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Wine Glass Robot

# Concept, Motivation, Purpose

Our group's goal is to create a robot that plays the wine glasses through the stick-slip phenomenon. The slip-stick phenomenon can occur at any time two materials rub on each other. When the frequency of slipping and sticking enters the range perceptible by humans as a pitch (20-20000 Hz), we hear the effect as a tone. This is why car brakes or closing doors sometimes squeal, why shoes squeak on wet floors, and why a bow is able to make strings (or other materials) resonate when dragged across them.

Currently, musicians who play on wine glasses are called Wine Harpists and are severely limited by the fact they can play at most two distinct, discrete pitches at a time. The goal of this project will be to create a module that can replicate the discrete pitch of a Wine Harpists and expand on that idea by automatically adjusting this pitch using the water level in the glass. The modular design would allow for multiple wine glasses to play complex musical pieces.

# Prior Art

Our team did not find any examples of functional wine glass playing robots that used the slip-stick phenomenon to generate sound. This presents us with the opportunity to build the first musical machine that uses this effect. However, following are several examples of similar ideas.

# Glass Tango

Glass Tango is a wine glass resonance musical machine made by previous students of this course [1]. It comprised of multiple wine glasses, each with a specific water level, being turned by a belt at their base. Each glass contacted a stationary actuator, which used a wet sponge to create friction and resonate the glasses. The team originally planned for 15 wine glasses, but ended up with 5 due to time constraints. They also ran into issues with the reliability of the machine - the actuators could not reliably apply the correct amount of pressure to create a tone, and irregularities in the wine glasses caused problems when turning them.

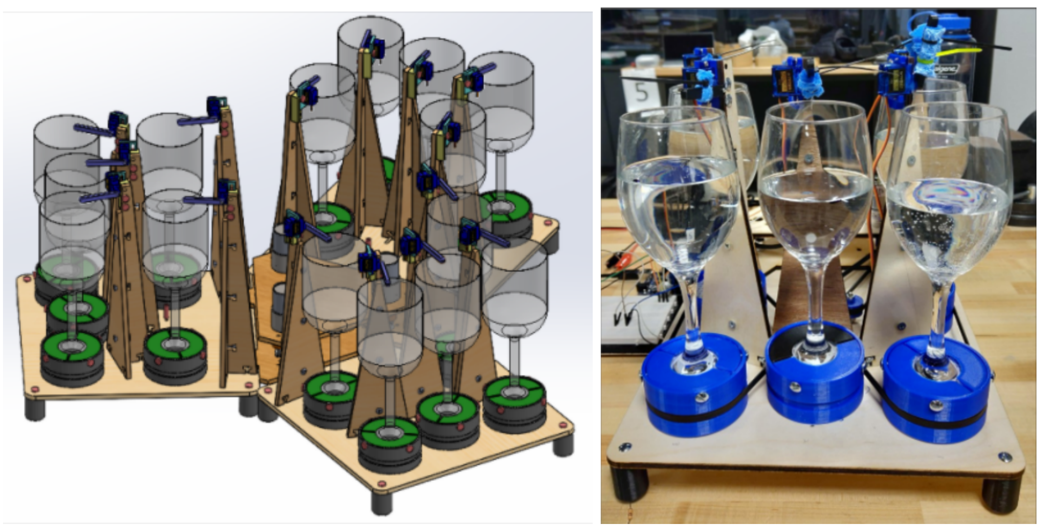

Figure 1: Examples of the Glass Tango from [1]

## Glass Armonica

The Glass Armonica was an invention by Benjamin Franklin and is essentially an array of bowls of different sizes that all rotate together. The player places their fingers in the rims of the bowls to make the different pitches. This allows for multiple notes to be played at a time [2]!

