INTERNATIONAL CONFERENCE ON LIVE INTERFACES

Designing Mechatronic Sound Systems Inspired by Sinusoidal Mathematics

Daniel J. Reyes[1], Ajay Kapur[2]

California Institute of the Arts, Valencia, U.S.A.
[1] danielreyes@alum.calarts.edu
[2] ajay@karmetik.com

Abstract. This paper describes three sonic mechatronic systems designed with the influence of sinusoidal properties and the intention to produce a sonic result. The main purpose of this paper is to illustrate the various techniques taken in constructing such systems by analyzing the process of translating natural phenomena recurring in nature into physical emulations with a sonic aspect. The three mechatronic systems described in this paper are categorized into three parts: sculpture, musical interface, and a hybrid of the two. Post-Wave is an interactive robotic interpretation of Redwood Wave, a kinetic sculpture by Reuben Margolin. Sinu serves as a circular sequencer utilizing photocells and LED's to trigger MIDI. Lastly, Cymbalic is a hybrid sculptural interface inspired by the findings of mathematician Leonard Euler.

Keywords: Post-Wave, Sinu, Cymbalic, mechatronic, sculpture, musical interface, sinusoid, kinetic

Introduction

Within the understanding of modern day acoustics, the sine wave remains to be the fundamental root of its study. (Benson 2007) The mathematical function describes a pure repetitive oscillation. This oscillation pattern occurs frequently in nature: light waves, water waves, shock waves, radio waves, X-rays and most importantly sound waves. (Rossing 1990) Although sound waves are extremely different from radio waves or ocean waves, all waves contain certain common properties. The simple fact that these waves occupy the space within you are sitting in, in a variety of formats, explains the reasoning behind adopting the sine wave as the overall aesthetic approach to designing these systems.

The purpose of this paper is to explore aesthetics driven by mathematical relationships. The following section will familiarize the reader with similar works in which sinusoids are used as a source of inspiration. Section 3 presents a mechanical wooden sculpture, Post-Wave, the first in a series of sinusoidal pieces. Sinu, a circular musical interface, is explained in detail in section 4, discussing aesthetic motives along with technical procedures. Section 5 completes the series with the presentation of Cymbalic.

Related Work

There are several kinetic artists and engineers who have used similar mathematical qualities in their work to recreate these naturally occurring phenomenas. Reuben Margolin's work is heavily based on waveforms. Initially, inspired by the crawling qualities of a caterpillar's movement, Margolin utilized mechanized actuators to simulate complex motions visible in nature. (Pop Tech 2014)

The Round Wave consists of nine concentric circles, each tied to a pulley system with a precise offset (figure 1). The result is a physical emulation of an expanding system of ripples formed by the dropping a small object into a pool of still water. Waves by Daniel Palacios is another example of a piece of related artwork. Waves is a sound installation consisting of a long piece of rope and two turbines (figure 2). The long piece of rope takes the shape of a complex wave form as the turbines rotate. The result is a three dimensional series of waves floating in space. The physical action of the rope cutting through the air creates the whistling sound heard by the observers. Not only does the sound sculpture visualize a harmonic series, but it also reacts and changes shape based on the presence of people around it (Palacios

2007). Another example with a more tangible aspect is a rotary sequencer inspired by the monomer (figure 3). The custom-made rotary sequencer stores a melody on a 10” acrylic disk embedded with small magnets arranged on a circular grid. Concentric circles are centered around a spindle and rotate over a line of magnetic sensors. The device is an attempt to replicate while improving the function of a traditional mechanical music box (Monomatic 2010).

