Pan Flute Musical Machine

A Project Completed For

Practicum in HUA: Musical Robotics

Constructing an automatic pan flute musical machine.

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Table of Contents

List of Figures

Concept and Purpose

The general concept for our musical robot is to take a pan flute and distribute the notes radially as opposed to linearly. At the center a valve will blow air from a pressure system over one tube to produce a note. The air will be adjustable to produce consistent notes for each length of tube. The key features we are conceptualizing in our musical robot, cover musical and visual aspects.

Musically we aim to create three separate units of panflutes that are played by the machine, each panflute covering a different octave. This will be capable of a wide range of notes, and open the door for harmony and polyphony due to the multiple units. To create visual appeal, one important choice we are making is to rotate the pipes as opposed to the valve in the center. This creates a stronger sense of motion, elevating the visual aspect.

Our purpose in creating a unique device like a mechanical panflute is to experiment with machines that are novel and interesting, and to create unique sounds with this machine that may not be able to be played by humans. Our machine would be able to accomplish many inhuman tasks, like playing notes for extremely long amounts of time or allowing for complex pieces that would normally require impossible amounts of precision. Another goal for our project is to study how mechanical airflow can create unique tones that can be replicated again and again. One of the most impressive parts of machines is that they can create the same tone repeatedly without error, and that they can play all the notes in time perfectly. By using this trait of musical machines, we can compose melodies that are enhanced by machines. By using different angles, we hope to create subtly different tones while also playing those tones in different octaves.

Finally, a major focus of our project is on the development of automated wind-based machines, rather than string instruments which are more common in musical machines. Using machines for wind instruments can produce new sounds and increase precision for each note, allowing for vastly different experiences when compared to traditional playing of wind instruments.

Motivation

The inspiration for this project came through the observation of countless musical robotics machines over the years, such as those created by Naezith (2020), Sohl (2016), and TeamDARE (2010). The goal of creating something unique that didn't simply rely on another form of percussion was the main driving factor to branch into wind based sound. Another goal was to explore forms of pitch variation that didn't rely on tension, whether that be a drum head or string. Lastly the use of wind as the sonic generator opens the door for unique variations due to other forms of resonance and harmonics that would otherwise be challenging to create. Preliminary testing shows variation on the desired note that can be achieved by moving the exit piece a few degrees each with their own unique pitch, timbre, and volume. Another driving factor for this project is the ability for self harmony and polyphony, gained through the three separate carousels of pipes. The last and potentially greatest motivating factor for this idea was the goal of creating something uniquely challenging that pushed our comfort and limits as a team. The integration of electrical, mechanical and programming to allow this machine to work will truly be one of our greatest challenges, not to mention the scope given the goal of three separate tube arrays.

Prior Art

When developing a musical machine, it is essential to research prior artworks completed before to both garner new ideas and learn from avoidable mistakes. The short video *Pan Flute Robot plays Beethoven - Ode to Joy* (naezith, 2020) depicts a simple robot consisting of a single servo motor with a rod attached. Attached to this wrong on tubes acting as flutes, which when spun around, are excited by a small air blower held by a hand above. Although this is a small-scale and simple example, this takes upon a similar base structure that we aim to achieve in our project. It displays that with a stationary blower, a servo rotating tubes of varying lengths is capable of producing not only sound, but also recognizable harmonies.

Figure 1.1 - Panflute robot plays Beethoven - Ode to Joy (Naezith, 2020)

Similarly, but at a much more advanced stage in the development lifecycle, we can see a similar pan flute playing robot in *Panflute first system test* (TeamDARE, 2010). This pan flute robot consists of a metal frame that holds a full pan flute, moving it side to side to produce sound from a blower. The blower is attached to an arm that is able to adjust the height and angle of the air output, but not any movement in the horizontal direction.

