriate sensors and technology to acquire the gestural data. Two types of data

needed to be captured: continuous variables, and discrete, event-based signals, which Max Mathews referred to as *triggers* [19].

Piezoelectric sensors were selected to capture the discrete signals. To improve their accuracy, signal conditioning was applied through software to set appropriate thresholds and prevent unintentional triggering. These sensors were chosen for their low cost and simplicity. However, during testing I found that other sensors could have been a better choice. This use of "unsophisticated engineering solutions" [20] has been identified as a common but troublesome trend in DMI design. Though more robust technologies exist, they require an advanced level of expertise to implement. However, use of lower tech solutions (like the piezo sensors here) comes at the cost of reduced accuracy and precision in the gesture acquisition.

A SoftPot linear position sensor was used to capture the sliding gesture. This can function as an event-based control, where a single value can be specified by a single touch, or a continuous control, where a stream of values can be sent with a continuous motion. Again, conditioning was applied through software to attenuate the input signal to a suitable range and to freeze values at their last position until further modulated. Other sensors were considered and may be substituted in future iterations. One promising alternative is the use of force sensors made of conductive paper [21], which could expand the physical area of the sensor across an entire surface of the instrument and be configured for 2 dimensional X-Y control.

A study by Marshall et al. [22] on performer preference of input gesture found preference for pitch selection by a "pressing" gesture (i.e. use of buttons or keys) over "sliding" gestures. While this suggests that the instrument might benefit from a different mode of input for pitch selection, the sliding control works well for the glissando type pitch modulations of the Noisebox.

Finally, to capture the physical manipulation of the instrument, the MPU-6050 accelerometer-gyroscope sensor was used. Accelerometers and inertial measurement unit (IMU) sensors are among the most widely used sensors in DMIs today [20]. Some IMU sensors also integrate a magnetometer, which orients an object in the physical world by measuring the Earth's magnetic field [23]. The MPU-6050 lacks a magnetometer, so instead a function was added that would "zero out" the instrument's physical orientation over time to keep the performer's controls consistent and predictable.

Sensor fusion for the MPU-6050 is contained onboard the sensor's integrated circuit firmware[17]. Accelerometer and gyroscope data is correlated to provide highly accurate measurements of three axes: yaw, pitch and roll. Additional signal conditioning was applied to the continuous data stream to limit the sampling rate of the sensor to 50Hz. This was found to be high enough to be extremely responsive, while sufficiently limiting

[17] MotionFusion™, by Invensense: http://invensense.com/

the bandwidth to an acceptable range for the serial communication protocol that connects the sensors to the Raspberry Pi.

3.2.3 Mapping

Mapping objectives were laid out to create an instrument that could adhere to Wessel and Wright's principle of "low entry fee with no ceiling on virtuosity" [24]. This meant setting up simple and intuitive controls that could easily be understood and interpreted by a novice while containing sufficient nuance and complexity to reward continued practice with greater expression. The objectives were achieved by implementing one-to-one mappings for some parameters like turning individual voices on and off, and many-to-one and many-to-many mappings for frequency and timbral control of the sound synthesis [10]. Inspiration was taken from Wessel's research on timbre space for musical control [25] for higher-level parameters of overall sound output. In practice this was approached by creating two levels of control: first, on a low-level, voice-by-voice basis where the frequency of each voice can be controlled discretely and the number of simultaneous voices can be controlled, and second (high-level) by modulation and depth parameters of the FM synthesis that can be applied to all active voices simultaneously [26].

Consistent with research by Hunt and Kirk [27], Hunt, et al. [28], and Kvifte [29], more complex mappings were ultimately the most rewarding and engaging from a

performance perspective. Based on preliminary user testing, the instrument was most effective when the individual low-level controls were shifted out of focus and the performer began to work intuitively to shape the timbral characteristics of the overall sound output. This intuitive mode of performance also reinforces the benefits of tight coupling between performer and instrument and, in turn, the coupling of interface and sound production.

One of the biggest technical challenges to achieving this tight coupling is to achieve sufficiently low latency between gesture and sound. Wessel and Wright suggest acceptable latency thresholds of less than 10ms with a range of variation no more than 1ms [24]. So far, the Noisebox hasn't come close to this for a variety of reasons. One is the limitation of the Raspberry Pi Model B, with 512MB of RAM and 700MHz processor speed. Additionally, the synthesis and mapping algorithms could be rewritten to optimize performance. However, the instrument, which produces sustained legato tones and has been augmented with reverb and delay, is somewhat forgiving in this regard.

One innovative mapping strategy employed in the Noisebox is the voice selection algorithm. The performer is able to activate up to eight simultaneous voices. Once multiple voices are in play, the performer is able to select control of any single voice by orienting the instrument across a 180º horizontal plane. Thus, aiming the Noisebox to the performer's far left activates primary control of the first voice, and moving the device across the body to the performer's right side sequentially selects control of each

individual voice up to the last. In this way, the pitch, timbre and loudness of each voice can be modulated independently. While the voice selector is a discrete control, as previously mentioned, the instrument is most effective when the performer shifts focus from low-level concern of individual voices to higher-level control of timbral space.

3.3 User Experience Evaluation

The evaluation of user experience throughout the process is important to inform the design and assess its success. More comprehensive testing and analysis is planned in future phases that will fully guide the development of the instrument.

Several components of the design were implemented with the end user in mind. The main objective of building the Noisebox was to create an instrument that would be accessible, interesting and enjoyable for a performer. The aesthetic design was intended to remove the DMI and its user from typical performance configurations – for example, the performer hunched over a laptop or tethered to wires and auxiliary equipment. This was implemented by building a completely stand-alone instrument.

As an interface for control of sound, I tried to strike a balance between what Michel Waisvisz referred to as a “meager recreation of existing concepts and imitation of analogue worlds” [19] and the unchecked potential of computer-based instruments, described by Atau Tanaka as a “theme park one-man-band” [30]. This was carried out by using some of the aesthetic qualities and characteristics of acoustic instruments like the

use of familiar gestures and direct control over primary sound variables, while exploring the enhanced capabilities available exclusively in the digital realm such as the acquisition of ancillary gestures and use of more complex mappings.

Though not addressed in depth here, adequate feedback is an important and complex topic, and it is vital to creating a successful user experience [11]. The primary channel of feedback for the Noisebox is auditory. A secondary source is vibrotactile, conveniently present thanks to the sound production embedded within the instrument itself. The housing of the instrument creates a natural resonance chamber that provides significant haptic feedback. This is another way in which the Noisebox borrows from its acoustic counterparts.

Ultimately, the true measure of successful user experience will be demonstrated by continued use and adoption by multiple users. This is a challenge for all designers of DMIs and may not always have to do with the technical utility or usability of an instrument. Wessel and Wright suggest that instruments and interfaces succeed for mostly sociological reasons [16]. It seems that there is a general consensus though, that successful instrument and interface design achieves an optimal balance of engineering technology and musical sensibility. While still it its early development, the Noisebox shows promise in these areas. An important next step is to begin dedicated user evaluation to collect and analyze data for further development and refinement.

3.4 Takeaways and Future Work for the Noisebox

This section has summarized the process of designing and building a novel input device for a new digital musical instrument and placed it in the context of interdisciplinary research in the technical and creative fields of human-computer interaction, computer and electrical engineering, design, art and music performance. Consideration of these areas guided design of the Noisebox through the selection of gestures for instrument control, sensors and mapping strategies. User experience design was utilized to create an instrument that was specifically tailored to be functional and engaging for the performer and to encourage lasting and repeated use.

The current version of the Noisebox is an initial prototype. Throughout the process of designing and building, several areas have been identified to improve upon or redesign, including the separation of mapping layers into one or more discrete modules and refining of gesture acquisition data with better sensor technologies and circuit conditioning techniques.

Other important aspects of this project were not covered here but are integral nonetheless, and demonstrate areas for further research. Sound synthesis was achieved though a low bandwidth polyphonic FM synthesizer programmed in Pure Data. Improvements and optimization of synthesis algorithms and code are necessary to lower latency and improve overall performance and sound quality. The permanent physical

construction of the body of the instrument has been designed but not constructed, and will contribute significantly to the instrument as a whole (Figure 3.4).

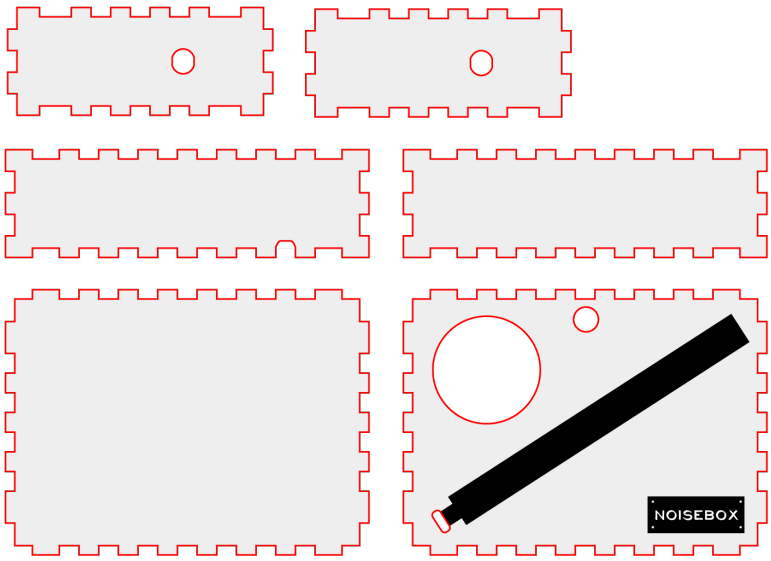

Figure 3.4 Early template of Noisebox laser cut panels for enclosure.

