Next-Gen Voice Coil Percussion

By Raymond Carter, Te Lu, Tim Rinaldi, Zebang Zhang

Concept

The goal of the project is to design and build a novel percussion actuator with a higher precision than currently known other actuators such as variable impedance, pneumatic, soft robotic variable stiffness, and piezoelectric actuators. The focus of the project is to create more complex sounds than a simple hit on the drum and allow for more control in exciting percussion instruments. The end result will be a system easily programmable through midi in which pitch maps an event to a specific actuator and velocity directly corresponds to physical actuation response. Alternatively, the system can function by simply plugging in a headphone jack with a music player and the percussion robot will play along with the beat of the music. The team will explore the advantages and disadvantages of voice coil actuators and implement a control system with the acoustics of drums in mind. Additionally, the team will determine whether a viable actuator and or parts for one are available and affordable or if ones with the desired characteristics can be designed and manufactured reliably.

Motivation

Expressivity is a key component to what makes music exciting and engaging, especially at live performances. Humans are able to infuse their own creativity and emotional experience in a piece by manipulating the dynamics of their instrument. For this reason, increasing the dynamic range of intensities a drum can be excited at could benefit robotic drum sets by allowing more nuance and expression. Another essential part of expressivity is tone color or timbre, since hitting on different parts of the drum head can produce very different sounds. For example, while hitting the center of the drum and the edge of the drum are both a single hit for the robot, hitting the center produces a much more saturated sound and hitting the edge makes the sound that is quieter and in a different tone color. Another example can be the action of muffling frequently done by percussionists where they use their hand or some other object to produce pressure on the drum head and in turn produce a dampened sound when the drum is hit. Not only could this be utilized in pre-written midi, but also through interactive experiences where the intensity of the drums is adaptable and mirrors the excitement of an audience. Robotic systems are precise enough to overcome human limitations in terms of speed and accuracy but this can also be a downside if expressivity and nuance of performance is ignored. New actuation techniques could elevate robotic percussion systems from being sequencers to performers by adding back the human abilities of accents and variable power. For these reasons, "Next-gen" actuators could be tools for exploring new possibilities in robotic percussion.

Purpose

The purpose of implementing "Next-Gen" percussion actuation is ultimately to control characteristics such as pressure sensitivity, controlled velocity with a wider range, and a more predictable response. Some characteristics of actuators that will be measured and compared throughout the project include: max frequency, max frequency under continuous use, max velocity, dynamic range (expressivity), loudness of the actuator itself, and response time. Voice coils appear to be an appropriate choice for the following reasons: high-resolution, powerful, quiet, fast motion demands actuators with low position quantization, high acceleration, low mass, low friction, low hysteresis, direct control via current, no backlash. By designing the actuators, the team will have control over the visual aspect of the system. A goal is to improve the aesthetics of existing drum systems to be suitable for more interactive and captivating performances. The dynamics of drum acoustics and specifically of drum rolls and ghost notes, will be investigated for mechanisms directly interacting with the drum head (rather than with a stick). Similar types of articulations, including dampening and muffling the drum head while playing and varying the sounds by hitting different parts of the drum will also be investigated. Finally, a static system will be designed and built with the purpose of the robot being able to be universally mounted to many types of percussion instruments.

Prior Art

To determine the novelty of this project, few similar designs and resources were examined. First, the expression of mechatronic systems or robotic instruments was examined. Generally robotic instruments are implemented to be faster and more precise but other aspects such as articulation and dynamics are more complex. Expressivity in the context of musical robotics involves special focus on increasing parameters of controlling the instrument and the resolution of them. Meaning and emotion are transmitted from a performer to a listener when music is played but this cannot be accomplished with a robot built only for technical precision. One perspective, viewing expressivity as transitive, sees the relationship between performer and listener as one-way and describes that the expression of robotic performances are often dependent on the composer which leads to an experience for the audience that may feel distant. However, this may not be the case if expressivity is taken to be intransitive where a listener or viewer feels embodied through the music and can ascribe meaning to it which does not necessarily require the performer to have emotion. Sonic nuance and visual performance are two areas of focus that can enhance expressivity by allowing robotic performances to be anthropomorphized. Tension can also be built and released through purposely limiting the capability of robotic instruments at times.

Next, methods of evaluating musical robotic striking methods were explored, and some common actuators include linear and rotary solenoids, pneumatic actuators and servos. The actuators are determined by evaluating their characteristics such as latency, maximum loudness, dynamic consistency, and maximum repetition rate. The results of the evaluation showed that linear solenoids scored the best in low latency, pneumatic solenoids showed high loudness consistency, digital servos had a high dynamic consistency, and rotary solenoids had the best maximum repetition rate.

Beyond these traditional solenoid actuators, other novel actuation methods used in musical robots were also explored. Variable stiffness actuators, or VSAs, have the ability to control the position, force, and stiffness of the percussion robot at the same time. The mechanism of VSAs is similar to the human muscular-antagonistic mechanism, which makes it a good fit for simulating human-like motions. The percussion robots that implemented VSAs have also demonstrated the ability to perform double strokes, which has only been performed by humans before. This also shows the potential of the VSAs that they can be used to perform drum rolls by changing the stiffness to alter the response of the actuators. Another novel actuator that was examined was a drum piezoelectric actuator consisting of a short, thick-walled steel cylinder as shell with 2 thin composite disks in the middle. The thin composite disks consist of one ceramic shell and one piezoelectric disk. Polarizing the disk along the thickness direction to produce racial displacement under voltage, and the disk obtains large transverse deflection. The actuator obtains twice the piezoelectric charge coefficient compared to a cymbal actuator which consists of the same ceramic material. After that, a robotic drum machine with variable impedance actuators, or VIAs, was examined. It was demonstrated that the damping and stiffness of the VIAs can be altered by changing their impedance. While the simulations showed promising results and high potential of this type of actuator, the velocity range of the motors proved insufficient for the application. The VIA has also been proved to be able to produce the damped oscillations necessary for a double stroke roll, and this could be a potential design consideration in this project. Finally, voice coil actuators in percussion robots were examined. Voice coil actuators(VCA) offer another solution for the actuator technology besides solenoids and DC motors, as the simplest form of non-commutated motors, consist of linear motors with magnet and coil winding, and offer high-precision continuous linear control of motion with minimal power. VCAs (voice coil actuators) are useful for precision motion actuation because of their lack of mechanical hysteresis, torque ripple, and backlash. Some motion systems have demonstrated positioning accuracy of up to 0.5nm. Two requirements of VCA relate to force on the flexure bearing and heat dissipation. For this reason there is a tradeoff between dynamic response, acceleration, and heat dissipation. The governing equation is the Lorentz force resulting from current passing through a finite length conductor. The paper offers many graphs demonstrating tradeoffs and peak conditions of many design parameters, as well as the upper limits and constraints of a system being defined. These will be referenced later as we continue designing a system to meet our determined specifications.

Requirements

Timbral Variation

We would like to emphasize the timbral variation of our design, where the percussion robot can produce a variety of sounds rather than a simple hit. First, the robot should be able to hit the drum at different dynamics where the volume can be adjusted as needed. Next, as the timbre of the drum changes dramatically depending on the location of the hit, the robot should be able to reach multiple locations on the drum, especially the center and near the edge of the drum. Another way to create timbral variation is by hitting the drum muffled to create a dampened sound. The design should also add little to no noise to the system.

Dynamic Range

The dynamic change depends on the force or the velocity that the robot hit on the drum. As the actuator increases the force to hit on the drum, the dynamic range will change from soft to strong. Typically, a drum kit played by a human will produce a dynamic range between 90 dB to 130 dB, depending on which drum or cymbal was hit. In this application, the drum robot is only able to hit drums, not cymbals and it should not only produce loud hits, but also quiet ones to improve from the simple on/off action of solenoids. Thus, a dynamic range of 50 dB to 100 dB is required for the drum robot.

Drum Hit Speed

In this application, how fast the machine can play is limited by the voice coils. However, voice coils will be able to play at the faster speed than the solenoids since the lighter coil instead of the heavy magnet is moving. We would also like the robot to be able to achieve a max speed of 13 hits per second, and this translates to a 52 inches per second max velocity given the 1 inch of actuation distance. The machine is expected to have high temporal accuracy with a very precise control model. Latency wise, the machine will implement a low level control circuit, meaning that there is less processing and in turn creating less latency. An acceptable latency should be less than 50 ms.

Visual Aesthetics

Optimizing the visual experience of this robotic machine by incorporating more noticeable movement would be in conflict with the goal of its actuators, to increase precision and expressivity. This travel distance of the end effector is limited and the actuators must be mounted using a rigid frame. Despite this, visual interest can be added in other ways through the use of additional electronics. LED lights around the top of the actuator could indicate when hits occur and their color could be dependent on the velocity or intensity. As there would be multiple actuators mounted on each drum, if they are activated consecutively the lights would add movement and excitement. In darker environments, this dynamic lighting would bring performances by the actuators to life and allow listeners to visualize the sonic events occurring. This aspect of the design would be most significant in times of tension and release during a composition especially because of the increased expressivity given by color which would increase interaction with an audience.

User Experience and Usage Workflow

To increase the ease of use and the compatibility of the robot with virtual instruments and DAWs, the system should be programmable or controllable using midi. Presets of certain motions can be mapped to different keys on a midi keyboard, such as a hard hit, a soft hit, a drum roll, a flam, etc. There can also be certain actions of the actuator mapped to keys on the midi keyboard, such as lifting up, dropping, and hitting down the shaft. This allows for even more control over the robot. Controllable parameters include the power of lifting up or hitting down, the time it takes to lift up or hit down, and the duration of holding in place.