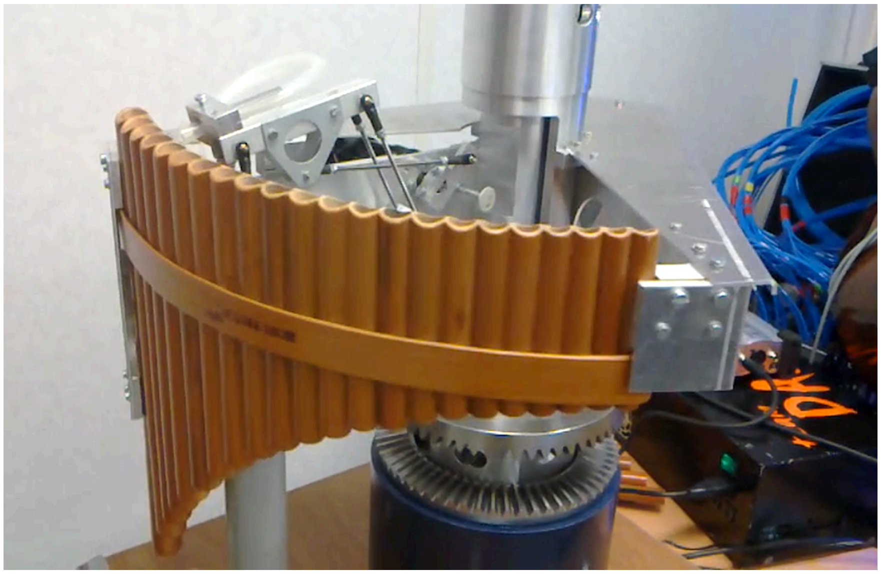

Figure 1.2 - Panflute first system test (TeamDARE, 2010)

This design cleverly limits the movement in two bodies to provide a more accurate and clear tone. Despite our planned musical machine bearing closer resemblance to that of the first prior example discussed, we can certainly take note of the build quality and learn from the importance of direction of airflow onto the pan flute while constructing our designs.

The general physics for a pan flute can be modeled by a closed-end air column (. Sound is produced when the column of air within the tube is excited and vibrates. The movement of the air is fixed at the closed-end causing different wave patterns for different harmonics. The general equation for the frequency produced is:

$$Frequency = speed\ of\ sound\ /\ wavelength$$

Although the final information we have garnered does not include a direct example of a past artwork, it does provide us with essential insight into the mathematics behind the pan flute. Notably, the following formulas (Sohl, 2011) bear great use for our design concepts:

$$Wavelength = speed\ of\ sound\ /\ frequency$$
$$Sounding\ Length = 2.4123 * Wavelength$$

These formulas are extremely useful for our team during the design of our pan flute musical machine as it will aid us in determining the specific length each tube must be in order to produce the correct pitches.

Overall, it is vital to look upon similar past examples during any design process. The past works of pan flute robots and the science behind tube length to produce pitch give us great insight into our designs moving forward. Therefore, by learning from other's mistakes and incorporating the aspects that produce desirable outcomes, we will be sure to construct an exemplary musical machine.

Requirements

There are several requirements crucial to all musical machines. These machines are complex and vary in many aspects of design. The initial decision on how we approach designing our project is to choose between building it from scratch, rummage, or off the shelf. For our project, since we require many custom 3D printed structures, we will be constructing it from scratch.

The goal of our robotical interpretation of the pan flute is to reach a three octave range in pitch. Additionally, it is important that notes are able to be played simultaneously to produce chords, but also individually when necessary. The speed of change in pitch is also an important consideration so we can produce intricate musicality and melodies.

Our preliminary design consists of a central air pump unit with three outputs, each with a pneumatic solenoid attached. These pumps will then each lead to a valve which is located in the center of a rotating disc. Each of these three discs will have tubes of varying length that the valve can excite by blowing air, creating varying pitches. These discs can be rotated using stepper motors and the solenoid will allow air through when playing a note. The air will be blown into the pipes using standard quarter inch tubing. The tubes will have controllable input for the height and angle, which will help obtain consistent notes from each tube. The electrical system will involve three subsystems integrated together. The three subsystems are the servos, the stepper, and the solenoid. The first step of our design process will be to prototype one unit as a proof of concept, before sinking materials into all three parts. Lastly, the device must be interfaced for midi control with Ableton Live to allow proper composition and interaction with other instruments.