Use of the Raspberry Pi Model B has revealed limitations for processing the bandwidth necessary to sample sensor data at sufficiently high rates and for performing advanced digital signal processing. Experimentation with the newer Raspberry Pi 2 and other development boards, like the BeagleBone Black and Intel Galileo will likely provide better results. Finally, implementation of feedback requires dedicated attention to ensure that sufficient responsiveness is available for the performer.

Work continues on the development of the Noisebox. A new prototype of the instrument is currently being built after taking into account the above considerations.

Additionally, the project will implement increased user testing and evaluation to ensure that the product will be functional and enjoyable to use in the hands of musicians and artists.

CHAPTER 4: MUSICIAN SURVEY ON NEW INSTRUMENTS FOR MUSIC PERFORMANCE

In the spring of 2015, I began a new section of research dedicated to identifying user trends in new instrument adoption and performance practice with technology. The study was in the form of an online user survey administered to musicians of all levels and backgrounds. Background questions focused on musicians' performance and training backgrounds, preferred musical performance styles, and primary instrument choice. This section was followed by questions about their use of technology in performance, what tools they use and how often, and what factors influence their use of new DMIs and interfaces. A final section had them rank their familiarity and frequency of use for a number of instruments, interfaces and devices.

The survey was intentionally broad, and, by itself, not meant to definitively solve any major user interaction or DMI design problems. Its purpose was to correlate DMI use and adoption with background, primary performance instrument, and musical style. The hypothesis of this study is that there are different levels of guidelines and methodologies that can be followed for DMI design. One the one hand, there are certain general recommendations that can be made for designers of instruments for all performers. Beyond this, various communities of performers have different needs, and

only by clearly identifying and understanding the target user can designers begin to create instruments and interfaces that musicians will truly want to use and adopt.

While the survey has been administered and the results tallied, the study is still ongoing at the time of this thesis. This section describes the methods used to construct and administer the survey, and reports the preliminary results and intended future work.

4.1 Related Work

This study took into consideration two previous surveys that were conducted in 2006 [31] and 2008 [32]. Both differed considerably from my own but there were several areas of common interest and overlap. Ultimately, they all are concerned with the use and adoption of new digital musical instruments.

The first survey, administered by Thor Magnusson and *ixi audio*[18] was a phenomenological, qualitative survey investigating performers' relationships with both acoustic and digital instruments. *ixi audio* is an ongoing experimental project that creates software based digital musical instruments and environments for generative music. While the study did not specifically address the design process, it looked at the factors that influence performers' adoption of new instruments and new technology, and compared experiential and perceptual differences between acoustic and digital instruments. Although the survey specifically targeted computer musicians, for the most

[18] ixi audio: http://ixi-software.net

part, the respondents didn't necessarily indicate a distinct preference for acoustic or digital instruments, but instead gave many insights into how their experiences differed, and identified strengths and weaknesses of both. Other parts of the survey asked questions about affordances, limitations, entropy, control, and the embodiment of both acoustic and digital instruments.

The second work that provided some background for my own survey was a project entitled *Taxonomy of realtime Interfaces for Electronic Music Performance (TIEM)*[19], directed by Drs. Garth Paine and Jon Drummond at the Virtual, Interactive Performance Research Environment at the University of Western Sydney in partnership with the Electronic Music Foundation (EMF) and IDMIL. This project created a database of new digital musical interfaces via an online questionnaire where performers and designers could submit information about their devices. Questions were a mix of qualitative and quantitative, arranged in 6 sections: general description, design objectives, physical design, parameter space, performance practice, and classification.

The entries were compiled and a taxonomy was developed for digital instruments and interfaces. The study identified the difficulties of creating such a framework, and reviewed various methodologies of previous classifications, like those of Hornbostel and Sachs [33], and more recently, Birnbaum, et al. [34]. Prior to Birnbaum's work, most

[19] TIEM: http://vipre.uws.edu.au/tiem/

taxonomies were based on organizations of sensor types, nature of interfaces, gesture classifications, and mappings between interface and sound generation [35]. Birnbaum's organization was based around a multi-dimensional space with seven axes (Table 4.1) that incorporated many of the same concepts and some new ones that are more specifically tailored to the vast diversity of the DMI landscape.

Axis	Dimension
1.	Role of Sound
2.	Required Expertise
3.	Music Control
4.	Degrees of Freedom
5.	Feedback Modalities
6.	Inter-actors
7.	Distribution in Space

Table 4.1 The 7 axes of Birnbaum's dimensional space for musical devices.

The taxonomy developed out of the TIEM study draws deeply from Stan Godlovitch's research on music performance. In his book *Musical Performance: A Philosophical Study*, Godlovitch presented an idealized model of "complete performance" [36], in which he describes a holistic performance practice as an interconnected network of relations between musicians, musical activities, works, listeners and performance communities. From this multidisciplinary approach, the TIEM project assembled a new taxonomy (Figure 4.1) intended to address the complexities of classifying digital and electronic instruments and interfaces, which were often unaccounted for or left without a clear designation when classified using older systems.

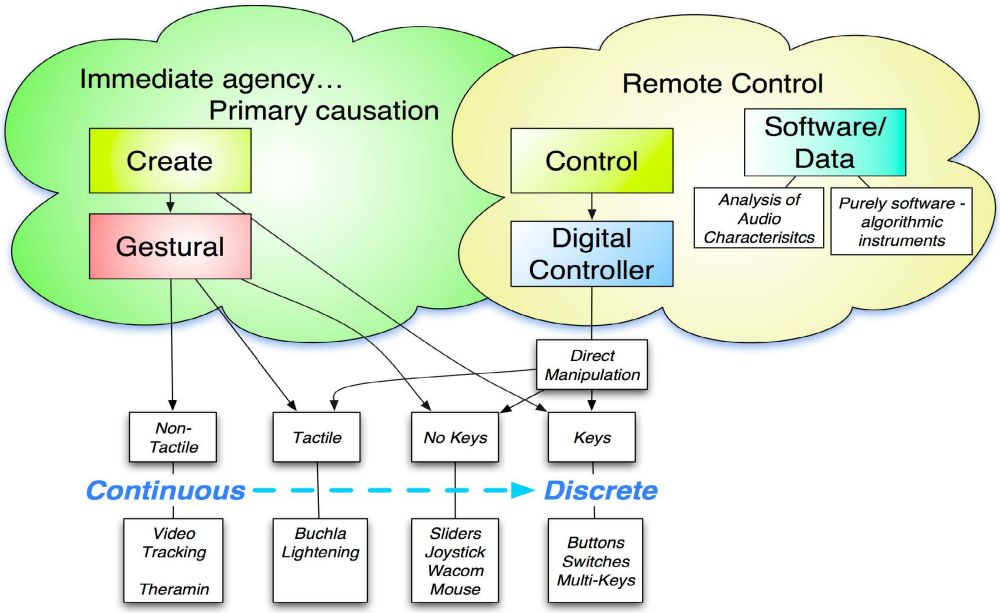

Figure 4.1 The TIEM Taxonomy of Digital Musical Instruments and Interfaces.

4.2 Current Survey on New Instruments For Music Performance

The study presented here shares common ground with both of the previous works but seeks to identify new information about what DMIs and interfaces musicians prefer for performance and what factors influence the adoption, continued use, and even rejection of new technology. It correlates DMI preference and use with musical training and background, and choice of primary instrument and musical style, hypothesizing that these factors greatly influence the types of instruments and interfaces chosen, as well as behaviors around adoption, experimentation and rejection.

As mentioned before, this is an ongoing project, and this section describes the initial part of the study: the delivery of the survey, preliminary results, and some early

observations, along with indications for more in-depth analysis of the results and future areas of focused work.

The survey was broken into three sections:[20]

1. Collection of background information about respondents' musical training, background, and performance practice
2. Questions about use, adoption and abandonment of new DMIs and interfaces in performance
3. Ranking of familiarity and frequency of use of several different DMIs and interfaces, ranging from popular, commercially available devices to experimental and alternate instruments and controllers.

4.2.1 The Survey

The survey was administered online using Qualtrics Survey Software and administered in April 2015[21]. Musicians above the age of 18 were recruited through social media invitations[22] and active musician email lists. The survey closed with 119 respondents, exceeding the established goal of 100, which was determined to be large enough to get a reasonable number of responses and a wide array of inputs.

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[20] See Appendix A for survey questions. Full survey results can be viewed online at https://goo.gl/xgXvhb

[21] See Appendix B for Institutional Review Board approval of the study.

[22] Invitations and solicitations were sent out via Facebook, Twitter and Reddit.

The questionnaire contained 30 questions that were a mix of multiple choice and short answer. It took about ten minutes to respond. In the interest of maximizing responses, the survey was kept as simple and straightforward as possible. None of the questions were required, so respondents could leave blank any sections they did not wish to answer. Additionally, the survey was entirely anonymous and did not collect any personal identifying data. Table 4.2 shows the average response rate for each section out of 119 total participants.

