Combining Acoustic Percussion Performance with Gesture Control Electronics

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Abstract

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Gesture control in music performance utilizing live electronics is a topic receiving much development and exploration. The methods and implementations of gestural control vary. Gesture tracking has been used to directly create sounds as in the case of the well-known electronic musical instrument, the Theremin. It has also been used to control processing of electronics in musical works combining acoustic and electronic sounds. This study is mainly focused on the application of

gesture tracking techniques combined with performance on acoustic percussion instruments.

The first portion of this study is devoted to examining the methods of gesture control that have been developed in order to establish a context for the subsequent sections. Following this overview, available methods of gesture control and the various sensors used to achieve this control are evaluated to determine which of them can be most effectively combined with performance on acoustic percussion instruments. The pairing of gesture control and percussion is of particular interest because unlike many other acoustic instruments, percussion instruments require large physical movements in order to be played. This characteristic makes percussion instruments uniquely appropriate for performance with gesture tracking technologies.

The final section of the paper deals specifically with performance issues and considerations encountered in the percussion solo *Percussivometers* (2014) by Marcin Pączkowski. The piece utilizes an accelerometer worn on each hand in order to detect the motions of the performer. The gestures are then used to control multiple parameters of audio processing and synthesis. The combination of movements required to execute the performance of the acoustic instruments and those required to control the electronics necessitate special consideration and preparation for an effective performance. This paper attempts to elucidate these considerations and offer guidance to musicians exploring similar performance paradigms.

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Chapter 1 – Gesture Control Explained

Origins of Gesture Control in Electronic Instruments

Since electricity and electronics were first developed people have been exploring ways of using these discoveries to create music. As technology has developed so has the music and instruments being created to take advantage of new musical possibilities using these electronic means. With the development of digital technology and the rapidly decreasing cost of the technology, many people now have access to sophisticated methods of creating instruments that allow for new and original performance and sound possibilities. This has led to the creation of many new digital musical instruments (DMIs) that vary widely in appearance and function. Following in this chapter is a brief overview of some of these developments and how they relate to the main focus of this document: percussion performance on acoustic instruments incorporating sensors for gestural control of live electronics.

Many early electronic instruments were based upon a traditional musical keyboard layout. The majority of early synthesizers incorporated a piano like keyboard to give the performer control over electronically generated sounds. The widely known Theremin is an exception to this trend, and is one of the earliest examples of a gestural electronic instrument. This instrument, originally developed in 1919, used two heterodyning oscillators to generate a pitch derived from the difference in the two oscillators' frequencies. The Theremin is played by movement of the performer's hands in relationship to two antennae. One hand is used to control pitch, while the other hand is used to control the volume. The Theremin is monophonic but is capable of producing continuously variable pitch. This is a contributing factor to the difficulty of playing the instrument.[1] In the development of electronic or digital instruments this aspect is important to consider, the control the performer has versus the difficulty in playing the instrument. Most often as the level of control the instrument provides the performer increases so does the difficulty in playing the instrument. The opposite is also true. An instrument that is easier to play usually offers less control to the performer. The expressive capabilities that the Theremin gives to a performer have not been matched by many of the

[1] Vail, *The Synthesizer*, 5.

electronic instruments that have followed it, which has contributed to its longevity.

Another early electronic instrument is the pseudonymous instrument invented by Friedrich Trautwein in 1928. The instrument known as the Trautonium used a wire that the player pressed against a metal bar to produce a sound. The pitch was determined by the location that the wire contacted the bar. Like the Theremin, the Trautonium was monophonic and had a continuously variable pitch. However, the design of the Trautonium incorporated markings that denoted where the performer must touch the wire to the bar in order to produce a specific pitch. The Trautonium incorporated another notable feature that the Theremin did not: the ability to change the timbre of the sound produced by the instrument. This was accomplished by filtering of the harmonics that were generated.[2]

This selection of harmonics is something that naturally occurs in acoustic instruments as result of the design and materials that are used in construction. In electronic instruments, however, the harmonics, and as a result the tone of the instruments can be manipulated independently of the physical form of the instrument. This leads to a

[2] Ibid. 8.

larger question to consider when discussing electronic and digital instruments: what are the determining factors in the design of the interface with which a performer interacts? As Bert Bongers elucidates using the example of string instruments, the design and method of playing violin and cello are determined by the sound that is desired from each of the instruments. In the case of a violin the pitches are higher and the strings are necessarily shorter than those of cello, resulting in an instrument that can be held under the player's chin. A cello conversely requires longer strings to produce the desired lower pitches, therefore resulting in an instrument that is large enough to rest on the ground and be supported by the player's legs.[3]

In the case of electronic instruments these physical limitations are greatly reduced, and with the current level of technology and broad selection of sensors available today, are essentially nonexistent. The considerations that go into the design of the interface of a DMI often have less to do with sound and much more to do with the desired level of control, methods of interaction, and visual appearance of the gestures required.

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[3] Bongers, *Physical Interfaces in the Electronic Arts*, 41.

Digital Music Instruments and Gesture

At this point a more thorough definition of what a DMI and gestural control are will be useful. In the text "New Digital Instruments: Control and Interaction Beyond the Keyboard," Eduardo Miranda and Marcelo Wanderley provide an explanation of both. The first chapter of their text provides an apt definition of a DMI: "An instrument that uses computer-generated sound can be called a digital musical instrument (DMI) and consists of a control surface or gestural controller, which drives the musical parameters of a sound synthesizer in real time."[4]

The term gesture is less easily defined, as the meaning is dependent on the context and field of study in which the term is being applied. Claude Cadoz and Marcelo Wanderley attempted to provide some clarity to this issue in their article "Gesture – Music." A selection of the particularly relevant definitions of gesture from the article follows:

> G. Kurtenbach and E. A. Hulteen. 1990. "Gestures in Human-Computer Interaction." In B. Laurel (ed.): *The Art of Human-Computer Interaction*, Reading, Mass.: Addison-Wesley, page 310

[4] Miranda and Wanderley, *New Digital Musical Instruments*, 1.

A gesture is a motion of the body that contains information. Waving goodbye is a gesture. Pressing a key on a keyboard is not a gesture because the motion of a finger on its way to hitting the key is neither observed nor significant. All that matters is which key was pressed. Using your hand to show the motion of a falling leaf is a gesture. A teenager flailing at a video game joystick is not gesturing but rather is operating a controller that senses in which of eight possible directions a stick is being pushed. Beckoning with your index finger is a gesture. Handwriting is not a gesture because the motion of the hand expresses nothing; it is only the resultant words that convey the information. The same words could have been typed – the hand motion would not be the same but the meaning conveyed would be. Sign languages are made up of gestures. Directing traffic is a gesture language.

C. Hummels, G. Smets and K. Overbeeke. 1998. "An Intuitive Two-Handed Gestural interface for Computer Supported Product Design." In I. Wachsmuth and M. Fröhlich (eds):

Gesture and Sign Language in Human-Computer Interaction, 1998, p. 198.

Most definitions of gesture boil down to the definition of Kurtenbach and Hulteen (1990) "A gesture is a motion of the body that contains information. Waving goodbye is a gesture. Pressing a key on a keyboard is not a gesture because..." ... Therefore, we employ the definition: "a gesture is a movement of one's body that conveys meaning to oneself or to a partner in communication." That partner can be a human or a computer. Meaning is information that contributes to a specific goal. For gestural product design, describing the surface of an object or using the object are considered to be gestures, because these contribute to the creation of the final product. However, getting one's hand to the place to start creation or manipulation is not considered a gesture, because it is a necessity to move your hand, but it does not contribute to the final product as such. The way you move your hand to reach this point is not important.

M. Goldstein. 1998. "Gestural Coherence and Musical

Interaction Design." *Proceedings of IEEE SMC98 Conference*, Oct. 1998.

Music is a performing art, and part of the quality of the musical experience comes from the relationship between the player's physical technique and the sound that is produced. A listener can appreciate this connection visually (and viscerally) whether in a live concert or in the mind's eye while listening to a recorded performance. Our rich tradition of musical instruments has created a repertoire of gestures (bowing, blowing, banging, etc.) that are closely tied to familiar sounds.

A. G. E. Mulder. 1998. *Design of Virtual Three-dimensional Instruments for Sound Control*. PhD Thesis, Simon Fraser University.

The word gesture has been used in place of posture and vice versa. The tendency however, is to see gesture as dynamic and posture as static. The notion of a musical gesture that at the time it occurs involves no actual human movement but merely refers to it is quite common. Obviously, musical

> expression is intimately connected with human movement, hence the existence of such an idiom. In the following, hand gesture and hand movement are both defined as the motions of fingers, hands and arms. Hand posture is defined as the position of the hand and fingers at one instant in time. However, hand posture and gesture describe situations where hands are used as a means to communicate to either machine or human. Empty-handed gestures and free-hand gestures are generally used to indicate use of the hands for communication purposes without physical manipulation of an object.[5]

Kurtenbach and Hulteen's definition is both problematic and useful for this discussion. It is an important viewpoint to consider as it is from the perspective of Human-Computer Interaction, which is closely related to the development of DMIs. The beginning of their definition, "a motion of the body that contains information," works well when applied to gestural control in music, however their refinement of the definition poses problems. Any of the motions they describe, including those they

[5] Cadoz and Wanderley, *Gesture – Music*, 20

classify as not being gestures, could be motions containing information when used with a gestural controller.

Hummel, Smets, and Hulteen offer a useful refinement to this definition, stating: “we employ the definition: ‘a gesture is a movement of one's body that conveys meaning to oneself or to a partner in communication.’ That partner can be a human or a computer. Meaning is information that contributes to a specific goal.” Defining meaning as “information that contributes to a specific goal” coincides well with the application to the DMI context.

The following two definitions serve to clarify the relationship between gesture and music, the last of which was written in specific reference to DMIs. Miranda and Wanderley for their purposes define gesture as “any human action used to generate sounds.”[6] For the purposes of this paper, this definition needs to be amended. Gesture will be defined as any human action that is used to generate or manipulate sound by acoustic or electronic means.

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[6] Miranda and Wanderley, *New Digital Musical Instruments*, 8.

Gesture Control in the Context of Percussion

Given this definition for gesture we can now examine gestural controllers as they apply to music. Miranda and Wanderley establish three categorizations for gestural controllers for music.[7] These three categories are augmented instruments, instrument-inspired and instrument-like controllers, and alternate controllers. Multiple examples of each of these types of controllers can be found, including examples that are specifically related to percussion instruments. These controllers that relate to percussion performance will be used as examples to establish a context for the following chapters.

Augmented instruments are traditional acoustic instruments that have had sensors added to them in order to allow control over sound and electronics. These instruments still maintain their acoustic abilities, which are only supplemented with, not replaced by, the sensors.[8] An example of this type of instrument is Fernando Rocha's hyper-kalimba. The hyper-kalimba is a standard kalimba that has had a piezo microphone, two pressure sensors, and three accelerometers added to it.[9] Data from these sensors is sent via USB to a computer running a

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[7] Ibid. 19-43.
[8] Ibid. 21
[9] Rocha, *Works for Percussion and Computer-Based Live Electronics*, 46.

Max/MSP[10] patch that uses the input to control parameters of electronic processing of the sound. The effects that are used include pitch transposition, ring modulation, delay, reverb, and looping. Rocha's hyper-kalimba gave new performance and expressive capabilities to the kalimba without hindering any of the standard performance techniques on the instrument. For percussion instruments that are held by the player, this method of augmentation can be very effective. However, many percussion instruments, particularly those used in western musical traditions, are not held or even touched directly by the performer; often a mallet or stick is used to play the instrument. Thus, this type of hybrid instrument would not be a viable option for adding gestural control to a large number of percussion instruments.

Instrument-inspired and instrument-like controllers are controllers that are modeled after existing acoustic instruments. They are designed in a way that allows players to use techniques already developed playing acoustic instruments to play an electronic instrument. This opens up new original sounds to a musician without having to learn new techniques. The instrument-inspired category of

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[10] Max/MSP is graphical programming language and environment distributed by Cycling 74.

controllers applies more readily to the topic of gestural control. These controllers do not necessarily try to imitate exactly the acoustic instrument they are modeled after – in fact they can differ substantially. An early example of one such controller is the Sequential Drum developed by Max Mathews in the late 1970s. This instrument used contact microphones to detect the impact of sticks with a rectangular surface. Additionally, the x and y coordinates of the impact points were obtained using a grid of grounding wires.[11]

The third category mentioned, alternate controllers, are controllers that do not attempt to recreate an existing acoustic instrument. There are numerous examples of these controllers, as the form that they take is limited mainly by an inventor's imagination. The broadness of this category has led musicians to deconstruct the taxonomy into further classifications. Axel Mulder in his paper "Towards a Choice of Gestural Constraints for Instrumental Performers" classified the controllers as touch controllers, expanded-range controllers, and immersive controllers. Touch controllers, as the name suggests, require a performer to make physical contact with a controller, and as a result provide haptic feedback. Expanded-range

[11] Mathews and Abbot, *The Sequential Drum*, 45-59.

controllers may or may not require physical contact, but not to the extent of touch controllers. Additionally, the range of the controller is limited, meaning that a performer may leave the controller and no longer interact with it. Immersive controllers allow the performer a great deal of freedom of movement, and the performer is unable to leave the controller.[12] Relating an alternate controller to percussion performance is somewhat contradictory to the essence of an alternate controller, but it can still be done. One such example is the Radio Drum, designed by Max Mathews and Bob Boie. This instrument is comprised of two batons or sticks, which act as emitters. The batons are manipulated above an antenna receiving board. A control unit tracks the movements of the individual sticks in three dimensions. It can also track rapid movements of the sticks, which can be used to send trigger signals. Andrew Schloss and Peter Driessen have expanded the percussion-like controls of the Radio Drum. For their purposes they did not use the control unit but instead sent the raw data directly to a computer.[13]

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[12] Mulder, *Towards a Choice of Gestural Constraints for Instrumental Performers*, 329-337.
[13] Schloss and Driessen, *Towards a Virtual Membrane*.

The Performer's Relationship to the Controller

In order to better understand the nature of performing with DMIs, or with the use of sensors in general, it will be useful to explain the relationship of the performer, the gestures, the interface, and the sounds being produced. Multiple explanations of these relationships exist,[14] but they share common points. The instrument can be thought of in two parts. The control surface or interface, as it will be called here, and the sound production unit. For the instruments of interest to this paper, the sound production unit is almost always a computer. The performer interacts with the interface, and these gestures are then sent to the sound production unit, which will in turn produce the sound for the performer and audience to hear. The way the gestures are used for sound production is established by a system of mapping the gestures to some aspect of the electronic sound. These mappings can be to any number of effects or synthesis parameters that the performer is able to control via the interface. This broad definition of the components of a DMI still leaves many points for consideration in the creation of such an instrument. These points include what gestures will be used, what

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[14] Notable sources for this topic of discussion are Axel Mulder's paper *Virtual Musical Instruments: Accessing the Sound Synthesis Universe as a Performer* and Miranda and Wanderley's *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard*.

methods will be used to capture the gestures and convert them to electrical signals, what parameters of sound synthesis or processing will be controlled, how will gestures be mapped to the parameters, and what type of feedback will be given to the performer.

