Abstract

Pyrophones are stunning instruments that use combustion to generate vibrations through glass tubes to create music. The team's original intent was to construct a robotic pyrophone. Although intriguing, these instruments are a safety hazard. An emulation can be created to imitate this instrument much more safely. The robot will accomplish the emulation by using glass tubing and LED strip lights to match the appearance of a pyrophone and a striking mechanism that will resemble the sound created from the vibrations. The robot will consist of thirteen tubes tuned between notes C4-C5. The robot will use a striking mechanism to excite these thirteen tubes, creating sound and eventually music.

1. Motivation and Purpose

Robotic instruments are a novel and exciting way to create new and unique music, but they often lack visual appeal while creating music. At the same time, these robotic instruments create some visual appeal, usually due to the distinct lack of a human, whose body language adds emotion and appeal. Fire has enamored humanity and grasped our attention due to its dangerous and sporadic nature. This appeal of fire led us to look into creating a robotic pyrophone that uses fire to help make a more visually attractive robotic instrument.

Background:

2. Prior Art

French physicist and musician Georges Frédéric Eugène Kastner invented the pyrophone in 1870. The design uses combustible gas inside a glass tube, and the vibrations of the flame create a pitch [1]. As quoted from the original patent, "If such a gaseous mixture, exploding in small portions at a time, be introduced at a point about one-third of the length of the tube from the bottom, and if the number of these detonations be equal to the number of vibrations necessary to produced a sound in the tube, all the acoustic conditions requisite to produce a musical tone are fulfilled" [2]. The tube length determines the pitch created, with shorter tubes creating a higher pitch and longer ones having a lower pitch. The pyrophone is similar to a pipe organ, and Kastner's first pyrophone had keys like a piano in a wooden frame. In more recent developments, robotic pyrophones have been created. The most notable is Andy Cavatorta, partnered with Stella Artois, who has created a visually stunning and fully robotic pyrophone. He invented a system that moves the flame nozzles instead of controlling the gas flow, which is much safer than the original design of controlling the gas flow [1].

Image 1

Original pyrophone by Kastner [3]

Image 2

Robotic pyrophone by Cavatorta [1]

3. Concept

One thing we noticed with most of the pyrophones we saw is that the torches are ignited whether the note is being played or not. Keeping the torches lit while not in use would waste a significant amount of gas with no actual benefit. Our concept would be to build off of a similar design to what Andy Cavatorta had but add an on/off control for the gas flow and arc lighters to ignite the gas. This would allow us to conserve gas and access more staccato notes by igniting and cutting the gas flow, creating quick, short explosions.

(not)Pyrophone:

4. Purpose

However, sadly, the explosive nature of the instrument makes us turn away from this idea as it is more likely to blow up in our faces. We also lack a safe environment to test in. This led us to shift away from the explosive pyrophone to something safer. To keep a similar form, we will create a percussive aerophone or chimes and add more appeal through synchronized LEDs, emulating the fire we originally dreamed of.

5. Prior Art

Robotic chimes have been developed in the past. Rochester Institute of Technology (RIT) has a class dedicated to building robotic instruments, and in years prior, they developed robotic chimes [4]. Their techniques include using solenoids to strike the outer edge of metal piping to create a pitch or using mallets to strike underneath the tubes. The RIT robotic chimes do not have a visual aspect other than the mechanisms required to make sound.

Image 2

RIT engineering students building a robotic chime [4]

Organotron, developed by Sherif Habashi, is a robot that strikes wine glasses to create music. The glasses are struck with a solenoid system driven by a keyboard interface on the robot. The glasses can also be tilted so that the robot can produce different sounds [5].