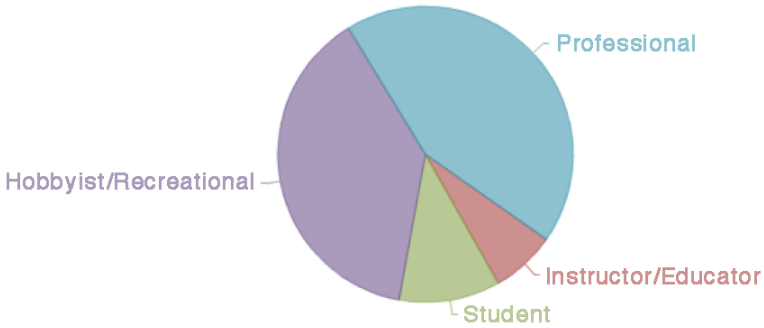
#	Section	Responses	% of total
1.	Background Info	103	87%
2.	Adoption and Use	89	75%
3.	DMIs	76	64%

Table 4.2 Musician Survey response rate per section.

4.2.2 Participants

The majority of the participants identified themselves either as professional musicians or hobbyists, while a few others selected either student or instructor/educator (Figure 4.2). For musical training, responses were spread over a wide range, from self-taught to university and beyond. The next two questions were the biggest indicators of what kind of performance practice the participants engage in: their instrument of choice and their primary musical style. Instrument choice was dominated by the most common instruments found in popular music: guitar, piano and keyboards, bass, drums and voice. Well over half of the participants identified the main type of music that they play as one

of three general styles: rock/popular, experimental/avant-garde/computer music, or classical.[23] For the last background question, the survey asked how long participants have been playing their primary instrument, and the overwhelming response was 10 years or more (76%).



Answer	%
Professional	43%
Hobbyist/Recreational	38%
Student	11%
Instructor/Educator	7%

Figure 4.2 Responses to Survey Question 1:
"What best describes your engagement as a musician?"

4.2.3 Use of Technology in Music Performance

The second section of the survey asked several questions about what devices and technologies participants use in performance, and what factors influence them to try new technology, or discontinue using it. Overall, respondents were mixed about how often they use new technology, with answers evenly distributed between 'always', 'often', 'occasionally', 'seldom' and 'never'. The main ways that users learn about and try new

[23] Genre categories were adapted from last.fm. This source was selected as it attempts to organize all potential music genres into sufficiently broad main categories. However it should be noted that this endeavor can be highly subjective and thus must be taken as such.

instruments and devices are by seeing them used, either by friends and bandmates or during live performance. This is important, as it shows that some sort of personal experience with a device is necessary to create interest.

The main topic of this study was to identify some areas in DMI design and production that could increase adoption and use of new and innovative technology. The responses here indicate that musicians are more likely to use something they are already familiar with and have had the opportunity to see it up close (Figure 4.3). This recalls the point made by Wessel and Wright [24] that many new instruments succeed for social and cultural reasons, rather than technical ones. This remains a challenge for designers of DMIs, as so much of this work is done in research and experimental phases, long before it reaches the hands of the general public.

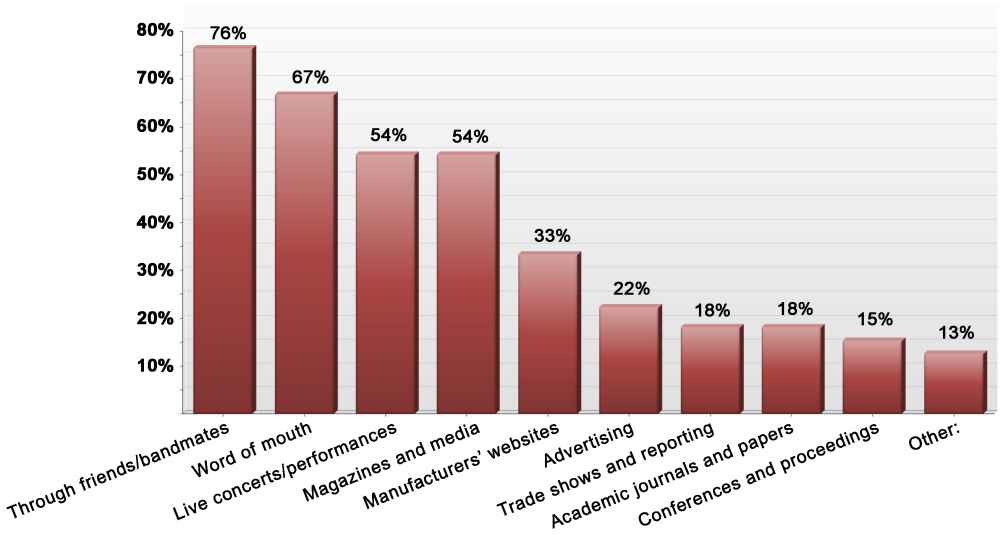


Figure 4.3 Responses to Survey Question 7.
"How do you learn about new electronic and/or digital tools for music performance?"

Another important area of this section focused on factors that cause musicians to discontinue use of a particular instrument or device. One multiple-choice question asked, if respondents had stopped using certain devices, "Why did you stop using them?" (Figure 4.4). The questionnaire offered several choices along with an "Other" text box in which they could offer their own response (Table 4.3). Their written responses were ultimately more informative and indicated that a primary issue was the atrophy of aging technology as newer technology continually replaces older technology, and the lack of support and updates to keep devices current and compatible with other equipment.

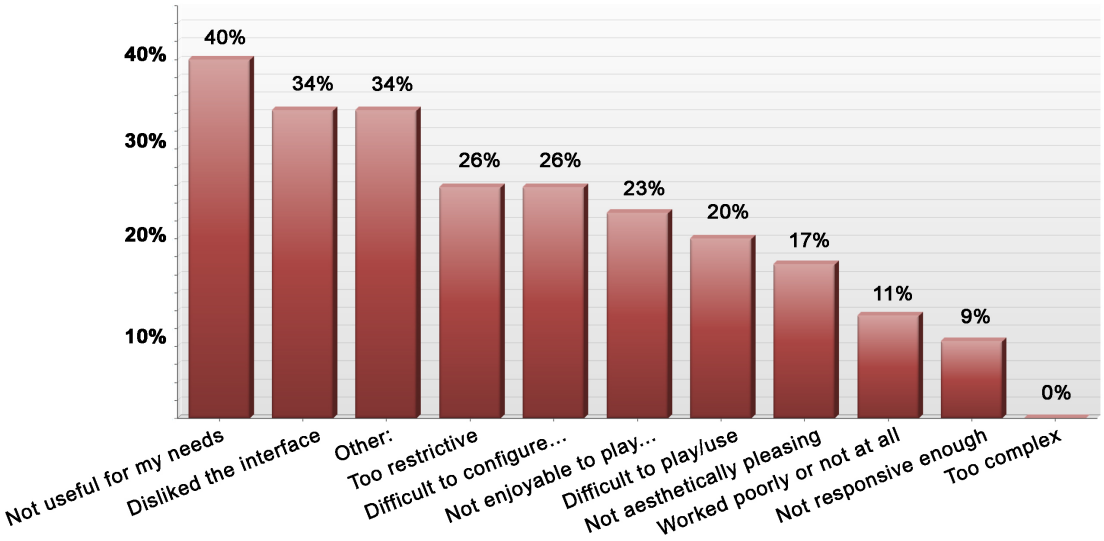


Figure 4.4 Responses to Survey Question 13.
"Why did you stop using certain devices?"

It also shows a stark contrast with traditional and acoustic instruments, which are often valued for adherence to historical and traditional continuity (for example, prized

guitars and the popularity of 'reissue' instruments, and loyalty to longstanding traditions of design and craftsmanship in orchestral and classical instruments). With technology changing so quickly, DMI users seem to be caught in a quandary. On one hand, they may prefer to stick with a tried and tested piece of gear that might be threatened by lack of continued support and cross-compatibility with other hardware and software; while, while on the other, they may get caught up in an "arms race", continually adopting new gear and trying to keep up with the pace of rapidly advancing technology.

Other responses:
Instruments fell apart too easily, and I ran the risk of damaging them beyond repair or during a live performance.
Age and better tech option
Difficult to maintain and keep current with collaborating technology
New, better technology
Thin sound
I only use performance specific interfaces
Do not run with current OS
Cost too much to repair
The company stopped firmware updates for the AudioFire 2
They are not multi-timbral

Table 4.3 Textual responses given to Survey Question 13 "Why did you stop using certain devices?"

On the same question, one multiple choice option that received a surprisingly low response was people abandoning DMIs because of issues around complex set up and configuration. Personal experience has shown that this continues to be an issue that plagues DMI development, and it was a primary consideration in the development of the

Noisebox as a simplified stand-alone instrument. But simplicity comes with a trade-off, as some of the most rewarding aspects of digital musical instruments are the computational power and complexity that can far outpace their analog counterparts.

One factor that may have contributed to the low response for this choice is the open-ended designation of DMIs. A majority of the DMIs that respondents reported using are commercial products, many of which are specifically engineered for user-friendliness and "plug-and-play" workflows. Devices like these generally have much lower thresholds for complexity in configuration and operation. On the other hand, users of non-commercial devices including early prototypes and homemade do-it-yourself instruments are likely to encounter significantly higher complexity levels but will potentially be better prepared to deal with them, as they are inclined to be much more involved in the design and building stages of instruments rather than being solely a consumer.

A final question in this section asked whether respondents felt like they had all of the electronic and/or digital tools for music performance that they needed. 13% answered yes, while 87% either answered no, or "yes but still interested in trying and acquiring others". This shows, at least among the diverse group survey respondents, that there is abundant interest in continuing to use and experiment with new technology.