The feedback is an important consideration in this type of system. Unlike playing acoustic instruments, there is not inherently anything to give the performer feedback on how gestures are being translated into sound. For example if a musician plays a chord on a guitar, the feel of the fretboard and strings allows a tactile sense of what notes will sound. The player can also look at the fretboard to visually identify where the fingers are resting on the strings. When strumming the guitar the player can feel the strings as they are set to vibrate, and also receive immediate aural feedback from the sound of the guitar being played. None of this feedback is necessarily present in the case of a DMI, instead it must be explicitly designed into the instrument. In the case of what Rovan and Hayward term an "open-air"[15] controller, a performer has only proprioceptive and auditory feedback to guide the performance. That is to say the only feedback that the performer may receive is the sound

[15] In *Typology of Tactile Sounds and their Synthesis in Gesture-Driven Computer Music Performance* Rovan and Hayward term non-contact sensing technologies as "open-air." Examples they include are near-field capacitive measurement, infrared, ultrasound, and video.

being produced and sensation of moving one's arm. This is far less precise than the feeling of touching a guitar string, or being able to see that a finger is placed on the proper fret. Rovan and Hayward explain this feedback process as such:

> A prototypical computer music performer using an open-air controller might control his or her performance through a combination of feedback loops operating at different rates. Consider the tasks in turn:
>
> 1. Think ahead (initial intention)
> 2. Initiate movement (performance gesture)
> 3. Gauge performance gesture through vision and proprioception
> 4. Hear resulting sound
> 5. Adjust gesture from vision and proprioception
> 6. Adjust intention from hearing
> 7. repeat...
>
> In this scenario, the performer receives feedback through hearing, proprioception and visual cues. Nevertheless, this scenario presents a severe obstacle to the evaluation of gestural accuracy. This is due to the fact that—by their very nature—such systems

ignore the fastest and most immediate channels of feedback which control movement: muscle tonus (thin air) and tactile sensations (non-contact).[16]

The paper then goes on to discuss the limitations of this type of feedback. The qualities they list as the drawbacks of this type of system are:

- Visual feedback is typically only needed by beginning performers. (Regardless of instrument, experienced performers seldom rely on visual cues.)
- Visual displays are inadequate, often impractical in performance.
- There are much more important visual functions during a performance. Important visual functions during a performance could include interacting with the audience, interacting with other performers, reading music as well as dramatic aspects.

[16] Rovan and Hayward, *Typology of Tactile Sounds and their Synthesis in Gesture-Driven Computer Music Performance*, 357.

> • Mechanical channels of feedback are more tightly looped psychologically and physiologically— in time and space— than vision (or audio).
> • Difficult—if not impossible—to achieve consistent control and repeatable results.
> • Requires long training and special skills.
> • Never accurate in absolute coordinates. Instead of aiming for an absolute position in space, one typically nudges the body (or a body part) precisely in the direction of certain landmarks, in response to a feedback stimulus.[17]

Clearly there is a need for another type of feedback system in order to make a refined open-air instrument. There are multiple methods of incorporating feedback systems for a performer. Rovan and Hayward have designed a system they call VR/TX that uses a specially designed transducer to provide tactile feedback.[18] Other systems have been developed and documented by Sinclair and Wanderley,[19] and Bert

[17] Ibid. 360.
[18] Ibid. 363.
[19] Sinclair and Wanderley have detailed the development of a system they call Dynamically Interactive Musically Physical Environment (DIMPLE) in their paper *A*

Bongers. Bongers has incorporated haptic feedback in his instruments by utilizing small loudspeakers, motors, or solenoids.[20] Miranda and Wanderley classify feedback using two different methods. The first method is primary versus secondary feedback. Primary feedback is visual, auditory, and tactile-kinesthetic feedback, and secondary relates to the sound produced by the instrument. The second method of classifying feedback is passive versus active. Passive feedback is that which is inherent in the physical nature of the system. Active feedback is a reaction that is produced as a response to an action from the performer.[21] Using this system we can classify Bongers' tactile feedback as primary, active feedback.

The preceding discussion of DMIs and specifically gesture controlled musical interfaces has served to establish the context for the rest of the document. The development of and considerations that go into the creation and performance of these instruments has provided inspiration for the author's interest and exploration of blending acoustic percussion instruments with sensor-based lived electronics. In a way, the systems that will be discussed are similar to an augmented

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Run-time Programmable Simulator to Enable Multi-modal Interactions with Rigid-body systems.

[20] Bongers, *Anthropomorphic Resonances*, 128

[21] Miranda and Wanderley, *New Digital Musical Instruments*, 11.

instrument – acoustic instruments and sensors being combined to create a hybrid acoustic and electronic piece of music. However, the distinguishing factor is that the sensors are not placed on the instruments, rather they are worn on the body of the percussionist. This has some important advantages. If the sensors were attached to an instrument they would likely be controllable only when the percussionist is playing that particular instrument. Since it is often the case that a percussionist will perform on a large setup of instruments, this could require a larger number of sensors to be utilized and result in a more complex setup. By attaching them to the performer, the sensors can be utilized no matter what instrument is being played, or even when no instruments are being played. There are of course a number of other considerations when wearing sensors on the body of the performer, and these will be addressed in the remainder of the document.

Chapter 2 – Survey of Sensors

Choice of Sensors

This section of the document will provide an overview of sensors that can be implemented for gesture control in combination with percussion instruments. There are an abundance of methods and sensors available that could be used for this purpose; however, the four that will be examined in this chapter are an accelerometer, flex sensor, Leap Motion, and Xbox Kinect. Of these devices the first two are electronic components available from hobbyist electronic suppliers. The remaining two are commercial products available to consumers. The models and details of the sensors will be included below.

These sensors were chosen based on a number of considerations. As the purpose of this section is to serve as a guide for others wishing to implement sensors for gesture control in percussion music, cost and availability were important factors. There have been multiple papers documenting more complex or more costly gesture tracking systems than what will be discussed here. The implementation of such systems would be prohibitively expensive or complex for widespread use.

In his paper "3D Gesture Acquisition," Emmanuel Fléty details his ultrasonic ranging system for tracking a percussionist's gestures.[22] This system is used to control synthesis and sound processing parameters, as well as spatialization parameters. This method yields accurate tracking of the percussionist's location in space. A similar result can be achieved with the sensors detailed in this paper, and in an easier manner. An additional method of gesture tracking that is prohibitively expensive is the use of motion capture systems. These systems track markers that are placed on the body of a person and yield very accurate positional data. The use of such a system is documented in "A Comparative Study on Wearable Sensors for Signal Processing on the North Indian Tabla." While the data gathered from such a system is useful and copious, the authors of the paper note that the system is "very expensive."[23]

Additionally, this paper is concerned with tracking of the performer's body for gesture control. The sensors to be described are all capable of this type of implementation. Some of the sensors could also be used to track motion of sticks or mallets rather than the body of the percussionist. This strategy of gesture tracking has been documented as

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[22] Fléty, *3D Gesture Acquisition Using Ultrasonic Sensors*, 197-208.
[23] Benning, Kapur, Till, Tzanetakis, and Driessen, *A Comparative Study on Wearable Sensors for Signal Processing on the North Indian Tabla*, 622.

well. In the paper "A Comparison of Sensor Strategies for Capturing Percussive Gestures" Diana Young's method of placing accelerometers inside sticks to capture gesture data is discussed.[24] This method is effective; however, by tracking the motions of the body of the performer, gesture tracking may be accomplished regardless of stick and mallet choice or the instrument being played.

Evaluation of Sensors

Evaluating the sensors in a way that will be meaningful for a large number of people presents a number of challenges. In Wanderley and Orio's paper "Evaluation of Input Devices for Musical Expression: Borrowing Tools from HCI" some of these challenges are discussed. One of the main difficulties is the qualitative nature of this type of evaluation. Wanderley states:

> To this end, it is possible to consider musical tasks as a way to create a sort of benchmark. Knowing the capabilities of a controller in a musical context, however simplified it may be, should be more useful than—or at least complementary to—

[24] Tindale, *A Comparison of Sensor Strategies*, 201.

> knowing quantitative data about single features regarding the output rate, the number of voices, or the precision in detecting gestures.[25]

Given this finding, in the descriptions of the various sensors that follow the intent is to suggest how the sensors may be effectively implemented. Additionally the "musical context" will be kept narrow. That is, the context will be control of processing parameters or synthesis parameters in combination with acoustic percussion instruments and technique. The evaluation will include suggested placement of the sensors and gestures that will yield the most useful data for various placements. The ways that the wearing of the sensors may affect the performance and technique on percussion instruments will also be evaluated.

Each of the sensors will be connected to a MacBook Pro computer and have their output run into a Max/MSP patch. For the purposes of testing the sensors, a "slider" object was used to visually represent the incoming data. It is important to note that once the data from the sensor is received by the computer it can be manipulated and implemented in a

[25] Wanderley and Orio, *Evaluation of Input Devices for Musical Expression*, 71.

multitude of ways. It would be impossible and unnecessary to attempt to describe all of these ways of making use of the sensor data. This being the case, a method of acquiring usable data from each of the sensors will be described, but using this data for actual control of electronics will be beyond the scope of this document. However, some possible uses will be mentioned.

Flex Sensor

The Sensor and the Setup

The simplest of the sensors described here is the flex sensor. The part used for testing is the four and a half inch flex sensor manufactured by Spectra Symbol.[26] This sensor is a variable resistor that changes resistance depending on how far it is bent. This means that to be used for gesture control it must be worn on some part of the body that bends. The position chosen by the author was the fifth finger of each hand. The sensor was sewn to the fifth finger on the back of a glove with the remaining fingers removed to allow for holding mallets or sticks. An

[26] More information about this sensor can be found at http://www.spectrasymbol.com/flex-sensor.

Arduino Uno microcontroller is used as the interface to the computer. The Arduino has the Standard Firmata firmware loaded to allow for interfacing with a Max/MSP patch. The patch activates the analog inputs on the board and receives data from the sensor. The data coming in from the sensors is scaled and smoothed to provide usable gesture information that is represented visually by the slider objects.

Findings

This sensor offers reliable control from bending of the finger it is worn on. The amount of smoothing required to make the data reliable did add some latency to the response of the slider. This could be adjusted to reach a compromise of precision and response suitable for individual uses. Trying to control the sensor with the fifth finger while manipulating sticks or mallets can be difficult depending upon the grip that is being used. Controlling the sensors while playing rapid strokes proved to be much more difficult than when playing single isolated strokes and manipulating the sensors between playing. With practice some of this difficulty could be overcome.

The attachment of the sensor requires a high level of care. The flex sensor must be attached in a way that allows it to slide across the surface it is on, as bending occurs. It also must be held firmly enough that it does not move side to side and result in poor precision or lack of control from the player.

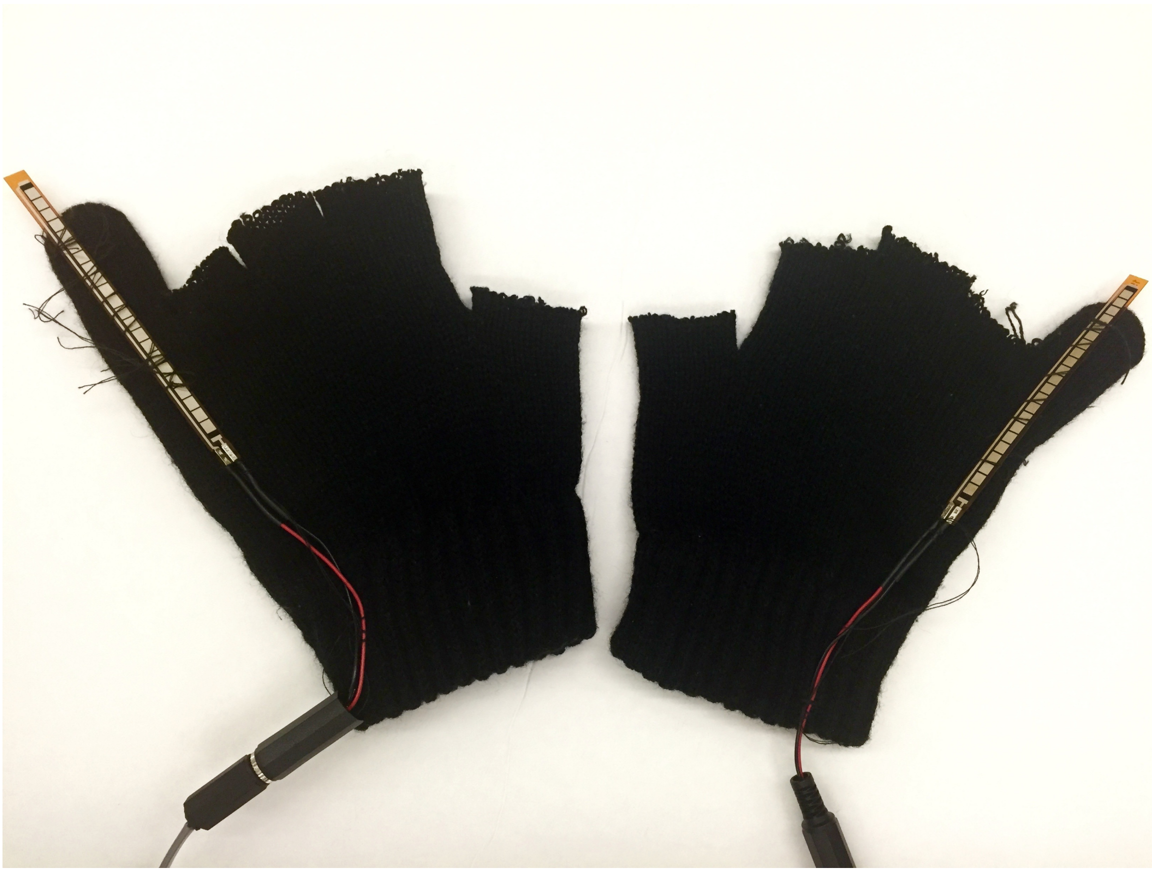

Figure 2.1 Flex Sensors– The flex sensors sewn to the fifth finger of a pair of gloves. The sensors are sewn on in a way that allows them to slide over the glove as the finger is bent. Standard eighth inch mono jacks are used for a detachable connection to the sensors.