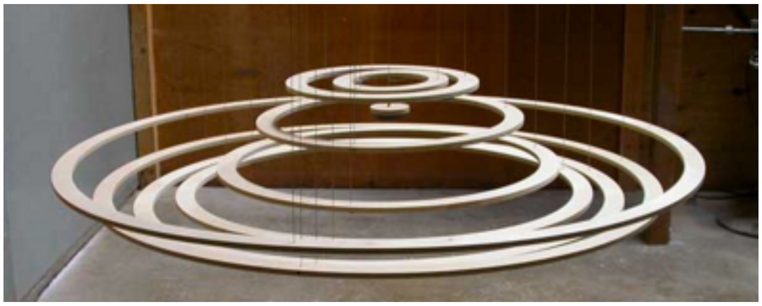

Figure 1. The Round Wave by Reuben Margolin

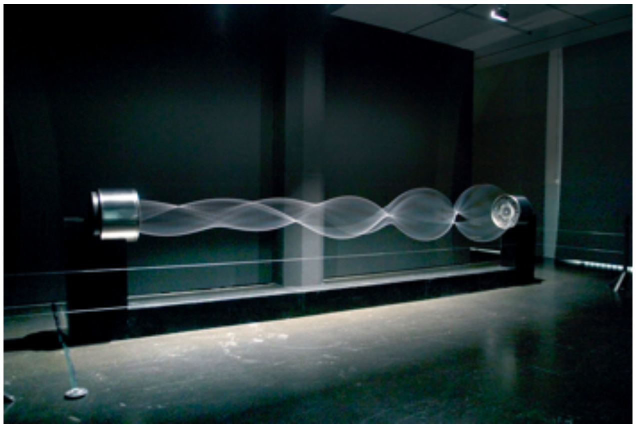

Figure 2. Waves by Daniel Palacios

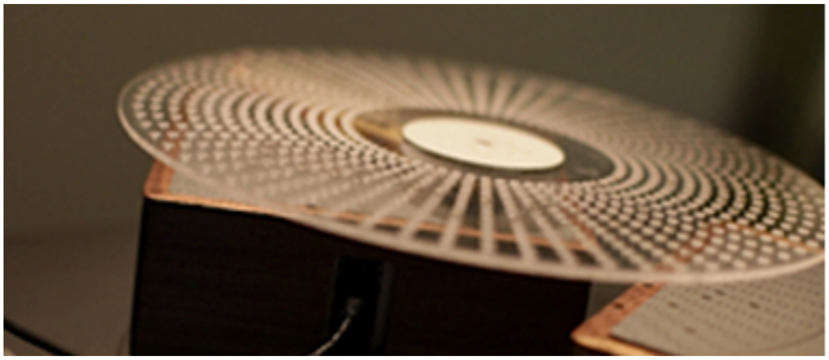

Figure 3. Modular Music Box by Lewis Sykes and Nick Rothwell

Mesmerized by a constant rolling ball entrenched within a metal rim in a hardware store he walked past every day on his way to work, Trimpin, a fifteen year old at the time, questioned how a ball can continuously roll around the rim if perpetual motion is non-existent. After further investigation, he was able to determine the display was pneumatically powered. Small holes blew out a puff of air when the ball passed over it, just enough to continue to momentum to drive it in circles. This fascination stuck with Trimpin, as he would later describe that he “was mesmerized by the sound and sight of this perfectly round ball constantly rolling in Zen-like repetition, and from that moment on I wanted to do something with spheres. I didn’t want to use anything fake- there had to be another way to keep a sphere in motion, probably using gravity.” (Focke 2011) Der Ring’s appearance is based on the display from the hardware store, although it’s functionality is completely different. The sculpture functions like a puppet, its’ angle is tilted around in a circle, causing the balls to orbit due to gravity. Each ring is attached to cable that runs through a set of pulleys and then into a sophisticated gearbox (figure 4).

Figure. 4 Der Ring by Trimpin

These mechatronic systems collectively share sinusoidal and sonic properties. Each utilize repetitive features found in our environment, and transcribe their dynamics into a kinetic representation of their physical behavior.

Post-Wave: Mechatronic Sculpture

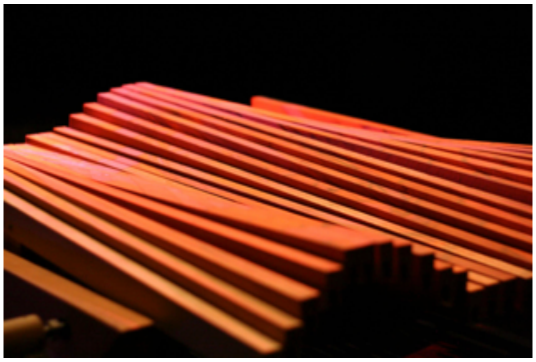

Figure 5. Post-Wave

Post-Wave is the first in a series of sinusoidal-inspired sound projects. Post-Wave is highly based on Reuben Margolin’s Redwood Wave. It served as an introductory study of mechanics and electronic design, in addition to being an assessment of carpentry skills (figure 5).

Design

The mechanical design is composed of two metal rods intersecting a set of 30 6” circles, each offset by one another. Then a set of 1” x 30” strips treated with dado cuts beneath sit on a pair of circles. To prevent the wooden strips from slipping off the circles, a rectangular strip of wood is mounted in the middle of the 1” x 30” dado strips, which is then secured between two wood strips perpendicular to its position.