4.2.4 Familiarity and Frequency of Use

The final section of the survey polled participants on a number of DMIs and interfaces. For each device they were asked to rank both their familiarity and frequency of use on a 1 - 5 scale. The devices were broken up into five categories:

1. Keyboards, synthesizers, samplers and other instruments
2. Computers and multi-use devices
3. Software and hardware controllers
4. Experimental and novel digital musical instruments
5. Alternate controllers

Overall, the rankings typically reflected each other from familiarity to frequency. Generally, familiarity received a higher ranking than actual use, but the correlations between the two metrics were consistent through all of the instruments from the most common (electric keyboards and MIDI keyboard controllers) to the most unknown (experimental instruments and controllers like the Karlax, Skoog and Audio Cubes).

While this section needs more analysis, it clearly shows that the most familiar and commonly used instruments and interfaces are ones that have been around longest and have the most recognizable form factors. In terms of the interface, piano style keyboards scored the highest (Figure 4.5), while sequencer and trigger-based hardware like drum machines and samplers also scored highly. Computers, tablets and mobile devices also received high marks, indicating an ongoing trend in using these multi-use devices for musical performance.

At this stage, it is hard to draw any significant conclusions from this section beyond a general indication that the more ubiquitous instruments and interfaces dominate the current landscape of digital musical instruments and controllers. It will be informative to analyze all of the lesser-known instruments across the rubric of performance style and primary instruments to understand which types of instruments and devices have potential to gain popularity in certain performance communities.

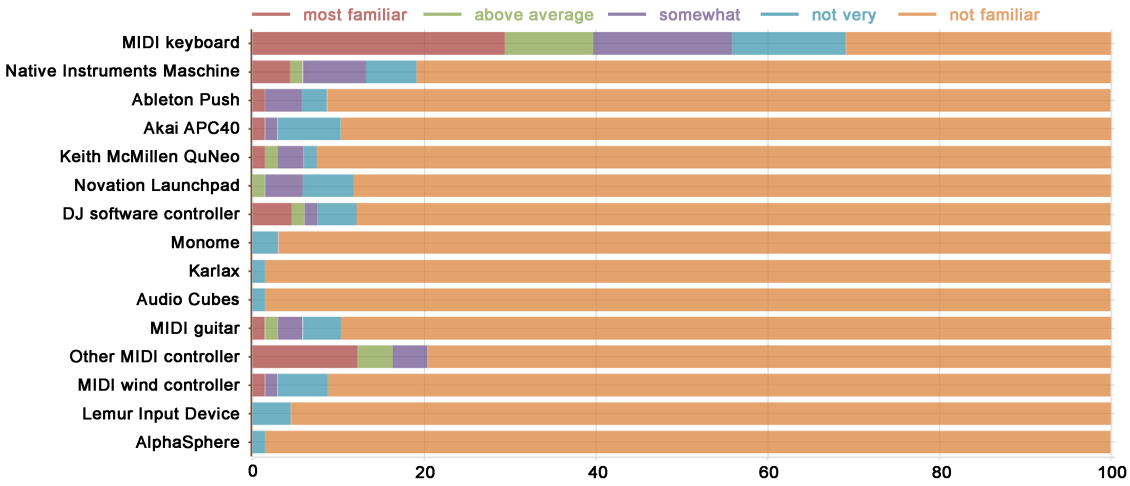


Figure 4.5 Responses to Survey Question 21.
Frequency of Use: Category 3 - Software and Hardware Controllers. Orange area indicates percent of "never used this device" responses; red indicates "use frequently".

4.3 Data Evaluation and Continuing Work

This work is still very much in the research phase, and without in depth analysis and correlation of the results it is hard to draw any significant conclusions. However, it is

already noticeable that responses vary significantly when broken out between different musical styles, primary instrument choice and musical training.

One noticeable difference is in how users tend to experiment with new technology across different musical styles. Participants who specified rock/popular and classical music as their primary style generally responded negatively when asked about experimenting with new technology, and their answers indicated a trend towards favoring well-tested and established gear. Most additions and upgrades to their set-ups include incremental improvements and upgrades to existing gear. By contrast, in the other high-scoring category of experimental/avant-garde/computer music, the trend was the opposite. Most respondents answered positively to experimentation with new technology and devices. Given the category, this makes logical sense. However, a more nuanced understanding of the data will come with further analysis.

The next step of the project will be to correlate responses to all questions based on the respondents' choice of musical style, primary instrument, and training background. Use of principle component analysis (PCA) and social network analysis (SNA) will illuminate the relationships that these three variables share. These analyses will bring into focus the individualized needs of different musicians and communities, which brings us to the consideration of user experience and user-centered design practice.

As this project continues, the results will adopt a user-centered focus, and look to identify ways that designers can build instruments to specifically address the needs of a

wide variety of performers and practices. I believe that more in-depth analysis will support my claim that approaching design from this viewpoint will enable DMI designers and builders to increase the use and adoption of their instruments and, one hopes, bring more of the new innovations and devices into common use.

CHAPTER 5: CONCLUSION

This thesis has covered the broad scope of work I have carried out as a student in the Intermedia MFA program. Through exploratory sound and multimedia artworks, to digital musical instrument making and research of user experience design practices, I have established a contemporary and relevant practice in digital musical instrument design. In conclusion, I consider the creation of a new instrument, the Noisebox, and information acquired from a user study to lay out a user-centered model of DMI design.

The Noisebox project was a crash course in how to design and build a digital musical instrument. I began this project with little previous experience, and used it as an experimental laboratory to test ideas, learn new skills and familiarize myself with previous work and publications in the field of DMI design and HCI. The work focused heavily on the engineering and technology aspects of design and the actual construction of the instrument. However, so far this project is not a good example of user-centered design because, apart from my own experience as a musician, little user input informed the project design.

On the other hand, the musician survey did not address technical design issues at all, focusing instead on the end user and user experience. It sought to answer who would utilize these new instruments, in what context (musical styles, performer background),

and why and how certain instruments would be chosen over others. Based on the results of this study, we can begin to make recommendations for how the design process of a new instrument could be improved that would lead to a better chance for the instrument to be adopted into wider use.

5.1 Integrating User Survey into Design

By applying some of the questions that were asked on the survey to the Noisebox, we see several areas that could have dictated the design in its earliest stages. Table 5.1 shows a list of some questions that a focus group could be asked. This level of user involvement from the outset would obviously lead to a very different instrument, and depending on the group surveyed, could vary substantially. However, by breaking the process up into stages, we begin to formulate a model for the conception and true user-centered design of a new instrument.

Potential questions for a Noisebox focus group:
1. What style of music do you want to play with this instrument?
2. What other instruments do you play, and what aspects of these instruments could be brought to a new instrument?
3. In what contexts would you want to play a new instrument?
4. What are some things that you want a new instrument to do that you can't do with your current instruments?
5. Would you use a new instrument alone, or integrate it into a setup with other instruments you already play?
6. What are some factors that would make this new instrument appealing to you?
7. What are some factors that would cause you to stop using this instrument?

Table 5.1 Potential Questions for a Noisebox Focus Group.

5.1.1 A Model for User-Centered DMI Design

A model for user-centered design can be constructed in three stages: preliminary, design and prototype, and testing (Figure 5.1). It is important to note that this is one possible model that was based on the research conducted here. Its most important feature is that the design process involves the user from the outset, and the instrument is built to the user specifications.

In the Stage 1, some basic parameters need to be established even before considering what a new instrument would be. What should the instrument do? Who would play it? What is the potential user's comfort level with DMIs and alternate controllers? What type of music would they play, and in what performance environment? These initial considerations could be addressed through a broad user survey (similar to one presented in Chapter 4), or they could be established by the designer(s) ahead of time. This phase could be carried out before planning the actual physical design and technical specifications.

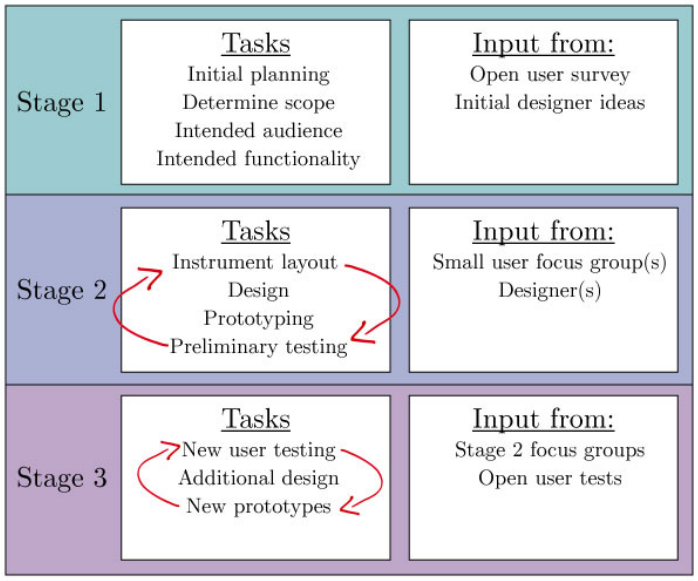


Figure 5.1 A suggested model for user-centered instrument design. Arrows indicate iterative cycles in Stages 2 and 3.

In Stage 2, after the basic scope of the instrument has been determined, a smaller focus group (or groups) could be assembled to address many of the high- and mid- level design elements: How should it be played? What size should it be? How can controls be laid out? What mapping strategies would be optimal? Working together with the designer, these can be developed down to the very low-level elements and technical specifications. This stage can extend from the initial design of the instrument through to early prototypes, and follow an iterative process: receive group input, design, prototype, get feedback/additional input, design/redesign, prototype, and so on.

The third stage opens up the new instrument to wider user testing. Assuming the instrument has progressed from design to workable prototype, there needs to be a

sustained period of expanded testing. The focus group(s) that have guided the design process could be considered “expert” users at this point. While their guidance and input is still critically important, the feedback of new users that have not been a part of the design process will bring fresh insights to the instrument. Based on this process, it is likely, if not imperative, that the instrument will continue the iterative design and prototype process until whatever time the designers feel like it is a completed instrument.