This design focuses mostly on function over form. However, due to the rotating discs, the musical machine will also be intriguing to watch. As the discs must be rotated to switch between pitches, we may experience issues with the speed at which musical notation can be played. However, this is combated by the inclusion of three circulating discs with blowers, allowing for three notes to be played simultaneously. In particular, this design aspect allows for additional advanced musical capabilities of our musical machine, including intricate harmonies and dissonance to be played.

Bill of Materials

Part Name	Quantity needed	Price Per Unit	Link
Groove Bearings	3	$9.99	VXB
Nema 23	1	$28.70	Stepper Online
Limit Switch	1	$5.99 (set of 10)	Amazon
Solenoid Valve	1	$7.99	Amazon
Stepper Driver	1	$25	Ebay
M4 x 15 Bolt	18	$59.95	AcerRacing
24 Volt Power Supply	1	$16.98	Amazon
12 Volt Power Supply	1	$12.99	Amazon
5 Volt Power Supply	1	$21.99	Amazon
Extra Materials (i.e. wood and/or 3D printing filament)	N/A	~$20	-

Design of Major Components

The mechanical system is a frame with three supports for supporting the radial pan flute. The pan flute consists of close-ended tubes held within a drum. The drum is supported by 45-degree groove bearings within the supports. Supports are used to position the servo with drive gear against the drum gear for rotation of the pan flute. Lastly, the air adjustment system consists of a rack and pinion servo and a servo directly connected to the tube for angle. This system is also elevated and connected by supports to the base.