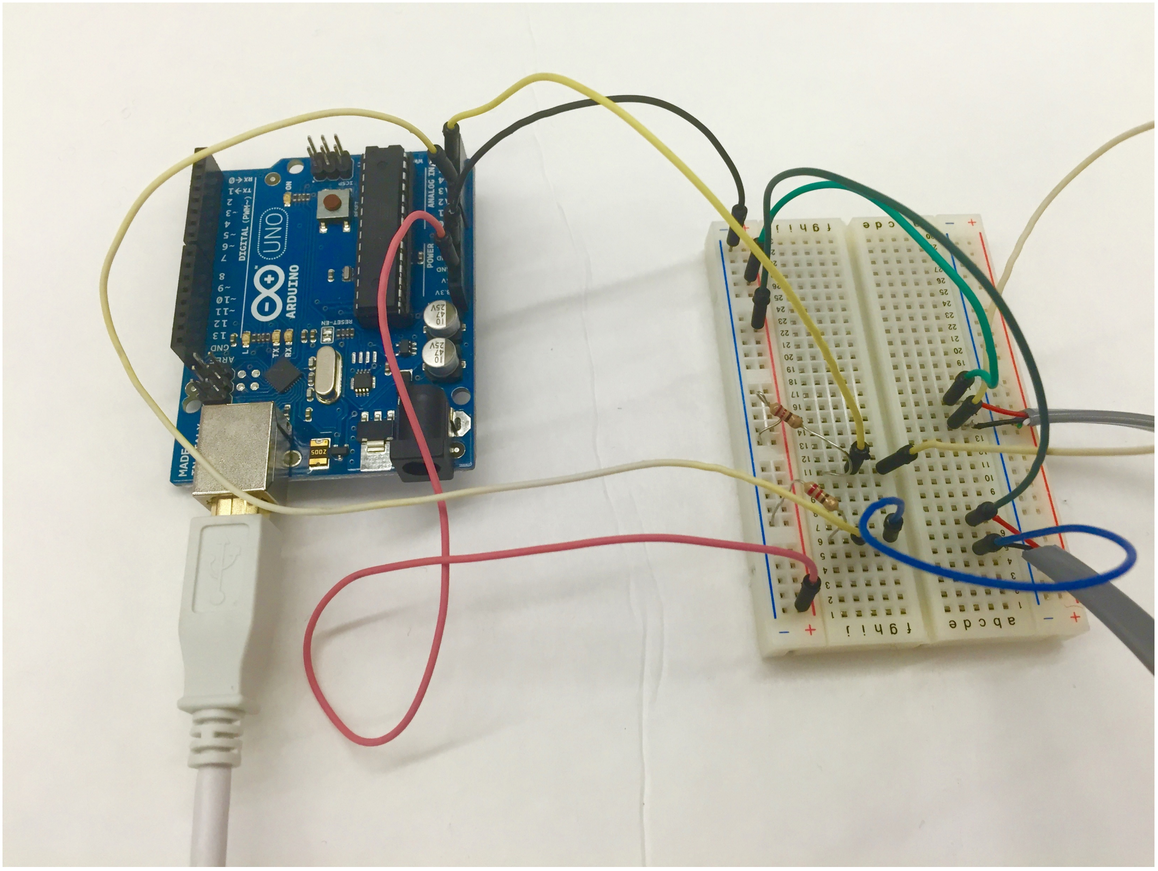

Figure 2.2 Flex Sensor Arduino Connection– The connection to the Arduino Uno for the flex sensors. The two gray cables on the right of the photo are connected to the flex sensors. A breadboard is used to make the connection to the Arduino.

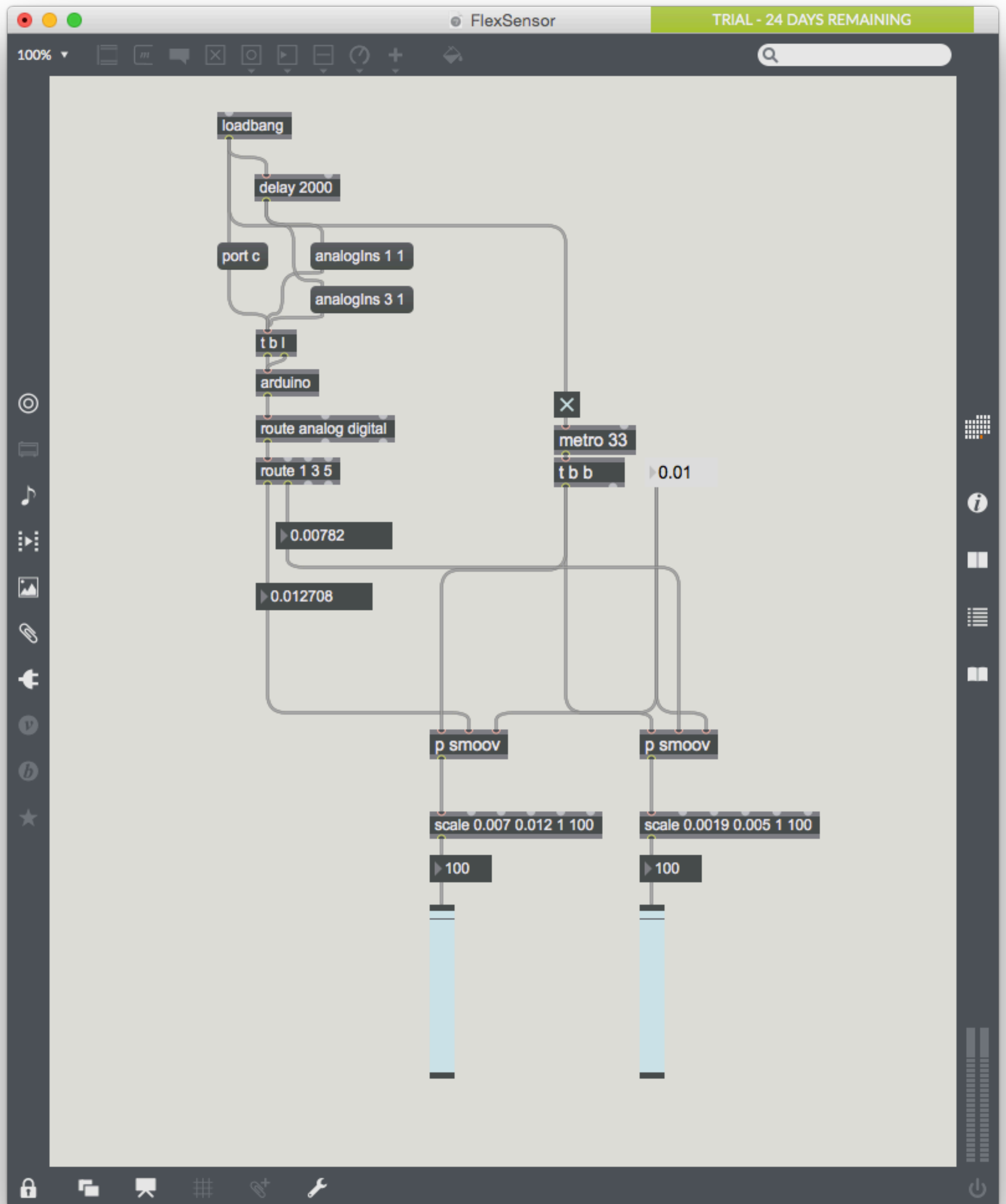

Figure 2.3 Flex Sensor Max/MSP Patch – The Max/MSP patch used for testing the flex sensors. The portion of the patch in the upper left of the image is responsible for receiving the data from the Arduino. At the bottom of these objects the raw numbers coming in from the sensors are displayed. The numbers are then smoothed and scaled and sent to the sliders at the bottom of the patch. In this image both sensors are currently not being flexed, and the sliders are both at their maximum value.

Accelerometer

The Sensor and the Setup

The accelerometer used for this test was the LilyPad Accelerometer ADXL335. The sensor was connected to the computer using a similar method to the flex sensor. An Arduino Uno with the Firmata firmware was again used to send the sensor data into a Max/MSP patch. The data is smoothed and scaled to a usable range. Unlike the flex sensor the accelerometer offers more than one data point. This model of accelerometer senses motion on three axes and yields motion data that can be used from each axis. A slider for each of the three axes is present in the patch.

Findings

The accelerometers were very responsive and had very little latency present. The quick response of the sensor means that in addition to directly mapping the motion of the hand to parameters, it would also be possible to track the rate of motion of the hand. This could then be used as another control parameter. The resolution of the control was also quite high. It was easy to manipulate the onscreen slider with precision. Additionally, the availability of three axes offered a large number of possible implementations for one sensor.

The accelerometer could be effective when worn in a number of locations on the body. For this test the back of the hands were chosen for the high level of control offered by this placement. The sensor was also quite forgiving in how it was attached to the hand. Only moderate care was required to orient the axes of the accelerometer with the directions of motion of the hand.

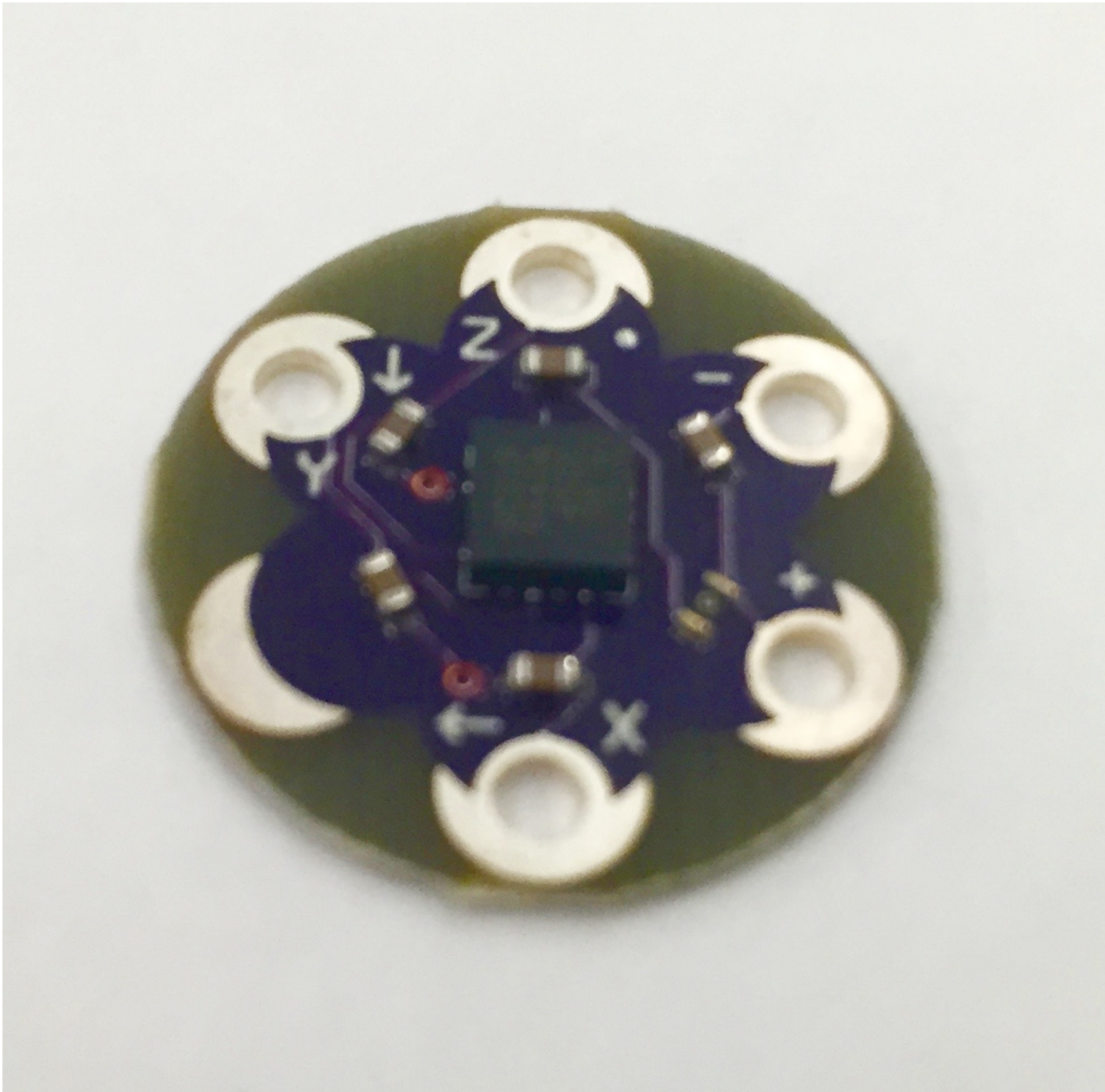

Figure 2.4 LilyPad ADXL335 Accelerometer – The LilyPad ADXL335 accelerometer is designed to be easily implemented in wearable applications. The labels for the X, Y, and Z axes can be seen printed on the sensor.

