Design and construction of a Trombone Robot

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ABSTRACT

Since the rise of electronic music in the previous century, people have sought to emulate the sound of known instruments for different purposes like sampling and perfect reproducibility. Thus, we now see a large variety of digital samplers that resemble the tone and character of real instruments. However, those samplers fail to deliver the same atmosphere as real instruments since loudspeakers can never emulate the same feeling and tone of the actual instrument. To close this gap, we propose a design of a trombone robot that can play music purely driven by the physical nature of the instrument itself, without the need for a digital sampler or even loudspeaker, but still fully programmable.
With our design, it is potentially possible to have a trombone automatically play simple melodies from MIDI files. The design is driven by pressurized air, pneumatic controls, electrical servos, a step motor, and is controlled by an Arduino device with a Python interface. Additionally, we show the implementation of the trombone robot and provide an overview of features that could further improve the usability and performance of the robot.

Keywords: Music Engineering, Trombone, Control Engineering, Pneumatics

PROJECT GOALS

The goal of this project was to build a fully automatic and controllable trombone robot, controlled by an Arduino device. The robot should be driven by pressurized air which enables the airflow through the instrument and also drives a pneumatic actuator for the trombone's slide. To control the positioning of the slide, a control mechanism, including a linear potentiometer, has to be implemented. To play the actual instrument, we planned to write a program that reads MIDI files and plays the notes accordingly. Furthermore, as an enhancement, we thought about attaching a MIDI keyboard to our device, to use the instrument as an analog MIDI player, however, this may be out of scope for this project.

STATE-OF-THE-ART

In the long history of music instruments, many people have tried to create automatic instruments. Some of them were novel designs, like the famous Marble Machine (link1) by Martin Molin and some were familiar instruments played by devices controlled by microcontrollers. A few examples can be found here (link2). However, there exist only very few versions of automated brass instruments. This may be due to the fact, that it is significantly harder to automate brass instruments due to the rather complicated role of the human lips for sound creation. However, we found some examples of a robot saxophone, a robot trumpet, and also a working implementation of a robot trumpet by a Japanese engineer who is known as tkrobosgru on youtube (link3, link4). Furthermore, in 2008, Toyota showed a trumpet playing ensemble of their Toyota Partner Robots playing a musical piece in synchronization and with high accuracy pitch (link5). These designs show, that it is in principle possible to realize our project. However, due to very little information online, we concluded that imitating the viabration of the human lips might be the hardest part of this project. A possible added value for our project could therefore also be a small study on suitable materials to emulate the physics of the human lips as close as possible.

METHODS AND MATERIALS

Besides smaller electronics and mechanical parts, these were the components used for the project:
1 Trombone, 1 Arduino Nano, 1 pneumatic actuator, 1 linear potentiometer, 2 solenoid valves, 1 servo motor, 1 step motor (incl step motor driver), 1 compressor, 1 latex sleeve (lips).

DESIGN AND CONSTRUCTION

As previously stated, the robot is mainly driven by pressurized air. Thus, besides the trombone, a compressor is the second key component. The compressor was used for two cases: The airflow through the artificial lips, providing the vibration that is needed to play the trombone, and also to drive the pneumatic actuator. We started to assemble the robot by installing the trombone on a stand and attaching the pneumatic actuator and the linear potentiometer parallelly to a mechanism that moves the slide (see figure 3). Attaching the actuator to a simple relay circuit with electronic valves lets us control the pressure on both sides of the pneumatic cylinder manually and move the slide by pressing two knobs.

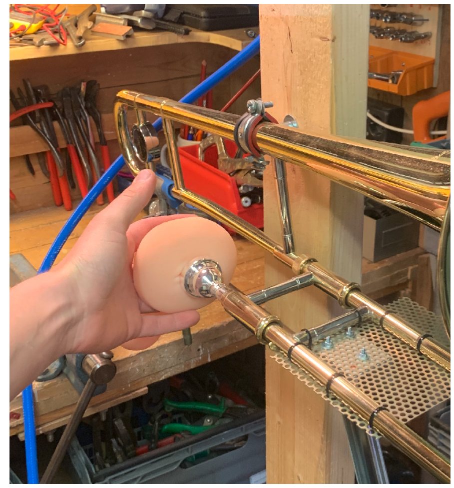
(a) View from the front.

(b) View from the side.

Figure 1. Assembly of the trombone including the pneumatic actuator (blue hoses) and the linear potentiometer (black cable)

To emulate the lips and create the right vibration needed to play the trombone, we first tried different materials like rubber bands or silicone hoses filled with water that we've clamped between an air outlet of the compressor and the mouthpiece of the instrument (see figure 2a) Caussé (2007)News (1999). However, none of the materials we used provided the right vibration to create a sound. A solution to the problem then was to use a latex sleeve that resembles a human mouth (see figure 2b).