Figure 2: Example of playing the Glass Armonica [2]

## KUKA Advertisement

In 2015, KUKA robotics released a series of commercials following a made up rivalry between Timo Boll, a professional table tennis player, and several industrial KUKA robot arms. Timo and the robots compete in table tennis and musical games. In one commercial, a single arm faces off with Timo, both playing music on a glass harp in front of them. Unfortunately, the advertisement was not completely real. The robot, while not CGI, did not produce sound as desired. The audio playing during the commercial is actually that of two professional glass harp players, Anna and Arkadiusz Szafraniec [3].

Figure 3: KUKA Robot "playing" the Glass Harp

## Euphonic

Although not made of glass, the Euphonic (Invented by Terence Jay) is an instrument that produces a very similar sound to a wine glass being rubbed. It also uses the slip-stick phenomenon, but with metal rods and resonators in place of glass.

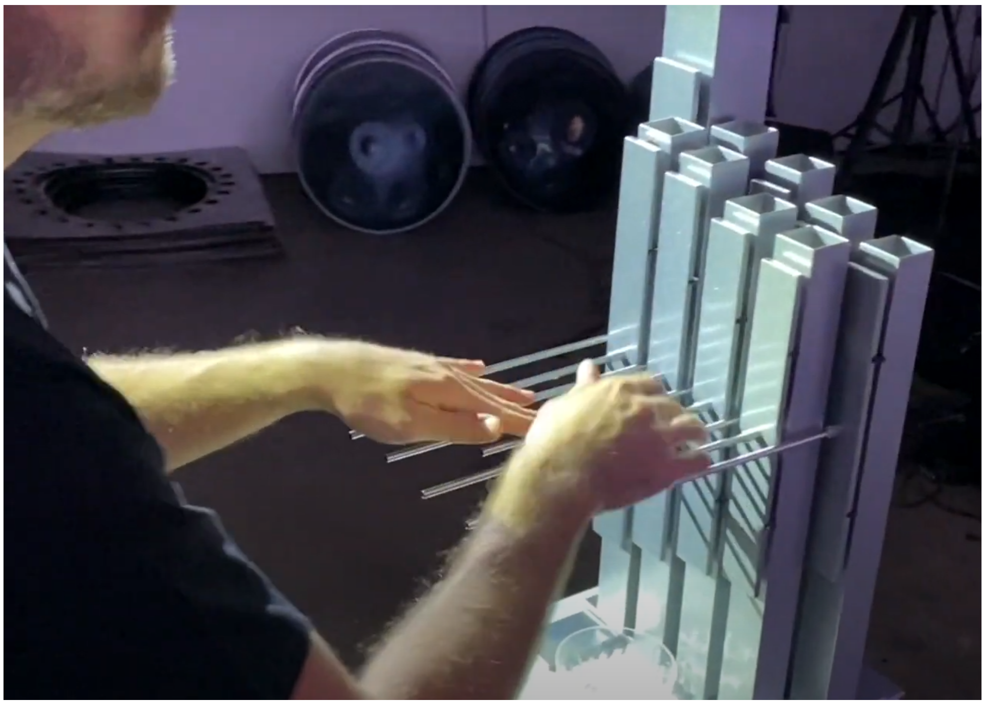

Figure 4: Friction activated Euphonic Array 1D [4]

Because the resonators of the Euphonic are tubes, you can control the volume by hovering your hand above the resonator tube. With this, the user can generate a tremolo effect that sounds very much like a vibraphone [4].

# Requirements

Timbre: What kinds or qualities of sounds will the instrument produce?

- Our goal is to replicate closely the alluring sound of the wine harp and attempt to adjust the pitch of it continuously
- Depending on the hardware we use in our design, there may be a significant amount of background noise caused by the motor, bearings, and other mechanical components. Our goal is to keep the volume of the glass at least 6dB (~4x as loud) above the background noise generated by the machine.

Time: How fast can the machine play? Is it temporally accurate? What latencies are acceptable?