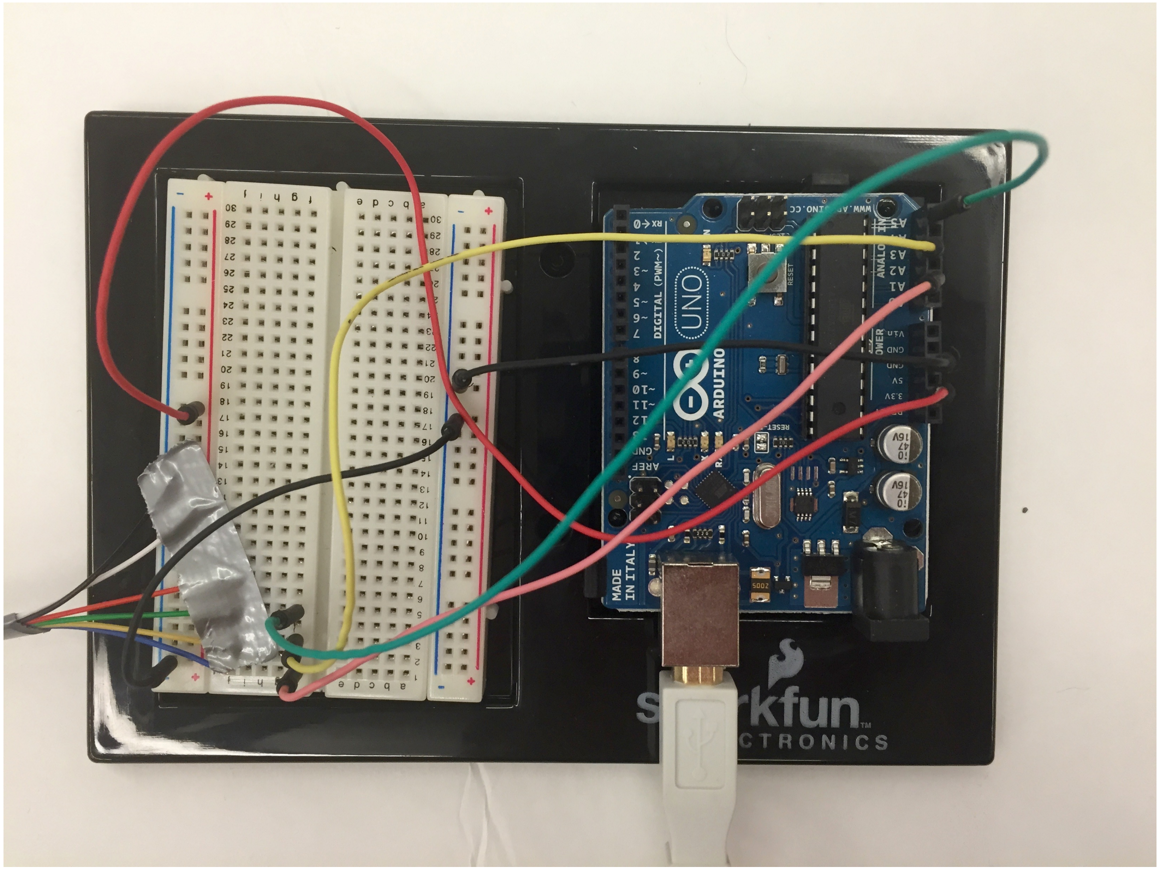

Figure 2.5 Accelerometer Arduino Connection – The connection to the Arduino for the accelerometer can be seen here. A breadboard is again used to make the connection to the Arduino. The cable connected to the accelerometer is taped down to the breadboard to keep the connections from coming loose. The connection is very simple. The 3.3v output from the Arduino is used to power the sensor. The connections for the data from the three axes are connected to three of the Arduino's analog inputs.

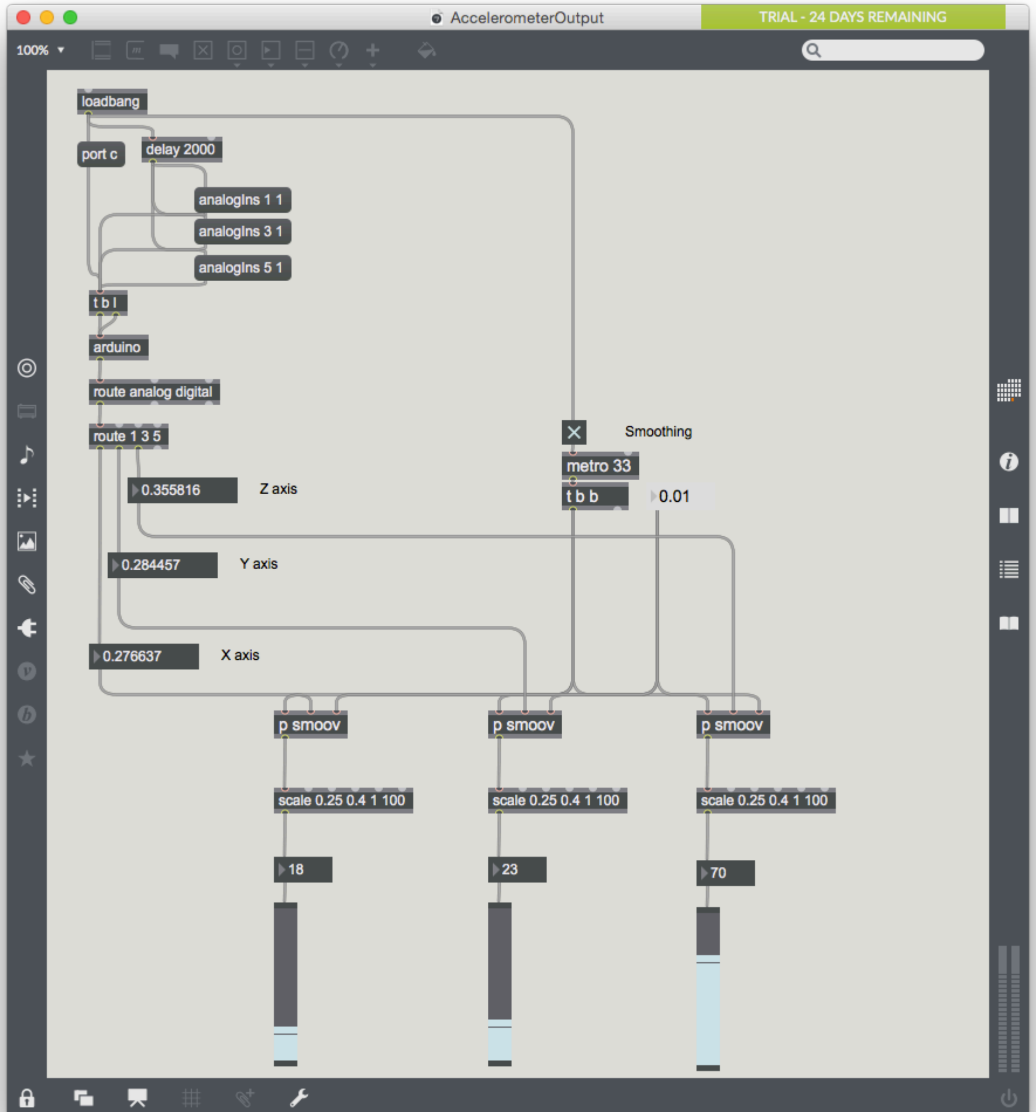

Figure 2.6 Accelerometer Max/MSP Patch – The Max/MSP patch used for testing the accelerometer. Again, the portion of the patch in the upper left of the image is responsible for receiving the data from the Arduino. The numbers from each axis are smoothed and scaled and routed to a slider object.

Leap Motion

The Sensor and the Setup

This sensor is a commercial device that is marketed as an intuitive method of interacting with a computer. The device uses infrared emitters and cameras to track the motion of hands in an area of about one square meter above the sensor. The Leap Motion is capable of tracking up to ten fingers simultaneously. It can also be configured to track "tools" instead of fingers. Since its release it has been utilized in myriad ways by hobbyists and developers to control various types of computer systems. Use as a music controller is also being explored.[27]

The Leap Motion connects directly to a computer via USB. It comes with software and drivers that allow for simple setup and configuration. In addition to the included software, an application written to be used with the Leap Motion called OSCMotion was used by the author to send the sensor data to a Max/MSP patch. OSCMotion sends the position data for each point being tracked as X, Y, and Z coordinates via Open Sound Control (OSC). OSC is:

[27] Two papers discussing different applications of the Leap Motion in musical contexts are: Ratcliffe, "Hand Motion-Controlled Audio Mixing Interface" and Tormoen, Thalmann, and Mazzola, "The Composing Hand: Musical Creation with Leap Motion and the BigBang Rubette."

> a protocol for communication among computers, sound synthesizers, and other multimedia devices that is optimized for modern networking technology. Bringing the benefits of modern networking technology to the world of electronic musical instruments, OSC's advantages include interoperability, accuracy, flexibility, and enhanced organization and documentation.[28]

Max/MSP is capable of receiving OSC messages, which allows for easy integration of the Leap Motion.

Findings

In order to make effective use of the Leap Motion it was necessary to configure it to track “tools” rather than fingers. By choosing this setting the Leap Motion was able to follow drumsticks being manipulated in its field of vision. This may seem to contradict the stipulation given earlier that the sensors would be used to track the motion of the performers body, however in this case different sticks and mallets may be used throughout a performance and still be tracked by the Leap Motion. When the Leap Motion was configured to tack fingers

[28] http://opensoundcontrol.org/introduction-osc, accessed March 30, 2015.

the sensor could not locate the players fingers when drumsticks were being held.

The Leap Motion was responsive, but did have some notable limitations. The area in which the sensor would track the drumsticks was difficult to define, and the sensor would sometimes lose track of the stick. The range of the sensor is also limited, and as such would require careful consideration to place effectively into a percussion setup. One of the most effective and reliable ways to integrate the Leap Motion into a percussion performance may be to place the sensor adjacent to percussion instruments and use a hand to interact with the sensor only when it is not playing the acoustic instruments.

It is also worth noting that in the setup described the Leap Motion will track two points at a time. However, it does not keep track of which point is the left hand and which is the right hand. Whichever hand it detects first will be point one regardless of whether it is the left or right hand. This means that the hand that is the first point and the hand that is the second point could change as the they move in and out of the view of the Leap Motion. They could also change unexpectedly as a result of the Leap Motion temporarily losing track of the hands.

Figure 2.7 Leap Motion Controller – The Leap Motion controller with USB cable attached.

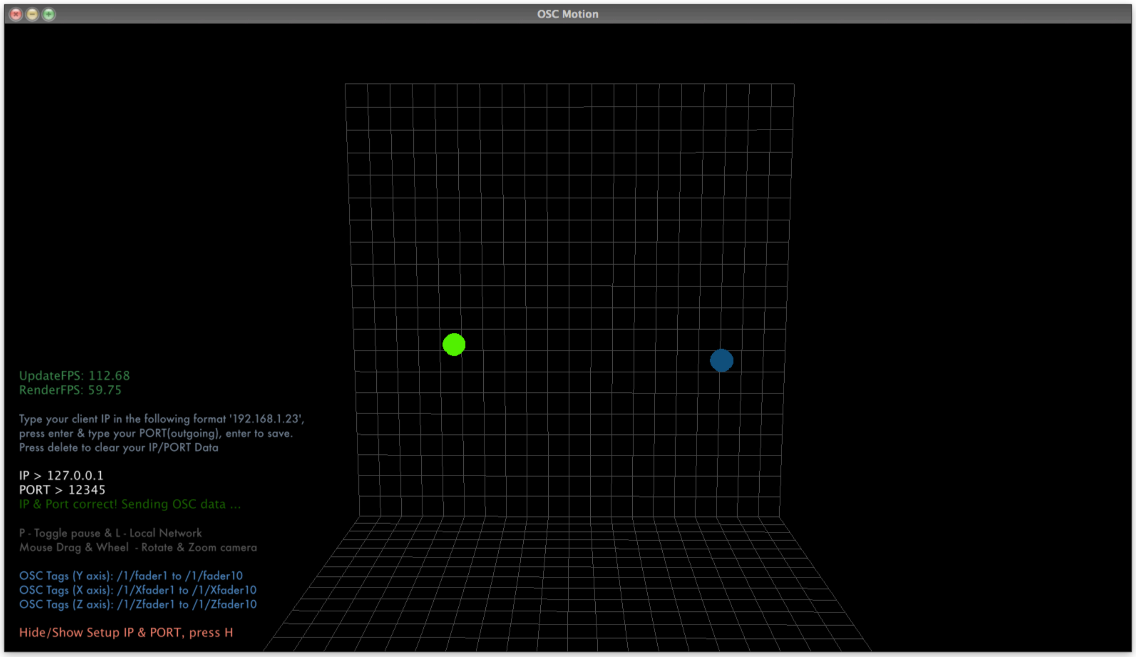

Figure 2.8 OSCMotion Application Window – The OSCMotion application window. The two dots are representations of the two "tools" being tracked by the Leap Motion. The lower left of the window displays the OSC configuration as well as the status of the tracking.

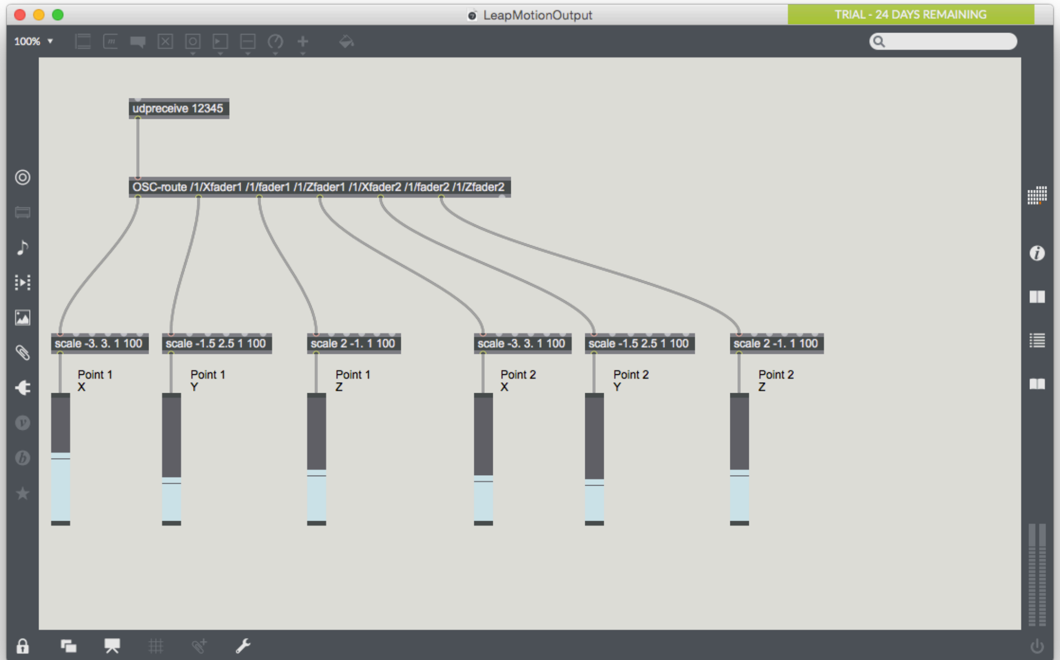

Figure 2.9 Leap Motion Max/MSP Patch – The Max/MSP patch for receiving the Leap Motion tracking data. The "udprecieve" object at the top of the window receives the OSC messages from the OSCMotion application. The OSC-route object below routes the messages using the OSC tags. The X, Y, and Z coordinates for each point are routed to a slider object.

Xbox Kinect

The Sensor and the Setup

The Xbox Kinect is also a commercial device that utilizes infrared cameras to allow for human interaction with computers. In this case the intended computer was the Microsoft Xbox 360 game system. However, the sensor uses a standard USB connection and as a result can be connected to a personal computer. The Kinect has also received a great deal of development by hobbyists since its release, and many diverse uses have been discovered.

To make use of the data from the sensor a program called Synapse is used in combination with two Max/MSP patches. Synapse is a piece of software that receives the data from the Kinect. This data is then sent out to a Max/MSP patch called Kinect-Via-Synapse. This patch allows the user to choose which parts of the body to track, and provides a graphical way of configuring the settings of the data output. The tracking data is then sent out via OSC. A second Max/MSP patch, created by the author, receives the data and again uses slider objects as a visual representation of the data.