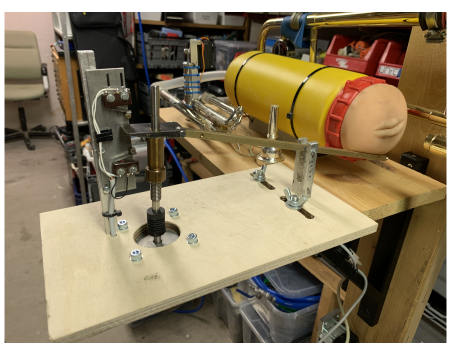
(a) Water filled silicone hose.



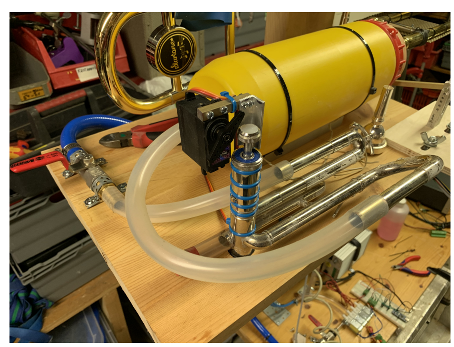
(b) Latex sleeve.

Figure 2. Different materials used to emulate the behavior of human lips.

To support the lips and also provide a resonance body, we've built a container that holds the sleeve with an air valve at the rear side. Furthermore, we've attached a *scissor mechanism* driven by a step motor to the mouth, to control the lips tension and play higher notes (see figure 3a). To switch the notes on and off, we've attached a valve from a trumpet to the air inlet of the container, which can be opened and closed with a servo motor (see figure 3b).



(a) Sleeve container with scissor mechanism.



(b) Air inlet valve controlled by servo motor.

Figure 3. Vibration and pitch producing units.

All the electronics were connected to an Arduino Nano device. The detailed wiring of the electronics and the programming are described in the next two sections. The first beta version robot can be seen in figure 4.

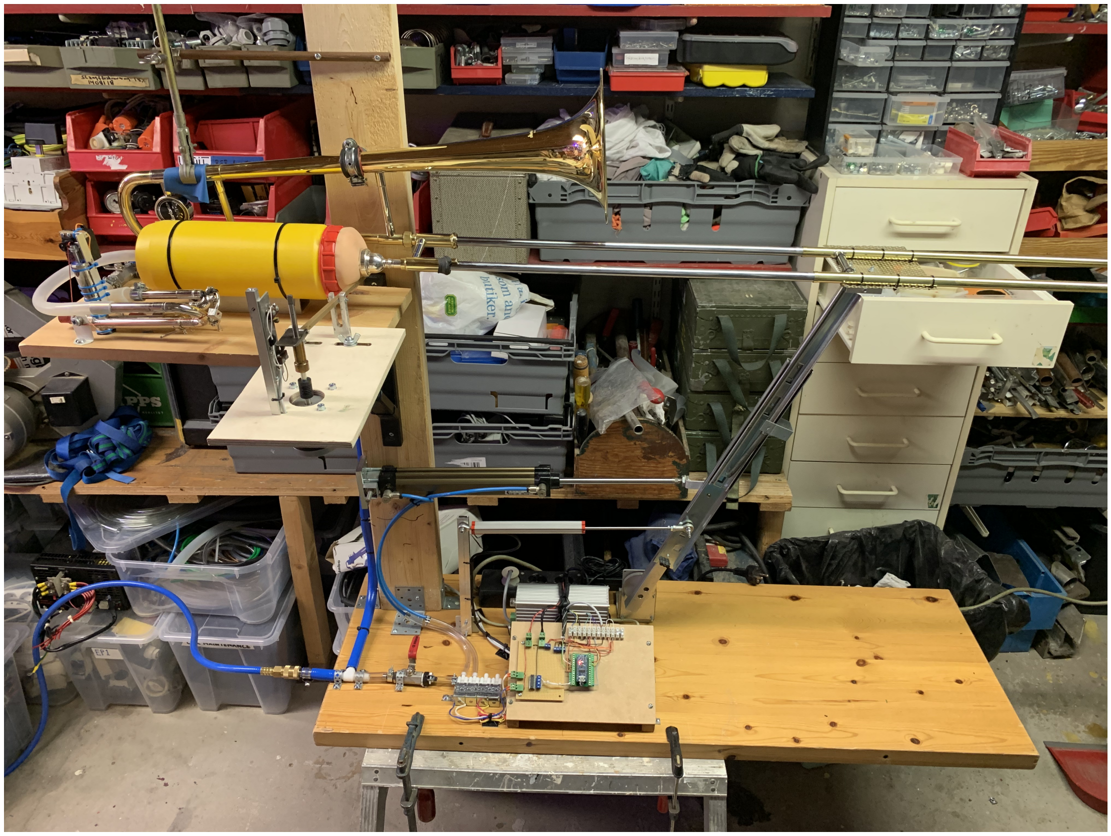


Figure 4. Beta version of the trombone robot.