- The machine will likely play relatively slowly because of the time it takes to change pitch and to begin the resonation
- While keeping a consistent pitch, the machine could potentially play quick notes and so the disadvantage of slow pitch modulation can be compensated for with multiple modules (this would have the benefit of also making the system polyphonic)

Pitch: What pitches and modulations should be possible? How can it be tuned? Will it be mono or polyphonic? How accurate is the pitch?

- The pitch should be able to change continuously (portamento).
- Depending on how fast we can change the water level, we could have a vibrato effect
- Initially, the instrument would be monophonic but adding more modules could make it polyphonic.
- The instrument would be tuned by filling the system with a precise amount of water
- The pitch the machine generates when told to play a certain note should be within +/-12 cents of the target pitch.

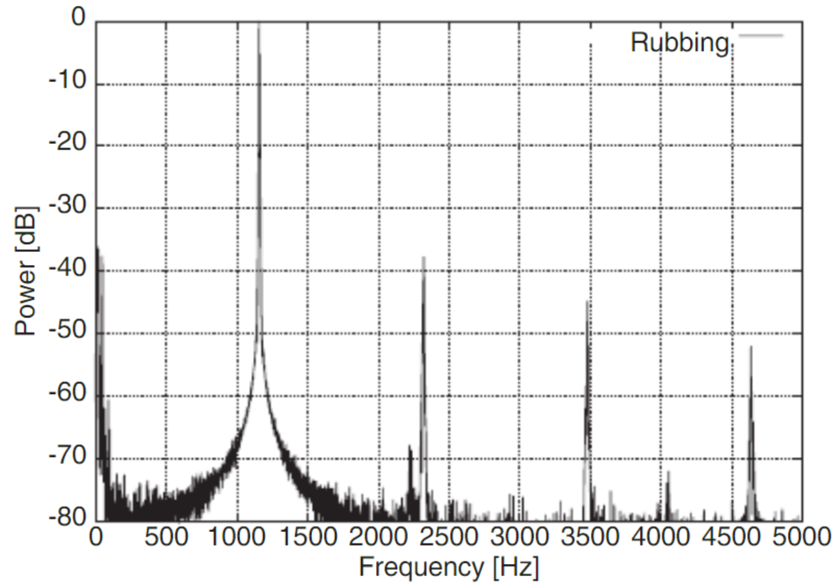


Figure 5: A Typical Frequency Graph of a Glass Harp [5]

Dynamics and Articulation:

- We expect the instrument to have very little dynamics given that there are no options for exciting the wine glass except spinning it. We will experiment with different amounts of pressure applied to the glass, as well as changing how fast it spins, in order to see if either variable affects the volume.
- For articulation, we would like the machine to be able to perform legato and staccato. Legato would be achieved by continuous excitation of the wine glass, whereas staccato could be replicated by short, intermittent rotations.

# Design

In order to achieve these requirements, we came up with several variations of the instrument based on two parameters: actuation and water location. This leads to 4 major designs

| | |
|---|---|
| Spinning the wine glass with a fixed exciter arm with the water inside the glass | Spinning the wine glass with a fixed exciter arm with the water outside the glass |
| Spinning the exciter arm with a fixed glass with the water inside the glass | Spinning the exciter arm with a fixed glass with the water outside the glass |

Figure 6: Variations of designs

On the following page are several sketches of these ideas.