5.1.2 Caveats and additional considerations

While it is easy to propose a tidy design flow, practical application is rarely so efficient. This optimized model assumes a willing and readily available target audience and testers, access to adequate facilities and funding, and the necessary time for multiple design, prototyping and testing cycles. Real-world design of DMIs may not always have these luxuries, and thus the multi-stage process must adapt to the conditions of the project. In the case of the Noisebox, primary limiting factors were time and funding. The initial design and prototype was financed out of pocket on a very small budget and a majority of the design time was dedicated to learning and applying new technology. In practice, the three stages presented here will overlap and mix together, and successful design will have to be flexible.

The model described above suggests a system that is guided by user input. However, designers bring their own ideas and interests into the process as well. Optimally, this relationship between user feedback and designer input should be symbiotic. Additionally, though it should go without saying, design decisions need to be made because they will provide the best outcome for the instrument and will best serve the needs of the end user. Again citing the Noisebox project, certain decisions were made from purely technical reasons. For example, the linear FSR sensor for pitch control (Section 3.2.2) was placed diagonally across the top panel of the instruments because of dimensional constraints.

Finally, the discussion here only takes us through the initial planning, design, and testing phases. Just because an instrument performs well in a lab or in user testing doesn't mean that it is a finished product guaranteed success out in the world. The challenges of bringing a new DMI from a prototype to marketable product are formidable. Issues of commercialization, production, marketing, and social and cultural awareness must be addressed. These areas are beyond the scope of this thesis, except to note that they contribute, along with models of design, to the complexity of the field.

5.2 Continuing Research

This thesis has outlined a trajectory from open-ended creative practice to focused research in the field of DMI design. The user survey discussed in Chapter 4, along with

ongoing training and research in the diverse disciplines of DMI design, has served to introduce me to the field and prepare me for a new phase of work. With applied study and experience in audio signal processing, user interaction design, sensor and hardware design, my research will continue at the Input Devices and Music Interaction Laboratory as a full time doctoral student at McGill University.

The user survey marks the starting point of my next phase of research: how to apply into the design cycle lessons learned from the actual practitioners of music – the end users into whose hands we want to deliver new devices, new technologies, and new possibilities of interaction. A model of user-centered instrument design was presented at the beginning of this chapter, and continued work and more in-depth analysis from the survey will shed light on the correlations between choice of instrument, musical style, training and other crucial elements that impact individual musicians' performance practice.

The disciplines of human-computer interaction and user-centered design are universal in some ways, and very specialized in others. For instance, good user-centered practices like employing user evaluation and feedback can be beneficial in any design field. But each will have its own methodologies, best practices, and relevant applications. It is important to have a keen grasp of both. In my process as an artist, designer and researcher, the work outlined here has covered some high-level concepts, like the technical skills needed to create interactive work and DMIs, and also the importance of

user input throughout the design process. Moving forward, my research will progress further into the specialized field of interface design for new musical instruments, which presents its own unique and highly demanding challenges.

5.3 Final Thought

Music has been a primary focus of my work throughout my life. My practice has grown from music performance to multimedia applications, installations, and experimental sound art. Finally, my practice has brought me to consideration of the tools we use for music production.

A primary characteristic of music is its existence as a medium of communication; this can also be said of other artworks discussed here. Technology has created tools that enable new forms of communication and interaction – from new models of music performance to reimagining some of the most basic ways that we relate to the physical, social and cultural world around us. As designers, technology alone can only bring us so far. We require a clear and nuanced understanding of all entities involved, both human and machine. Only by clearly understanding the entire interconnected ecosystem of technology and design, and the very human factors that influence them, can we refine our processes and achieve true synchronicity between research and practical applications in the outside world.

CHAPTER 6: PORTFOLIO

The following pages contain documentation of several works that I have created through the Master's of Fine Arts program at the University of Maine. Where sound and media files are available, links are provided to online sources.

1. Waking Life EP
2. Antecedents
3. Strangers
4. Further We Trod, Into The Night
5. fourSQUARE
6. untitled
7. From Pythagoras to La Monte
8. Post Provost/IMRC Concert
9. High Striker!
10. Unconquered Earth
11. Handsy Mapper
12. Inside Out

6.1 Waking Life EP, Sea Level (2012)

Media: Audio Recording

Sea Level is a pop/electronica project by composer and multi-instrumentalist Dan Capaldi. I was brought in at the beginning of the project as another multi-instrumentalist, along with drummer Christopher Sweet. As a three-piece live band we performed dense orchestrations of cinematic and ethereal pop music. Each member sang and played multiple parts, employing a number of electronic and digital musical instruments and controllers: samplers, loopers, laptop and software instruments, analog and digital synthesizers and effects modules, and a variety of MIDI controllers. *Waking Life* is the second of two extended play (EP) albums that we released over my two-year tenure with the band.

Figure 6.1 *Waking Life EP*, Sea Level. Album Cover

- **Sample track: "Never Sleep" -** https://goo.gl/CtBmDn
- **Album page:** https://sealevel.bandcamp.com/album/waking-life

6.2 Antecedents (2012)

Media: Photography

"Antecedents" was a series of photographs placed in a group show entitled *Transits* in November 2012. The images were taken during a trip to Ireland. As part of preparations for the web-based documentary project *Strangers*, I devoted myself to learning the basics of digital photography. While *Strangers* combined several elements into a multimedia work, the images here very much stood on their own.

The title speaks to my direct family lineage in Ireland. However, there was a metaphoric antecedent in these photos as well. The images form a bridge between history and the present, and the intimate and universal. Our relative insignificance in the cosmos is only made more concrete by coming to terms with both the ancient and the immediate. By understanding our own place in this vast world we can see not only its magnificence, but also its fragile beauty around us.

Figure 6.2 Images from *Antecedents*
Photos: John Sullivan

6.3 Strangers (2012)

Media: Web

In October 2012, I brought a camera and audio recorder to Ireland and documented the sights and sounds of my travels. When I returned, I used the images and audio as material for a documentary website. Beyond simply telling where I went and what I did, the piece attempted to convey the personal relevance of the trip on an emotional and metaphorical level. The title *Strangers* is borrowed from the Kinks song of the same name, and the song's refrain, "Strangers on this road we are on, we are not two, we are one" set the mood for this atmospheric web space.

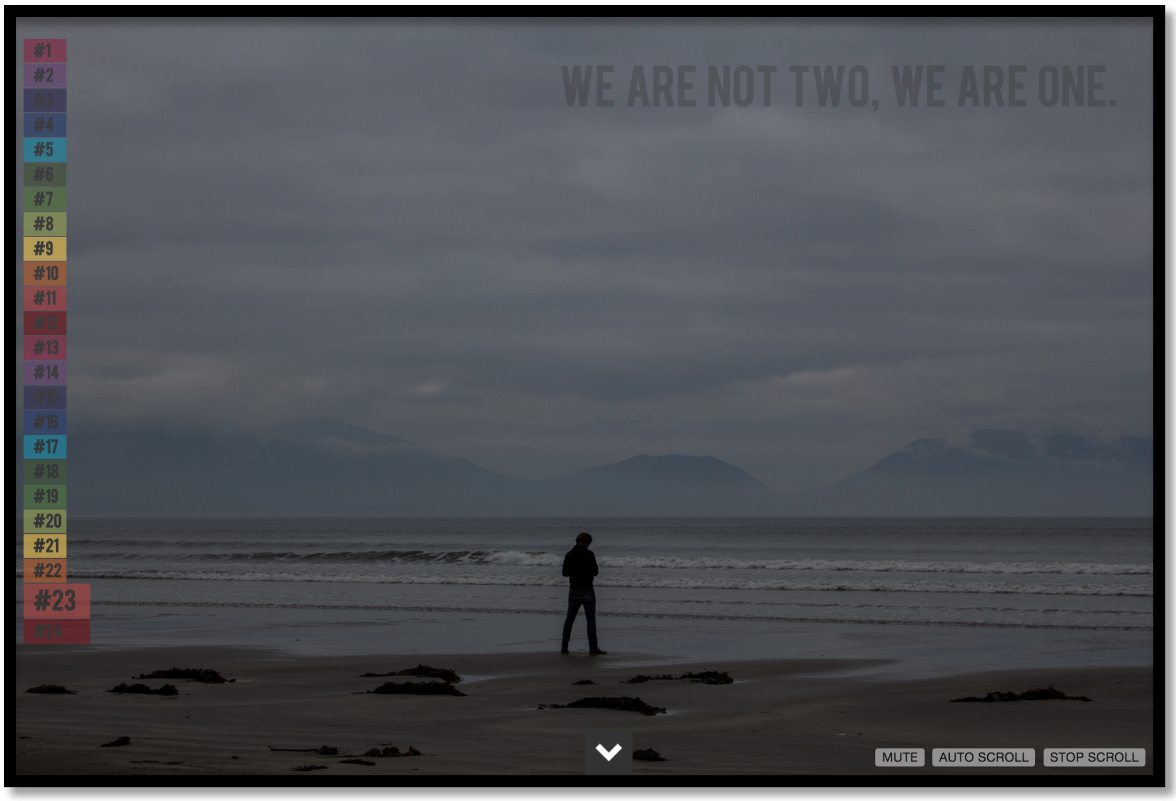


Figure 6.3 Screenshot from *Strangers*
Photo: Lindsey Parsons

- **Strangers website:** http://johnnyvenom.org
- **Audio track: "Captive":** https://soundcloud.com/johnnyvenom/captive

6.4 Further We Trod, Into The Night (2012)

Media: Audio

After spending a decade as a touring musician in rock and popular music groups, joining the Intermedia program spurred a return to more adventurous forms of music composition and production. Much of my current interest lies in exploring the boundaries between the styles and instrumentation of popular and experimental music. This is one such piece, utilizing mainly traditional instruments – acoustic guitar, bass, percussion and piano – augmented with sampled orchestral sounds, electronics and processing.