Preliminary Design

Actuator

To ensure voice coils were an appropriate actuation choice to meet the requirements proposed for the project, the following actuation techniques were analyzed: variable impedance, piezoelectric, pneumatic, hydraulic, solenoids, voice coils. The design matrix shown in figure **xx** assigns point values to desirable characteristics. Cells highlighted green represent 3 points, yellow represent 2 points, and red represents 1 point. Overall, it was determined that voice coil is most likely of the options to succeed in satisfying our requirements and is the best fit for this project.

	Variable Impedance	Piezoelectric	Pneumatic	Hydraulic	Solenoids	Voice Coil
Maximum Velocity	Medium	High	High	Low	High	High
Operating Loudness	Medium	Low	High	High	Medium	Low
Price / Manufacturability	Low	High	Medium	High	Low	High/Low
Latency	Medium	Low	High	Medium	Low	Low
Max Frequency	Low	High	Low	Low	Medium	High
Hysteresis	High	High	Low	Medium	Medium	Low
Position Precision	Low	High	Low	High	Low	High

Power consumption	Electric - Low	Electric - Low	Air - High	Fluid	Electric - Medium	Electric - Low
Size	Medium	Small	Large	Large	Small	Small
Travel Distance	Low/High	Low	Low/High	Low/High	Low/High	Low/High
Backlash	High	Low	Low	Low	Low	Low
Velocity Dynamic Range	High	High	Low	Low	Low	High
Score	24	30	21	20	28	35

Table 1. Actuator Application Design Matrix

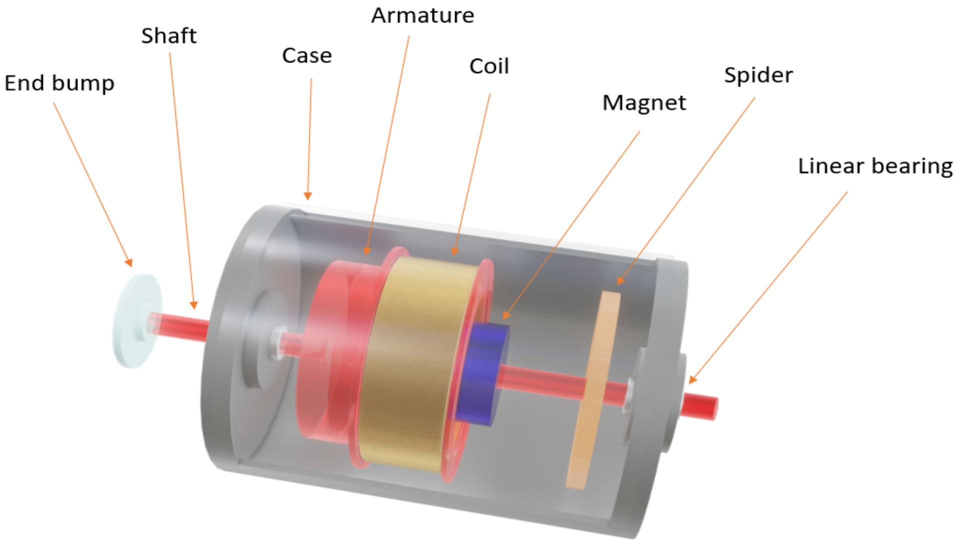


Figure x. Concept Next-Gen Voice Coil Design

Damper

As one of the main requirements of the drum robot, timbral variation can be created through a damping system. A C-shaped damper arm will be connected to and powered by a DC motor to apply pressure to the drum head, and in turn adds articulation. Applying different amounts of pressure to the drum head of drums such as toms can alter the pitch quite significantly. On the other hand, applying pressure to a snare drum can alter the timbre more, such as the duration of echos and rattles. The choice of a C-shaped arm is to ensure that the contact angle remains constant when the arm is rotated. The DC motor can be wired to the same motor controller as the actuator.

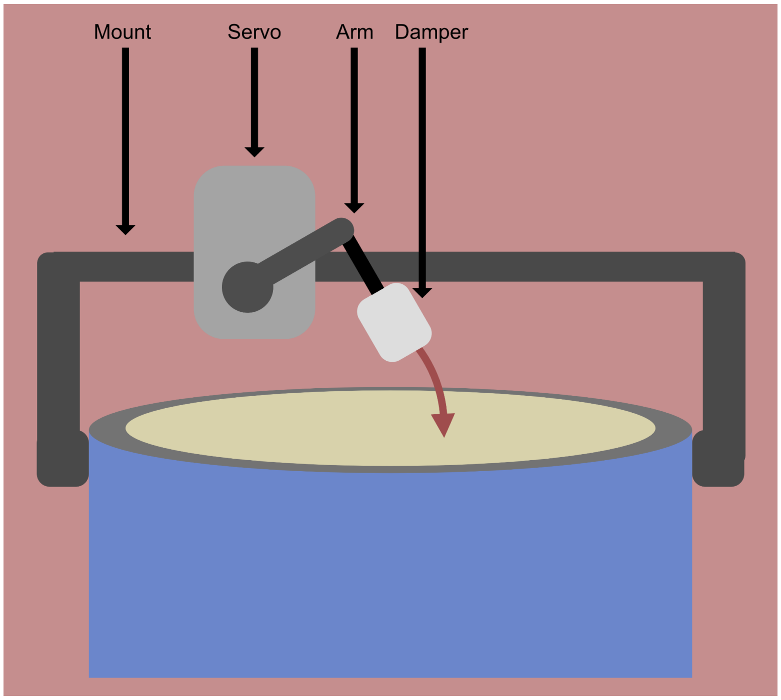


Figure 1. Concept Diagram of the Damper

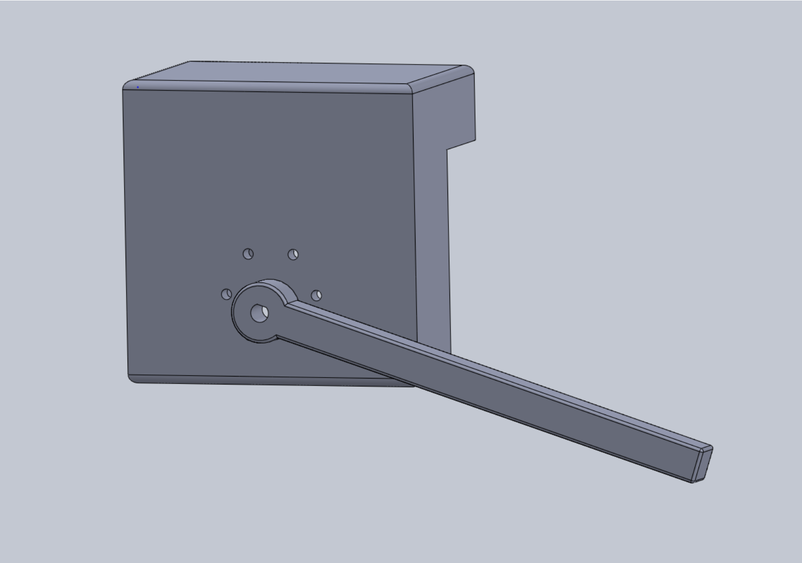


Figure 2. First Iteration of The Damper

Mount

The team has proposed three designs of mounting the actuators with varying complexities. A goal of the project is to increase expressivity not only through dynamics and precision, but also through exciting multiple different areas of individual percussion instruments. The simplest but most realistic design involves a set of multiple static and strapped down actuators held down with a universally fitting mount. Two other designs involve single actuators moving positions to hit different sections of a drum head and therefore achieve different sounds. The second design involves a rotating disk that is offset from the drum head such that an actuator can hit in multiple locations of a quadrant of the drum. The third system makes use of a four bar linkage with the powered joint rotating continuously and the end effector acting along an arc.