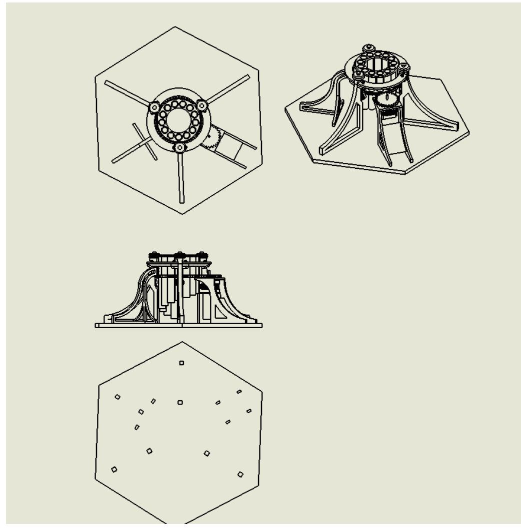

Figure 2.1 - Full assembly

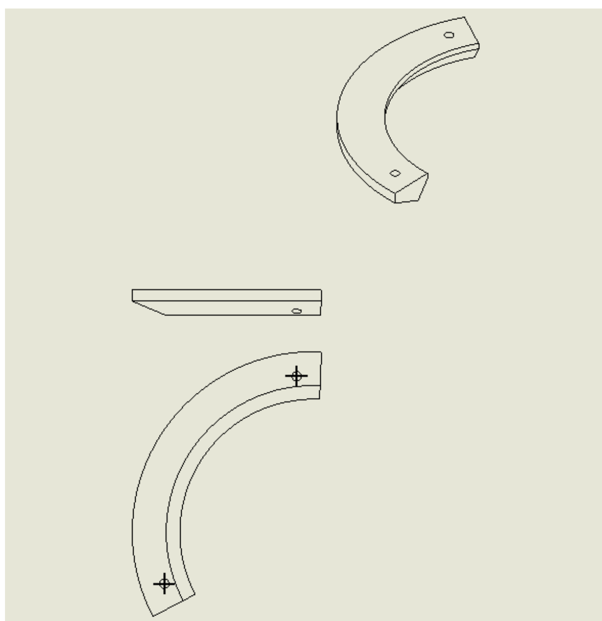

Figure 2.2 - Collar

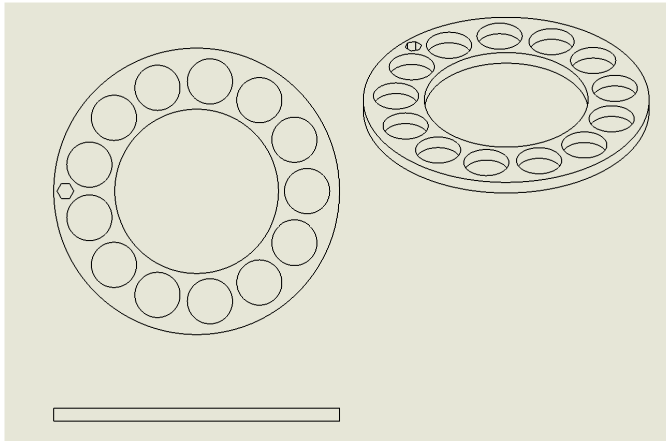

Figure 2.3 - Drum

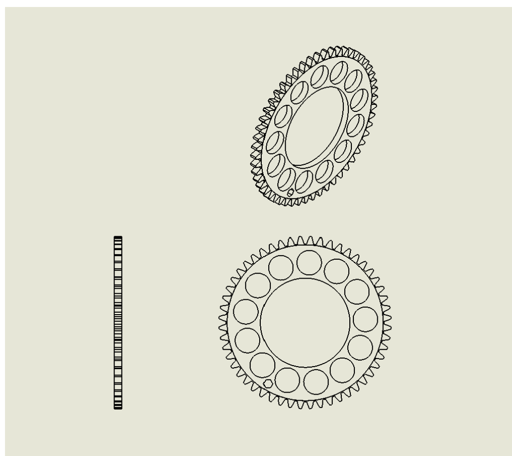

Figure 2.4 - Drum Gear

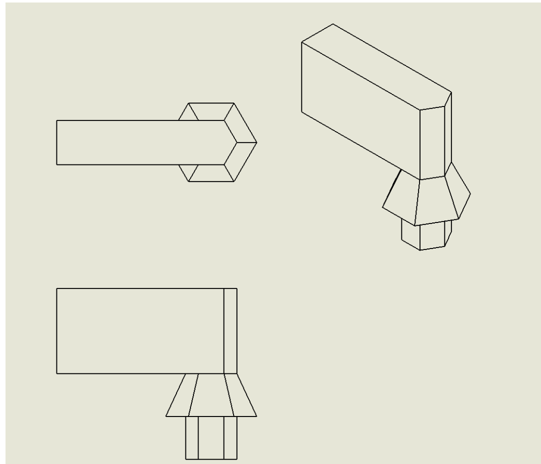

Figure 2.5 - Homing Flag

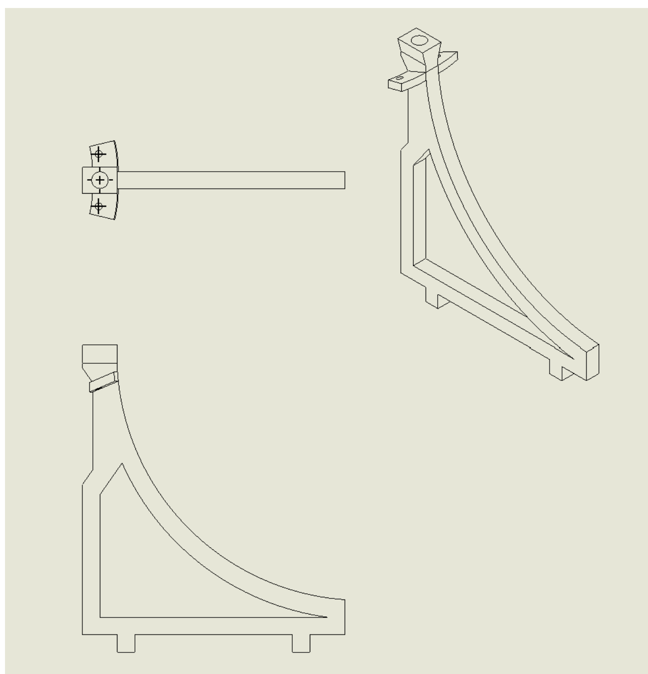

Figure 2.6 - Leg

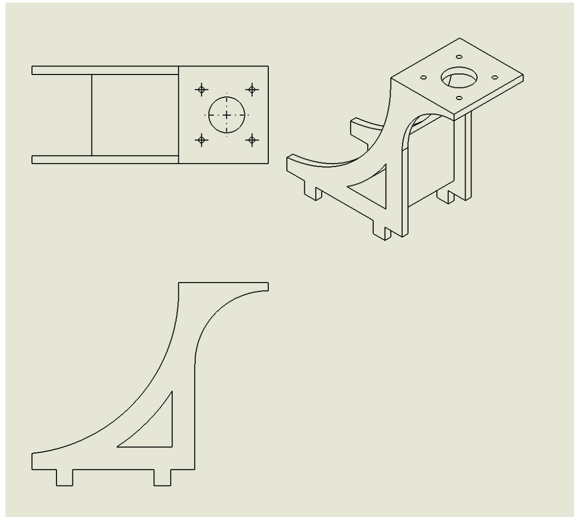

Figure 2.7 - Motor Stand

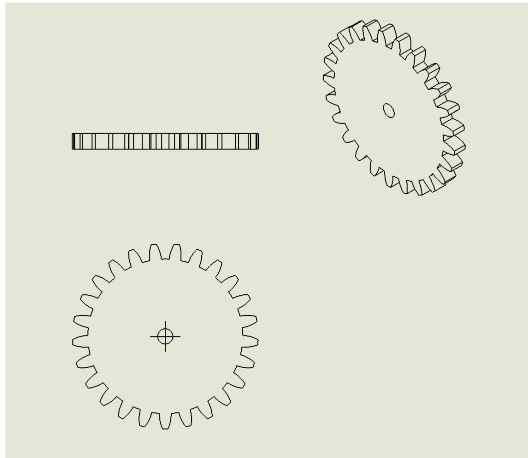

Figure 2.8 - Small Drive Gear