Assembly of the mechatronics

The final implementation of the system differs a bit from the initial system sketch that we've submitted in the project proposal. Below is a sketch of the final system followed by an explanation.

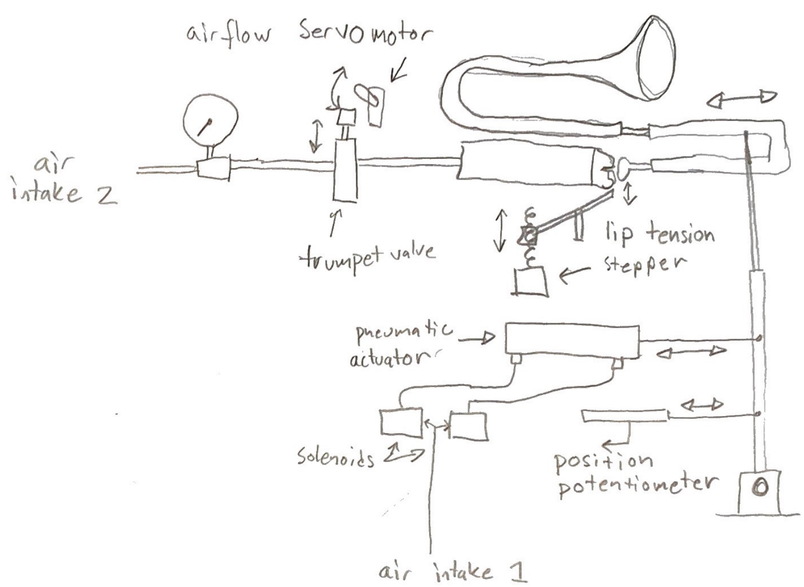


Figure 5. Final System Sketch

Let's follow the system along the two air intakes. Air intake 1 goes through a manual shut off valve (not in the sketch) and then supplies two pneumatic solenoids with pressure. When the Arduino gives a logic signal for the pneumatic actuator to move, it enables the solenoid corresponding to the desired direction and the piston moves. The position of the actuator is read by an analog signal from a linear potentiometer and fed back to the Arduino. Air intake 2 goes through a pressure meter and then into the trumpet valve. This valve is controlled with a servo motor directly from the Arduino. When the valve is on, air flows through the mouthpiece. Then there is the lip tension stepper motor with end switches on each outer position. If a switch is closed the Arduino will stop sending clock signals to the stepper driver and change the direction since it cannot move further.

Description of the control mechanism

In order to program the Arduino device, we flashed it with a so-called *Firmata* software that lets us communicate and control the Arduino in real-time with a computer. This has the benefit that we were able to write the controlling of our robot purely in Python, which facilitates, for example, the MIDI interface or other data structures. It would also allow us to implement more complicated control circuits, like a PID controller, for the positioning of the pneumatic actuator. However, due to the lack of a proportional pressure regulating solenoid valve, we could only implement a simple proportional control feedback loop, that moves the pneumatic cylinder to the left or the right, to reach the desired position. Unfortunately, due to the slow response time of a pneumatic system, this is not very precise and leads to an overshooting behavior of the actuator position if the air pressure and the valves are not thoroughly calibrated. With a proportional pressure regulating solenoid valve, we would have been able to control the speed of the pneumatic cylinder, which would allow a more precise and also faster adjustment of the trombone's slide.

Furthermore, we control the airflow through the artificial lips, i.e. the sound creation, with a trumpet piston valve to which we've attached a servo motor. By using a trumpet's piston valve, we can potentially allow intermediate flow rates by just pressing the cylinder down half-way. However, for the sake of simplification, we are only using a binary on-off setting here.

To control the tension of the lips, we've attached a *scissor mechanism* (see figure 3a) that allows putting more pressure on the lips, to play in higher vibrational modes and, thus, create higher pitches. This *scissor mechanism* is driven by a step motor, that can be controlled by a square wave signal and positioned accurately. However, this is a vast simplification of the mechanism of real lips which is controlled by many more muscles. Therefore, the creation of the right vibrational modes was the hardest part of the controlling and we don't consider our solution as optimal. A further improvement could be to attach more actuators to add more degrees of freedom to the controlling, rather than to have only one step motor for the *scissor mechanism*. However, this would be out of the scope of this project but could be carried on in a separate study.