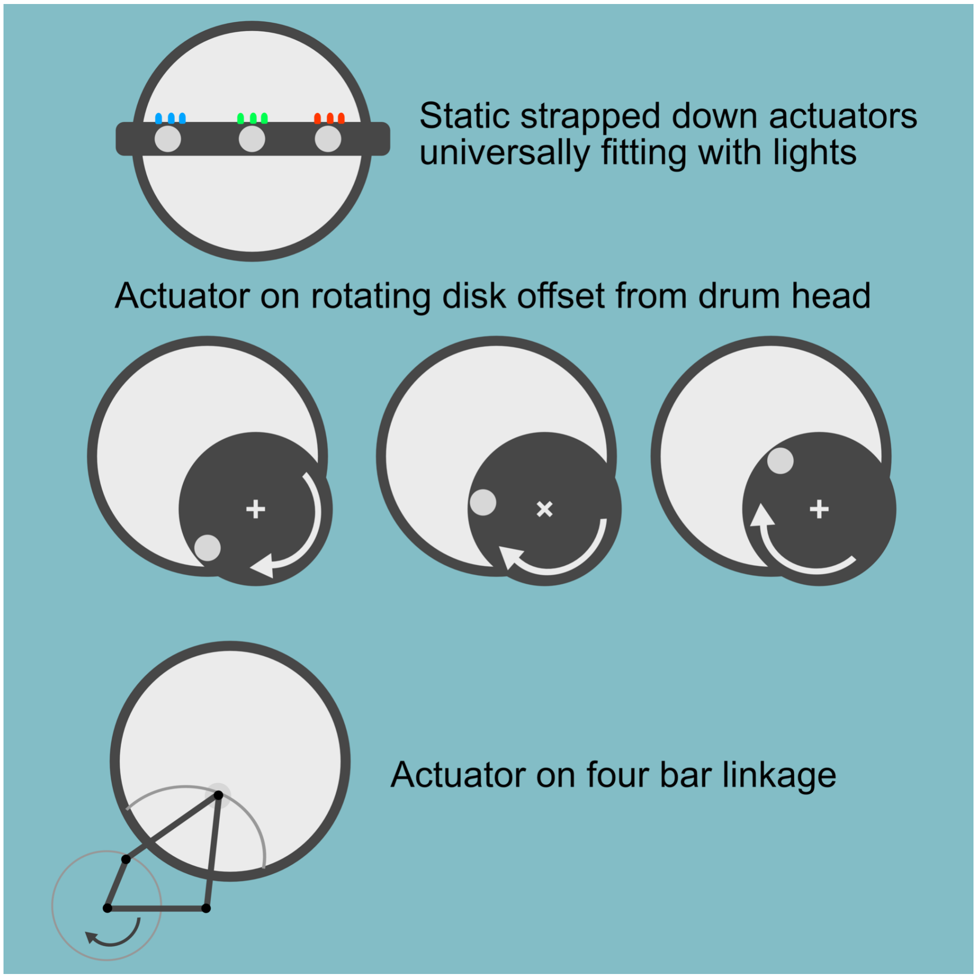


Figure 3. Three potential designs of the system

While these would be entertaining at a performance, incorporating multiple stages of actuators achieving precision poses issues that may be beyond the scope of the project.

Additionally, unless these were fast enough, events occurring at different sections of a single drum could not occur within a short duration of time. For these reasons, the first design was chosen so that the team could focus on elements of the project that would differentiate it from other percussion robotic machines.

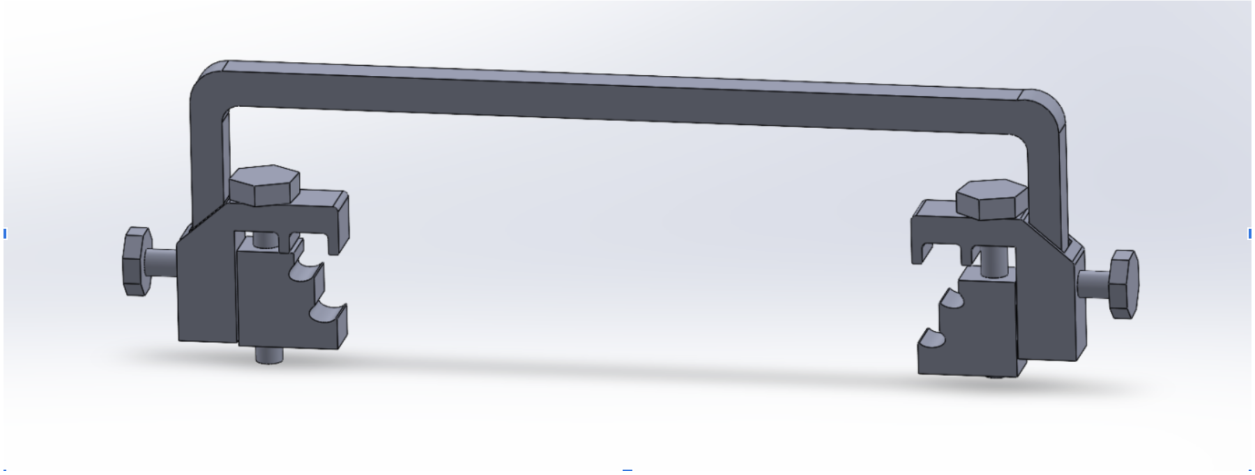


Figure 4. Concept CAD design of the mount

The 80/20 aluminum bar will have important roles in the whole system as it can fix both the actuators and the mounting system on the drums to make the robotic mechanics work well. All the cables and wires connected to the electrical components will go through the inside of the mounting system and be fixed tightly to avoid the loose wire affecting the performance of percussion. The majority components will be 3d printed components which is a good way to turn the sketch from the paperwork to a real object.

Electronics and Control

The first electronic control circuit consisted of a single RFP30N06LE N-channel mosfet to switch on and off the power to the voice coil. This mosfet can handle 30A at 60V. This control worked, but only delivered one direction control, which for the case of a voice coil, bi-directional was required.

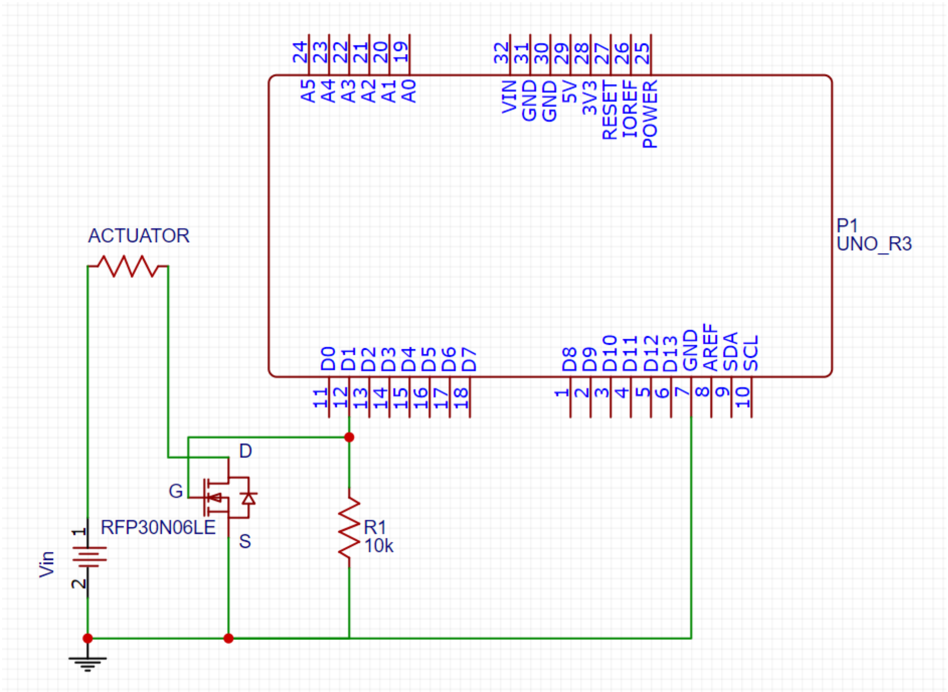


Figure 5. Wiring schematic for single direction control

What followed was an H-bridge of these mosfets to provide altering, bi-direcitonal control. This method worked, but the current draw proved problematic and control was unreliable.

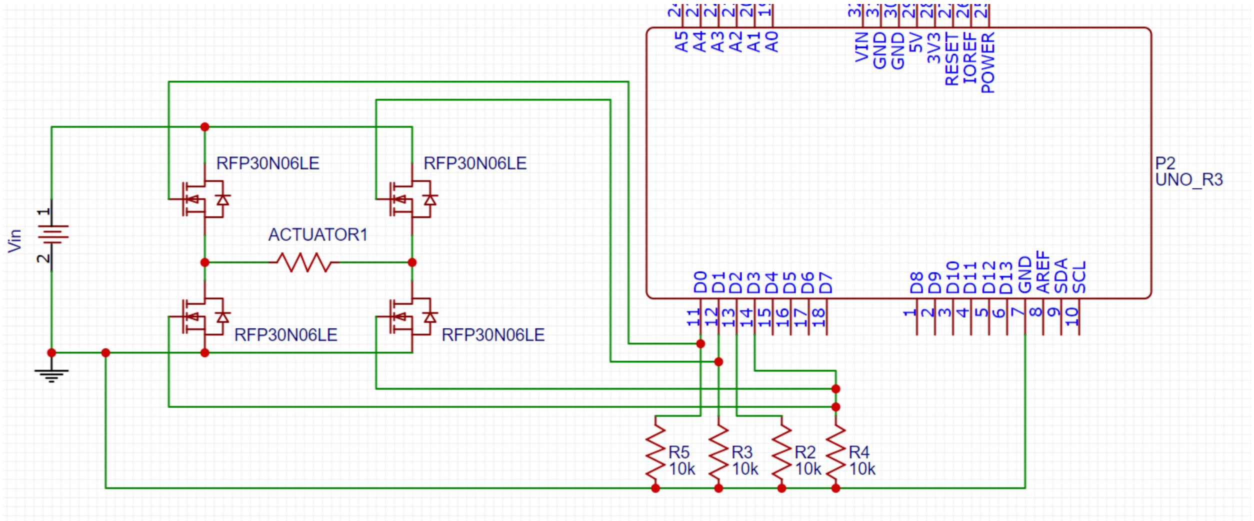


Figure 6. Wiring schematic for bi-directional control

After testing, diodes were recommended to be implemented between the pins on the microcontroller and the signals to the mosfets to prevent any chance of back-feeding. The team looked for a package that could do all of this that is already commercially available, so although this H-bridge circuit was workable, it was not utilized as a final design.

Lights

In order to incorporate aesthetic elements into the drum robot, the team proposed a jellyfish LED light strips concept. This was inspired from the analogous shape of a drum to the head of a jellyfish. There will be LED light strips hanging down from the bottom of the drum to simulate the tentacles of a jellyfish. To improve upon the performance aspect of the robot, the concept was whenever the drum is hit, the light strips will light up in a sequential manner, just like the light pulses of a jellyfish.