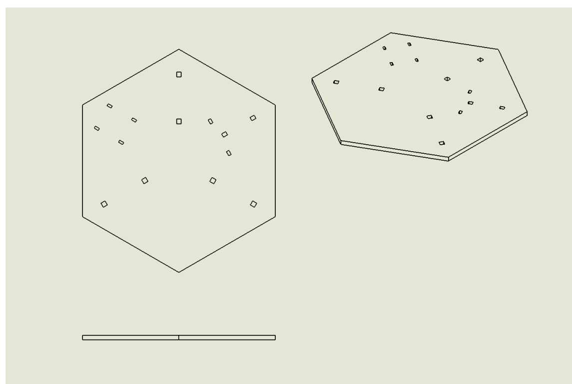

Figure 2.9 - Base Plate

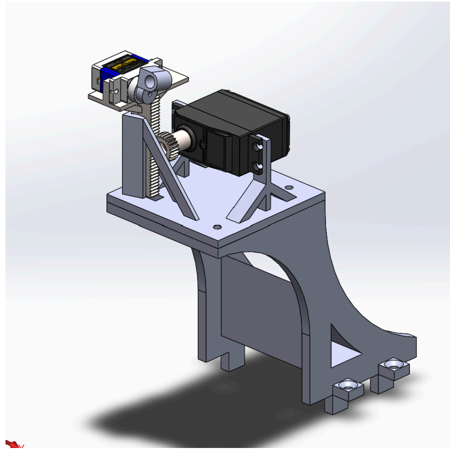

Figure 2.10 - Blower Assembly

(Note: This is v1, current design utilizes smaller servo)

The electrical system has 5v, 12v, and 24v power lines. 5v for the servos powering the air adjustment system. 12v for the solenoid valve to control the air. Finally, 24v for the servo/servo driver system. These subsystems were wired on separate powerlines and all connected to one arduino with a common ground for everything.

