The Third Room: A 3D Virtual Music Paradigm

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ABSTRACT
This paper describes a new paradigm for music creation using 3D audio and visual techniques. It describes the *Third Room*, which uses a Kinect to place users in a virtual environment to interact with new instruments for musical expression. Users can also interact with smart objects, including the Ember (modified mbira digital interface) and the Fluid (a wireless six degrees of freedom and touch controller). This project also includes new techniques for 3D audio connected to a 3D virtual space using multi-channel speakers and distributed robotic instruments.

Keywords
Kinect Camera, Third Space, Interface, Virtual Reality, Natural Interaction, Robotics, Arduino

1. INTRODUCTION
In the past ten years we have seen advancements in computer technology and interfacing in both music and digital media. In music, "*the Grid*" has had a huge impact on live performance and composition of electronic and computer based music. However, *the Grid*, by design, is rigid, and not well suited for melodic and improvised expression in performance, instead relying on loops and often pre-recorded material. In digital media, we have seen the advent of depth camera technology and how it has changed the way users interact with games, media, and art. With the release of Microsoft's Kinect[1] camera, and the subsequent hacking of the device for use with the computer, there was an immediate explosion of musical and non-musical projects exploiting the ability to ditch the tangible controller and let the users put themselves physically into the interaction. A lot of work has been done to use this kind of technology to connect musical generation with a dancer's movements[2][7][4], the dancer being an ideal candidate because of their high level of body awareness, physical ability, and movement vocabulary. Many other experiments have integrated this interaction into performance, however the performance tends to be more focused on spectacle, which manifests itself either as highly stylized body movements[2] or in over-the-top virtual interfaces[3]. However, very little experimentation has been done to use this interaction to create new environments for musical composition and performance. The potential of an interactive hybrid space where the physical and virtual collide in an immersive reality of sonic possibility and creativity has yet to be realized.

Inside a virtual composition and performance space one is free to create all manner of "impossible" instruments and interactions that could not be achieved in the physical world. However, it should not be our aim to replace tangibility. It is important to note, that the novelty of virtual interaction can undermine itself when it is relied upon too heavily, forcing users to completely abandon touch, one of the most important senses. The potential for combining these interactions is great, and there is a lot of work to be done in exploring new creative frameworks and approaches to the arts. The cumulative effect of integrating virtual and physical interactions reinforces the unique qualities of a new creative space.

This project was influenced by the many Kinect projects that used the interface to create virtual interaction with sound and music. Projects like AHNE, the Audio-Haptic Navigation Experiment, which is an audio-haptic user interface that allows the user to locate and manipulate sound objects in 3D space with the help of audio-haptic feedback. Developed by Matti Niinimäki[4], this project strives to address the problem of how to guide a user in a 3D space, providing both audio and haptic feedback, in the form of a glove, to inform the user of their proximity to the invisible sound objects. While addressing this issue in a unique and intuitive manner the actual sound created by the interaction seemed more of an afterthought to the novelty of the technology.

Other musical projects involving the Kinect camera use it as an extension of performance practice and expression, such as Qi Yang's augmented piano performance system[13]. Yang uses gestures and a small projected area above a keyboard to create new extended techniques for manipulating the sounds of the piano, allowing the performer to affect multiple controls in a way previously impossible with traditional synthesizer controls. This approach integrates the new technology into an instrument with a long-standing practice of techniques and performance. The success of a system like this on the future of performance is limited to the number of practitioners who adopt it as a new extended technique. However, if new instruments are created specifically for this new technology, a whole new field of music composition and performance can be realized. One that can be as rooted in, or removed from, traditional musical practices as the user/composer/performer wishes it to be. This new practice will exist in a true third space, as it bridges the gap between physical and virtual interaction, but it will do so by utilizing real spatial data to link the two spaces, transforming it into the *Third Room*.