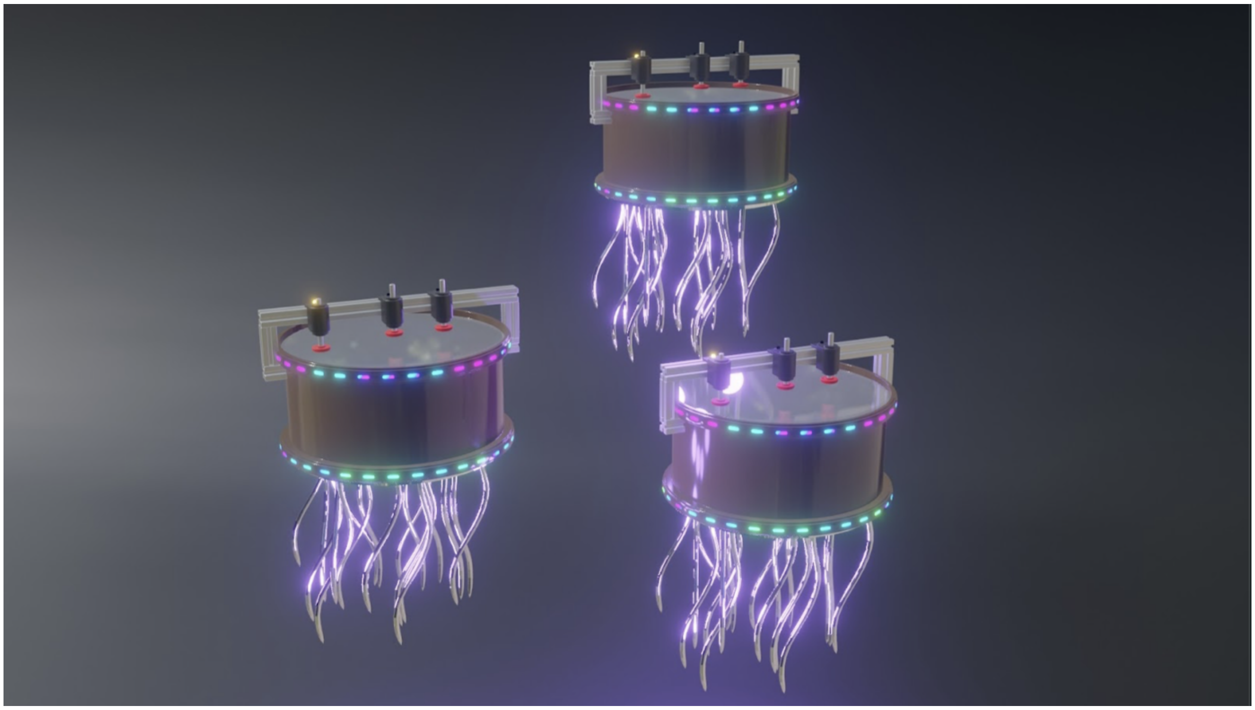


Figure 7. Jellyfish concept image of the LED light strips

This lighting setup will be realized using a microcontroller which will determine the brightness of each LED. To achieve a cascading effect where the LEDs are sequentially lit from the top to bottom, emulating a wave going through a jellyfish, the LEDs will be individually addressable. The wiring diagram below indicates how the communication will occur through a serial to parallel shift register.

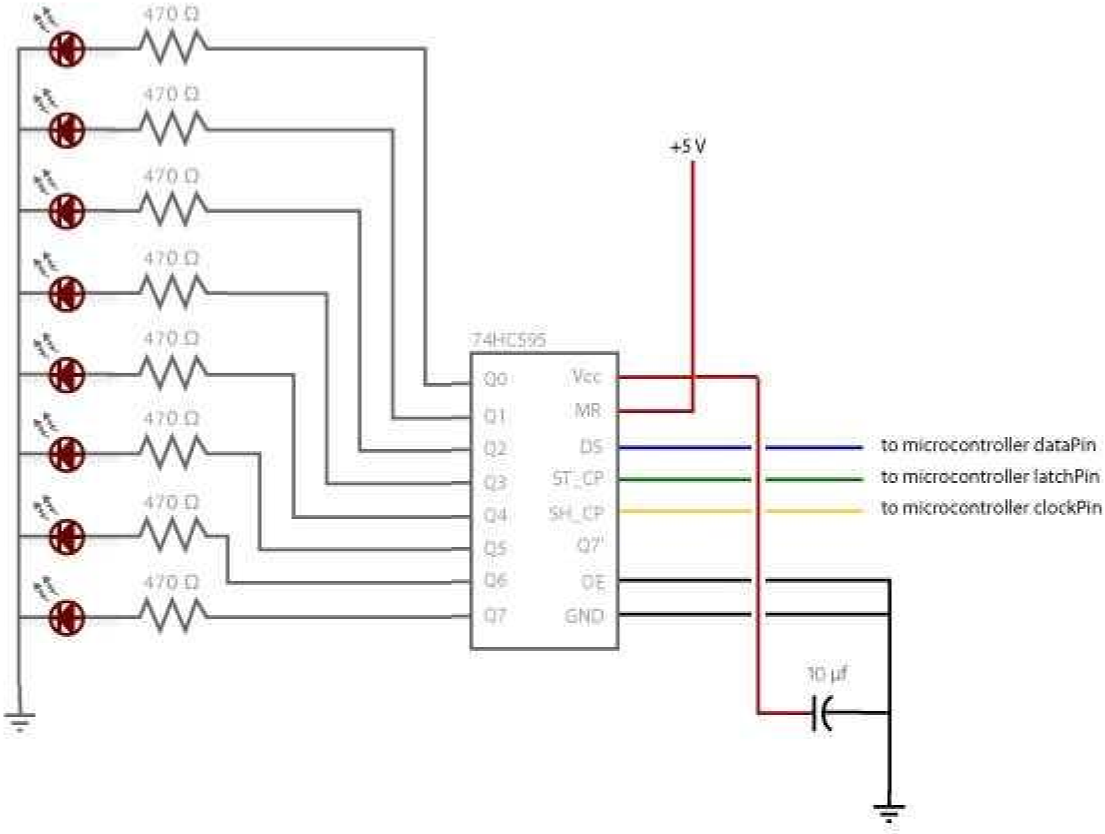


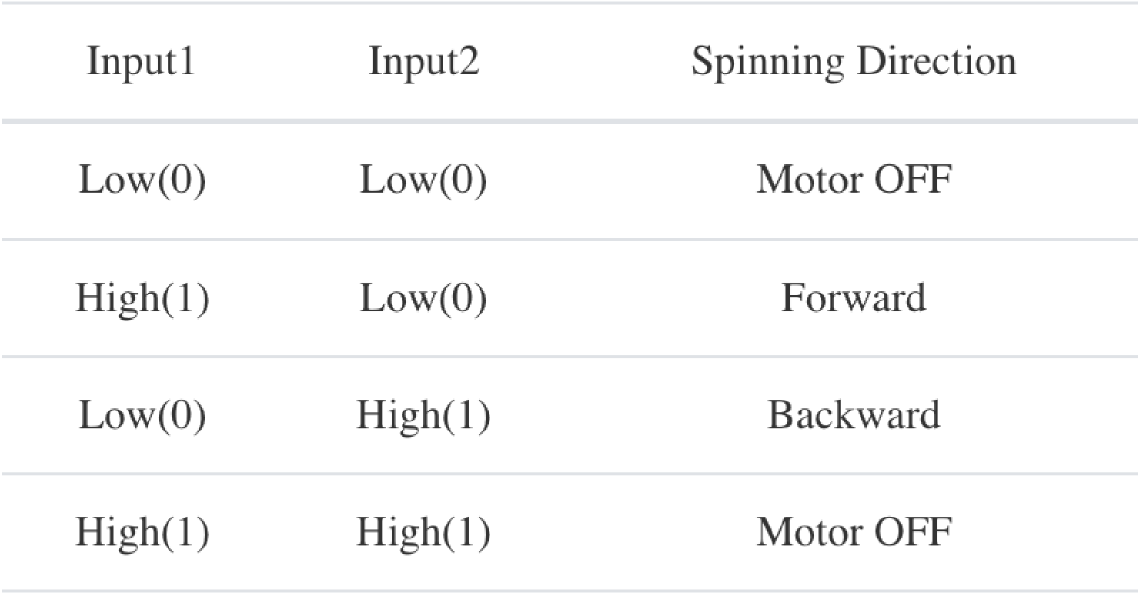
Figure 8. Lighting Wiring Diagram

The light pulses are triggered the same way as the actuator, with midi notes. Different gestures signal the pulses to occur at differing speeds so a viewer is able to associate what they are seeing with what they are hearing.

Final Design Modifications

Electronics and Controls

The system dynamics and power range of the designed voice coil actuator were unknown at the time of preliminary design, but after experimentation it was determined that it can meet required speeds at 2A 12V. The first iteration of the voice coil was less efficient and required 5A to meet the same standard. Additionally, its control method and dynamics changed in the newest iteration. Originally, power flowing one direction through the coil caused it to be attracted to the center of the cylinder, half of its stroke length. When power flowed the opposite direction, it repelled the center and moved to whichever end of the actuator it was biased towards. This behavior complicated control because it required power direction to change not once, but twice to accomplish a stroke. The most recent design does not have this behavior and is approximately half the size. The control of position in time is governed by the direction and magnitude of current flowing through the coil where each direction corresponds to the shaft reaching an end of the actuator making a full stroke. For this reason, an H bridge circuit was utilized for powering the voice coil. An L298N motor controller supplies sufficient power and can be controlled by a microcontroller with PWM. Two pins on the board govern direction and control if the actuator is powered as displayed in figure **xx.**



Input1	Input2	Spinning Direction
Low(0)	Low(0)	Motor OFF
High(1)	Low(0)	Forward
Low(0)	High(1)	Backward
High(1)	High(1)	Motor OFF

Figure 9.