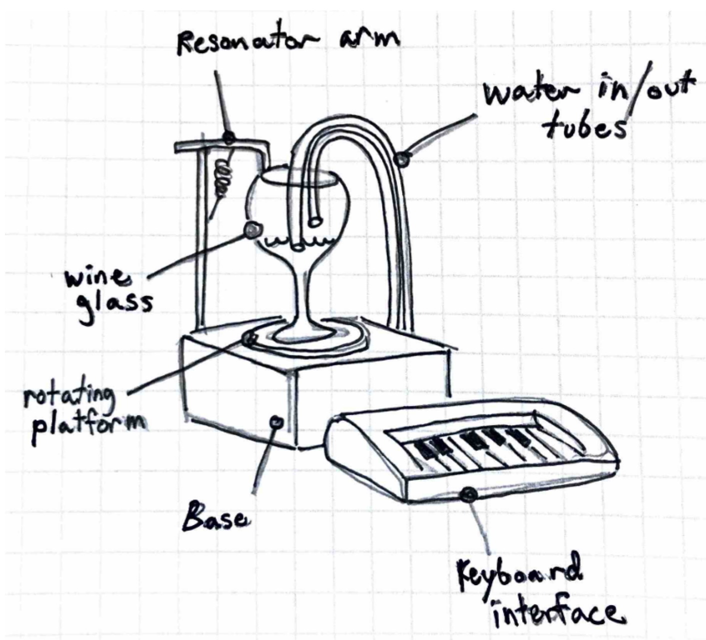


Figure 7: Sketch of the first design with a motorized base

Motorized base, discrete pitches: The glass automatically turns, and the user controls the pitch with a keyboard. A microcontroller adjusts the level of water in the glass using pumps and tubes. The turntable would be powered by some sort of stepper motor to achieve speed control.

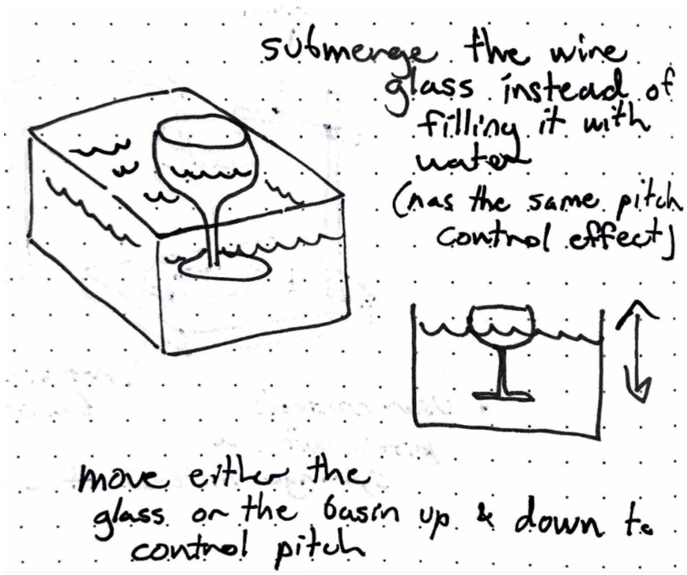


Figure 8: Sketch of the inverted submersion design

In order to control the pitch of the glass, it’s not actually required that the water is inside of it. Although initially counterintuitive, submerging the glass partially in water has the same effect as filling the glass with the water around the same water level [7].

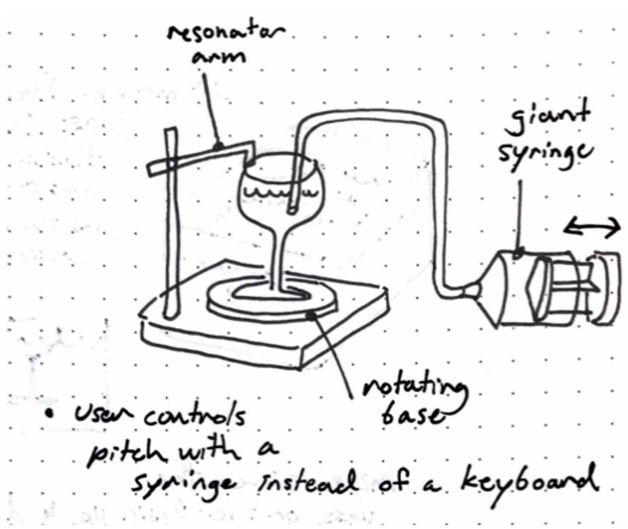


Figure 9: Sketch of pitch control with a syringe

Syringe pitch control: To actuate the amount of water in (or out) of the glass, this design uses a large syringe which could be actuated manually or with some linear actuator. Instead of discrete notes, the isntrument controls the amount of water in the wine glass allowing for precise, sub-semitone pitch control.