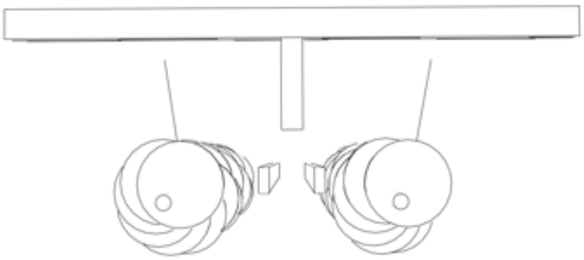

Figure 6. Profile Sketch

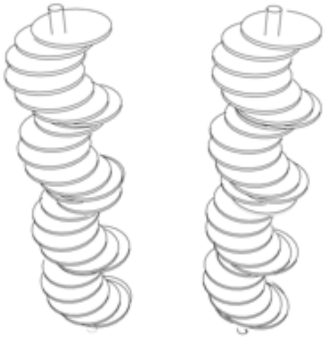

Figure 7. Sketch of Cams

Implementation

The two rods are then coupled to two separate DC gearhead motors. The two motors are powered and controlled with an Arduino Uno using Polulu's Dual VNH5019 Motor Driver Shield. A Microsoft Kinect is used via Processing to detect blob depth and position using the SimpleOpenNI library. Depth and X-position data is sent via serial to Arduino. Thus, depth controls the speed of the motors, and X-position determines which motor is being controlled.

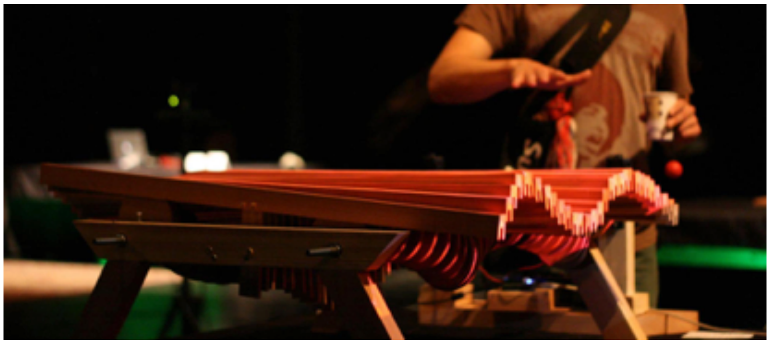

Figure 8. Interaction with Sculpture

The result is a surprisingly well executed mechanical acoustic emulation of the sound produced by waves on a body of water. The physical action of the wood strips sliding back and forth on top of the wood circles makes for a soothing hypnotic audible result. The wave moves slowly when a user is not present, yet as soon as a user place his hand on top of the wave, a reaction is immediately identified, engaging the observer to discover his or her ability to control the sculpture (figure 8).

Sinu: Musical Interface

Sinu is an attempt at producing a rendition of the traditional music box. This particular rotary sequencer uses a set of eight photocells suspended above a set of eight LEDs. A 11” acrylic disk is divided into 16 slices, each containing 8 holes for the LED to shine through as it passes the “playhead” (figure 9). The circular disk is place onto a direct-driven turntable motor mounted on the main enclosure. A set of nine LED push buttons, 3 rotary potentiometers, 1 linear potentiometer, 1 LED power indicator, and two switches are also mounted on the enclosure.