An Arduino Uno was the chosen microcontroller and is wired to the motor controller, the lighting circuit, and two sensors. It is also wired to the computer it is controlled by over serial communication. It outputs a PWM signal to control the power of the voice coils. Because motors and actuators are currently limited, power output can be controlled through quickly cycling power input on and off in bursts. The relationship between PWM output on the arduino and the speed and force of the actuator is unlikely to be linear and must be mapped and calibrated to be used effectively.

Behavior

A full hit of the drum, or repetition of hits, is controlled by time parameters and intensity parameters. Initially, before powering, the end effector is resting on the drum due to gravity and must be pulled up before a strike. To strike, power can be turned off so that the end falls to hit the drum unforced, the coil can be powered in the opposite direction for a more forceful hit, or any combination of the two can be accomplished by specifying the amount of time to pause before powering. This occurs on the scale of ms and must be timed precisely to achieve wanted sound. Immediately after the end strikes the drum any combination of three things can occur. Power can be maintained so that the voice coil muffles its own hit, it can be immediately pulled back to accomplish another stroke, or it can be unpowered and left to bounce and rebound from the surface of the drum. Each of these actions have an impact on the timbre and articulation of the drum hit and demonstrates the strengths of utilizing voice coils over traditional solenoids. This does however make a control loop necessary, and complicates software design.

Sensors and Feedback

While the original design plans involved using only a Sharp IR distance sensor to achieve feedback of the position of the end effector, its minimum distance reading must be at least 7cm away. This is because the sensor's readings become nonlinear at distances shorter than its focal point. To accomodate this two actions were taken. The sensor was positioned to face upwards so that the end of the shaft not hitting the drum's distance could be measured at a farther distance. Additionally, a time of flight laser sensor was utilized inside the voice coil that only required a 3cm minimum range. Both sensors are implemented to optionally be utilized in a control system.

Software Design

To control the drum machine for composition and performance, a Max For Live patch running inside Ableton Live converts midi information from the DAW to serial information sent to the arduino. The Arduino maintains the control loop that occurs in which signals are sent to the motor controller to power the actuator moving the shaft which the sensors detect and send distance information back to the arduino in result. The arduino utilizes velocity and pitch information over midi to control the type, timing, and intensity of drum hits. Figure **xx** depicts waveforms to visualize how the input parameters of the voice coil in time affect the type of drum hit that results.

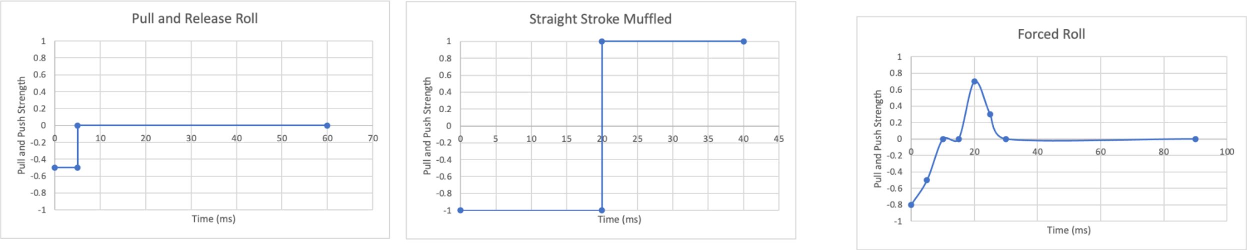


Figure 10.

Because of the large range of sounds the instrument can produce, the full range of octaves on a keyboard are utilized. While the velocity of a note hit is an effective control method, some hits have a preset velocity which is controlled by the midi note as some gestures are only effective at precisely defined speeds.

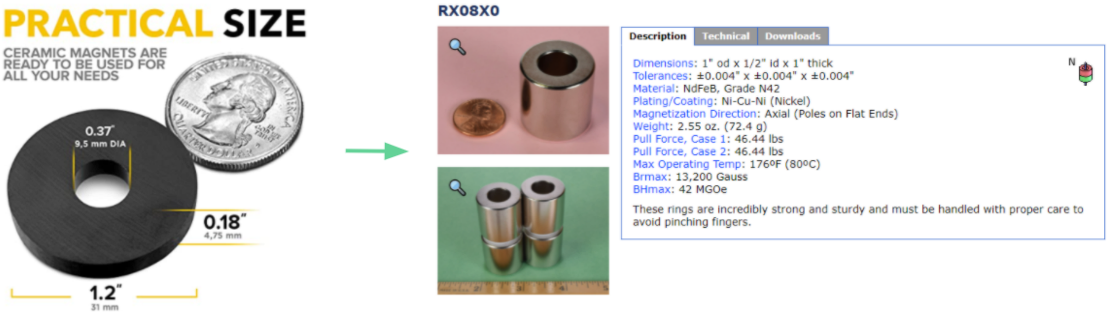
Limiting Mechanical Noise

One concern with the actuator involves the mechanical noise it adds to the performance. While some musical machines are designed with the added noise in mind, the purpose of this actuator is to increase the nuance and control over percussion instruments and for this reason the sound of its actuation should not overpower the sound of the drum. The actuator design has undergone multiple iterations with differing shafts and internal materials to limit the mechanical sound produced at high power and frequency. While linear bearings mitigate much of the sound, the internal shaft still rattled within it. To reduce this, the material TPU was used as it is more pliable and absorbs more of the horizontal vibrations that occur with the vertical stroke. The PWM frequency that the Arduino uses to control the power of the motor originally produced a high pitched hum. To reduce this, the frequency was increased to over 30kHz which is outside the range of human hearing.

As the purpose of the instrument is to surpass the limits of solenoid and other actuator driven percussion instruments, fine control of the speed and power is necessary. While power to the actuator is determined by the PWM signal sent to the motor controller, the resultant actuator hit force and velocity do not scale linearly with power. This is due to dynamics introduced by magnetic induction that occurs within the actuator which follows an inverse power law. To allow fine control of force and velocity, a function was written to convert a float value between 0 and 1 to a byte (range 0-255) controlling PWM frequency. To determine the function mapping these values, we tested the actuator at various powers finding that 150 was the lowest value that the actuator reacted to. Knowing that the PWM range was between 140 and 255, the following function was determined to make the relationship between desired velocity (range 0-1) and PWM value linear: PWM_val = 140+115*v^2. Overall, determining the relationship between power and velocity assisted in the control of this instrument as the midi velocity information can be used to control the drum in an intuitive and straightforward manner.

Magnet and Coil Changes

The first design of the Next-Gen VCA included two ceramic disks with a pull of around 1 pound per. The team stacked more magnets to increase the magnetic field inside the VCA, which dramatically increased performance. The coil winds on the first coil were around 20 winds with a length of around 2 inches. After testing this configuration, the VCA was able to push and pull with an average current draw of 3 amps. This design was improved upon when upgrading to neodymium as the magnet source type. Neodymiums have a much higher energy density, which allows them to have a much higher pull force at the same size. The team chose a 1” x ½” x 1” neodymium ring magnet, which alone can pull around 46 pounds. This greatly improved performance because of the increased permanent magnetic field. Having a higher magnetic field allows for less current amount needed to drive the coil in the actuator.



Dimensions: 1" od x 1/2" id x 1" thick
Tolerances: ±0.004" x ±0.004" x ±0.004"
Material: NdFeB, Grade N42
Plating/Coating: Ni-Cu-Ni (Nickel)
Magnetization Direction: Axial (Poles on Flat Ends)
Weight: 2.55 oz. (72.4 g)
Pull Force, Case 1: 46.44 lbs
Pull Force, Case 2: 46.44 lbs
Max Operating Temp: 176ºF (80ºC)
Brmax: 13,200 Gauss
BHmax: 42 MGOe

These rings are incredibly strong and sturdy and must be handled with proper care to avoid pinching fingers.

1.11875 lbs Pull :(

46.44 lbs Pull!!! :)

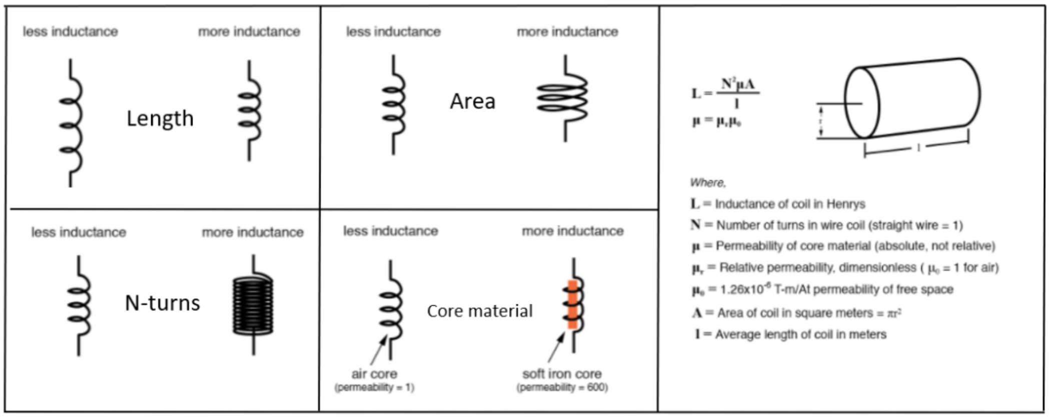
Figure 11. Old ceramic magnet versus new neodymium magnet

The team also greatly improved the coil winds to 150 turns. Both factors greatly improved the actuator with drawing an average of 1.1A with the same push and pull force performance as the last design. The final design had a dramatic weight reduction in the armature, which allowed for the force to be less when powering the coil, which in result made the resulting output force greater. The team stuck with the neodymium ring magnet, but widened the coil length for higher control resolution, and increased the turns to 200. All of these factors greatly improved performance and the resulting current draw average came to less than an amp for the same performance as the previous designs. Each design improved on inductance greatly, which decreased input current. Factors including coil length, area, turns, and core material greatly changed the inductance.