This project aims to forge a new approach to musical composition and performance by developing a system that incorporates 3D spatial data, a virtual environment populated by virtual objects, a physical environment populated with

[1] http://www.xbox.com/en-US/Kinect
[2] http://ethnotekh.com/project/ethno-tekh-v2/
[3] http://www.v.co.nz/#the-motion-project

[4]http://sopi.media.taik.fi/2011/09/01/ahne-—-audio-haptic-navigation-environment/

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physical objects, and sound design with robotic instruments, linking both spaces, that is expressive and has the potential for a wide range of complexity. Together these elements create the *Third Room*, which is what we will call this new hybrid space for music composition and performance. In this paper we intend to show the potential of the *Third Room* interactive musical environment as the basis for future development of new musical systems and as a new approach to composition and performance. In section two we will discuss the system we developed as an initial approach to the creation of the *Third Room*. In section three, we discuss immersive audio environments, dealing with spatial data and sound, and methods for extending the connection between the physical and the virtual by use of robotic instrumentation. Section four covers the design and implementation of a new kind of musical interface, the Ember, and its use in the *Third Room*. Section five introduces a new kind of abstract interface that has no musical predecessor, a kind of hand sculpture for inquisitive exploration of musical and environmental control through tangibility. In conclusion we will discuss the future of the *Third Room* and the potential for extension across new technologies such as virtual and augmented reality.

2. SYSTEM OVERVIEW

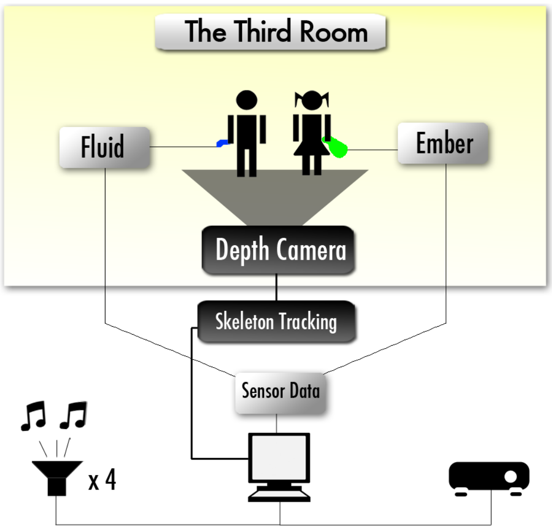

Figure 1: Inputs – Fluid, Ember, Kinect. Outputs - Quadrophonic sound, projected *Third Room*

When a user enters the physical room their body is detected by the Kinect's depth camera. Their skeleton data is used to track their movement through the physical environment, displaying their position in the projected virtual environment and enabling virtual modes of interaction. In the first iteration, the virtual room was populated by different kinds of objects that the user can interact with, using their own body as the interface. However, it was found that users had a difficult time finding these objects, so in the latest version the users control object creation and destruction through various gestures. The virtual objects interact differently with the user and the environment, depending on their type, and each has their own sonic characteristics or affects the sound of other objects. The virtual ball is an object that a user creates by waving, it can be thrown and caught, and holds a note value that is triggered when it hits the walls of the room. The "blob" is an object created when two or more users group together in close proximity, a bass note is triggered as an amorphous shape envelops their avatars; the parameters of the tone are randomly assigned to the different joints making up the shape, and the note will change as people enter and exit the group. The "box" makes up the virtual environment itself and has various interaction possibilities. The boxes can be turned on and off like buttons, transforming the entire virtual room into a step sequencer allowing for a different level of compositional control. Looking ahead, the system is setup for the inclusion of newly designed instruments and objects that may be added in various incarnations of the project.

Also present are a pair of real objects that play an active role in the *Third Room*. The Fluid, an abstract remote, designed as a hand sculpture, invites the user to explore different ways of holding it. As they explore the physical nature of the object they simultaneously are manipulating the sound and the projected environment, learning to control it through the process of discovering its abilities. Also present is an electronic kalimba-style interface, called the Ember, which offers the possibility of melodic creation within the immersive experience. When a user plays the Ember a new object is created that corresponds to the played note. This new object can then be manipulated inside the virtual room by any of the users. The other sensor data from the Fluid and the Ember is collected and used to make macro level changes to the soundscape as well as the virtual environment. By combining the physical and virtual interactions we increase the depth of possibility for the subtleties of musical creation within the space. This combination of all the sensors working together allows the users to interact in both virtual and physical ways, bridging the two spaces, helping to create the *Third Room*.