The minimalist works of artists like Steve Reich, Terry Riley, and La Monte Young inspired the composition of this piece.

Figure 6.4 Promotional photo for "Further We Trod, Into the Night"

- **Audio:** https://soundcloud.com/johnnyvenom/further_into_the_night

6.5 fourSQUARE: Death by Pop Song (2013)

Media: Audiovisual Installation

fourSQUARE was the first large-scale multimedia installation that I produced. A collaboration with Sally Levi[24], the piece recreated an urban school playground with a foursquare court in the center. Via overhead infrared camera, visitors were tracked through the space and a responsive audio soundscape was generated based on their movements and activities.

The piece was an exploration of the emotional depth of childhood, from loneliness and alienation to joyful exuberance, based on the social interactions of a school playground.

[24] http://sallylevi.com

Figure 6.5 Scene from *fourSquare*
Photo: Adam Kuykendall

- **Video clip:** https://vimeo.com/63339098

6.6 untitled (2013)

Media: Interactive audiovisual software environment

This piece was a software application that processed live video for projection into a special 360º projection space. A video feed was captured via Kinect as both an RGB video and depth map. The video feed was modulated by incoming audio. The incoming audio was analyzed in Max/MSP and frequency, amplitude, brightness and noise parameters were extracted. These were mapped to video processing variables, which split, moved and recolored the output video. Except for the Max audio analysis program, the piece was written in Processing programming language, with communication between the two environments handed with UDP (User Datagram Protocol).

The piece was conceived for use in the specialized 360º video projection space in the IMRC Center at the University of Maine. However, the facility was not fully finished at the time of creation, and it was presented as a proof-of-concept prototype in April 2013.

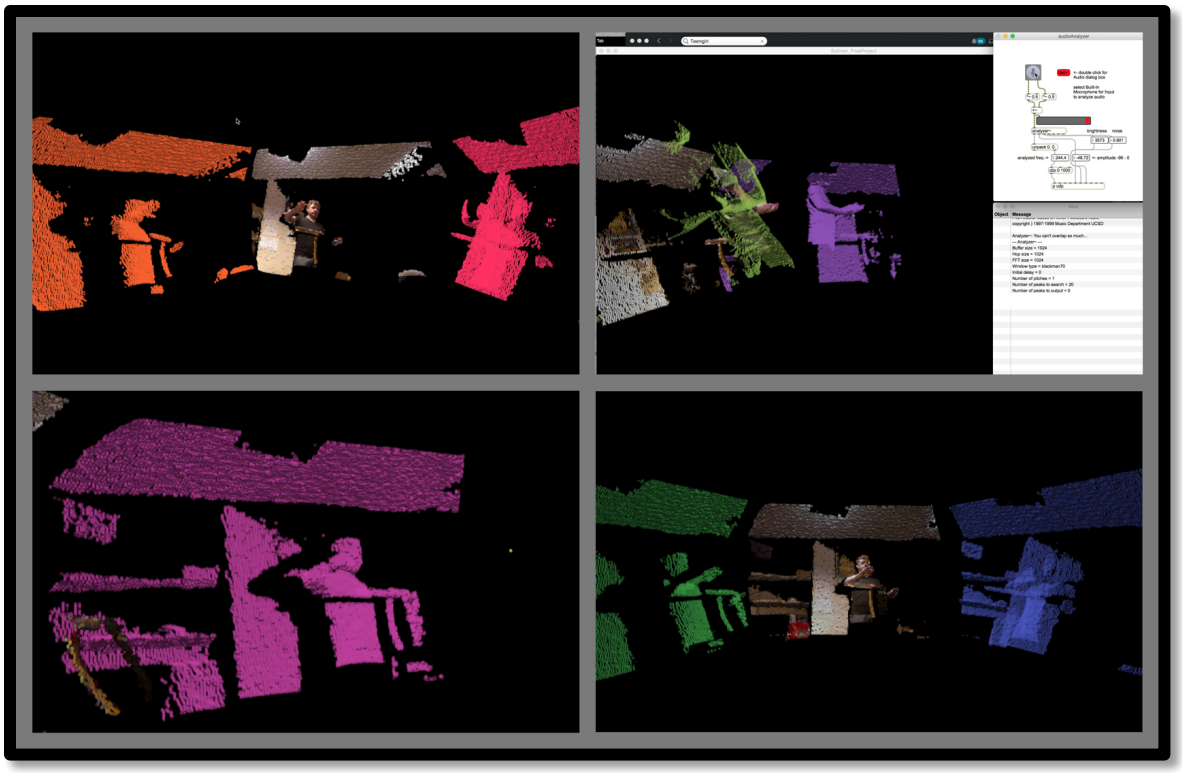


Figure 6.6 Screenshots from *untitled* video tests

6.7 From Pythagoras to La Monte (2013)

Media: Sound Installation & Lecture

As I began to study sound synthesis, I created this combination installation/lecture piece to contextualize the interdisciplinary research I had been doing on harmony, tuning systems, timbre and sound synthesis. With Pythagoras and La Monte Young as historical bookends, the piece reviewed how harmonic concepts have been understood and utilized in composition from traditional music theory through modern and experimental compositional forms.

The piece itself was an additive synthesis-driven surround audio environment, controlled by computer vision. A grid was laid out on the floor, through which visitors could walk and control several audio parameters that served to sonically demonstrate audio principles.

In addition to research in audio synthesis and harmony, much of the design of this piece was based on interface design and mapping structures. The room was designed as an interactive space (the primary interface), while an iPad interface was designed for wireless control of the synthesizer's several different modes (secondary interface).

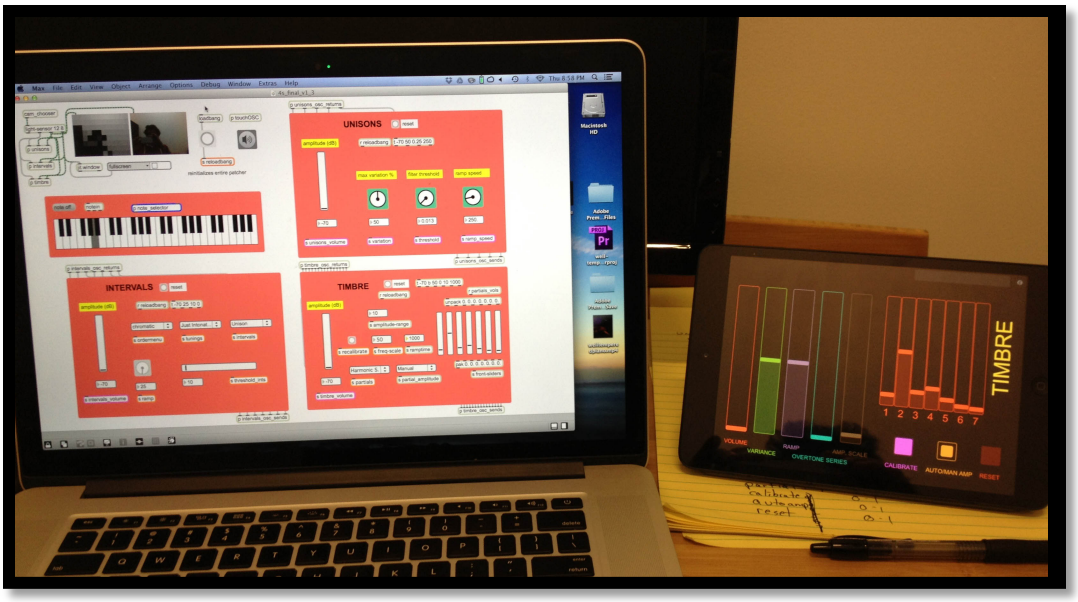


Figure 6.7 Screen interfaces for *From Pythagoras to LaMonte*

6.8 Post Provost – Farewell Concert (2013)

Media: Music Performance

In 2013, I performed my last concert with Post Provost, an indie rock band that I co-founded with singer-songwriter Dave Gagne and several others. The concert was held at the University of Maine's IMRC Center and marked the inauguration of the new facilities, which serve as the home of the Intermedia program.

From 2007 to 2011, Gagne and I played in a reggae band named EastWave Radio. While looking to make music outside of the reggae genre, we collected a number of songs for a side project, which eventually came to be Post Provost. The group formed as a musical collective based around the songwriting of Gagne, James Walsh, and Sam Franklin.

Figure 6.8 Image and flyer from final Post Provost concert
Photos: Amy Pierce, Ramsay de Give

- **Audio:** http://johnnyvenom.bandcamp.com/album/ancient-open-allegory-oratorio

6.9 High Striker! (2014)

Media: Site-specific multimedia installation

In 2014, I collaborated with sculpture and intermedia artist John Carney to create *High Striker!* Based on the classic carnival game of strength and accuracy, this version was a video-based fully playable game for up to 6 people. We designed new force sensors (See Section 2.3.2) and created 6 individual playing stations. Each player was given a mallet and attempted to strike the target with enough force to trigger a full video playback. The videos, which were projected onto a large multi-panel window, behaved much like the mechanism in the classic game. In the original, the force of the mallet strike would propel a lead weight vertically towards a bell. The player wins if the target is struck hard enough to ring the bell. In our recreated version, the force controlled the playback of a random video clip, propelling it forward according to the strength of the blow. If the force was not strong enough, the video would begin to play but then slow and reverse back to the beginning.