Nex-Gen “VCM” - explained

$$\vec{F} = \int_U I\, d\vec{u} \times \vec{B}$$

Governing equation is Lorentz force (dependent on current)



$$L = \frac{N^2 \mu A}{l}$$

$$\mu = \mu_r \mu_0$$

Where,

L = Inductance of coil in Henrys
N = Number of turns in wire coil (straight wire = 1)
μ = Permeability of core material (absolute, not relative)
μ_r = Relative permeability, dimensionless ($\mu_0 = 1$ for air)
$\mu_0 = 1.26 \times 10^{-6}$ T-m/At permeability of free space
A = Area of coil in square meters = πr^2
l = Average length of coil in meters

\

Figure 12. Contributing factors of coil inductance

Actuator Iterations

With each actuator iteration came better efficiency, lower costs, and less material. The Next-Gen VCA started as a simple cylindrical design to prove the concept of this type of actuation at the 3D printed level. After printing and testing this design it proved quite effective, but it could be much improved upon. The following designs each improved on elements missing from the previous.

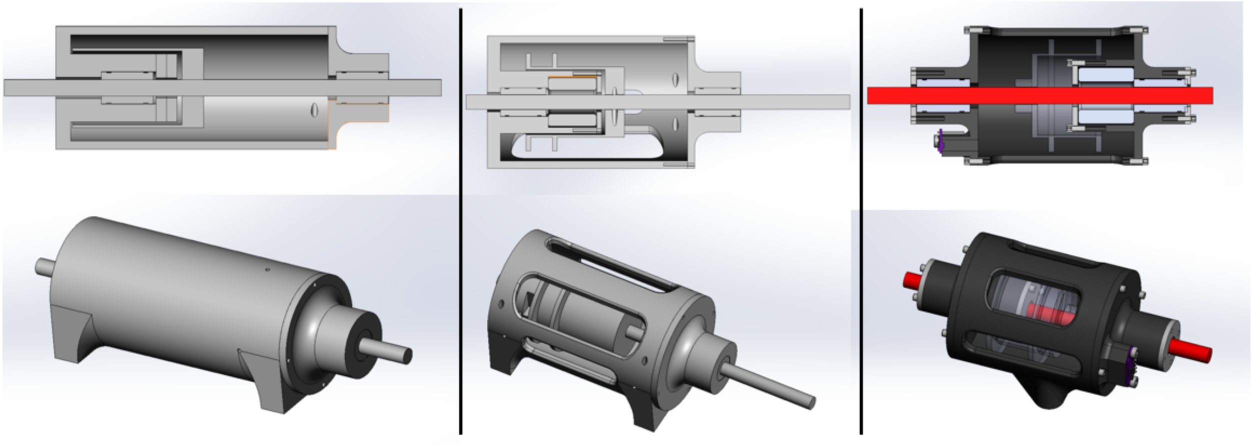


Figure 13. Design history of Next-Gen Voice Coil Actuator

The second design was able to showcase the internals of the system through cut-outs, adding to the performance aesthetics. The diameter of the armature was increased with a decreased length due to the change in magnet. The overall length was also greatly reduced. In this design though control was problematic. The magnet was placed in the direct center of the case. This meant that when the coil was sent with a certain polarity the coil attracted to the center, but when switched polarity the coil repelled. The problem was that the repelling was not controlled to a certain side.

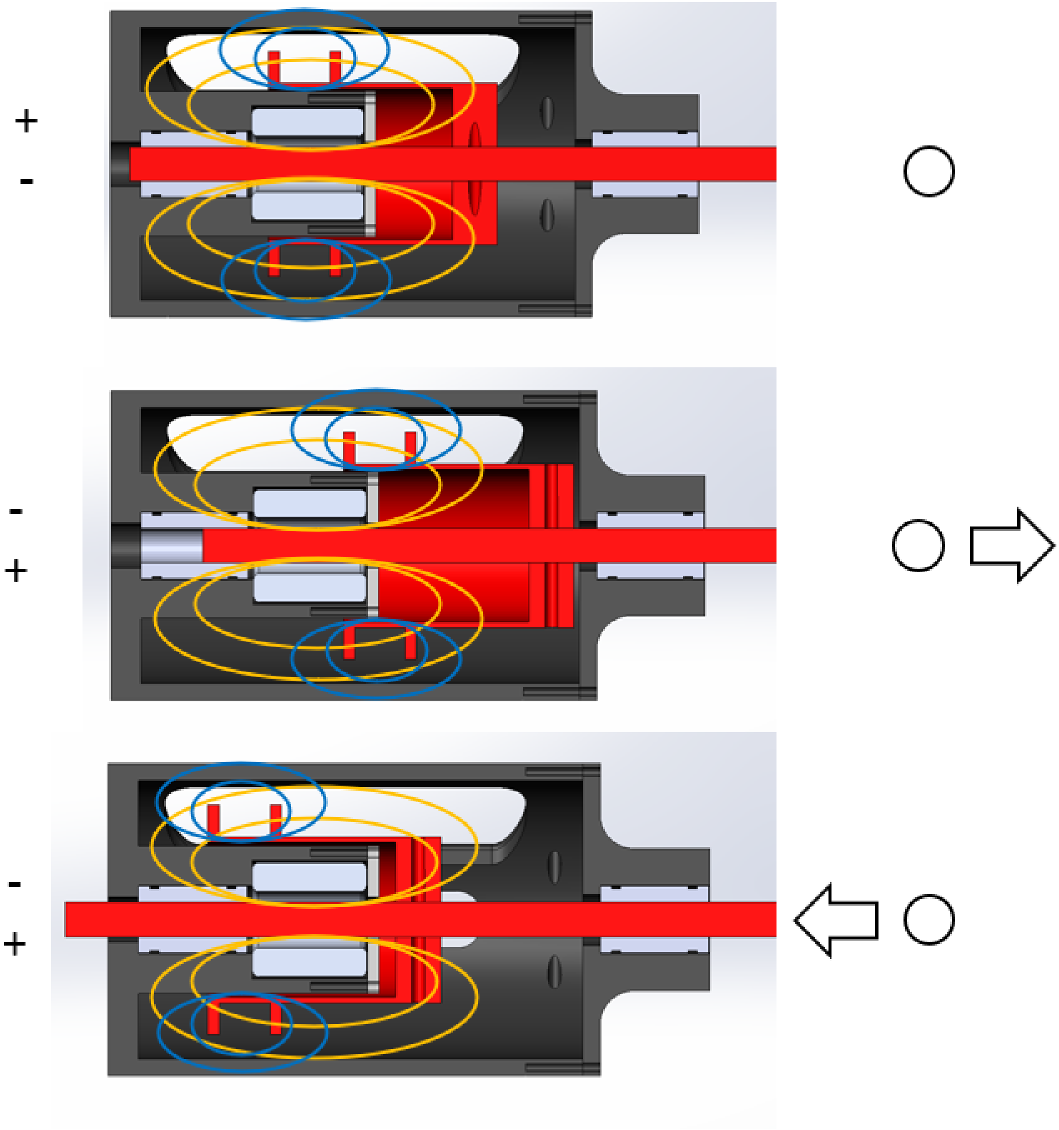


Figure 14. Next-Gen VCA v2 polarity results with magnetic flux lines

Controlling this three position actuator with a two position controller wasn't effective and thus the design was altered.