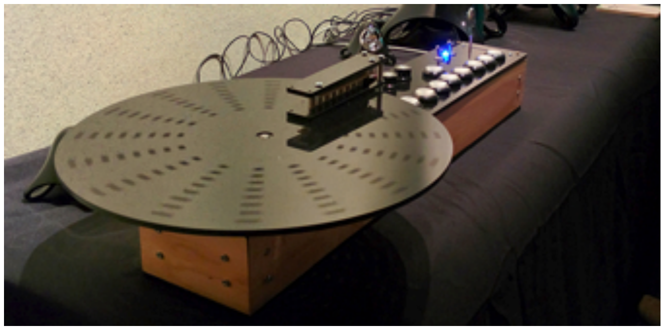

Figure 9. Sinu

Functionality

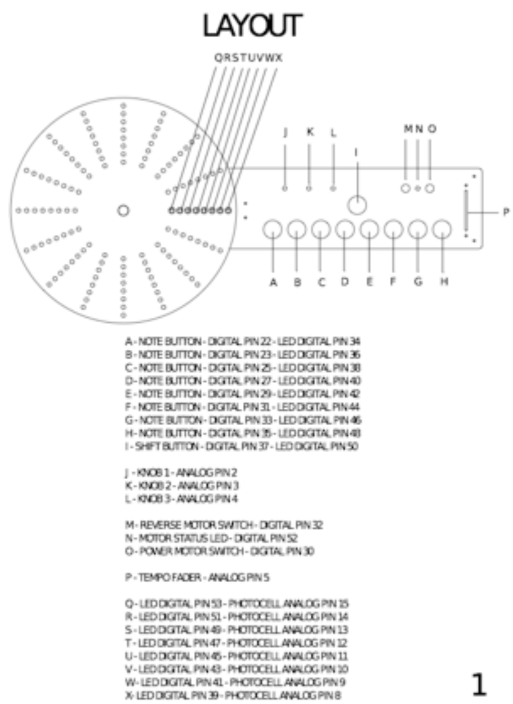

Figure 10. Arduino Pin Assignments

The functionality of the buttons A-H are to act as steps of a conventional sequencer. Button I functions as a shift button that enables the user to switch between sequences. When first powered, a sequence can be entered by pushing buttons A-H. Once this has been done, LED Q will turn on and the position marker of the sequence will flash at position 1 (LED in button A.) A second sequence can be entered by holding down button I and selecting any button B-H. When a sequence is entered on any pattern I+A-H, the corresponding LED Q-X will turn on. Each pattern I+A-H corresponds to a note in the scale specified in the program. Basically, as LED Q-X passes through the playhead containing photocell Q-X, the position marker of the sequencer iterates through the sequence. Switch O turns on the motor, and switch M reverses its direction. Linear pot P controls speed of the motor. Rotary pots J-L can be midi mapped to control any parameter desired.

Implementation

Sinu is controlled using an Arduino Mega with an Arduino Motor Shield Rev3. The design consists of four custom made PCBs: a photocell board, LED board, button board, and a custom Arduino shield to direct all connections to the Arduino pins. Voltage readings from the photocells and buttons are directed to the main Arduino shield with 10 conductor ribbon cable. The LEDs that are located beneath the photocells are controlled through the digital output pins of the Arduino. The button PCB houses all the buttons, its' LEDs, switches and pots found on the face of the enclosure. All of the connections are then routed, via ribbon cables, to the main Arduino shield. An Arduino sketch determines how the sequencer functions. When a trigger is received from a photocell, Arduino sends a midi note number to ChucK. ChucK then sends out a midi note message through an IAC Midi Bus to be received in Ableton to control any MIDI instrument. The final result is a circular sequencer with the ability to perform alternative forms of musical expression.

Cymbalic: Hybrid Interface-Sculpture

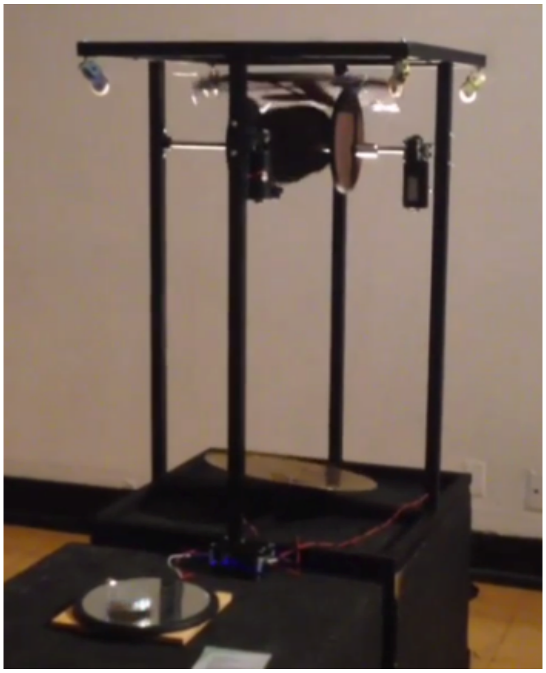

Figure 14. Cymbalic

Cymbalic is the third mechatronic sound sculpture in this series of sinusoid inspired works. The realization for this particular mechanical sound study came from the novelty science toy, Euler's Disk. The disk is used to demonstrate the dynamic system of a spinning disk on a flat surface. The smoothed disk is made up of thick and heavy chrome-plated steel. The mirrored base by which is spins on has a slight concave, keeping the spinning disk centered on the plate. Mathematician Leonard Euler was the first to study this phenomenon in the 18th century. (Moffatt 2000) The sculpture is a naive approach in recreating the motion taken by the Euler's disk.