We wanted to rank these ideas based on the following criteria: ease of building, visual aesthetic, and the consistency of the sound produced.

To get the data about the ideas consistency, we set up some basic prototypes:

Figure 10: Prototyping Rotating Glass design

First we tested the spinning wine glass with a fixed rotator and found that it had decent sound properties, but it was slightly inconsistent (mainly due to the fact that the glass rim is not a perfect circle).

Next, we tried a fixed wine glass setup:

Figure 11: Prototyping Spinning Exciter design

Surprisingly, we could get pretty consistent sound out of this setup when rotating the exciter back and forth. Finally, we proved that the pitch of the sound does change when the glass is submerged in water

Figure 12: Testing Inverted submersion for the glass harp

The pitch changes from this experiment were extremely smooth and it was able to produce a large pitch range when just moving the glass about two inches.

Finally, we used this data to create the decision matrix below:

| Category | Weight | **Fixed Glass, Water Out** | Rotating Glass, Water Out | Fixed Glass, Water in | Rotating Glass, Water in |
|---|---|---|---|---|---|
| Ease of Building | 3 | **2** | 2 | 1 | 3 |
| Visual Aesthetic | 3 | **3** | 3 | 1 | 2 |
| Consistency of Sound | 5 | **2** | 1 | 2 | 1 |
| Totals: | | **25** | 20 | 16 | 20 |

Figure 13: Decision Matrix

Based on the ratings, we decided to use the design with a fixed glass and water housed outside of the glass. From our initial ideas and the prototypes, we decided to keep the rotating exciter on top of the wine glass. During our testing we also ordered a block of Rosin thinking that it may have a similar effect on the wine glass as it does to a violin string [7]. Initially we believed we could apply rosin to the exciter stick, as “without rosin, the hair of the bow will slide across the strings and won’t provide enough friction to produce any sound” but during testing we figured out that we could just use the rosin block directly and this produced the best sound.

In order to change the water level, we decided to use a syringe with a linear actuator, because it was the simplest design and we were able to find a sufficiently large syringe.

Overall for the final design, we wanted a large enclosure that could be laser cut and a bar at the top to mount a motor with the spinning exciter. A CAD model of this design can be found on the next page.