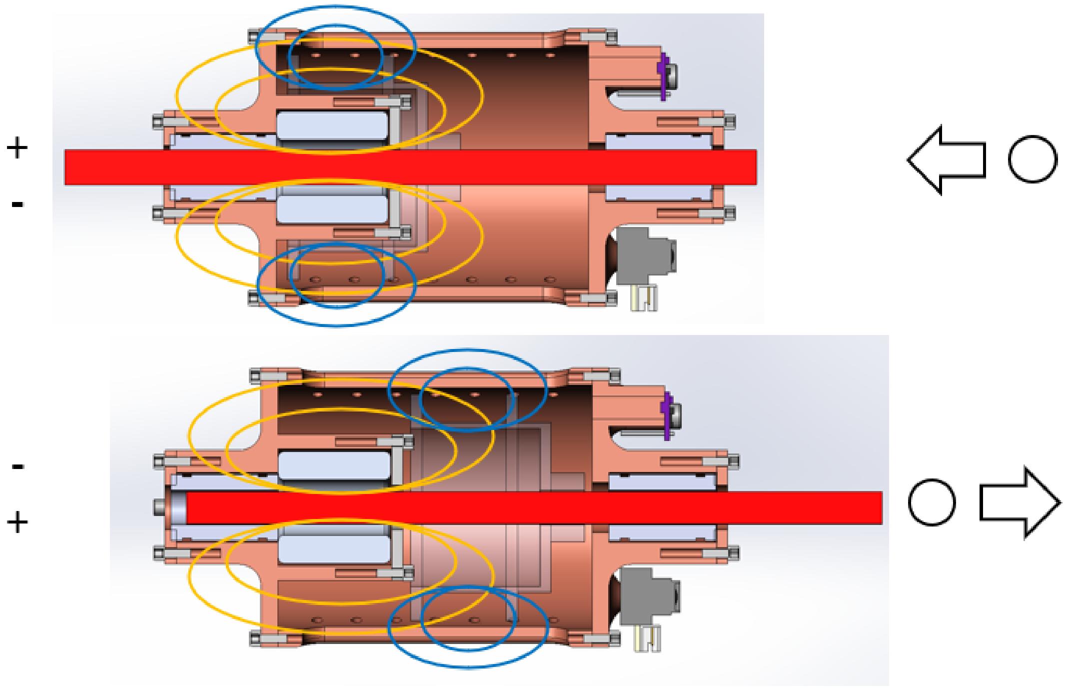
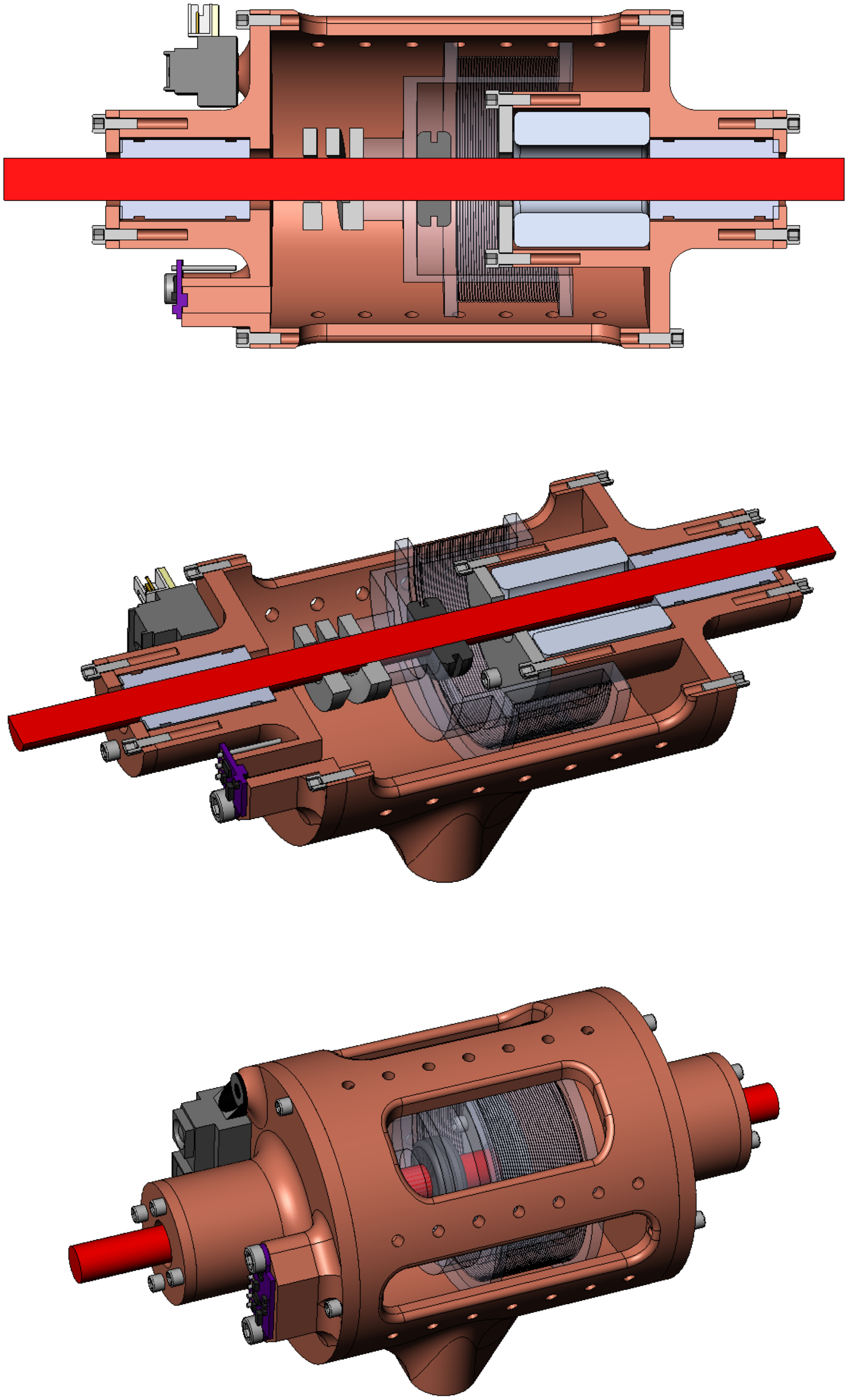


Figure 15. Next-Gen VCA v3 polarity results with magnetic flux lines

The Next-Gen VCA v3 altered the placement of the permanent magnet by shifting it to one side. This forces the coil to never move past the toggle point of the magnet's polarity, thus resulting in two position options. This design is optimal for the controller and makes the control operation much easier and predictable. The v3 also incorporated a Sharp GP2Y0A21YK0F distance sensor along with a VL53L0X TOF laser sensor to measure the distance traveled by the armature. This allows for future position control and PID control possibly. The v3 design is compact and extremely lightweight due to halving the size, thickness and increasing viewing hole sizes. Although the material was reduced, the design is sturdy and elegant as seen in stress testing.



Figures 16-19. Next-Gen v3 actuator final design

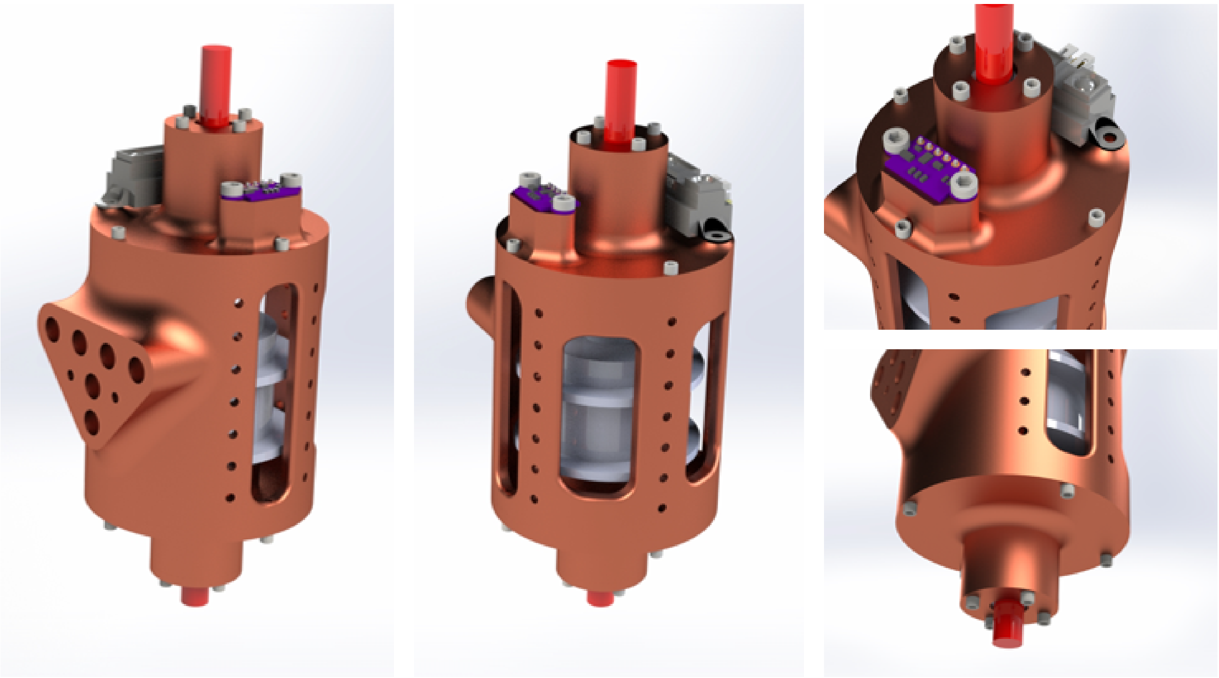


Figure 20. Next-Gen v3 actuator final renders

Mounting System

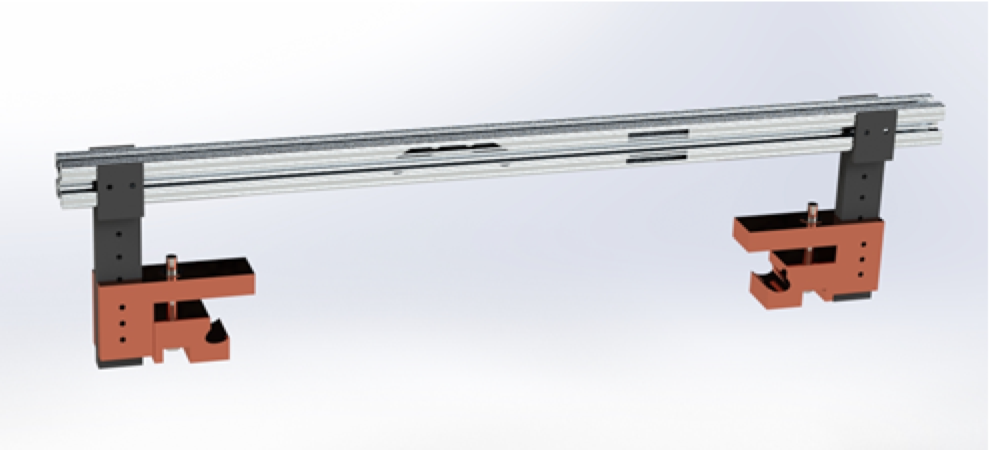


Figure 21. Next-Gen v3 VCP mounting system

The mounting system is used to fix and support the 80/20 aluminum bar on the both edges of the drum without touching the drum heads. The estimated total weight of the aluminum bar, actuator and the damper is more than 5 pounds. In order to distribute the weight of the items evenly on both sides of the aluminum bar, so that the system will not be damaged due to uneven weight distribution. Also, the length of the aluminum bar should be the same at both ends of the part.