The only two points on the body that are tracked in the final patch are the hands, though there are fifteen potential tracking points to choose from.

Findings

The Kinect is very effective for tracking large motions of the body. The sensor is capable of tracking a larger range of motion than any of the other methods discussed. Additionally, this tracking is done with a high level of precision. The Kinect can be used to track movement of the hands relative to the body, but it is also capable of tracking the position of the body in space. This means that the sensor can be used for control by the performer when moving to different locations in the performance space, as long as the locations were within the view of the cameras in the Kinect.

The main limitation of the Kinect is the latency of the sensor. It does not respond instantly to movements and as a result works best when used to track large or slow movements of the performer.

One final, notable feature of the Kinect was its ability to keep track of the performers hands even when they were behind a marimba. This could be useful in a number ways. This can be seen in figure 2.12.

Figure 2.10 Xbox Kinect Sensor – The Xbox Kinect Sensor.

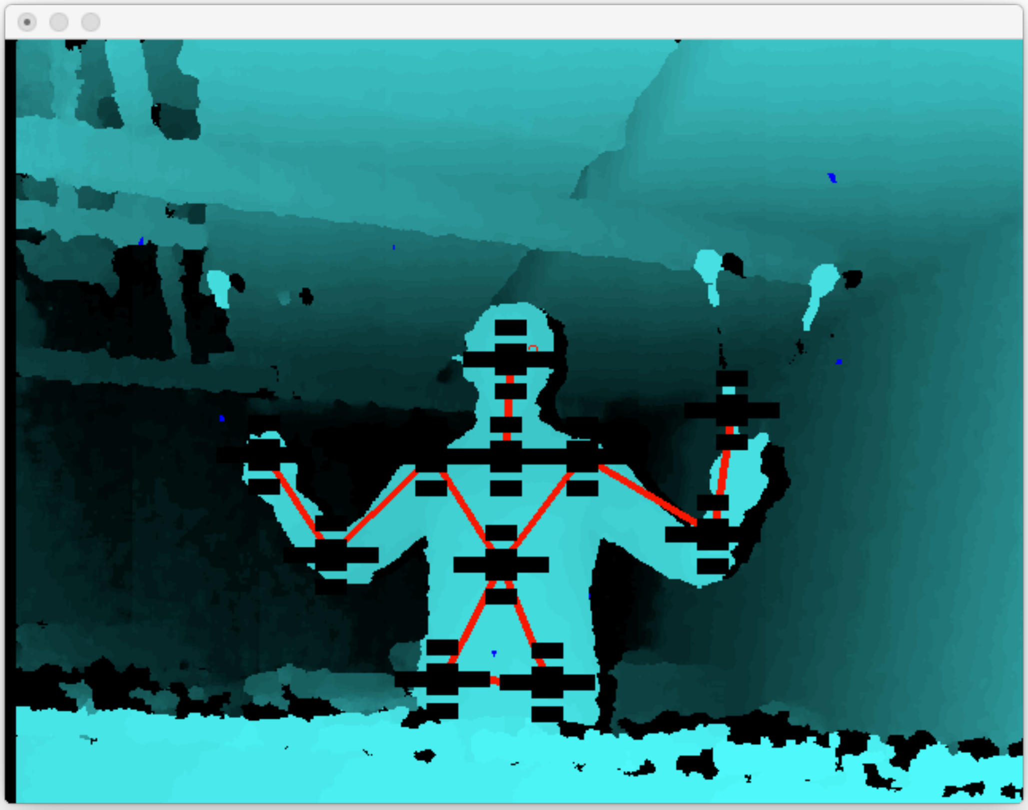

Figure 2.11 Synapse Application Window – The Synapse application window displaying the Kinect tracking the body position of the author. The points that can be tracked are marked by the black plus shaped symbols on the body. Notice the author is holding marimba mallets in each hand and standing behind a marimba.

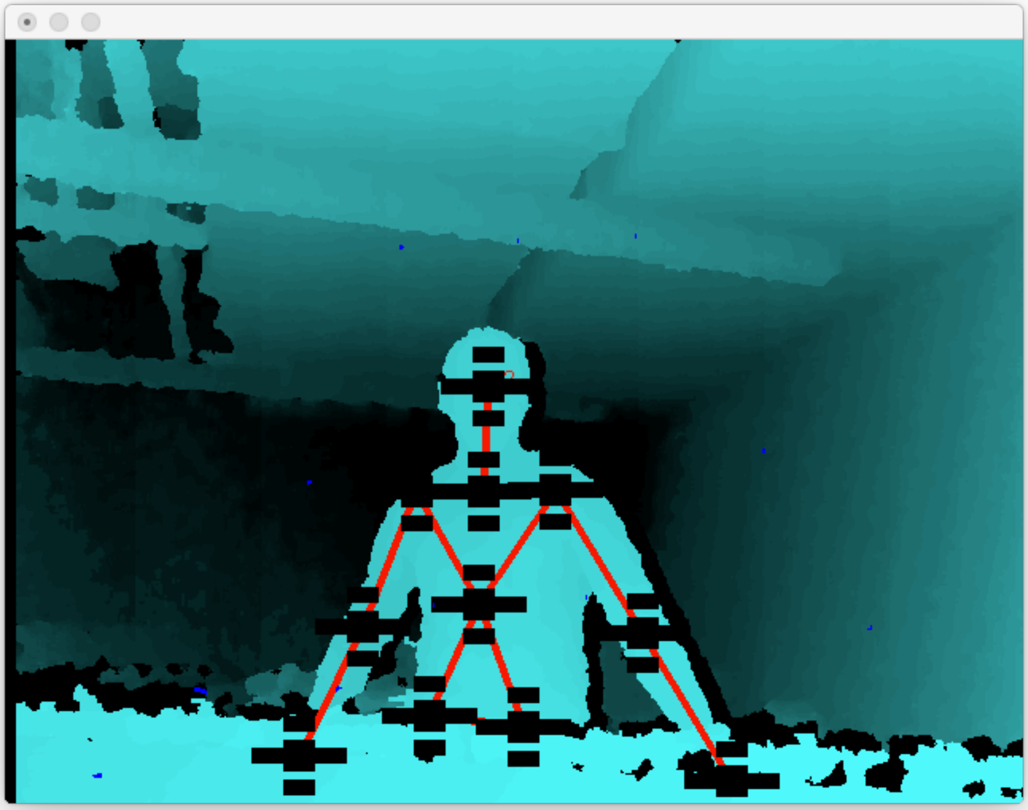

Figure 2.12 Synapse Application Window – This image shows that the Kinect is able to track the hands of a performer even when they drop below the marimba.

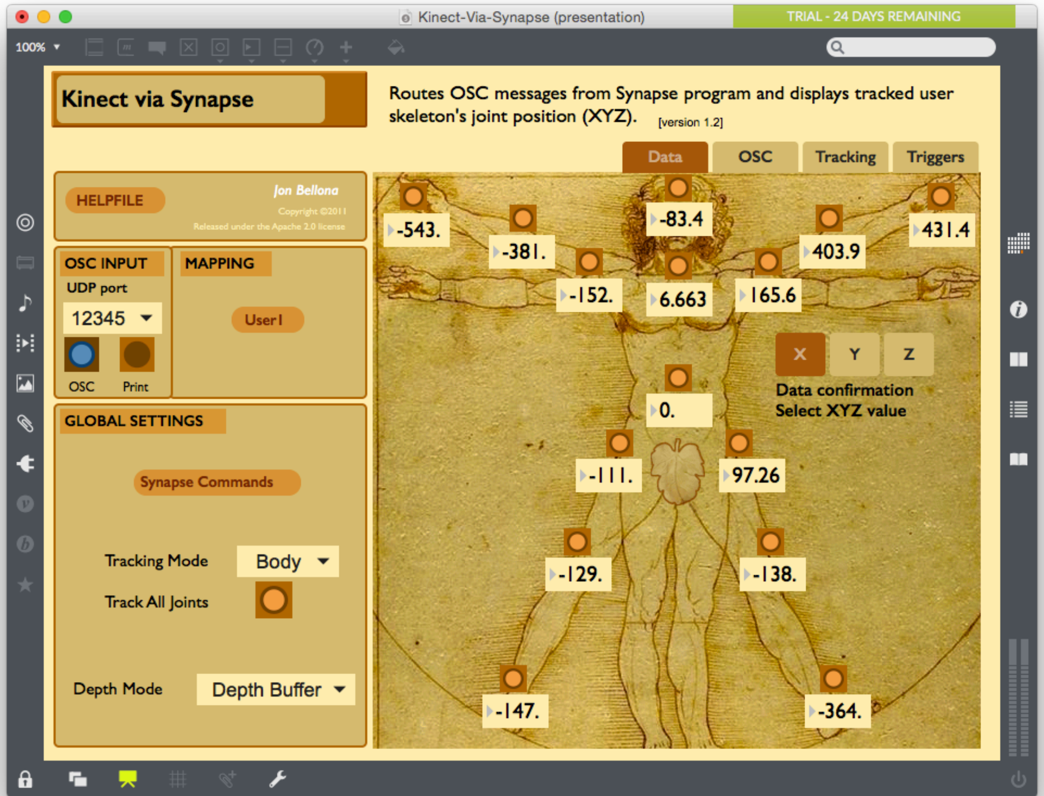

Figure 2.13 Kinect-Via-Synapse Window – The Kinect-Via-Synapse window displays the positions of all the points being tracked by the Kinect. It also provides a method of sending the position information out via OSC.

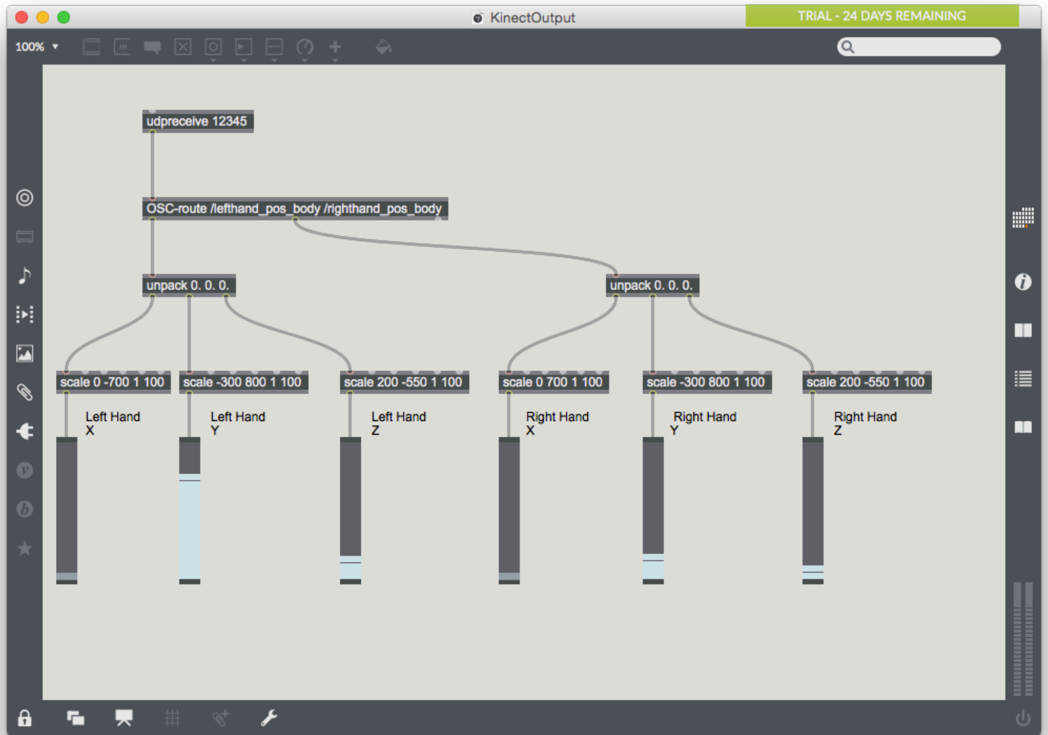

Figure 2.14 Kinect Max/MSP Patch – The Max/MSP patch for receiving the Kinect output. This patch functions in same manner as the patch for the Leap Motion. That is, by receiving the OSC information and routing it based on the OSC tags. Here the position of each hand is being routed to slider objects. More than two points can be tracked however.

Mapping of Sensor Data

The topic of mapping the data from the sensors to parameters is a complex one, whether it is to control processing or synthesis. Strategies for mapping sensor data have been discussed in-depth in multiple papers by Wanderley.[29] That level of discussion pertaining to mapping is beyond the scope of this paper, however some considerations should be mentioned on this topic. In deciding what type of gesture will be mapped to a particular parameter it is important to consider the level of precision necessary to yield satisfactory results. The level of precision required will depend on the level of expression needed by the performer. In the example of synthesis, if a performer is required to change the pitch of synthesis to specific frequencies, the difficulty in execution will depend upon how the pitch control is implemented. A possible method of controlling pitch would be to map the parameter to the x-axis of an accelerometer worn on the wrist of a percussionist and controlled by the rotation of the arm. If the performer can slide continuously between a range of pitches this would be much more difficult than having the synthesis jump from one pitch to the next.

[29] Wanderley, "Evaluation of Input Devices," and "Mapping Strategies for Gestural and Adaptive Control" are two particularly useful papers on this subject.

Parameters of sound processing may require less precision than those of synthesis to yield satisfactory results. Listeners are less likely to be as sensitive to discrepancies in audio processing than to discrepancies in pitch. As such, these parameters could be mapped to sensors yielding less fine-grained control, or gestures that are more difficult to precisely execute.

Final Thoughts on the Sensor Tests

There are of course many more sensors that are available for use in tracking percussive gestures. Those chosen for discussion here are relatively easy to implement and readily available, and as a result are good starting points for individuals interested in combining gesture control electronics with acoustic percussion instruments.

Additionally, all of the setups described above used Max/MSP as the software to receive and utilize the sensor data. It should be noted that there are a number of other options available, and that Max/MSP was chosen due to its visual interface. Other popular software options include PureData, SuperCollider, and Ableton Live, and there are of course other options as well.

The same note should be made about the Arduino hardware that was used. There are other ways of interfacing sensors with a personal computer, but the Arduino is affordable, readily available, and a relatively simple solution.

The methods used by the author should not be considered the only method, or the best method of utilizing these sensors. The choices of software and hardware should be made by the user weighing the needs of the particular application.

Chapter 3 - Preparing and Performing a Percussion Solo with Gesture Control Electronics

The remaining portion of this document will be a detailed explanation of a percussion solo written for the author that incorporates gesture control with acoustic percussion instruments. An overview of the structure of the piece, the notation, and the electronics will be given. Additionally, aspects that are unique to performing with this type of setup will be addressed.