3. IMMERSIVE AUDIO ENVIRONMENT

3.1 Using Kinect as Sensor Input

The Kinect camera allows us to transform our bodies into what is essentially a large digital sensor. In itself it is simply a combination of cameras but when used with "Natural Interaction" libraries such as OpenNI and NITE[5] it becomes a very powerful tool for interaction. The main function of these types of libraries is to recognize a body in space and capture different types of data including hand recognition, gesture recognition, and skeleton tracking. Skeleton tracking is the process of recognizing a body and then inferring the location of each major joint and limb of a person's body in three-dimensional space[6]. Skeleton tracking is the main technology used in conjunction with the Kinect camera as a video game controller as well as the driving force behind this project.

The skeleton tracking for this project was achieved in Processing[6] using the SimpleOpenNI library developed by Max Rheiner[5], which allows easy access to the main functionalities of the OpenNI and NITE libraries. Once setup, tracking becomes very easy, and does not require a calibration pose, which means a user can simply walk into the space and the program automatically starts tracking their skeleton data. The skeleton data is sent via Open Sound Control[12] (OSC) to the virtual room's program where the user is displayed as a digital avatar. Multiple users can be tracked at once, but the program sometimes gets confused if a user passes between the camera and another user. However, the program is robust and can easily drop and add users as they enter and exit the space.

3.2 Placing User in 3D Environment

The virtual room is a 3D computer generated space that was created using the Cinder[7] C++ library and OpenGL[8] as seen in figure 2 below. Where the room was once prepopulated with

[5] http://www.openni.org
[6] http://processing.org
[7] http://libcinder.org
[8] http://www.opengl.org

virtual objects, now it is at the user's discretion to create and destroy these objects. As soon as the user is detected their "body" appears inside the virtual room represented by an avatar, through which they can interact with the objects. One of the objects is a virtual ball that the user can pick up and throw across the room, where it bounces without friction or gravity, creating a variable rhythmic and melodic loop. Another kind of object, the blob, is a special object that requires multiple users to create. When two, or more, users come within a certain vicinity of each other their avatars become enveloped in an OpenGL mesh that triggers a different kind of sound. While inside the blob the users have a new found controllability of this sound until they move apart. If new users join the blob the note changes and the parametric control is dispersed among them. All the virtual interaction is based on a combination of proximity, 3D hit testing, and very simple gestures, eliminating the need for advanced gesture recognition or a glove interface. Instead, to grab an object the user just finds it in the virtual room and "touches" it. To create a ball object the user simply waves at their avatar. To clear the room of objects the user reaches across their chest with their right hand and pulls it back across in a quick swipe motion. Simple gestures like these were designed in lieu of using advanced gesture recognition to facilitate a wider range of interactions.

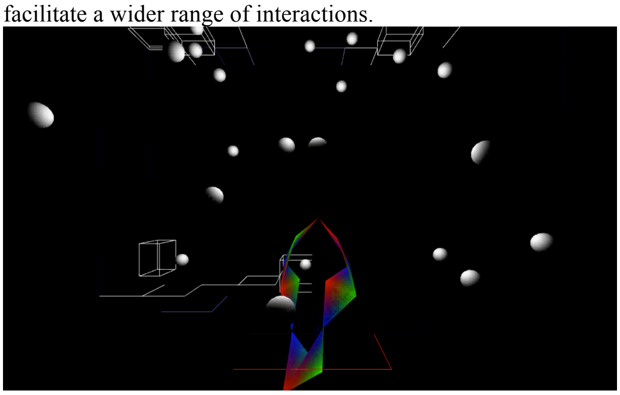

Figure 2: Virtual Room with user

A varying amount of scaling is required to position the user's avatar in the virtual room, which needs to reflect the size of the corresponding physical space. The main issues arise from the coordinates that come from the Kinect as they need to be scaled down quite a bit. This is handled in processing by simply mapping the output of the Kinect to the dimensions of the virtual room. In the virtual room application a built-in GUI gives top-level access to the room size so that the installation can be customized to fit spaces of different dimensions easily and during setup.

One of the most difficult aspects, other than the limitations of the Kinect camera itself, was developing a system of visual cues to help the user identify their location in relation to the other objects in the room. This was the major flaw in the first iteration of this project, where the objects lived within the room and were statically created and could not be destroyed. After seeing many people struggle to find the objects a new approach was developed. Hence, we introduced the means to dynamically create and destroy objects. This simple gesture interaction gives people the opportunity to interact with the *Third Room* while removing the struggle to orient them within it. Lighting within the virtual room can be used to help create visual cues, where objects glow brighter when the user is within certain proximity. However, lighting in OpenGL has proved to be difficult to master, we hope to improve the use of lighting as both an aid to interaction as well as a means of stylized presentation.