# Final Design

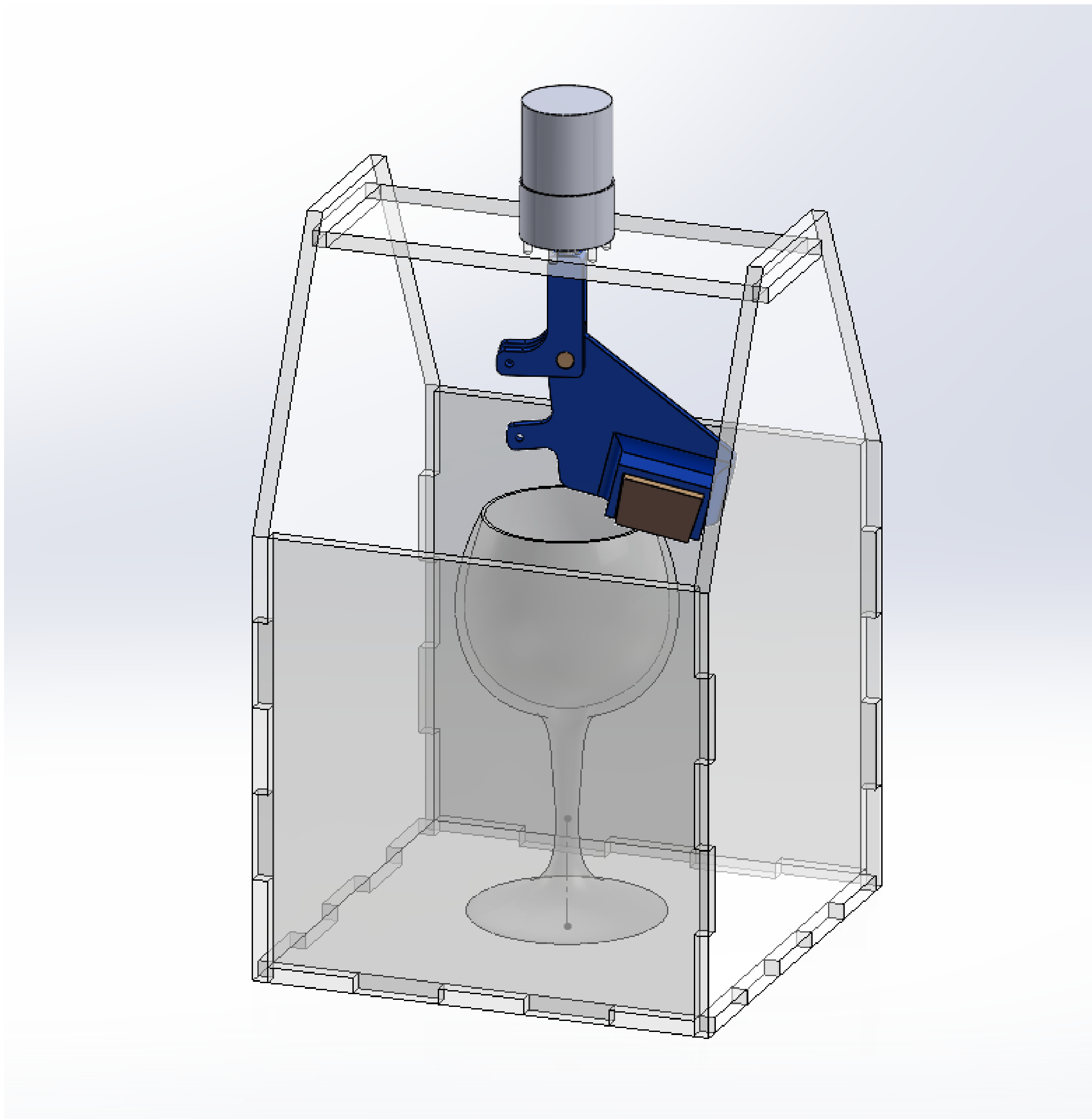

Figure 14: Final CAD design of the wine glass enclosure

BOM

| Part | Manufacturer | Part number | Specs | Quantity | Cost | Vendor (link) |
|---|---|---|---|---|---|---|
| Syringe and tube | WERTYCITY | 1 | 550 mil volume, 2.7” int. diameter | 1 | $13.49 | amazon |
| Acrylic | various | 2 | 12”x24” | 1 | $20.00 | |
| DC Motor | various | 3 | 12V 5W 100 RPM | 1 | $12.00 | |
| Linear actuator | ECO-WORTHY | 4 | 12V 8” | 1 | $43.00 | amazon |

Figure 15: Bill of Materials of the completed prototype

First build of the completed design:

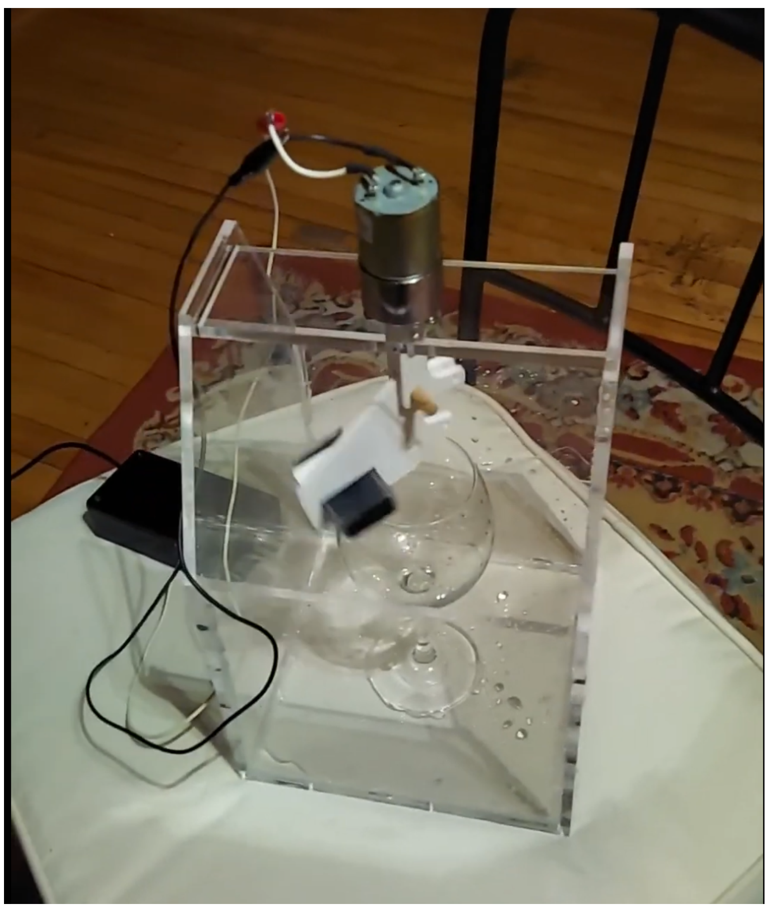

Figure 16: Built model of the Wine Glass Robot

Figure 17: Syringe Assembly

# Evaluation

To evaluate the design based on our criteria we go through each requirement and rate how well the final prototype accomplished it.

Figure 18: Wine Glass Module completed for testing

Timbre: We were able to get the alluring sound that we hoped for from the wine glass which was a great success. Unfortunately though, the pitch changing did not work the way we expected. It seemed that filling too much water dampened the sound and we were not able to change the pitch continuously quickly. Instead we decided to stick with discrete pitches and record those sounds

Time: We thought that the sound from the instrument would start and stop immediately with the exciter but this was not the case. It took significant time for the glass to start resonating from a full stop and after several minutes of playing, the rosin would wear down or get wet and we would need to wipe down the glass and rosin before playing again.

Pitch: Unfortunately since we were not able to consistently get a good sound from the prototype when there was a significant amount of water in it. We suspect that the water began damping the vibration, stopping the glass from resonating. We could not change the pitch continuously like we had hoped. However, we were able to generate different pitches discretely and recorded them for the final composition. We were even able to move the exciter module over a differently shaped glass to get more sounds.