Overview of the piece

The piece *Percussivometers* was composed in 2014 by Marcin Pączkowski. It is a multiple percussion solo that combines acoustic percussion instruments with electronics controlled by accelerometers. The acoustic instruments used in the piece are a metal chain, paper (sheet music), guiro, Tibetan bell, opera gong, two suspended metal pipes, two cymbals, four metal blocks, four tom-toms, and field drum. (Figure 3.1)

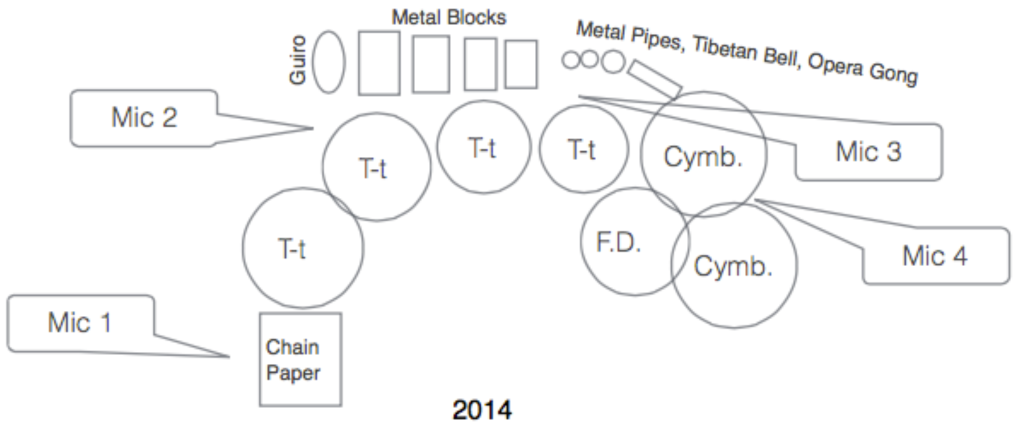

Figure 3.1 *Percussivometers* Setup Diagram – The *Percussivometers* setup diagram.

The equipment used for the electronic portion of the piece includes a 3-axis accelerometer worn on each hand of the performer with a wireless transmitter, a computer running SuperCollider, four microphones, audio interface, and a loudspeaker system using two stereo speakers or optionally six speakers utilizing ambisonic technology.[30] The performance notes from the composer help to understand the nature of the piece:

[30] Ambisonics is a surround sound system that can create a full spherical sound field. The details of this system are beyond the scope of this document, however more information can be found at http://jahya.net/blog/introduction-to-ambisonics/ and http://www.ambisonictoolkit.net/wiki/tiki-index.php.

> The piece is involving live electronics media controlled by accelerometers. Subsequent processes are activated by advancing process numbers using a foot switch. Sound is processed in real time based on information from accelerometers and microphones.
>
> Improvisation is an important element of the piece. There are extended sections depending on performer's ability to improvise.[31]

To expand on this summarization further, an explanation of the way the electronics are implemented through various sections of the piece will follow. The opening of the piece is an exposition and introduces us to the sounds of the acoustic instruments without any electronics being utilized. Every instrument is heard in the opening section with the exceptions of the chain, paper, and guiro. This acoustic-only introduction is important in this piece as it familiarizes the audience with what the unprocessed sounds are. This context allows for a fuller understanding of the piece later on when the sound field

[31] Pączkowski, Performance notes for the piece *Percussivometers*, 2014.

becomes much more dense as a result of the electronic sounds being added.

At bar sixteen a new section begins. This section is where the electronics are first implemented. At this point in the piece there is a single struck note on one of the cymbals that is immediately muted with the left hand. This note is then followed by a fermata. This bar serves as a demonstration of the unprocessed sound in the same way that the preceding fifteen measures had. In bar seventeen the electronics are activated and another single muted cymbal note is played. The SuperCollider program then processes this note. The processing is controlled by rotation of the left hand around the x-axis. This processing and control continues up to measure twenty-two at which point the processing is changed. However, the control method remains the rotation motion of the left hand around the x-axis. At measure twenty-two the performer is indicated to begin bowing the cymbals rather than striking, but also continue controlling the electronics in the same manner. The processing is again changed at measure twenty-five, and the section concludes with one final long, bowed note on the lower of the two cymbals.

The next section of the piece begins at measure thirty. In this portion of the piece the right hand holds yarn mallets and the left holds hard rubber mallets. The left hand plays rolls on the metal blocks while the right hand rolls on the cymbals and toms. There are electronic sounds heard in the portion of the piece, however their control is intentionally incidental and resultant from the motions used to play the rolls.

Following this section, beginning at measure forty, there is a new application of the electronics. The performer plays the notated part on the toms, and while this happens the sound is being recorded for granular synthesis which will be played back at measure fifty as the performer reaches the end of the notated tom section. The playback of the sampled performance is controlled by the motion of the performer's hands. Initially there is one layer of playback, which is controlled by the left hand accelerometer. The x-axis controls the rate of playback and the y-axis controls the dynamic. As this section continues more layers of playback are added in, and both hands are utilized to control the rates and dynamics of the layers.

Following the sample playback the first of two "build" sections arrives. In this section, which spans from bar fifty-four to seventy-four, the performer plays an improvised passage based on instructions in the score. This portion of the piece is performed on the drums and metal blocks. Over the course of the section the performer increases in both speed and dynamic. While this happens the accelerometer data is being used to track the rate at which the performer's hands are moving. This information is used to control synthesis parameters, which will be discussed in more detail below.

The next section is very similar to the opening of the piece except that at this point electronic processing is being applied to the acoustic instruments. Immediately following this, beginning at measure eighty-nine percussion "instruments" that are held in the hand and manipulated are used, again with granular synthesis controlled by the motion of the performer's hands. The instruments include a guiro, a metal chain, and a page of the score that is removed from the music stand and torn.

This leads to the final portion of the piece, another build section. This section functions similarly to the earlier build section, however new processes are used and sampled layers of the acoustic instruments are added into the sound field. As the player approaches the end of the piece "air-strokes" or "fake-playing" are inserted into the strikes on the acoustic instruments. There is a gradual transition from playing the acoustic instruments to playing only strokes in the air and allowing the electronic sounds to take over. The electronic sounds continue to be controlled by the rate at which the performer's hands are moved, and the performer is instructed to walk off stage while still playing. The sound stops when the hands of the performer stop moving, ideally just as the performer leaves the stage.

Notation

A piece of this nature — one that makes use of accelerometers to control live electronics — requires some special consideration for the method of notation. The piece does contain large sections of improvisation, but even in these sections it was still necessary for the composer to have a method of indicating the desired gesture to the performer. To accomplish this each accelerometer was given its own line in the score, as were the electronic sounds. The accelerometer score indications are lines rising and falling that indicate the to performer which direction to move the hand. A rising line is interpreted by rotating the hand inward in the case of the x-axis, or by lifting the hand so that the top of the hand is tilted towards the forearm in the case of the y-axis. The axis to be utilized is identified by the letter X or Y being printed next to the lines indicating the rotation. (Figure 3.2)

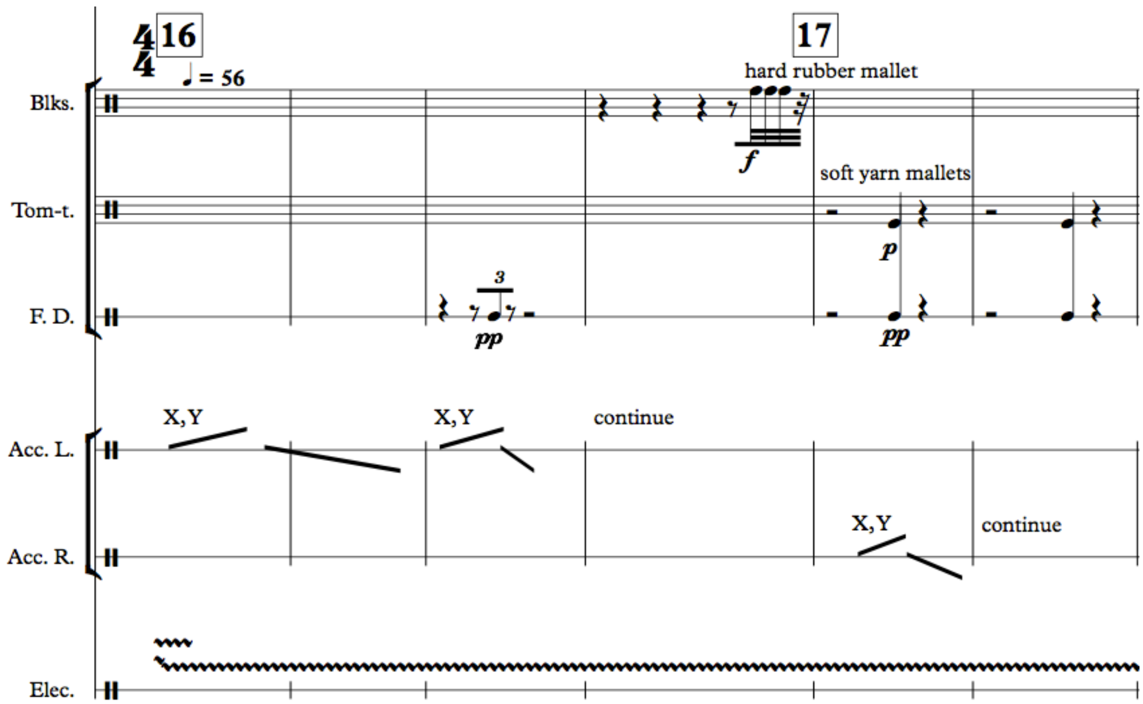

Figure 3.2 Accelerometer Performance Notation – The accelerometer performance indications can be seen on the lines of the score marked Acc. L and Acc. R.

In some portions of the piece motions of the hands used to control the electronics are left entirely to the discretion performer. In these instances the accelerometer lines in the score have wavy lines for the duration of the improvised gesture section. (Figure 3.3)

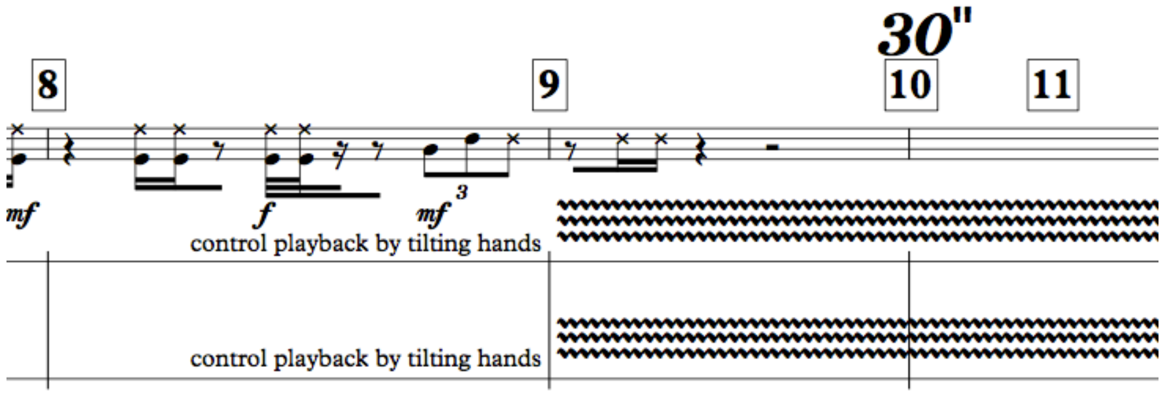

Figure 3.3 Improvised Accelerometer Notation – The indication for improvised control of the accelerometers.

These same wavy lines are used on the Electronics line on the score. They indicate to the performer when electronic sounds should be heard as well as the number of layers of electronic sound when multiple processes are combined. (Figure 3.4)

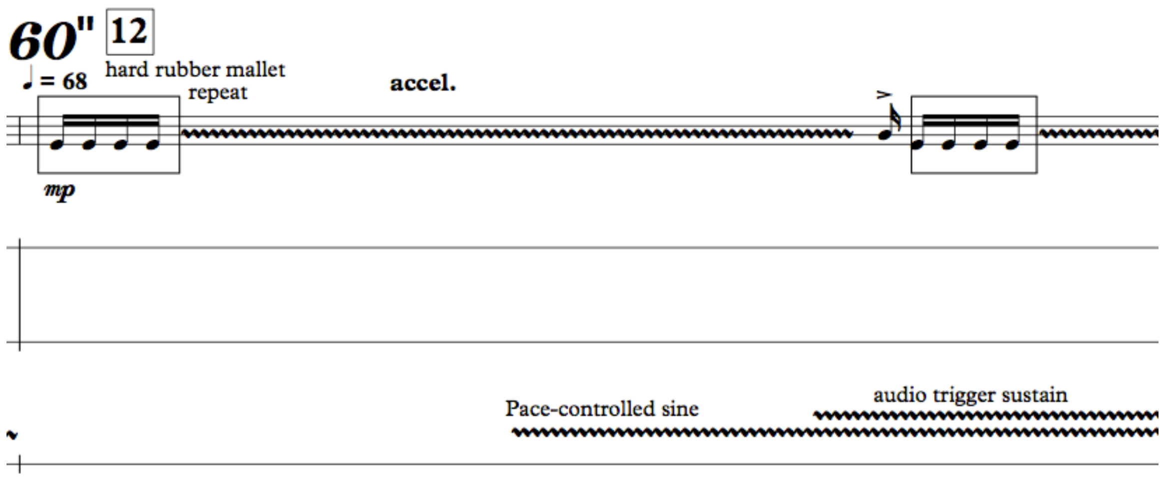

Figure 3.4 Notation of the Electronics – The wavy lines at the bottom of the score excerpt represent the layers of electronics sound that should be heard at a given point in the piece.

This method of notation while not exact in its direction to the performer, adequately conveys the intentions of the composer. It gives enough information to create the desired performance while also being easy to understand and read. As such it is a very successful method of notating a unique aspect of this type of musical performance.

The Electronics

The electronics used for *Percussivometers* include two LilyPad ADXL335 accelerometers. One is worn on the back of each hand of the performer. They are sewn to thin cloth gloves with the fingers removed to allow for uninhibited use of the fingers in the performance. Wires are attached to the gloves and connected to the accelerometers using conductive thread and heat shrink tubing. The wires are then fed under the performers shirt to a location on the waist where a wireless transmitter is worn. The wires connect to a custom made PCB via RJ12 connectors. Mounted to this PCB is an XBee antenna that is used to transmit the sensor data another XBee antenna connected to a laptop via an Arduino microcontroller and USB cable. A small polymer lithium ion battery powers the wireless transmitter.