3.3 Surround Sound

The sonic aspect is, of course, a very important part of the work as well, and many considerations have to be made about what sounds are used and how every part contributes to the whole. With each constraint placed upon the sound design of the room and its objects, the more the resulting soundscape becomes a composition of the creator. With that in mind, further consideration had to be made so that the users have the freedom to contribute creatively to their own experience whether it be solitary or as a group. A compromise must be made between the intentions of the composer/creator and the will of the users. Presenting too much freedom can make it too hard for the users to create something they can enjoy, while conversely, too much limitation voids the compositional possibilities of the users, who, by interacting with the *Third Room*, become both performers and composers.

Continuing the exploration of space, the piece utilizes four speakers, in quad sound configuration, to help create a surround sound experience. Each sound follows the object as it moves through the room, further integrating the two spaces. Depending on the virtual object, the visual interaction and sound is different, resulting sometimes in a one-to-one style interaction, while others are less straightforward. The more objects that are put into motion or interacted with, the more complex the soundscape becomes. The level of interaction is compounded when the physical objects are used as well.

The sound design and synthesis was created in Native Instrument's Reaktor[9] using a custom built set of instruments. Simple sine tones are used as the primary melodic content to allow for a greater dynamic range. However, greater melodic, timbral, and rhythmic complexity is achievable. Each ball object has a corresponding note value attached to it, and when the ball is thrown around the room it creates a deconstructed melody. As it collides with the "walls" it triggers the corresponding note. Depending on the decay time, which can be manipulated through the system, if the ball triggers the note before the previous note has decayed, it instead triggers the next note in a harmonic series. There are several different sets of harmonic series' that can be activated, each providing a different palette to work with. These harmonic series' are based off simple mathematical equations ranging from a natural harmonic series and others that are related to the serialized electronic experiments of Karlheinz Stockholm, specifically his *Elektronische Studie II*[14].

Using the smart objects, the users can take more advanced control of the overall sound characteristics. The Ember allows for specific note creation as well as parametric manipulation, including setting the decay time of the note objects and choosing the harmonic series being used. The Fluid can be used both to create sound and manipulate the environment, depending on how it is held and moved.

3.4 Robotics & Machine Lab Experiment

Recently, this project was setup in the main classroom of the Music Technology program at the California Institute of the Arts. Commonly known as the Machine Lab, it is home to the collection of robotic instruments that make up "The Machine Orchestra"[10]. These instruments hang around the perimeter of the room and provide an interesting spatial experience when played. Most recently, an array of solenoids was installed into the grid of the ceiling, so, when this project was set up as an installation it was modified to send messages to the robots as well. The virtual balls, as they bounced around the virtual

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[9]http://www.native-instruments.com/#/en/products/producer/reaktor-5/

room, triggered the robots as if they were bouncing off the robots themselves. When they bounce off the walls inside the program they trigger the nearest corresponding robot, and in the case of the ceiling solenoids, they trigger the nearest single solenoid. The result is an immersive experience that further merges the physical and virtual rooms, creating a unique space where the virtual is able to reach back into the physical world and touch it. This experience was so interesting and pleasing that it lead to the development of a new kind of robotic instrument, designed to be hung from the ceiling and integrated into the physical environment. This kind of interaction further joins the physical and virtual environments, allowing users to reach in and touch the virtual, and have the virtual reach out and touch the physical.

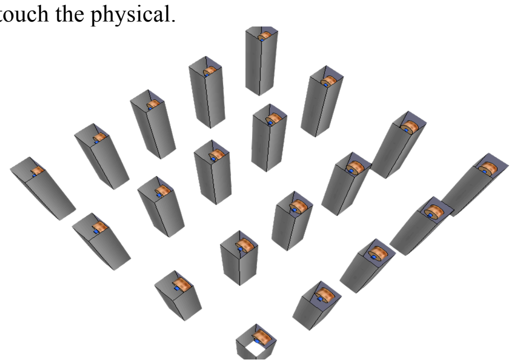

Figure 3 - Modulet Grid: custom built solenoid driven Robotic 3D sound scape

Inspired by the success of this project, we have designed a new set of robotic instruments known as the *modulets* that are 20 modular solenoid units that are arranged in a 4 by 5 grid as shown in Figure 3. These solenoids are encased in a 1-inch square tubing with a blue LED that lights up when triggered. The *modulets* are portable and now travel with the *Third Room* to bring the robotic 3D audio experience to other venues beyond the CalArts Machine Lab.