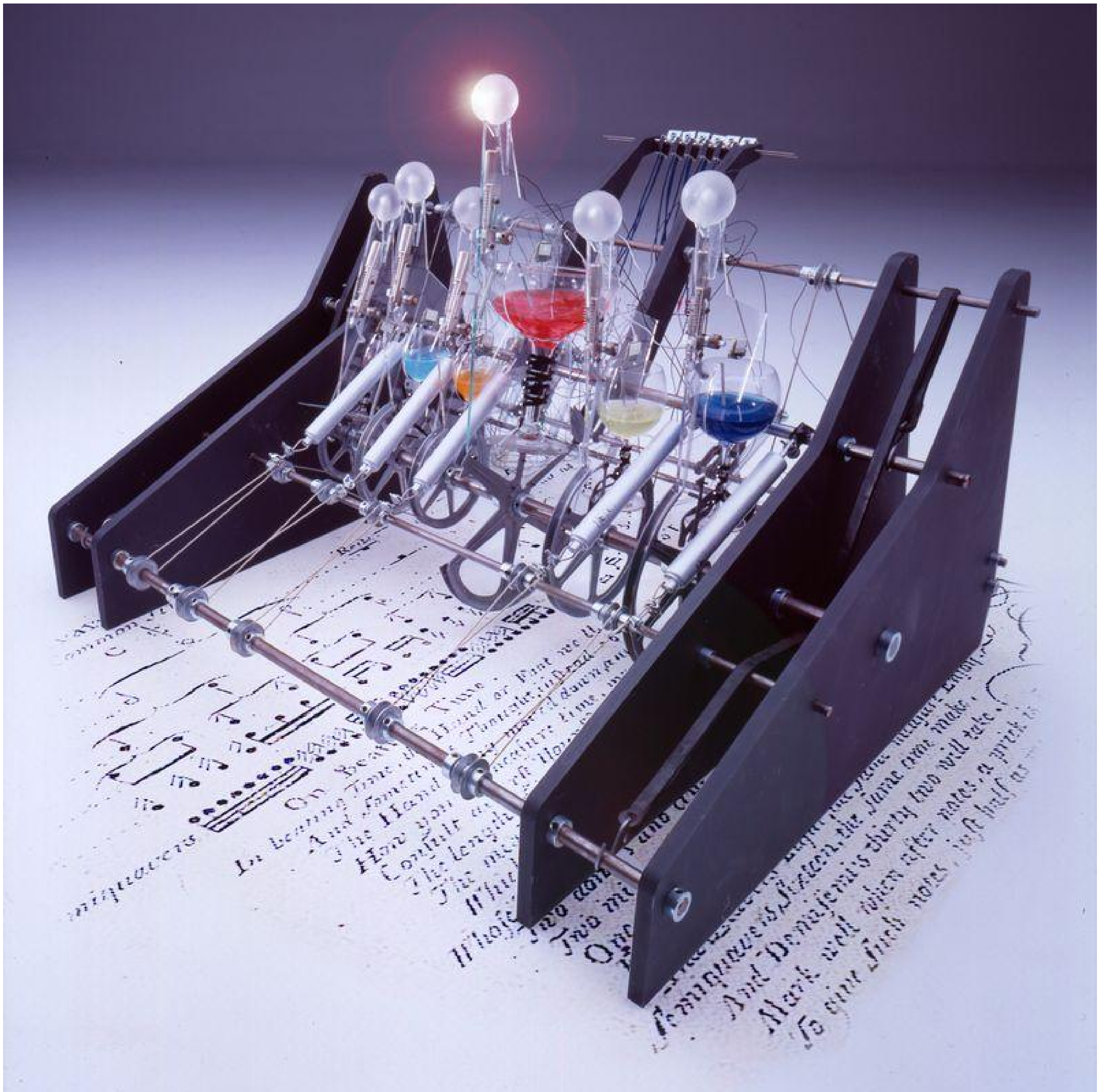

Image 3

Sherif Habashi’s Organotron robot [5]

6. Concept

Our concept is to create a more visually appealing chime resembling a pyrophone. This will be done using vertical glass tubing while incorporating LEDs to resemble flames. Our robot will use a mallet or other percussive striker to generate the pitch on varying lengths of tubing, like that of Habashi's robot. This concept is a robotic chime but in the shape of a pyrophone.

7. Requirements

The robotic instrument will visually emulate the look of a pyrophone. The robot will achieve this by using tall glass tubes with LED strips running through the middle to look like flames. The instrument will be able to play from C4-C5, allowing the composer more freedom when writing for the instrument. The robot should also be visually appealing in and out of action. The instrument will also have a balanced and soft timbre and be of fixed tuning. The team's goals are no noticeable latency during live play, consistently pitched notes and consistent dynamic range.

