Sliding Harmonic Tubes

Jake Schwartz
WPI, Electrical and Computer Engineering
jlschwartz@wpi.edu

Owen Weber
WPI, Mechanical Engineering
oweber@wpi.edu

Sean Obert
WPI, Mechanical Engineering
smobert@wpi.edu

Matthew Cloutier
WPI, Electrical and Computer Engineering
mrcloutier@wpi.edu

ABSTRACT

This paper presents the background, design and implementations of a novel robotic musical instrument that is a modernized and automated version of the traditional pipe organ. The instrument combines elements of the traditional pipe organ and Drumbone among other influences. These are all combined to create a self-playing device that's capable of producing unique pieces of music. Utilizing PVC pipes, stepper motors, and pneumatics the system is able to adjust pipe lengths in order to change pitch and slide between pitches. These capabilities are not possible with conventional organs.

The instrument integrates MIDI control through Ableton to allow for easy control and syncing with other robotic and synthesized systems. The machine was built with PVC tubing for the pipes and 3d printed material for the reeds and mounting of components. The system features four pipes with a variety of pitches that have a timbre that sounds between a slide whistle and a pipe organ. While this project was mostly successful it included a few challenges that provide room for future development and improvements. The challenges identified were relating to air distribution, limited pitch range and integration of software and hardware.

1. INTRODUCTION

1.1 Purpose and Motivation

The goal of this project is to create a low-cost museum piece that can play unique music not playable by a traditional pipe organ. The instrument will combine elements of a pipe organ and a slide flute.

Unlike traditional pipe organs, the aim is to explore unique compositions that are not possible with conventional organ design. This includes being able to “slide” from one note to another, similar to a trombone or a slide flute. This instrument will be self-playing and include visually engaging moving pipes.

1.2 Prior Art

Traditional Pipe Organ

Figure 1: Traditional Pipe Organ

A traditional pipe organ is the most significant prior art for our project. The key features for this instrument consist of a set of pipes that each produce a single pitch [1]. These pipes are driven with pressurized air. The pipes are divided into ranks and stops and are controlled by multiple sets of keyboards. In more modern organs the pipes are opened and closed with solenoids. Pipe organs can have from a few pipes to tens of thousands of pipes [2].

Some advantages of a traditional pipe organ are that it produces a continuous non decaying sound unlike a piano. Also, the instrument is loud enough that in almost all cases it does not require amplification. The main disadvantage of the instrument is its complexity and size. Up until the late 19th century it was the most complex human-made device. Another disadvantage is that to play the instrument, either large air pumps or a group of people pumping baffles are required.

The reed mechanism and airflow of this instrument have provided influence on this project especially in the design of the excitation system.

Drumbone

Figure 2: Blue Man Group Performance Featuring the Drumbone

This instrument is made and most popularly played by the Blue Man Group, and it combines percussive sounds with sliding action of a trombone or a slide whistle. It is commonly made of PVC or other plastic pipes and makes a unique sound that can be played individually or in an orchestra. Because of its size and actuation, it also has a visual and performative aspect as it requires 3 people to play it [3].

The choice of PVC as a material for the Drumbone can prove to be a major advantage for saving price on high-cost projects. Additionally, the sliding action and the resulting pitch effects not only allow for a unique tone but also add a compelling visual aspect to the performance.

Pipe Organ Robots

Figure 3: Pipe Organ Robots

Pipe organ robots are compact, desktop miniature versions of traditional organs created using 3D printed parts. These robots aim to automate the performance of pipe organs by using solenoids to control the flow of air through the pipes, each of which is typically tuned to a specific pitch. The solenoids are activated by MIDI commands, allowing the system to play music without the need for human intervention [4]. They demonstrate how traditional instruments can be modernized and turned into automated robots.

One key feature One key feature of these mini robots is the inclusion of MIDI as an interface for fully autonomous control. Because of this, the machine can be programed to play parts that may be impossible for a human to perform. Additionally, it opens the possibilities for what human-robot performances can do. Like the use of PVC on the Drumbone mentioned above, the use of 3D printed parts allows for relatively low-cost prototyping and production. In this age, 3D printers are so prevalent that this makes the project more accessible to those that may not have the budget to develop an instrument using traditional manufacturing methods.

2. Requirements

2.1 Sound Characteristics

The timbre of the instrument should be between the sharp timbre of a slide whistle and the warmer tone of a traditional pipe organ. Each note on the instrument should be able to be sustained continually without fading. The pipes together should be able to produce a span of two full octaves which will allow for a broad range of pitches. The ability to slide between notes and play notes on and off while moving is also an important aspect in order to create the unique sound we are intending.