4. EMBER: DIGITAL MBIRA INTERFACE

The "Ember" is a handheld digital interface modeled on the mbira, a traditional African lamellophone[3], pictured on the left side of figure 4. The driving force behind the Ember's design was a desire to create a new kind of digital instrument that could be played expressively and not just another knob filled or grid based MIDI controller. Furthermore, the Ember is not just a digitized traditional instrument. The functionality and form of the traditional instrument were used as the point of departure to create a new kind of handheld digital instrument.

4.1 Physical Design

The impetus behind the physical design was to create a handheld instrument that allowed for both melodic and continuous control. Being modeled on the mbira, the mechanics of the Ember are directly related to that of a lamellophone, in that the sound is generated from the vibrations of long tongue-like plates that are fixed at one end. A lot of consideration was put into the physical design of the Ember and it has gone through several revisions.

Originally it looked very similar to an mbira, other than the fact that it was made of cardboard and had all manner of sensors and wires sticking off of it, as seen on the right half of figure 4. However, it became very apparent that the design of the original prototype was cumbersome to hold and to play. A combination of too many sensors and the shape contributed to awkward playing and an inability to hold it steady with one hand. So, a radical redesign was necessary if musical proficiency was to be achieved.

First, a method of holding it securely with one hand was needed. The mbira is designed with a hole that the player places their pinky through to support the instrument. So playing on this idea a new body shape was designed that included a hand hole, so that the user's left hand can fit through it, allowing them to easily and comfortably hold the instrument with one hand. Although this restricts the use of the left hand, it adds a level of stability while playing and frees up the right hand to do other tasks, on or off the instrument. The shape of the body and placement of the handhold were designed to position the two hands at a comfortable angle. This angle allows for ease of play and also promotes prolonged playability by keeping the wrists straight and avoiding awkward or unhealthy wrist positions.

Second, the amount of sensors needed to be trimmed down to accommodate the new body shape. In the end, nine piezo powered tines, two membrane potentiometers, and a joystick. The sensors are distributed between the two hand positions; the tines and the membrane pots for the right hand and the joystick for the left. In this setup the left hand becomes responsible for switching functionality, scrolling through lists, or adding expression through the joystick, while the right hand is primarily responsible for melody and continuous control through the tines and the membrane pots.

Figure 4: A traditional mbira (left) and the first prototype of the Ember circa 2012

When the shape was set we modeled it using high-density foam to finalize the body size, ergonomic features, and layout. The bridge for the tines was laser cut with rasterized insets to help hold the tines in place and help isolate the vibration of the individual tines. The tines themselves were laser cut out of 1/16" acrylic and don't actually vibrate like a real mbira. From the first design experiment it was concluded that a stiffer tine allowed for greater control over attack velocity and provided more consistency overall. The final prototype is pictured in figure 5 without the top of the bridge so the piezo films are visible.

4.2 Electronic Design

For this interface a unique method of using piezo films was developed to simulate the tines of the mbira. Sandwiched between the bridge and the laser cut acrylic, the piezos are safe from accidental triggering while picking up direct hits to their connected tine. When the keys are struck, the piezo picks up the vibration and registers it as a Note On message, even detecting different velocities depending on the pressure applied when played. Due to the body shape and hand positions it is not played like a traditional mbira, instead it is played with one hand, and it seems that striking the tines grants greater control than plucking.

The membrane potentiometers were chosen because they can be controlled with a single finger, allowing the user to manipulate them while playing the tines at the same time. In the context of the *Third Room* the membrane potentiometers are used to control the amplitude envelope of melodic and sequenced pitches in real time. The Ember also includes an analog joystick designed as a utility device, giving the user a kind of "mouse" on board the instrument. However, this simple sensor is also quite useful when used to add expression. The joystick features a button as well, which can be used to change functionality of the joystick itself, or used to cycle through the different harmonic series.