Figure 6.9 *High Striker!* installed at the IMRC Center, University of Maine
Photo: Christine Carney

6.10 Unconquered Earth (2014)

Media: Audiovisual Installation

During the summer of 2014, while residing in New York, I completed an internship at Harvestworks Digital Media Art Center. While there, I provided technical assistance to other visiting artists, led a workshop on embedded computing (which was the genesis for the Noisebox musical instrument), and collaborated with other artists to produce new creative works. One such piece was Unconquered Earth, with Frances Wang, Nicholas Kiray, and Menglong Wu.

Unconquered Earth was an interactive installation in which observers could personally experience the seismic destruction our planet is capable of through the investigation of geological data. The installation displayed the earth's most destructive historic earthquakes and current seismic activity, using an interactive globe, visualized data, and an audiovisual interactive environment that responded to the destruction. The work served as a dialogue between humans and nature: the constant struggle against a force beyond our control.

- **Webpage:** http://www.harvestworks.org/aug-29-31-unconquered-earth/
- **Video testing:** https://vimeo.com/104568976

6.11 Handsy Mapper (2014)

Media: Audio Signal Processing Software

Handsy Mapper is a software mapping application written in Max. It provides a mapping interface for the Microsoft Kinect to control the CataRT concatenative synthesizer. The Microsoft Kinect is a popular hands-free game controller that is easily modified to function as a gestural interface. The CataRT is a software synthesizer built in Max by researchers at IRCAM (Institut de Recherche et Coordination Acoustique/Musique). A form of granular synthesis, concatenative synthesis plays segmented "grains" from a segmented sound sample. The grains are generated and placed in a two-dimensional mapping space according to sound descriptors. This piece explores different mapping strategies for controlling the synthesizer with open-handed gestural movements.

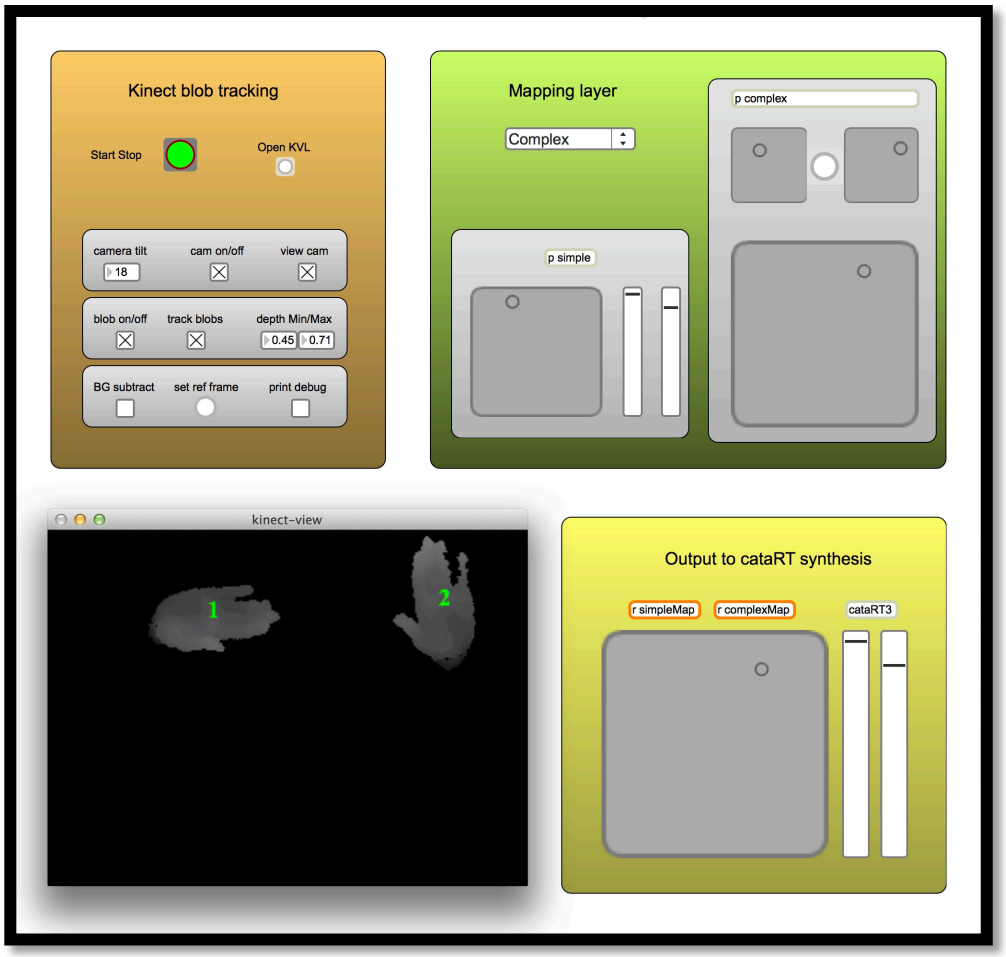


Figure 6.10 Screen interface of *Handsy Mapper*

- **Video demonstration:** https://vimeo.com/131494715

6.12 Inside Out (2015)

Media: Audiovisual Installation

In the spring of 2015, I joined artists Marlon Schumacher and Graham Boyes in producing a large installation project for Montréal's Nuit Blanche Festival. The piece explored the conflicting concepts exemplified by Internet culture: public outrage over surveillance and data gathering, while more and more personal information is willingly uploaded to social networks and online sharing services.

The multimedia piece was installed in three interconnected spaces. Each room had its own specific focus: the first with a repurposed photo booth that captured visitors' self portraits, the second with a working payphone connected to an internet chatbot, and the third receiving and resynthesizing audio and video feeds from the other two spaces. Each room contained its own 4.0 surround generative audio piece and synthesized video project wall.

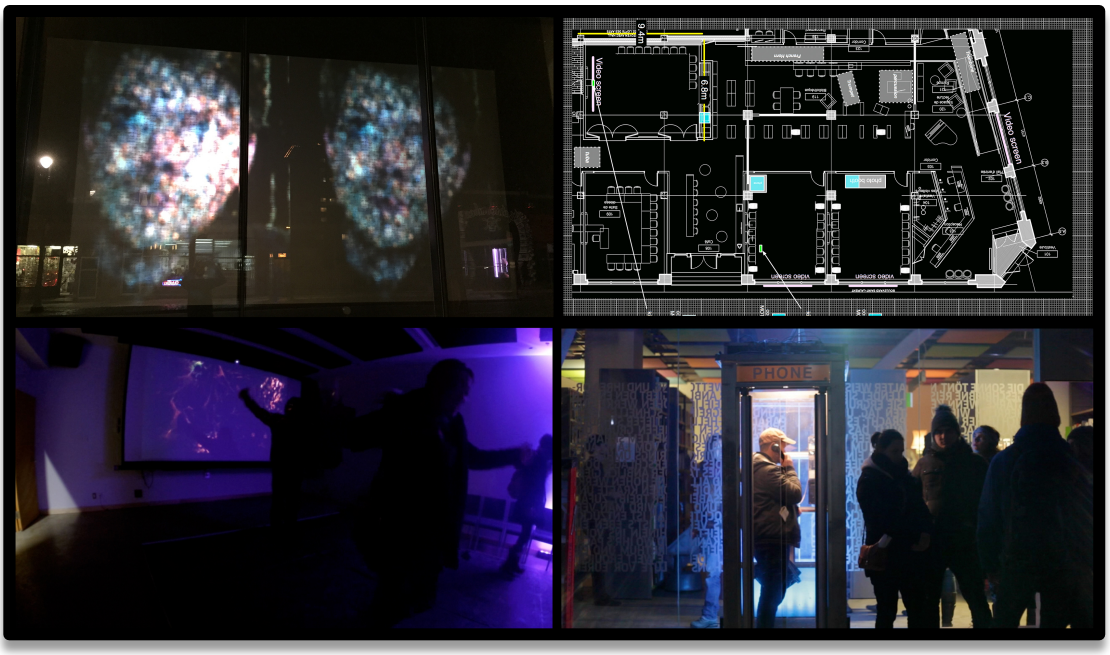


Figure 6.11 Images from *Inside Out*, 28 February 2015

- **Short documentary:** https://vimeo.com/135427471
- **Website:** http://insideout-project.com
- **Video demonstrations:** http://insideout-project.com/information/

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APPENDIX A: USER SURVEY QUESTIONNAIRE

You have been invited to participate in a research study. The purpose of this research is to gather data to better understand performing musicians' uses of and attitudes towards new electronic and digital music instruments in order to better guide future research and development in this area. You must be at least 18 years of age to participate.

What You Will Be Asked to Do: As a participant, you are asked to complete this online survey. It may take approximately 10 minutes to complete.

Confidentiality: This study is anonymous. You will not be asked for any personal information, nor will any personal data be stored. Data collected from the survey will be stored offline on a secure external hard disk, and destroyed after 5 years.

Risks: Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits: While this study will have no direct benefit to you, this research may help us learn more about how the design of musical instruments can better fit the needs of performing musicians.

Voluntary: Your participation is voluntary. You may choose to stop at any time, and you may skip any questions you do not wish to answer. Completion of the survey implies consent to participate.

Q1 What option best describes your engagement as a musician?

- ❍ Professional
- ❍ Student
- ❍ Instructor/Educator
- ❍ Hobbyist/Recreational

Q2 What is the main type of music that you play?