8. Prelim Design

For this machine, we started by looking into what kind of materials we wanted to use for the sonic part of the machine. Thinking about mimicking the pyrophone visually, we decided on using glass as it is transparent and would allow for lighting inside the pipes in place of the fire that usually is there. With this in mind, we started looking into actuation methods. One method was to use a mallet head directly on the end of a solenoid. We thought this would not be very visually appealing. We decided to base our actuation control on the modular percussion system that already exists for drums and functions well. We decided to reuse and modify the system that already works in our preliminary design. Using the already-made system will save time and resources on the software/control aspects of the machine, allowing us to put more in on the other elements of the machine. Since this system swings sticks instead of just "punching" with an actuator, it adds more noticeable visual movement.

The next step in the basic design was to look at what kind of sticks we use on this system. Knowing that we wanted to avoid harsher clangy timbres, we borrowed a variety of percussion mallets on a wine glass to get a judge of how the contact sounds. After trying a variety of different mallets, we decided we wanted to use a softer rubber mallet or a medium/hard yarn mallet. Both of these did not produce a clang with the glass and instead produced a nice tone similar to a pyrophone.

With all this, we drew a basic model of what we wanted to make in CAD. Since we were hitting the tubes, we decided that we would be best off suspending the tubes like tubular bells. This suspension will limit the mounting's dampening effect. Additionally, needing to learn how to calculate the tones of the pipes for this preliminary design, we kept all the pipes identical in length, and we plan on subtractively tuning the pipes once we get them in hand. Additionally, even though we plan on making at least eight pipes to play one scale, we are still determining where precisely the sound of these pipes will land, so we will make that decision once they are in hand.