2.2 Interaction and Compatibility

The instrument should be fully automated with no human interaction requirement. In the context of a museum piece that is constantly in motion, it should be able to run autonomously with little interaction or maintenance. Also, being controlled by a computer opens up the ability to interact with other robots or computer-controlled instruments.

2.3 Aesthetic Goals

The main focal point of the machine should be moving components that can visualize the sounds being produced. This movement will create not only a unique auditory experience but also a dynamic and interesting visual experience for the audience.

3. Design and Implementation

3.1 Sonic Objects and Excitation

The sound-producing elements of this instrument are custom 3D printed fipples mounted to the bottom of PVC pipes. The length and diameter were chosen to produce specific ranges of pitches. The fipple is excited when solenoids are opened, allowing air to flow over the edge of the fipple.

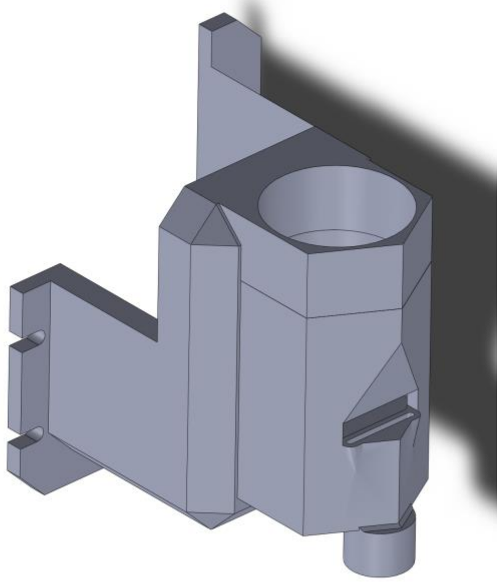

Figure 4: The fipple design of the smaller, higher pitched tubes also incorporated integrated mounting and a cutout for the NEMA 17 stepper motor housed underneath

3.2 Motion and Actuation

The motion of the pipes are driven by the use of stepper motors. In the small pipes, a closed loop belt and pulley system was used to push and pull the floating tube up and down the linear slide rails. On the large tube, though, the motion was driven by an open loop chain and sprocket system, also on a longer length of the same rail.

Actuation of each pipe is controlled by a pneumatic solenoid. When the solenoids are activated, air is directed into each pipe to produce a pitch.

Figure 5: The rough sliding mechanism for the smaller tubes. Belt and idler pulley not shown

3.3 Pipe design

During the design stage, several equations were found to predict the tone of a pipe based on the length and diameter of the pipe. Using this, pipe lengths were determined to allow for the desired 2 octave range. However, during initial prototyping and testing of these calibrated tube lengths, the pitches did not allign whatsoever. Additionally, it was found that the air pressure and sliding of the tube had a very unpredictable harmonic effect and it seemed as though random pitches would be played. Eventually, through trial and error in testing, a happy pipe length of about 430 mm on the high tubes and 1200 mm on the bass tube fully retracted was determined. Although, the pipes were still not 100% predictable and the desired pitch range was impossible. These pipes were later tuned and are capable of the following notes:

Pipe 1, 2: G#4, G4, F#4, F4, D4, C#4, C4
Pipe 3: D#5, D5, F4, D#4, E4, D3
Pipe 4: B3, C4, C#4, D4, D#4, A#3

For plumbing the pipes together, a singular large tank air compressor was used. Due to the size of the bass tube, it was expected to require more air, so the bass tube received its own outlet from the tank and hose. This tube also got its pressure control from the air tank regulator. All the remaining air was plumbed through a second regulator to further reduce the pressure for the small tubes. All four tubes also used their own solenoid to actuate individual pipes.

3.4 Material

The two main materials used in this build are PVC in the pipes and ABS plastic. Due to it's high strength and durability. ABS was chosen for many of the 3D printed parts with PLA serving as a replacement for parts that were not economical to build with ABS. For mounting and sliding the tubes, an extruded linear rail was used to maintain a straight path for the tubes.

3.5 Electrical

The electrical system integrates the stepper components, a solenoid, a limit switch and microcontroller together, A microcontroller sends signals to a stepper driver which then drive the stepper motor. The solenoid is controlled by the microcontroller through a N channel TIP31C MOSFET, and input is taken from a limit switch as well. ESP32s were chosen as the microcontroller due to their low cost and general ease programming. Two different sizes of stepper motors were used, NEMA 17 for the small pipes and NEMA23 for the larger pipe. Two different motor controllers were also required due to this. The motor controllers chosen were the TMC2209 and the TMC5160t plus. Each pipe has a completely separate control system with the only shared part being power supplies. 12 volt is required to control the solenoid, 24 volts is required to drive the motors as well as power the larger motor controller and 48 volts is required to drive the large NEMA 23 stepper motor. A diagram is shown below detailing an overview of the electrical system as well as the implementation of the system on a PCB.