FINAL RESULT

The final result of our work is shown in figure 6. To increase the sound quality, we've adjusted the tension of the lips and improved the *scissor mechanism*. Furthermore, we've replaced the original solenoid valves we've used for the pneumatic piston control by a pair of industrial valves. This enables us to adjust the speed of the piston more precisely and improve the slide positioning. Additionally, we've attached two pressure gauges to the robot: One to measure the pressure of the airflow through the instrument and one to measure the pressure on the solenoid valves. This enables us, to adjust the right pressure setting directly, without trial-and-error, and also adds a nice design feature in the *steampunk theme*.
Unfortunately, we were not able to use the robot as a MIDI player due to a lack of controlling precision. However, we've implemented a random cycle of different notes and rhythms, that creates music in the theme of *musique concrète*, which is still a huge achievement in our opinion. A video of the final result can be found here and a short showing of the robot here.

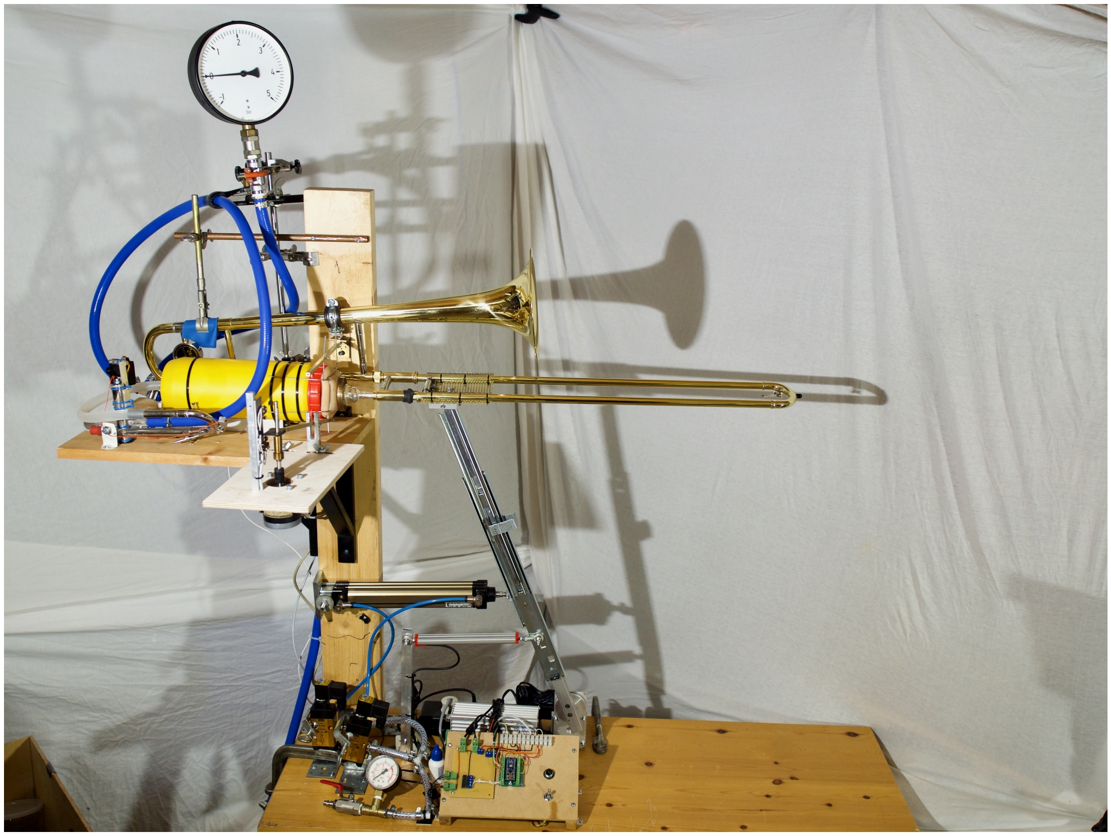


Figure 6. Finished Trombone Robot

OUTLOOK

Although we are very content with the outcome of this project, we still see a lot of potential improvements. First of all, the sound quality of the robot is not optimal. It is very difficult to find the right tension setting of the artificial lips. If the tension is too low, the tones created sound scattery and if the tension is too low, the vibration is to fast, to produce a typical trombone sound. A lot of research could go into finding an optimal system to emulate the behavior of real lips while playing a brass instrument.

Furthermore, the positioning of the slide could be improved. It would be beneficial to have a pneumatic actuator and a linear potentiometer that have the same range as the trombone slide. With the current design, we had to place the actuator and the potentiometer on a radial mechanism, which entails a large tolerance for the movement.

Additionally, the use of proportional pressure regulating solenoid valves for the pneumatic actuator would enable precise and fast positioning of the slide, enhancing the sound quality and increasing the possibilities to use the robot as MIDI player strongly.

ACKNOWLEDGMENTS

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