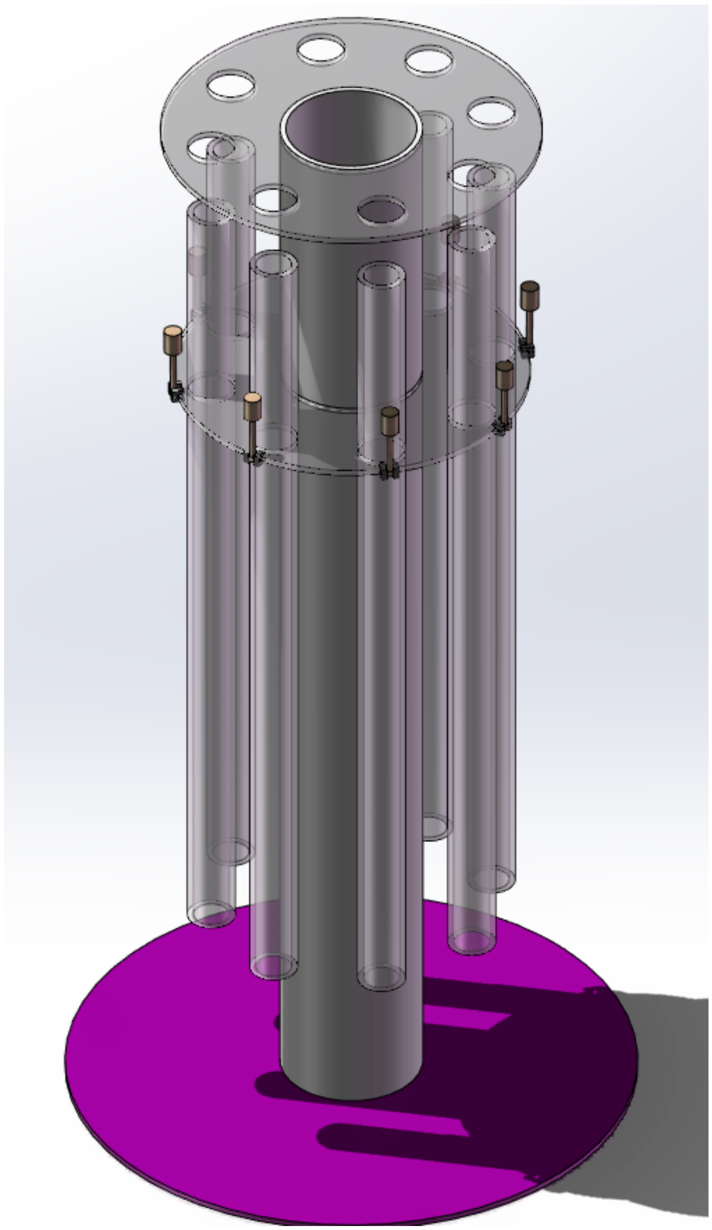

Image 4

Preliminary design of the (not)Pyrophone

Using these factors, we made this basic design shown in Image 4. We were inspired to mimic some of the structures of Andy Cavatorta's pyrophone, with the pipes being in circular arrangement (other options being linear, rectangular, triangular, hexagonal, etc.). We chose this configuration due to how it loops around itself in the octave and is similar to the design most wind chimes use, which we are emulating in some ways. In the center of each pipe, individually addressable RGB led strips will be programmed to mimic flames when notes are played. Additionally, in the middle of the arrangement, one big pipe will be used as the structural backbone of the machine. We plan to use this as an additional bass note for the system by making this center pipe into a percussive aerophone.

Around this stage in the process, we got our first test piece in hand to use as a basis for our design. To start with, we ordered an eighteen-inch tall, four-inch diameter glass vase for initial testing as it was the most easily accessible glass tube/vessel with a similar diameter to what we had wanted to use in the preliminary design. This diameter would make it easy to put the LED strips inside each tube without running much risk of the strip coming into contact with the tubing. However, once we got this vase, it was clear that something was wrong as it did not produce a pleasant sound as expected. With some additional research, we found that contrary to our prior beliefs, the frequency of tubes when struck (from the sides, not the top like percussive aerophone) is inversely related to diameter. Using nominal material properties for glass and a wind chime frequency and length calculator [6], the vase, assuming it was open-ended on both sides, would be upwards of 2000hz. At this range, other factors like impurities play a significant role in the sound, forcing us to move in a different, thinner dimension as we moved into our final design.

9. Final Design

Our final design will incorporate thirteen custom-length glass tubes tuned to a full chromatic scale, plus an additional note (Image 5). Knowing how we had to switch to using significantly thinner pipes than we originally wanted, we settled on using 16/11mm x 60cm (outer/inner diameter x length) borosilicate glass (Pyrex) tubing used for PC water cooling. The chosen tubes were relatively cheap. Using the previously mentioned frequency and length calculator for a tube of this diameter, C4 (the lowest note in the octave range we were aiming for) was about 60cm, the same length as an uncut tube. The rest of the scale got progressively shorter, so we could easily cut the tubing down to the desired length. The design has mallets to strike the suspended tubes. The strikers will use solenoids and a 3D-printed frame. The design will not have a fixed base but, instead, be suspended from the top. A circular design and LED strips to look like fire will also be used to emulate a pyrophone. An Arduino Mega will drive the LEDs, a simple microprocessor, and the same microcontroller used by Professor Barton on many of his previous robots. The modular percussion robots use this microcontroller, and we would borrow their code. A diamond tip drill bit, lubricant, and a drill press can drill small holes into the tubing for suspension. The team created a complete bill of materials (appendix A) was created for the final design.