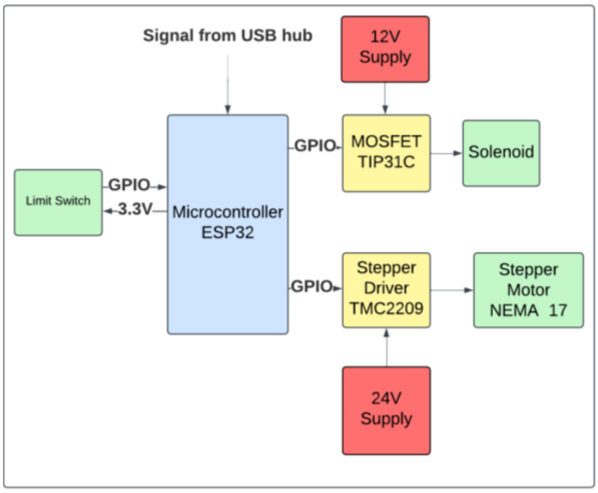

Figure 6: Small Pipe Electrical Flow Char

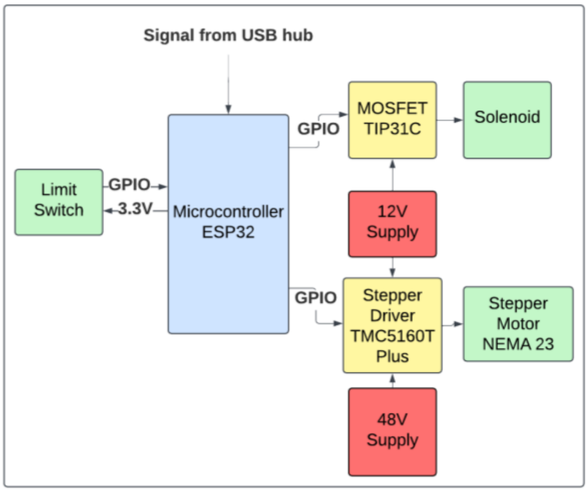

Figure 7: Large Pipe Electrical Flow Chart

3.6 Software

The software is designed to interface with Ableton and work with the instrument through a Max For Live linking program made by Scott Barton [5]. The software will take in midi commands and interrupt and convert them to steps for the stepper motor and also interrupt whether or not the solenoid should be activated or not. A homing processes was also developed to ensure that the tubes start at the same length at the start of every piece. After the pitches were tuned and the number of steps between each pitch was determined the notes were programmed as steps from the home position. An overview of this software process is shown in the diagram below.

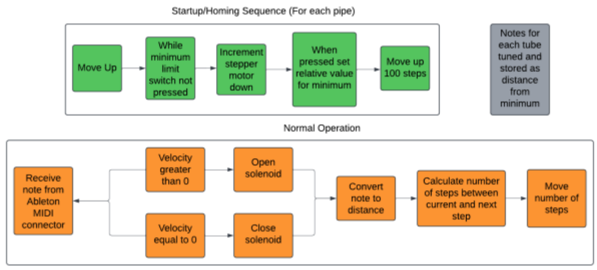

Figure 8: Software Overview Flowchart

4. Conclusion, Challenges, and Future Work

This paper has presented the implementation of a novel robotic musical instrument that integrates design elements inspired by a traditional pipe organ, MIDI-controlled mini pipe organs, and the Drumbone. The instrument represents a unique approach to automated music-making, blending acoustic principles with modern robotics and MIDI control. Unlike traditional pipe organs, this machine introduces the ability to "slide" between notes through a dynamic, linear motion system, creating continuous pitch transitions that are not possible with conventional fixed-length pipes. The result is an instrument capable of producing a distinctive timbre and playing styles. Its integration with MIDI allows for integration with other robotic and virtual instruments as well.

While this project has overall been successful several challenges were encountered during the process. These include power supply compatibility issues with the solenoid causing interference, programming difficulties with the larger stepper driver and issues with having too many MIDI devices to connect to Ableton. In addition to this there are a few challenges that could be improved in the future. One issue that should be explored further is proper pressure regulation for the individual tubes to ensure a consistent tone and air flow rates achievable. Another challenge faced was the actual pitch range of the instrument did not line up with what was calculated. This could be investigated further by looking into the relationship between pipe length, diameter and reed design. Addressing the challenges will expand the functionality of the instrument as well as the music making possibilities.

5. REFERENCES

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6. Appendices

Additional information on the project can be found in the below GitHub repository:
https://github.com/mrc624/Sliding-Harmonic-Tubes