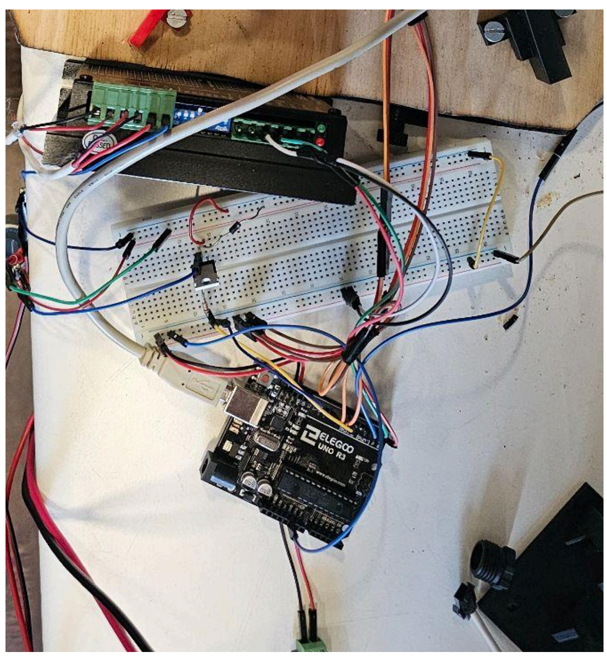

Figure 2.11 - Electrical System

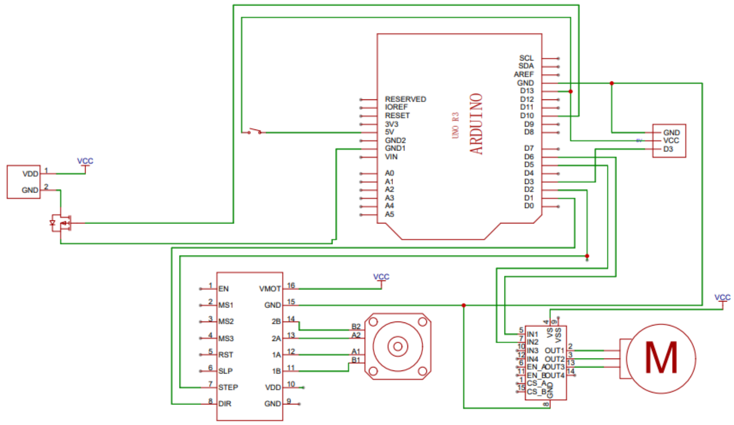

Figure 2.12 - Electrical Schematic

The code for this machine consists of two Arduino files, one Python program, and a MAX patch to communicate with the arduino through a serial connection. To tune the machine, the first Arduino file should be loaded onto the machine and the machine should be homed. Then, the user can open the Python program, which requires the machine to be homed again each time it is run. The GUI that launches after this program completes its homing setup is shown in Figure 3, in the Results section. The user can use this GUI to tune the panflute, ensuring accurate angles, heights, and positions for each note. Once this tuning is done, the user should press the "Save file" button on the GUI, and paste the two last lines in the text file (saved as "machinepos.txt" in the path the program is run) into the second Arduino program. This ensures that the angles and heights for each of the notes are correct during live playing of the instrument. To then play the machine with Ableton, the user should upload the second Arduino file onto the machine, and drag the MAX patch into Ableton under a MIDI track. If this is done correctly, the user can use notes C5 to C6 as notes that the panflute can play, with B4 acting as a "airflow off" note, closing the solenoid on the machine to prevent airflow to the device.

Evaluation Methods and Results

Once the mechanical and software portions of the Pan Flute Musical Machine were complete, we were able to conduct testing to evaluate the success of our design. To ensure the optimal pitch and tone for each of the thirteen possible notes produced, we developed an Arduino script combined with a Python GUI using Github Copilot to test and set the prime height and angle servo motors of the blower. As seen in Figure 3, once the height and angle are set and the desired tone of the set pipe is reached, one could simply click the corresponding tube number to save its position. Once servo heights and angles are set for all thirteen tubes, the “Save File” button can be clicked. This button saves all positions in a text file with the format “[Height],[Width],[Stepper Position]”.