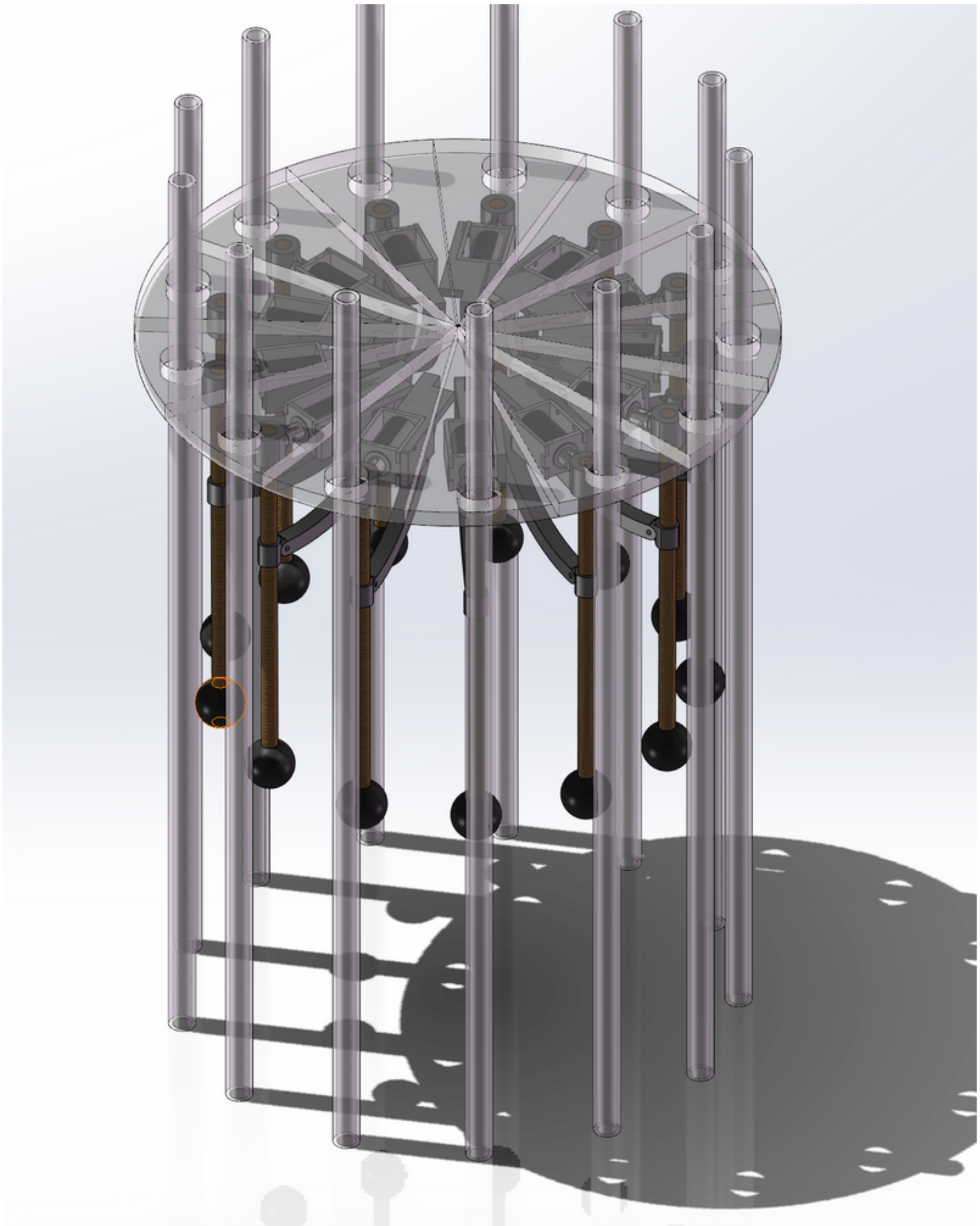

Image 5

Original Final Design (with uniform tube lengths unlike the actual product)

10. First Module

The first module was created by 3D printing a plastic mount holding both the mallet and the solenoid. The mount can adjust the length of the striker by sliding the striker deeper into the fixture. This module was set up to a solenoid driver on a breadboard, driven by a 24V power supply, and activated manually using a push button. The glass tubing was held by hand while the striker hit it and produced a quiet but adequate sound. The solenoid, however, was very loud and took away from the sound level of the glass tubing. This could be fixed with faster solenoid control, not allowing it to click fully. Another discovery made at this point in the process was that the previously designed 3D-printed mount for the mallet and solenoid was flexible. The mount flexed when the solenoid actuated. The 3D printing also took way too long to manufacture (mainly to make 12-13 more with only a few weeks left in the term). Knowing this, we switched to laser cutting these mounts out of acrylic as it would be more rigid, fit the clear aesthetic we were going for, and be quick and cheap to manufacture. The next steps are implementing a microcontroller into the system to operate the solenoid, creating a system for the LEDs, and manufacturing a mount to hold the tubing, strikers, and solenoids.