The microphones used are four small diaphragm condenser microphones. Microphones of varying quality and expense have been used in performances of the piece, and little difference, if any, has been noted. As they are being used in a live application, and the sounds are being processed there is little concern for highly accurate sound reproduction. The use of four condenser microphones necessitates an audio interface that has at least four microphone inputs with phantom power. The number of outputs required depends on how the piece will be performed. A typical stereo performance will require two outputs — a left and right audio channel. A performance utilizing ambisonic playback will require up to six outputs.

In addition to the outputs for the loudspeakers it is beneficial to have a reliable monitoring system for the performer. In the author's performances a wireless monitoring system made by Shure has been used. Not only does using a wireless monitoring system in conjunction with the accelerometer's wireless transmitter free the performer from any cables that could be cumbersome, it also enables the performer execute the end of the piece as the composer intended. This intention being to walk off of the stage while still using gestures to control the electronics.

The SuperCollider Program

The live electronic portion of the piece comes from a program written by the composer in the SuperCollider language. When the program is loaded for a performance the performer is presented with a graphical user interface (GUI) that displays the various processes that are used and advanced through during the piece. (Figure 3.5) This GUI includes a visual display of what process number the program is currently on, and provides the performer with other necessary and useful information. A level meter for the audio input of the four microphones is included and well as a graphical display of the data being received from the accelerometers. The display of this information allows the performer to quickly confirm that everything is functioning and configured correctly. In the setup and performance of a piece of music utilizing live electronics this type of quick visual confirmation can be invaluable.

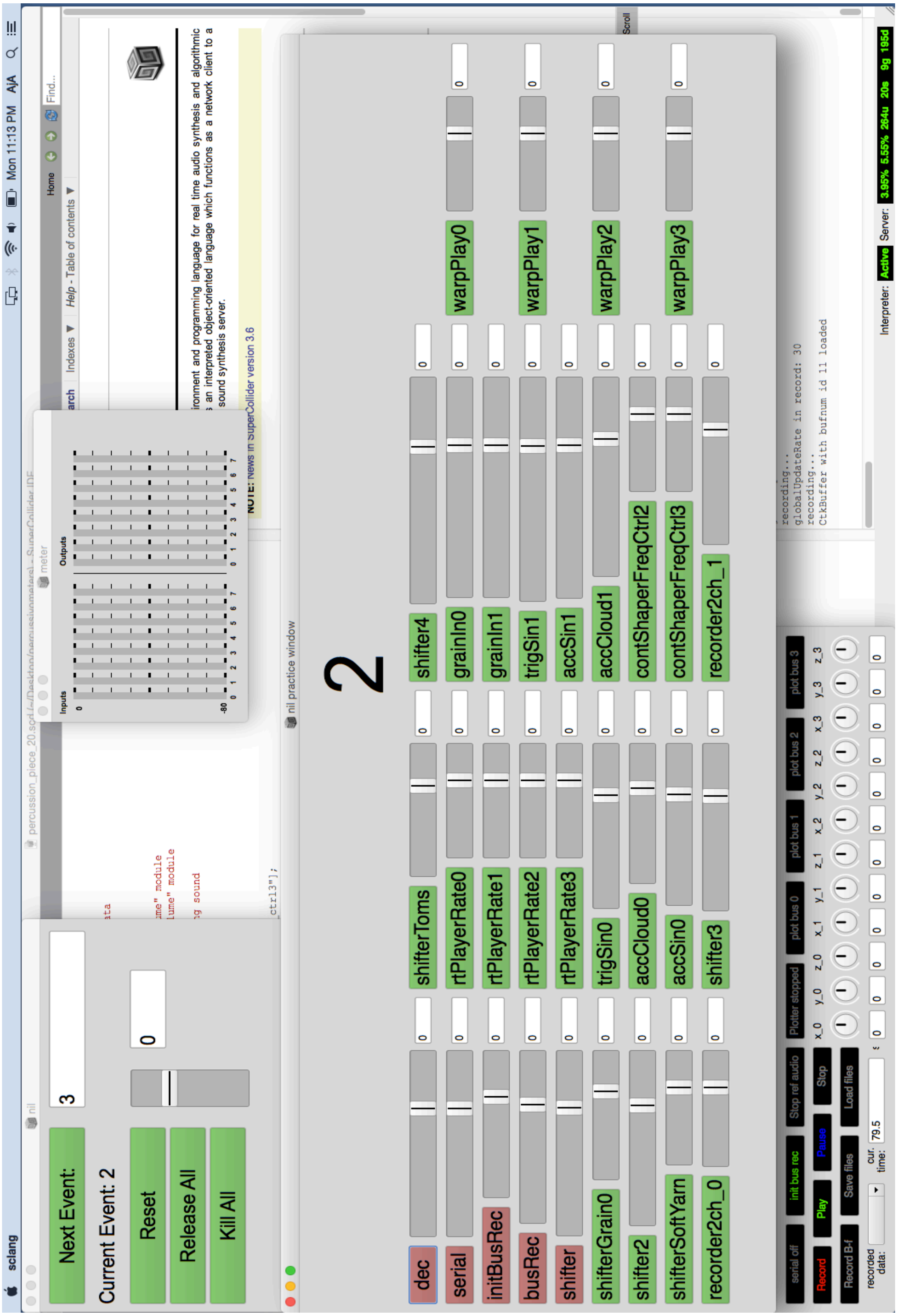

Figure 3.5 SuperCollider GUI – The GUI of the SuperCollider program for *Percussivometers*.

The processes that are applied by the program include synthesis, granular synthesis, sampling with variable rates of playback, sustain of acoustic sounds, and pitch manipulation. The particular process or processes that are currently active are advanced by the use of a midi foot pedal connected the computer running the program. Certain points in the piece require exact timing of process changes with what is played on the acoustic instruments. It was because of the necessity of synchronization that a foot pedal was used, rather than an assistant, to change the processes. The use of a foot pedal operated by the performer allows much more accurate synchronization of the electronic and acoustic portions of the piece than an assistant controlling the program. It also enables the performer to have complete control over the pacing of any and every performance of the piece.

Gesture Analyzation

As discussed previously in this paper, percussion performance lends itself readily to performance with gesture control or motion tracking live electronics. This is due to the very physical nature of playing percussion instruments. In the discussion of the gestures used in the piece *Percussivometers*, specifying three categories of gesture will help define and clarify the subject.

The first category to discuss will be termed natural gestures. These gestures are movements that are unaltered from normal percussion playing. They do not require any extra consideration from the performer beyond normal technique employed in the execution of a musical passage.

An example of this type of gesture occurs at measures fifty-four through seventy-four and at measures eighty-nine through 104. In the first section, beginning at measure fifty-four, the performer plays sixteenth notes on the lowest tom-tom, initially at the tempo of sixty beats per minute. The tempo gradually increases at the performers discretion, as does the number of instruments being played. In the culmination of this section the performer is playing improvised structures reaching a tempo of 180 beats per minute. Throughout this, the accelerometers are tracking the rate of the strokes being played. As the rate of playing increases, the parameters of synthesis change and the density of the electronic sounds increases. Additionally, there is a layer of electronic sound that responds to and enhances particular frequencies picked up by the microphones. This type of processing results in electronic sounds that are being controlled by, and responding to the performer, but do not require any action beyond performing exactly as one would without the electronics being present. The section at measure ninety-six works in the same way. The accelerometers track the rate of the performers strokes, and the electronic sounds build in intensity and density as the frequency of the strokes increases. This section however transitions into the third category of gesture that is discussed below.

The second category is termed exaggerated gestures. This group is defined as gestures that are enhanced movements that are used to play the acoustic instruments. This enhancement can come in a few different forms. In some instances the exaggerated gesture is simply a larger version of a motion necessitated by the acoustic performance. For example the height of the rebound of a particular stroke may be greatly increased as well as the duration of the movement’s execution. The effect of this larger, slower motion is that there is a greater range of data tracked by the accelerometer and the effect is processed more slowly producing a more dramatic effect for the listener.

Examples of this type of gesture occur frequently in the piece, but an extended section that serves as a prime example can be found in measures seventy-nine through eighty-eight. In this section both hands must be used to perform the notated acoustic part of the piece. Also, both accelerometers are being used to track the movement of the performer's hands. Due to the simultaneous role of each hand, being responsible for both playing of the acoustic instruments and the control of the processing of the electronics, the gestures of playing the acoustic instruments must also be those that are used to control the electronics. At this point in the piece the sounds that microphones pick up are being processed immediately and played back through the speakers. The motion of the hands translates directly to the sound that is heard from the speakers. The listener hears both the sustain of the acoustic instrument, in the case of the instruments that have a sustaining sound, and the electronically processed sustain of the sound. The performer is able to control the electronic sounds after the impact of the mallet on an instrument. When a percussionist plays an instrument the motion that occurs after this impact can be referred to as the rebound or upstroke. This upstroke is what the performer uses to control the electronic processing in this section of the piece. The speed at which the notes occur, more specifically the amount time between the notes allows the performer to exaggerate the motions used in playing the instruments. What normally would be small lift of the mallet after playing a note can be enlarged into a much greater motion. For example in measure seventy-nine on beat three, the performer plays a quarter note on both the lowest tom-tom and the field drum, and the dynamics are pianissimo and piano respectively. If the electronics were not a consideration it is likely that the execution of these notes would begin and end with the mallets approximately one inch or less from the heads of the drums. However, because the electronics are tracking the motion of the performers hands it is necessary to make the upstroke much larger than typical. In the case of the author's performance of the piece this manifested as an upstroke with a height of more that twenty-four inches rather than the one inch that could have been used in a purely acoustic performance.

The third category of gesture will be referred to as artificial gestures. A gesture of this type is one that is not necessary for the acoustic performance in any way. It is a motion that executed solely for the manipulation of the electronic portion of the piece.

This type of gesture takes many forms throughout the piece. The first of occurrence of this type of gesture is also the first time the electronics are heard in the piece. At measure seventeen the electronics are activated for the first time and a single choked note played on cymbal is processed. The right hand is used to strike the cymbal with a mallet, while the effect applied to the sound of the cymbal is controlled by the rotation of the left hand around the x-axis. This rotation of the left hand is not necessary for the execution of the playing of the acoustic instruments, and in fact slightly complicates it, as the left hand is also responsible for dampening the struck cymbal. Another example of an artificial gesture begins in measure fifty. In this section of the piece the performer is controlling the playback of multiple layers of recordings from the previous ten measures. The playback is manipulated in speed and amplitude by rotation of the hands around both the x and y axes. While this is happening no acoustic instruments are being played. The movements that are being performed are entirely for the purpose of controlling the electronic portion of the piece. One final example of artificial gesture occurs in the last section of the piece when the performer gradually transitions from playing on the drums and metal blocks to playing strokes in the air that do not make contact any acoustic instrument. The piece ends with the performer playing strokes in the air and walking away from the percussion setup. At this point the performer is “playing” the electronic sounds by controlling them with the rate of the strokes. This final portion of the piece exemplifies the artificial stroke in its purest form.

Performance Considerations

Performing a piece of music for percussion with live electronics presents a number of issues and special considerations, with which a performer must deal. Fernando Rocha specifically addresses this topic in his dissertation, "Works for percussion and computer-based live electronics: aspects of performance with technology."[32] A great deal has been written on performing with live electronics, and some dealing specifically with the considerations of controlling the electronics using gesture control. There are aspects of the preparation and performance that must be considered and handled appropriately in order to deliver an effective performance. This point of view is shared by a number of people in the field of music with live electronics. Andrew Schloss summarizes this aspect well:

> It is now necessary, when using computers in live performance, to carefully consider the *visual/corporeal* aspects of the performance; that is, to consider the *observer's* view of the performer's modes of physical interactions and mappings from gesture to sound, in order to make the performance convincing and effective. Even though these are in many cases "extra-musical" requirements, I believe that it has

[32] Rocha, *Works for percussion and computer-based live electronics*, 25-29.

> become necessary to deal with them directly, because the integrity of the performance is in jeopardy.[33]

This viewpoint applies directly to the scenario of acoustic percussion instruments being processed with gesture control electronics. From studies such as Boughton and Stevens' about the relationship of movement and gesture to communicating music expression to an audience, we know that there is an important connection between visible gesture and perception of how a performance sounds to an audience.[34] Boughton and Stevens looked specifically at this relationship as demonstrated on the marimba, citing its "relatively restricted" expressive capabilities. If we are to accept this description of the marimba, we can also say that the expressive capabilities of the non-pitched percussion instruments used in *Percussivometers* are equally limited, and as such the visible gesture is highly important to these instruments as well. However, now the performer is dealing with electronically processed instruments, which adds greater expressive capabilities and control to the instruments. It is important to note that this enhanced expressiveness comes in a way

[33] Schloss, *Using Contemporary Technology in Live Performance*, 239.
[34] Boughton and Stevens, *Music, movement and marimba*, 150.

that is very unfamiliar to an audience. Compared to an acoustic instrument the electronic sounds the audience hears are highly abstracted from the motion the audience sees. When a performer hits a drum there is a visible action that is easily connected to the sound that is heard. Conversely, when a performer rotates a hand ninety degrees to, for example, change the frequency of synthesis this isn't a relationship that the audience is familiar with, and as a result the change in sound may not be connected to the motion. Further abstracting the motion from the sound is the fact that the sound does not originate from the point of the motion. When the drum is struck the stick is seen impacting the head of the drum and the sound disseminates from this point. However, in the example of the rotating hand the sound likely does not come from the location of the hand. The sound will propagate from wherever the loudspeakers are located, which could be across a stage or an entire performance hall. Ultimately, this means that while the gestural control of the electronics in *Percussivometers* gives the performer greater expressive possibilities, this expressiveness does not necessarily translate to audience perception readily. The performer is left to find ways to make clear to the audience how the sounds are being created and manipulated by the performer.

Exaggerated Performance Gestures

In the piece *Percussivometers,* as mentioned previously, there are moments when the motion that the performer should make are indicated by the score, and there are other moments when the motions are left entirely to the performer. The latter happens in cases of exaggerated gestures and artificial gestures. It is the exaggerated gesture that we shall first consider.

When the performer has to decide how to perform an exaggerated gesture with no indication of how it is to be performed what are the considerations that should be weighed in determining how to execute the passage? The most obvious starting point in answering this question is the accurate performance of the notes written for the acoustic instruments. Whatever gestures are to be used, they must happen within the physical context of playing the written part, otherwise the performer has sacrificed the acoustic for the sake of the electronics. The next consideration may be how does the performer want the gesture to appear to the audience.