Design

At the core of its design, four cams are used to manipulate a larger flat 16” disk (figure 15). Two 1/2” metal rods, coupled to DC gearhead motors, each intersect a pair of cams. Each pair consists of two different sizes to make up for the offset in height of the intersecting rods. On the large disk suspended above, four equally spaced tuning pegs each hold a sitar string which then travels through a pulley, down to a cymbal. The sitar strings are fed through equally spaced holes in a cymbal which is mounted to the bottom metal frame, and then tied firmly. The intention is to have the cymbal take the motion of the Euler disk.

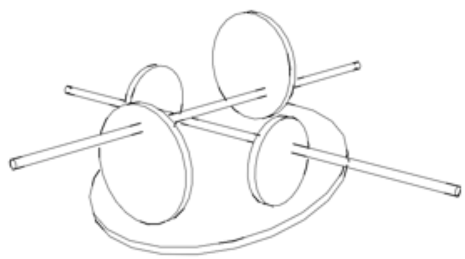

Figure 15. Cam Mechanism Sketch

The distance from the center of the circle at which the rod intersects determines the amplitude of the linear motion converted from by each cam. Each rod intersects the cam 7/8” from the center in order to prevent the larger disk from hitting the outer metal frame.

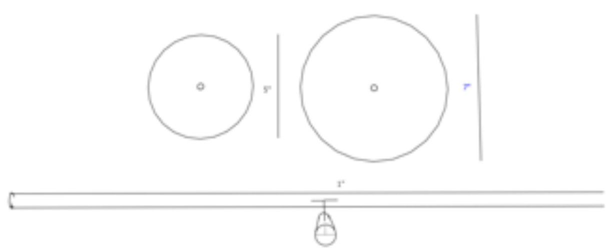

Figure 16. Cam Dimensions
circle2 = circle1 + 2offset
7 = 5 + 2(1)

Implementation

In order to create an element of human interaction, the increasing frequency that the Euler disk produces when spun is programmed to control the speed of the motors. An Arduino Uno paired with a Polulu Dual VNH5019 Motor Driver Shield is used to operate the sculpture. To detect the frequency of the disk, Adafruit’s Electret Microphone Amplifier MAX4466 is placed under the concave mirrored platform. Since the Arduino analog read rate samples at about a quarter of audio rate, an alternative approach was taken in order achieve more reliable results. A threshold on the amplitude is set to initiate the start of the motors. The speed iterates faster as long as the amplitude remains above the threshold. As soon as the amplitude falls under the threshold, the motors come to a sudden stop. The electric microphone proves to be very sensitive, enough to create a sudden movement when the disk is touched. This way, the user immediately experiences the interaction.

Conclusion

This collection of projects were completed at California Institute for the Arts. Each being a cumulation of the skills learned during the successive years. Repetitive motion can clearly be seen as the driving force of inspiration throughout each system. Circles are heavily used throughout each system as a means to convert or translate motion. The series of offset circles in Post-wave modulate the angle at which its corresponding wooden strip is positioned. When the succession of circles' phase is altered from one another, a wave motion is translated. In Sinu, the circle is the object that defines the recurring feature a sequencer functions by. A sequencer has the tendency to loop at a certain point in its array of values. The circle is the ideal visceral representation of that quality. Cymbalic is an impulsive reaction to a fascinating phenomenon. Another set of circles with an offset in attempt to emulate a naturally occurring motion. Circles here are a means of translating rotary motion to a series of offset linear motions to recreate a wobble motion. Each technique varies, yet with a similar intention to utilize a fundamental sequence such as the sine wave, and develop a unique interpretations of objects which inhibit a relatable kinetic.

References

Benson, D. J. *Music: A Mathematical Offering*. Cambridge, UK ; New York: Cambridge University Press, 2007, 13-14.

Moffatt, H. K. "Euler's Disk and Its Finite-Time Singularity." *NATURE -LONDON-*, no. 6780 (2000): 833.

Monomatic. "Modular Music Box | Monomatic." *Modular Music Box*, October 1, 2010.
http://www.monomatic.net/modular-music-box/.

Palacios, Daniel. "Waves." *DanielPalacios*, 2007 2006. http://www.danielpalacios.info/portfolio/waves/.

Rossing, Thomas D. *The Science of Sound*. 2nd ed. Reading, Mass: Addison-Wesley Pub. Co, 1990, 31-32.

Tech, Pop. *Reuben Margolin's Kinetic Art*. Accessed October 28, 2014.
http://poptech.org/popcasts/reuben_margolins_kinetic_art.

Trimpin, ., & Focke, A. (2011). Trimpin: Contraptions for art and sound. Seattle, University of Washington Press.