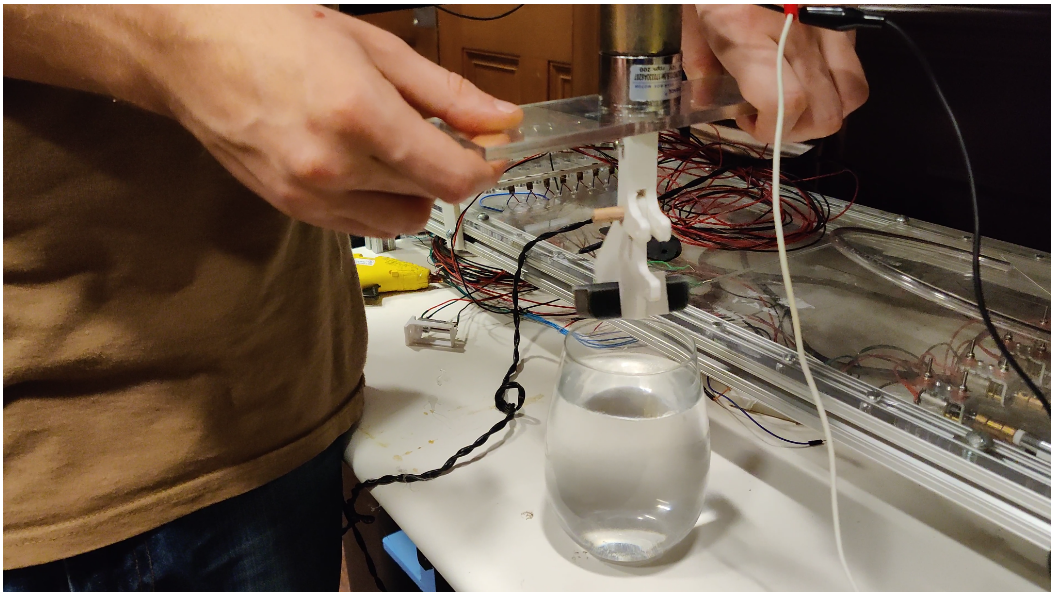

Figure 19: Testing the exciter on other glasses

Dynamics: We were able to extract different sound characteristics by spinning the exciter at different speeds. The natural tremolo of the instrument can be either faster or slower depending on the amount of voltage applied to the DC motor. Unfortunately, we were not able to get much dynamic range out of the instrument. It would resonate the glasses quite loudly, but as soon as the angular velocity of the exciter dropped below a certain threshold, the resonance would get quieter and quieter until it died out.

## Results

Overall, our group was able to successfully create a module that excites a wine glass robotically and can emulate the wine glass harp. Unfortunately we were not able to get the pitch bending to work as we hoped because we did not account for the damping effect the large volume of water would have on the sound. Despite this, by putting discrete amounts of water into the glass we could create distinct pitches to be recorded for a composition that still has the character of a robotic instrument. Finally, we also tested the mechanism on other glasses to show that it is flexible enough to excite other objects. Future groups could use this project as a proof of concept to base their musical machines off of.

## Musical Usage

This instrument is most well suited as a drone or pad in the background of a peaceful composition. While there are some interesting variations of the natural tremolo, it would not provide enough of a change to compose a full piece. The natural tremolo itself leads into a basic rhythm that can be built upon by other instruments like percussion. By using the differently shaped glasses, complex harmonies can be produced especially when these are recorded and layered. It is possible to create several modules to emulate the layering in the real world which is left for future work.

## Reflections

Overall, the team was decently successful in realizing our initial ideas as discussed in Evaluation. The major hurdle that was faced had to do with the damping effect caused by large water levels and could potentially have been mitigated with the use of different glasses or more tuning. Possibilities for future improvements would include selecting a better quality wine glass for the instrument and trying to tune the pressure of the rosin on the glass along with the thickness of the glass for optimal sound while submerged. However, this was a very instructive project and the team was able to learn a lot through it!

## References

[1] Benevedes, E., Mitchell, K., & Starr, R. (2020). Glass Tango: A Robotic Glass Harp Humanities and Arts 3910: Musical Robotics Practicum.

[2] *Benjamin Franklin's Glass Armonica*. The Franklin Institute. (2021, March 19). Retrieved December 15, 2022, from https://www.fi.edu/history-resources/franklins-glass-armonica

[3] KukaRobotGroup. (2015, March 11). *The revenge: Timo boll vs. Kuka Robot*. YouTube. Retrieved December 15, 2022, from https://www.youtube.com/watch?v=lv6op2HHIuM

[4] *Euphonic Instruments - Euphonic Array 1D*. Euphonic Array. (n.d.). Retrieved December 15, 2022, from https://www.euphonicinstruments.com/

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[6] Quinn, D. B., & Rosenberg, B. J. (2015, August 17). *Inverted glass harp*. Physical Review E. Retrieved December 15, 2022, from https://journals.aps.org/pre/abstract/10.1103/PhysRevE.92.021003#fulltext

[7] 3Dvarius. (2022, September 15). *What is the purpose of applying rosin to your violin?* 3Dvarius. Retrieved December 15, 2022, from https://www.3d-varius.com/apply-rosin-violin/