Figure 5: Ember prototype circa January 2013

The combination of piezos and membrane potentiometers proved to be quite difficult to work with. Specifically we had to troubleshoot a lot "bleed" across the sensors. We found that the membrane potentiometer would create false readings across the piezos, and sometimes vice versa. We were able to control this contaminating data by a combination of resistors and diodes on the piezos, as well as a bit of Arduino trickery. As we saw the problem to be that the analog to digital buffer was not clearing itself out between analog pin reads, we decided to hook up empty pins to ground and read them in between each sensor. This acted as a sort of flush that rid the circuit of any leftover voltage and solved our data line problems very effectively. At this time a PCB shield is being designed and will hopefully further stabilize the circuit.

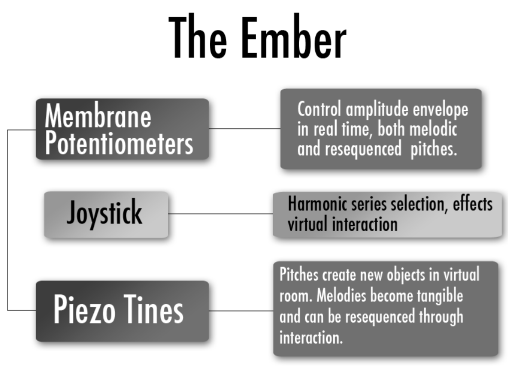

Figure 6: Interaction Diagram of the Ember

4.3 Sonic Design

While the Ember is a fully functional and customizable MIDI instrument, in the context of the *Third Room*, it serves a more specific function. When a user plays the Ember, the notes are sounded and a new, pitched object is added to the virtual room. This object can then be interacted with through the virtual interface. The melodies played on the Ember are deconstructed visually and remixed by interaction inside the virtual space. Essentially, whoever plays the Ember controls the palette of the composition, but does not control the composition itself.

5. THE FLUID: WIRELESS CONTROLLER

The other type of physical object is a handheld, wireless interface of sorts, called the Fluid that the user interacts with simply by holding it. Inside and out, there are a collection of sensors that capture data on how the user is holding it, and how they are handling it. In essence, it is a hand sculpture whose aesthetic quality is understood through touching. At the same time, the Fluid itself senses the user, how they are holding it, which direction their pointing it in, and whether or not they like the feel of the metal parts. This unique sensory experience is not limited to touch, as it is extended into the *Third Room*, effecting visual and aural aspects of the soundscape.

5.1 Physical Design

The most important aspects of the physical designs were as follows: that it be handheld and wireless; that the shape promote curiosity in that the user will explore different methods of holding it; and that the surface has various points where touch sensing could be achieved. With these considerations we designed the Fluid so that the user first explores it in a tactile way, learning through experimentation the sonic and visual reactions to the physical interaction.

The digital design was achieved in Solid Works creating a basic handheld shape and then warping it into something that would be comfortable to hold in more than one way. Since the object itself is abstract, its shape should not put the user at a disadvantage, meaning that it should not intimidate them from interacting with it. By designing a shape that is ergonomic and organic the interaction becomes two-fold: the user interacting with the object itself and the user then interacting with the sound through the object.

When finished, the model had to be prepared to be 3D printed. This meant hollowing out the device, while maintaining the structural integrity, cutting it in half, and designing a method of opening and closing it that was inherent to its design. Two extra pieces were 3D printed and electroplated for capacitive touch sensing.