- ❍ Acoustic/Folk/Country
- ❍ Classical
- ❍ Country
- ❍ Electronic/EDM/House
- ❍ Experimental/Avant-Garde/Computer Music
- ❍ Hip Hop/Rap
- ❍ International/World Music
- ❍ Jazz/Blues/R&B
- ❍ Religious
- ❍ Rock/Popular
- ❍ TV/Film/Theatrical
- ❍ Other: _____

Q3 Which of the following describes your musical training? Check any that apply.

- ❑ None
- ❑ Self-taught
- ❑ Private instruction
- ❑ Secondary school
- ❑ Some college/university training
- ❑ College/University - Undergraduate Degree
- ❑ College/University - Graduate Degree or beyond
- ❑ Other: _____

Q4 What instrument(s) do you play? List up to 5, in order of use.

1
2
3
4
5

Q5 How many years have you played your primary instrument?

- ❍ 1 year or less
- ❍ 2
- ❍ 3
- ❍ 4
- ❍ 5
- ❍ 6
- ❍ 7
- ❍ 8
- ❍ 9
- ❍ 10 years or more

Q6 How often do you use electronic and/or digital technology - instruments, controllers, or other devices - in performance?

Do not include electric amplification - i.e. electric guitars, amplifiers, etc. - or recording hardware/software, unless it is specifically a part of your implicit performance instrumentation, for example live sampling.

- ❍ Always.
- ❍ Often.
- ❍ Occasionally.
- ❍ Seldom.
- ❍ Never.

Q7 How do you learn about new electronic and/or digital tools for music performance?

Check any that apply.

- ❑ Word of mouth
- ❑ Through friends/bandmates/collaborators/etc.
- ❑ Music magazines (print & online), gear reviews, etc.
- ❑ Manufacturers' websites
- ❑ Advertising
- ❑ Academic journals and research publications
- ❑ Conferences and proceedings
- ❑ Trade shows and reporting
- ❑ Live concerts and performances
- ❑ Other: _____

Q8 Which factors would influence you to try a new piece of technology?

- ❑ Friends/bandmates/collaborators using it
- ❑ Favorable reviews from impartial sources
- ❑ Readily available
- ❑ Inexpensive
- ❑ Manufacturer's advertising
- ❑ Online demonstration
- ❑ Seeing it used in live performance
- ❑ Performer endorsement
- ❑ Consulting technical specifications/documentation
- ❑ Other _____

Q9 What technology do you use in music performance? List up to 5, in order of use.

1
2
3
4
5

Q10 How often do you experiment with new technology for music performance?

- ❍ Always.
- ❍ Often.
- ❍ Occasionally.
- ❍ Seldom.
- ❍ Never.

Q11 Are there technologies that you have discontinued using?

- ❍ Yes.
- ❍ No.

Q12 What device(s) did you stop using? List up to 5.

1
2
3
4
5

Q13 Why did you stop using them? Check any that apply.

- ❑ Not useful for my needs.
- ❑ Difficult to configure/set up.
- ❑ Difficult to play/use.
- ❑ Not responsive enough.
- ❑ Not enjoyable to play/use.
- ❑ Worked poorly or not at all.
- ❑ Disliked the interface.
- ❑ Not aesthetically pleasing
- ❑ Too complex.
- ❑ Too restrictive.
- ❑ Other: _____

Q14 Do you feel like you have all of the necessary electronic and/or digital tools for music performance at your disposal?

- ❍ Yes
- ❍ Yes, but interested in trying/acquiring others.
- ❍ No

Q15 What other electronic and/or digital tools for music performance are you interested in?

List up to 5.

1
2
3
4
5

For the following devices, rate both your familiarity and frequency of use in music performance using the following scale:

Scale	5	4	3	2	1
Familiarity	Very familiar	Above average	Somewhat	Not Very	Not at all
Frequency	All the time	Often	Occasionally	Seldom	Never Use

Q16/17 Keyboards, Synthesizers, Samplers and other instruments

	Familiarity					Frequency of Use				
	5	4	3	2	1	5	4	3	2	1
Electric keyboard/Digital piano	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Analog Synthesizers - Moog, etc.	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Digital Synthesizers - Yamaha DX7, etc.	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Electric Organ - Hammond, Vox, etc.	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Modular Synthesizers - Eurorack, etc.	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Buchla Lightning/Lightning II	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Theremin	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Akai MPC or other hardware sampler	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drum machine/Sequencer hardware	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
V-Drums or other electronic drum kit	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Roland SPD or other sample pad	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Turntables/DJ mixer	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Kaoss Pad	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q18/19 Computers and Multi-Use Devices

	Familiarity					Frequency of Use				
	5	4	3	2	1	5	4	3	2	1
Computer/Laptop	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Tablet - iPad, etc.	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Smartphone or other mobile device	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q20/21 Software and Hardware Controllers

	Familiarity					Frequency of Use				
	5	4	3	2	1	5	4	3	2	1
MIDI keyboard	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
MIDI Guitar	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
MIDI Wind Controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Native Instruments Maschine	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Ableton Push	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Akai APC40	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Keith McMillen QuNeo	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Novation Launchpad	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
DJ Software Controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Monome	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Lemur Input Device	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
AlphaSphere	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Karlax	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Audio Cubes	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other MIDI controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q22/23 Experimental and Novel Digital Musical Instruments

	Familiarity					Frequency of Use				
	5	4	3	2	1	5	4	3	2	1
Augmented Analog Instruments	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Eigenharp	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Continuum Keyboard	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Tenori-On	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Reactable	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Skoog/Skoog 2.0	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Custom-built/DIY instrument	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q24/25 Alternate controllers

	Familiarity					Frequency of Use				
	5	4	3	2	1	5	4	3	2	1
Microsoft Kinect	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Leap Motion	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Nintendo Wii	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other game controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Joystick	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Computer Vision/motion detection	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Environmental/Biological sensors	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Interactive performance/multimedia environments	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Custom-built/DIY controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Data Glove or other glove controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

APPENDIX B: INSTITUTIONAL REVIEW BOARD STUDY APPROVAL

(KEEP THIS PAGE AS ONE PAGE – DO NOT CHANGE MARGINS/FONTS!!!!!!!!!)

APPLICATION FOR APPROVAL OF RESEARCH WITH HUMAN SUBJECTS
Protection of Human Subjects Review Board, 114 Alumni Hall, 581-1498

PRINCIPAL INVESTIGATOR: John Sullivan
EMAIL: john.d.sullivan@maine.edu **TELEPHONE:** (505) 690-7746
CO-INVESTIGATOR(S):
FACULTY SPONSOR (Required if PI is a student): Mike Scott
TITLE OF PROJECT: Musician Survey on New Instruments for Music Performance

START DATE: 3/4/15 ~~2 March 2015~~ **PI DEPARTMENT:** Intermedia MFA
MAILING ADDRESS: 125 av du Mont Royal O. Apt 34, Montreal, QC H2T2S9 Canada
FUNDING AGENCY (if any):
STATUS OF PI:
FACULTY/STAFF/GRADUATE/UNDERGRADUATE Graduate

1. **If PI is a student, is this research to be performed:**

   ☐ for an honors thesis/senior thesis/capstone? ☒ for a master's thesis?
   ☐ for a doctoral dissertation? ☐ for a course project?
   ☐ other (specify)

2. **Does this application modify a previously approved project?** No. **If yes, please give assigned number (if known) of previously approved project:**

3. **Is an expedited review requested?** Yes.

SIGNATURES: All procedures performed under the project will be conducted by individuals qualified and legally entitled to do so. No deviation from the approved protocol will be undertaken without prior approval of the IRB.

Faculty Sponsors are responsible for oversight of research conducted by their students. By signing this application page, the Faculty Sponsor ensures that he/she has read the application and that the conduct of such research will be in accordance with the University of Maine's *Policies and Procedures for the Protection of Human Subjects of Research*.

Date **Principal Investigator** **Faculty Sponsor**
Mike Scott

Co-Investigator **Co-Investigator**

****

FOR IRB USE ONLY **Application #** 2015-02-22 **Date received** 2/23/15 **Review (F/E):** E
Expedited Category: _____

ACTION TAKEN:

✓ **Judged Exempt; category** 2 **. Modifications required?** Y **(Y/N) Accepted (date)** 3/4/15
____ **Approved as submitted. Date of next review: by** _____ **. Degree of Risk:** _____
____ **Approved pending modifications. Date of next review: by** _____ **. Degree of Risk:** _____
Modifications accepted (date): _____.
____ **Not approved. (See attached statement.)**
____ **Judged not research with human subjects**

Date: 2/26/15 **Chair's Signature:** Cynthia A. Eddy 12/2012

BIOGRAPHY OF THE AUTHOR

John Sullivan is a musician, artist, designer, and music technology researcher from the United States.

Sullivan was born in in Farmington, Maine where he graduated from Mt. Blue High School. He earned a BFA in Contemporary Music Performance and Composition from the College of Santa Fe in 2003. After working for a decade as a touring musician, Sullivan took a hiatus from music performance 2012 to continue his education at the University of Maine. There he established an interdisciplinary practice that combined research about user experience design and human-computer interaction with the creation of new digital musical instruments, sound art, and audiovisual installations.

In 2014, Sullivan was awarded a Chase Distinguished Research Assistantship to pursue specialized music technology research at McGill University in Montréal, Québec, where he currently resides. In the fall of 2015, he will commence his doctoral studies in music technology at McGill University.

John Sullivan is a candidate for the Master of Fine Arts degree in Intermedia from The University of Maine in August 2015.