A section of the piece that requires this type of consideration is that beginning at measure eighty. (Figure 3.6) At this point both hands are playing more spatial notes on the majority of the instruments in the setup. Also, the accelerometers on both hands of the performer are being used to control the electronics. The arrangement of the instruments with some of them being horizontal playing surfaces, such as the drums and the metal blocks, and others being vertical playing surfaces, in the case of the hanging pipes, bell, and gong, necessitates motions that would be adequate to cause changes in the electronic sounds. This means that a performer could choose to simply play the notated part and let the electronics happen as they may. This would result in an inadequate performance however. The sounds from the electronics would not be the result of artistic choice, and as such would be arbitrary. Additionally, in this situation the abstraction of the sound from the motion would be rather extreme. The audience would see only conventional movements that were being used to play acoustic instruments, and making the connection that the performer was controlling the electronic sounds would be difficult.

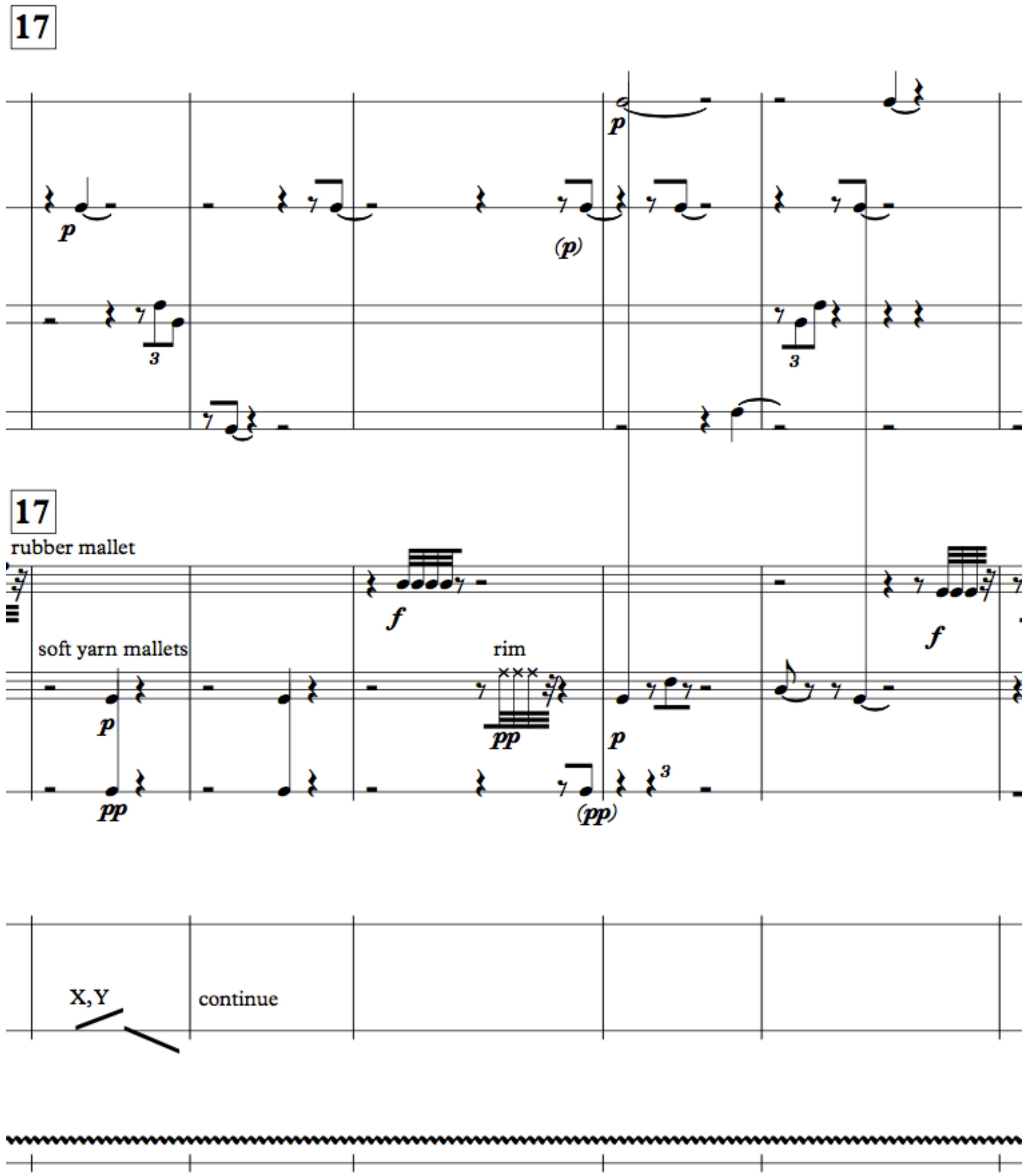

Figure 3.6 *Percussivometers* Score Excerpt – Measure seventy-nine through eighty-three of *Percussivometers*.

Going a step beyond this a performer can choose to add extra movements to control the electronics. As discussed previously the accelerometers respond to rotation of the hand in multiple directions. The same rotations are used to perform the strokes to play the acoustic instruments. This means that in the example being discussed, the performer is using the previously defined exaggerated gestures. The point that needs to be considered by the performer is to what extent the gestures will be exaggerated. The performer could simply increase the stroke height, thus increasing the degree to which the hand rotates in the execution of the stroke. The result of this being that the audience has the visual cue of the seeing the mallet move a greater distance. This provides some additional understanding to the audience that the electronics are being manipulated by the performer. The gesture can be exaggerated further. Instead of simply rotating the hand further, the arm can be employed to lift the hand from the elbow. This degree of motion is not necessary for the execution of the acoustic part nor will it necessarily have an effect on the control of the electronic part. It will however make it much more visually clear to the audience that the sounds they are hearing from the speakers are related directly to the movement that the performer is making. Clarifying this relationship and providing the audience with a visual cue to the intentions of the music will likely make the performance more enjoyable for the audience.

Artificial Gesture Performance Considerations

In sections of the piece utilizing artificial gestures the performer has a great deal of choice in how the gestures will be executed. It may seem that the possible gestures are somewhat limited given that the accelerometers are detecting movements of the performer's hands on only three axes, however the way the movements are executed and where the motion originates from can vary substantially.

A portion of the piece that serves well to clarify this point is that beginning at measure fifty. As mentioned previously in this portion of the piece the accelerometers are being used to control the playback of the sampled music played previously by the performer. At this point there are no acoustic instruments being played. The hands are only being used to control the electronics. The motions that are being used to control the playback are rotation around the x-axis and the y-axis of the accelerometer. Similar to the case of the exaggerated gesture the necessary motions to control electronics could be made in a minimalist fashion, using as little motion as possible. This would take the form of rotating the hand and bending at the wrist, and would result in a very uninspired performance from the audience perspective. For the reasons already discussed the audience may not connect the motion of the hands to the sounds they hear, and depending on how far away from the performer they are located, they may not see the motions at all. In the author's performance of the piece the solution to this problem was to use motions originating not from the wrists, but rather from the elbow or the shoulders. This provided the same movements from the perspective of the accelerometers, but resulted in a much more visible action for the audience. What could be a small bend of the wrist resulting in angling the hand upwards by forty degrees became a large motion resulting in the entire arm being moved in a much more dramatic manner.

Another outcome of using these larger gestures is that the resulting motions of the hands and arms resembled slowed down versions of the strokes used to play the acoustic instruments. By recognizing this, the performer is able to make a gestural connection between the electronic and acoustic elements of the piece. This is a subtle nuance, however these types of nuances are what can make a performance outstanding. Finally, the performer can add to the effect of the gestures by incorporating motion of other parts of the body, including bending of the knees and leaning of the torso to add to the visual effect of the gestures.

What can be concluded by this examination of the performance considerations pertaining to the gestures controlling the electronics is that these gestures are not secondary to the performance on the acoustic instruments. The gestures require an equal amount of preparation, in both the planning and practice of their execution, to the practice given to the acoustic parts of the piece. Roland Auzet came to a similar conclusion when writing about his percussion work that also incorporates gesture control electronics:

> A novel instrument demands a period of research and apprenticeship to develop ways of playing it. Because of the concatenation of instruments, triggering and gesture-following, the percussionist's body is moved in a radically different way. So the percussionist must master the musical and corporal space, in light of the fact that the performer's movements are informed by numerous functions, in multiple directions.[35]

In Auzet's piece *Le Cirque du Tambour* the method of gesture tracking employed involves a triangulation system using ultrasonic sensors,[36] a

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[35] Auzet, *Gesture-following Devices for Percussionists*, 395.
[36] Ibid. 393

very different technology from the accelerometers employed in *Percussivometers*. The end result is very similar however, processes being applied to acoustic percussion instruments are being controlled by the gestures of the player. In both implementations it is imperative that the performer invest the time to master the “playing” of the sensors and well as the percussion instruments.

Logistical Considerations for Practice and Performance

Performing a piece for percussion and electronics of any sort requires that some logistical difficulties be overcome. In the case of performing a piece for percussion and fixed media one must have equipment to play back the accompaniment, for both performances and when rehearsing. This can be a challenge due to cost, setup, and space, among other reasons. When the piece involves live electronics the difficulties can quickly become compounded. In the case of *Percussivometers* in order to practice the piece, not only must the percussion instruments be set up, but the four microphones, laptop, audio interface, sensors, and monitoring system must all be set up as well. This also means the requisite cables, stands, and power cords must be prepared. The amount of time required to be ready to begin a practice session can be substantial.

In order to overcome this careful planning of practice sessions was essential. To maximize efficiency specific sections would be isolated and only the required instruments and electronics would set up. There were also many practice sessions where the gestures would be refined without the use of the electronics. This was possible by first becoming well acquainted with the way the processing responded to the gestures.

After the sounds and control were well understood, the acoustic portions of the piece could be played while only imagining the sound of the electronics, rather than actually setting up all of the electronic equipment.

When a performance was impending it was essential to practice with the full setup and with the electronics. The same monitor system that would be used for performance was also used for these final practice sessions to ensure that it would function properly and to become accustomed to the way the electronics sounded in a particular monitor. Also, in the case of the wireless monitor the performer needs to know where the wireless pack can be worn and not interfere with the movements of the performance.

In the same vein, a performer needs to become accustomed to wearing the sensors, wires, and transmitter. To keep the wires from becoming cumbersome the piece was always performed with long sleeves. This served to keep the wires from becoming entangled on mallets or equipment. If the wires were to get caught it could result in a broken connection necessitating time-consuming repairs.

Conclusions

Percussionists have long used gestures as a method of expression in performance. As mentioned above, these gestures frequently offer expressivity through the visual perception of the audience. The expressive gestures used by the performer often do not directly affect the sound produced by the instrument, but they can affect the way the audience receives the music. For example, the visual appearance of a stroke can convey a legato or staccato sound, but the actual sound produced by the two strokes will be nearly identical. Gesture control electronics give the percussionist the ability to truly manipulate the sound being produced. These electronics can make real the implied nuances of percussive gestures.

The ways in which electronics can expand a percussionist's performance possibilities are numerous. Potential implementations include expanded sound possibilities that could not be produced with acoustic means, the ability for a single performer to produce the sounds of an entire ensemble, and creating spatialized sound fields that an acoustic performer is incapable of. Gesture control gives a percussionist a way of implementing all of these possibilities in a way that can be manipulated in real-time. The performer can achieve precise and intuitive control of these electronic applications using gestures that are already inherent in percussion technique or are natural extensions of percussion technique.

The use of gesture control electronics with acoustic instruments necessitates the consideration of the role of a performer as a composer, or at least an improviser. When a composition calls for a particular note to be played at a specific time in acoustic music, the composer had in mind a definite, expected result of the instruction. That result is the sounding of the indicated note. There is often room for the performer's interpretation to be imposed upon that note. This can manifest in the dynamic, articulation, mallet choice, or playing spot on an instrument. These choices are in some instances indicated by the composer, but in other instances they are left to the performer's discretion. This same line of reasoning applies to performance with gesture control electronics; however, the variation in the result of an instruction can be much greater. This is due partially to the fact that this type of performance is still very new. A standard practice has not been established for the notation or execution of this type of music. Additionally, the expected result of a gesture is likely not as straightforward as striking a particular note. This results in a greater responsibility for the performer to make musical choices, and for the composer to provide detailed instruction to the performer or be open to variance in multiple performances.

It is clear that there are a large number of considerations, complications, and inconveniences that must be overcome when performing with gesture control live electronics. There must be, then, some justification for the extra work involved in this type of performance. This comes in the form of the artistic control that a performer has when performing this type of music. When performing with fixed media electronics, the performer is bound to the unwavering electronic portion of the piece. Musical choices can be limited for a performer in a number of ways. For example there is no ability to play with timing in the piece. A performer cannot choose to take more time with a certain phrase should the performance space necessitate it. Even in some cases of live electronics, performers do not have the ability to alter the processing or synthesis, again taking away some artistic abilities from the performer. Gesture control is a solution to this problem. By enabling the performer to "play" the electronics in a similar way to the acoustic instruments, the expressive capabilities are greatly enhanced. This allows the performer to once again have control over the entire performance. The electronics become another musical instrument that when given proper consideration and preparation can be just as expressive as acoustic instrument.

Appendix A – Works for Percussion and Interactive Electronics

This is a list of works that involve acoustic instruments and live interactive electronics. Works that utilize live electronics that are not interactive in some way were not included. The list is short due to the very limited number of pieces that have been written for this combination. In a database being compiled by members of the Percussive Arts Society Music Technology Committee that contains approximately 500 pieces for percussion and electronics only three met the criteria to be included in this list. This scarcity of works aids in justifying the relevance of this document.

Of Mice and Men (1989) by Bruce Mahin, Pioneer Percussion - Vibraphone and interactive computer.

Le Cirque du Tambour (1999) by Roland Auzet, Unpublished – Percussion, live electronics, video, and acrobats.
    Video link: http://www.dailymotion.com/video/x26zqxr_le-cirque-du-tambour-2002-opus-2_creation

Dark Forest (2001) by Tim Place, Unpublished – Marimba and interactive computer.

A Gravidade Liberta (2003) by Ricardo Climent, Unpublished – Marimba with interactive electronics.
    Composer website: http://electro-acoustic.com

Improvisation for Hyper-kalimba (2008) by Fernando Rocha, Unpublished - Hyper-kalimba
Composer website: http://www.fernandorocha.info/en/

Dry (2013) by Ivan Andres Yague. Unpublished. – Percussion with live electronics.
Video link: https://www.youtube.com/watch?v=m9kFjxvCHik

Percussivometers (2014) by Marcin Pączkowski, Unpublished – Percussion with live electronics.
Video link: https://www.youtube.com/watch?v=SbNsNCnAofc

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