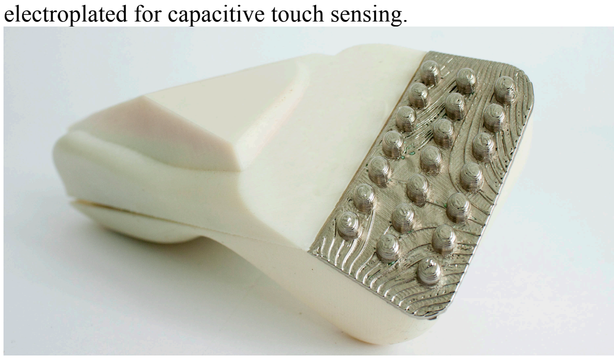

Figure 7: The Fluid Wireless Controller

5.2 Electronic Design

At the core of the object are an Arduino[10] Fio, an Xbee[11] WiFi chip, and a lithium battery. A custom shield PCB was designed and printed for the Fio with all the hook ups needed for an accelerometer, gyroscope, magnetometer, and three touch capacitance sensors. Two touch points, the electroplated pieces, are for absolute touch, while a third hidden sensor detects a user's proximity across a wider range. This way a user can be detected when they first go to reach for the object before they even touch it. The three positioning chips work together to return nine axes of information, which can be used to sense how the object is being held, and how the user is interacting with it. By detecting what the users are doing, specific interactions can be encouraged through audio, visual, or even haptic feedback (with the addition of a small weighted motor).

[10] http://arduino.cc
[11] http://www.digi.com/xbee/

5.3 Sonic Design

The Fluid has a different kind of authority over the audio and visual environment. Depending on how the user holds the object different interactions can occur. Hidden objects and instruments can be revealed through specific gestures. For instance, if held upright and shaken, a shaker style instrument can be accessed. However, touching the electroplated pieces can override this gesture, giving the user access to a different set of instruments, including an arpeggiator. Quick rotational movements across different axes can affect the orientation of the virtual environment or be used for score following. The combination of touch points, movement, and gesture allows for an incredible amount of depth and possibility for such a simple interface. We intend that its use demand curiosity and exploration on the user's part to discover what it is capable of doing.

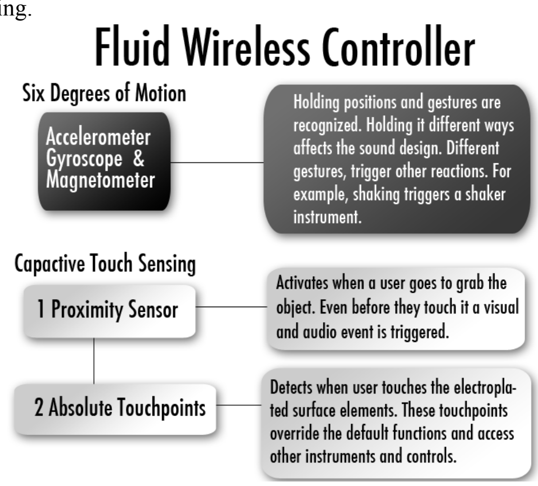

Figure 8: Interaction diagram for Fluid

6. CONCLUSION

This project started as an exploration of virtual musical interaction. But the project begged the question "why stop there?" Virtual natural interaction is both relatively new and novel but it does not seem to be able to overshadow the importance of tangibility. It is commonplace to interact with virtual realities through means of a physical object, just as it is becoming normal to create music with objects that can only manipulate audio signals inside a computer and have no intrinsic sonic abilities. The general consensus seems to force a choice between objects and bodies, but there is no reason they are mutually exclusive modes of interaction. In fact, the combination of the two throws light on new territory of interaction design. By creating more virtual to analog and analog to virtual interactions the space between them gets closer and closer. When the user enters a new space that is both real and unreal, the *Third Room* emerges and takes on the qualities of both. As seen with the experiment in the Machine Lab, the addition of robotics, solenoids, and motors can extend the connection between the real and the virtual, blurring the separation of space even further.

The future of the *Third Room* has not even been imagined yet. Some work has been done in exploring music in virtual spaces but most of it predates the depth camera and skeleton tracking technology of the Kinect[1, 9, 11] and of these the majority seem to focus on physical models of real instruments, instead of imagining whole new instruments. Along with the impending release of the Oculus Rift Virtual Reality headset[12], there will be a whole wave of novelties and gimmicks, video games and entertainment possibilities, but few will realize the potential for new and future musical practices in this long promised immersive technology. Soon we will be able to truly enter the *Third Room* with the combination of Kinect-style body tracking and full view VR headsets. Together these technologies will make it possible to merge these two disparate realities and it is then that the Third Room will take on a whole new meaning. It is in this Third Room that previously unimaginable musical possibilities will take place. Whole new families of instruments will be created, new forms of compositions written, new listening experiences shared, and new styles of performance will all emerge from this singular and infinite room. The studio as a space of musical creation will be reimagined, as the Third Room becomes a simultaneous performance and composition space, where the player controls their own musical world through interactions of their own design.

[12] http://www.oculusvr.com

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