11. Unfortunate Changes

As we were getting ready to get in the final build, we had ordered all our parts and they had started to come in, all but the most crucial part, the glass tubes. There was an issue with the supplier, which meant the glass tubes were not going to come in time for us to manufacture and compose, so we had to pivot. Looking at the Auto-Chimes project from previous years' practicums, we switched to using copper piping as we knew it could sound good and we could get it that weekend at Home Depot. In addition to the glass changing to copper, there was a miscommunication in ordering acrylic, and 12x24 sheets (not 24x24) were ordered, so we had to switch to a rectangular arrangement to fit all the solenoids on one sheet.

12. 13. Evaluation, Mistakes Made, Lessons Learned

Unfortunately, the robot was never fully functional. The robot had various issues that needed to be accounted for. Mechanically, the mount between the solenoid and mallet extended too far, which caused the mount to collide with the piping (this may be because of an oversight in the change in diameter between copper and glass, among other reasons). This is an issue, as the contact creates a damper meaning the tubing can not resonate. The system would work if the striker were positioned further away from the tubing. Electronically, the solenoid driver circuitry required more power than expected, which caused the circuitry not to work correctly. A solution to this has already been created, which is the Multi Solenoid Driver Module v1.1 (MSDM), which was developed by Scott Barton, Ethan Prihar, and Paulo Carvalho for their robotic zither, Cyther [7].