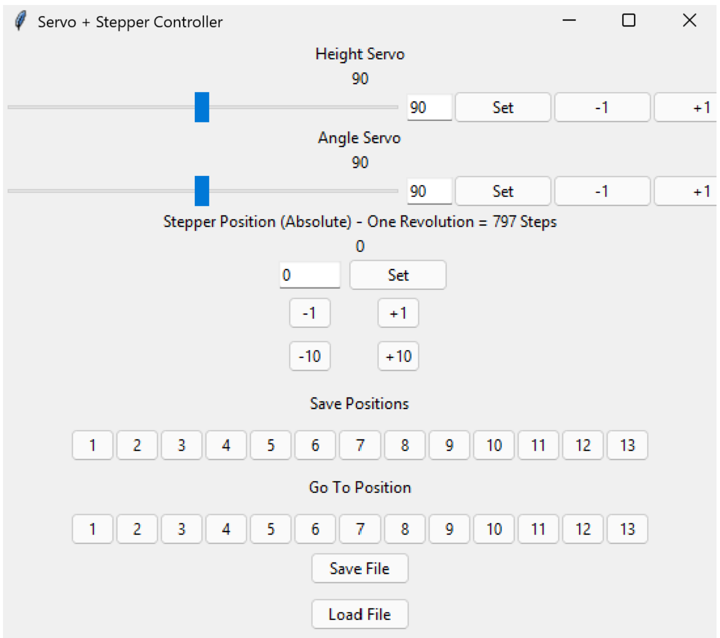

Figure 3 - Servo Control GUI

Once we finished tuning each note and had the text file saved, we loaded the servo height and angle values into our other Arduino script that handles the serial communication with Ableton using a Max for Live patch.

Now that we had all notes in tune, all that was left was to fine-tune the algorithm to determine the quickest direction of rotation for the pan flute to spin depending on the last played note. For example, if the pan flute had just played the C5 tube and now desires to play the A6, the tube disk should spin in the reverse direction to travel just two tubes of distance instead of eleven tubes had it chosen to spin in the opposing direction. To test this functionality, a serial connection to Ableton was established and a sequence of varying, random notes were rapidly played with repetition. All turns were observed as moving in the correct direction with haste.

While testing, there was one major issue that was observed. Since we desired optimal speed, we chose to set the stepper driver to its lowest number of microsteps, which is 400. However, since the Pan Flute Musical Machine has thirteen tubes and a gear ratio of 2:1, the number of steps per tube was calculated as follows:

$$Steps\ Per\ Tube\ =\ (400\ *\ 2)/13\ =\ 61.53846$$

Thus, since 61.53846 is not a whole number, this must be accounted for in code. Originally, we believed rounded would be sufficient as the error would not be very large. However, after deploying this method in our script, we quickly noticed the stepper beginning to drift away from the center of each tube. The longer it would play, the greater this error would become.

Reflection/Musical Usage

Ultimately, we were able to accomplish many of our goals technically and musically. Technically we achieved precise rotation of the flute to each note and the desired control of the airflow per note. We were able to accomplish mapping of each note position within our program. This allowed us to calibrate each note and musically achieve tones from each individual note. One significant musical achievement of this solution is our UI that allows personal selection of notes. This provides much more freedom to the composer and allows for specific selection of desired tones.

However, we also fell short of a couple of our technical and musical goals. Technically, we lacked the desired control of the solenoid. The solenoid was wired and fully controllable, but we struggled with integrating it with Ableton Live to open only during the note. Our solution to get a playable instrument within the time frame was to leave the air on anytime it was attempting to play and to have a programmed rest note for desired space. This solution lacked the precision to distinctly switch notes and produced slides whenever it was changing. Nevertheless, it was enough to provide a proof of concept for what the instrument would sound like, and the limitations of the machine such as speed between notes. Musically we were unable to complete three units due to time constraints and settled for one.

For future iterations the main improvements could include adjustable pressure per note, two more units, and most importantly precise solenoid control. When calibrating each note we found the desire to adjust pressure throughout the scale as opposed to just system wide. This would help with reliability, and allow for even more flexibility of tones to the composer. Two more units would reach our original goal and allow for the polyphony and harmony we originally desired. Lastly, getting the solenoid to only allow air when desired for a note would remove the undesired slides.

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