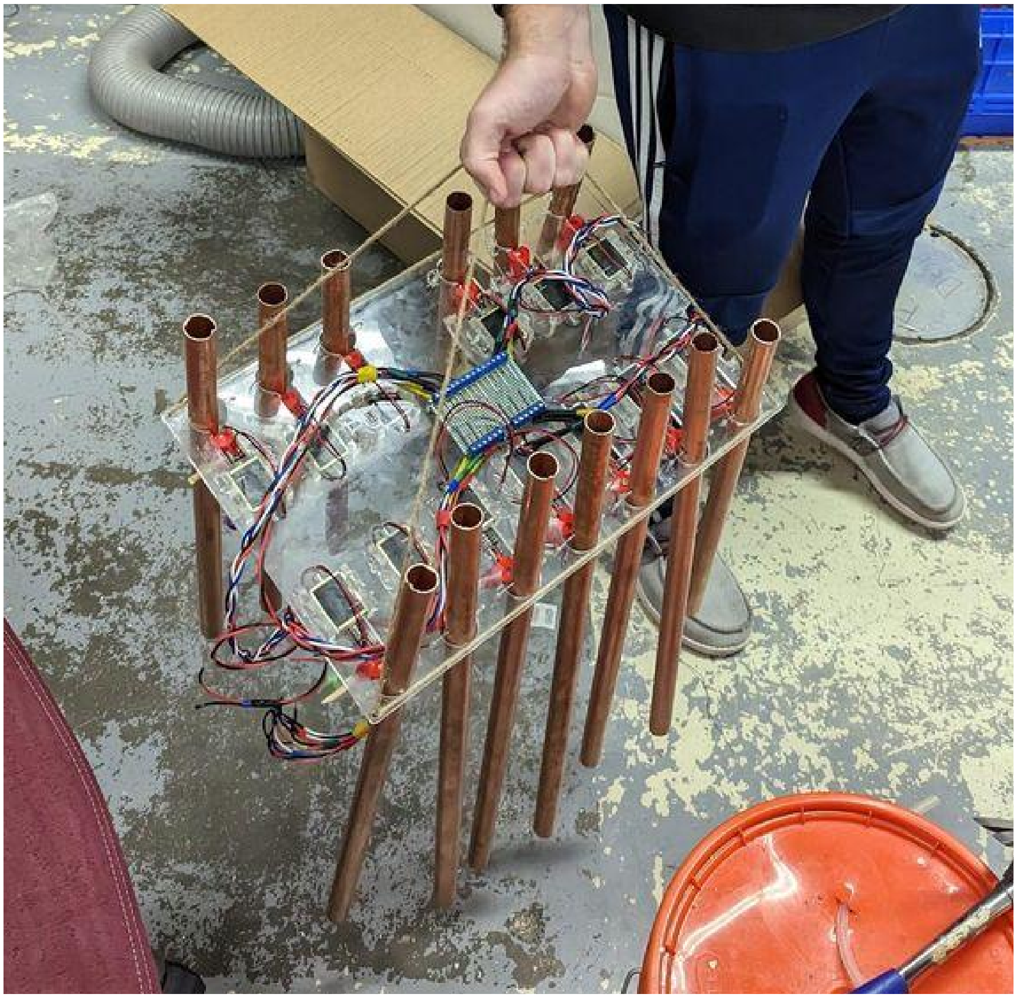

Image 6

Final Instrument

13. Future Work

This robot can be significantly improved upon. A functioning striking system will be required for the robot to be completed. LED strip lights can be integrated so that the robot can be more visibly appealing and emulate a pyrophone more accurately. Other opportunities are also present besides what can be changed to the already developed robot. A more modular instrument can be created, each having much fewer tubes than the original design. Another opportunity for further development is wireless communication to the robot using ESP32s, which we had planned on using in the very earliest stages of this design. Using this microcontroller would allow for the easier placement of the robot away from the controlling computer as you would not need to run data to the robot, only power. This would fit well with the smaller modular approach, which would also solve some of the power issues we ran into with testing this robot and allow for a more spatial audio experience.

14. References

[undefined] *Andy Cavatorta*. (n.d.). Andycavatorta.com. Retrieved December 19, 2022, from https://andycavatorta.com/pyrophone.html

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[undefined] Carvalho, Paulo, et al. “Cyther: A Human-Playable, Self-Tuning Robotic Zither.” *Digital WPI*, May 2017, digital.wpi.edu/concern/generic_works/dr26z0764?locale=en. Accessed 19 Dec. 2022.

15. Appendix

A. Bill of Materials

[Link to BOM]

Name	Purpose	Part #	Manufactrurer	Specs	Quantity	Unit Cost	Extended Cost	Link		
Arduino Mega	microcontroller	A000067	Arduino	atmega 2560 54 io pins (11 p	1	$48.00	$48.00	https://www.a	Electronics	$66.40
18 Pin DIP Socket	for solenoid Driver	ED18DT	On Shore Technology	2x9 pins	2	$0.22	$0.44	https://www.d	Chimes	$266.33
Large PushPull Solenoid	Actuation	413	Adafruit	12VDC 10mm throw 6N start	13	$13.46	$174.98	https://www.a	Lights	$247.82
12V Switching Power Supply	Solenoid Power	GEO651DA-1250	Adafruit	12V 5A max DC 2.1mm DC p	1	$24.95	$24.95	https://www.a	Actuation	$251.34
DC power jack	Power	163-4302-E	KobiConn	2.1mm dc barrel jack fits 5/16	2	$2.95	$5.90	https://www.a	TOTAL	$831.89
Adafruit NeoPixel RGB LED Strip	Fake Fire	WS2812	Worldsemi	60LED/m PWM Controlled 4n	2	$99.80	$199.60	https://www.a		
5V 10A Switching power supply	LED power	658	Adafruit	5V 10A max DC 2.1mm	1	$29.95	$29.95	https://www.a		
2-pin JST SM Plug + Receptacle	LED connection	2880	Adafruit		14	$0.68	$9.52	https://www.a		
300-500 Ohm Resistor	Resistor	294-470-RC	Xicom	470Ohm	14	$0.15	$2.10	https://www.d		
1000uF Capacitor	LED power	UPS0J102MPD	Vishay	1000uF at 6.3V	14	$0.48	$6.65	https://www.d		
Alphacool HardTube 16/11mm	Chimes	ROH1020314	Alphacool	Borosillicate Glass OD 16mm	15	$14.69	$220.35	https://www.a		
Adafruit Perma-Proto Halfsized Breadboard PCB	PCBs	571	Adafruit	3 half size breadboard pcbs	1	$12.50	$12.50	https://www.a		
Rubber Percussion Mallets	Wacking		Boao	6pack	3	$16.99	$50.97	https://www.a		
1/4in Acrylic	Structure			24"x24" 1/4" thick	2	$22.99	$45.98	https://www.a		