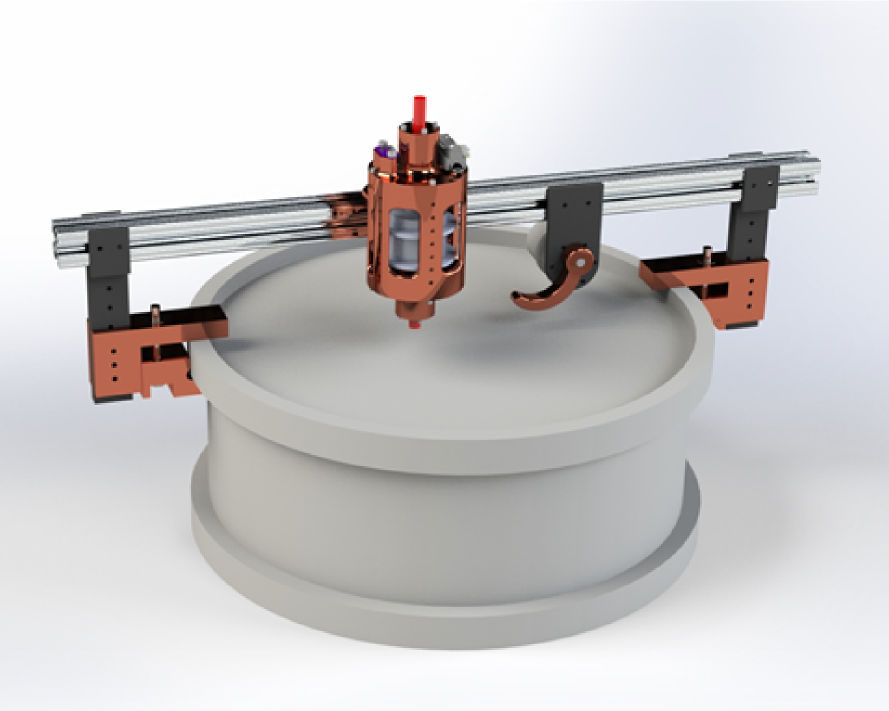
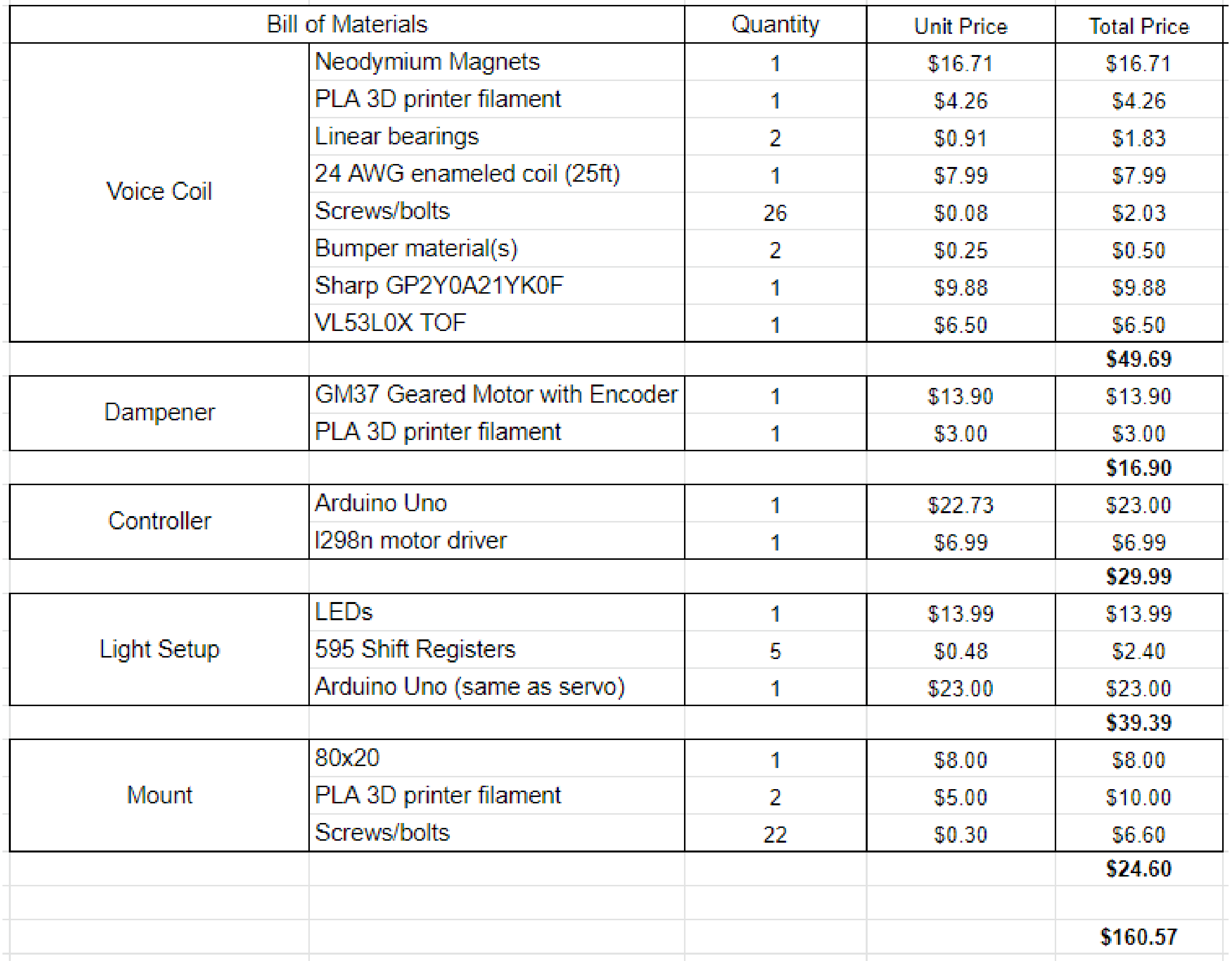


Figure 22. Next-Gen v3 VCP full mechanical system

The entire system was split into three parts (base, hold and splint) in order to avoid damage to the support due to torque, ensuring that individual parts are not subjected to excessive forces from different directions.At the same time, each single parts will be screwed by bolts and nuts (M7 size) to ensure that all parts are connected as a whole part. The shape of the base has been specially designed with a hook-like shape that allows the front end of the base to be inserted into the gap on the drum edge, allowing the system to grip and not fall off. In addition to this, small holes have been individually cut in each part, enabling the user to adjust the distance according to the size of different drums. Thus the mounting system can be used on different sized drums.

Bill of Materials



Bill of Materials		Quantity	Unit Price	Total Price
Voice Coil	Neodymium Magnets	1	$16.71	$16.71
	PLA 3D printer filament	1	$4.26	$4.26
	Linear bearings	2	$0.91	$1.83
	24 AWG enameled coil (25ft)	1	$7.99	$7.99
	Screws/bolts	26	$0.08	$2.03
	Bumper material(s)	2	$0.25	$0.50
	Sharp GP2Y0A21YK0F	1	$9.88	$9.88
	VL53L0X TOF	1	$6.50	$6.50
				$49.69
Dampener	GM37 Geared Motor with Encoder	1	$13.90	$13.90
	PLA 3D printer filament	1	$3.00	$3.00
				$16.90
Controller	Arduino Uno	1	$22.73	$23.00
	l298n motor driver	1	$6.99	$6.99
				$29.99
Light Setup	LEDs	1	$13.99	$13.99
	595 Shift Registers	5	$0.48	$2.40
	Arduino Uno (same as servo)	1	$23.00	$23.00
				$39.39
Mount	80x20	1	$8.00	$8.00
	PLA 3D printer filament	2	$5.00	$10.00
	Screws/bolts	22	$0.30	$6.60
				$24.60
				$160.57

Table 2. BOM for Next-Gen VCA Percussion system

Evaluation Methods

Timbral Variation

Variation was measured based on the quantity of distinct sounds a single actuator can produce. This requirement was especially difficult to determine because of the many ways the actuator can be controlled. For example, extremely quick hits are sensitive to timing variations which could either be triggered by looping in ableton, or programming full strokes in Arduino IDE. Additionally, we do not believe our team has exhausted the number of distinct sounds possible by interchanging various combinations of control parameters. One way to understand variation was to systematically loop through different time and velocity combinations of lifts, hits, rests, and dampener positions. While this was effective, it led to overheating and difficulty organizing the resultant sounds. The best method our team found to evaluate timbral variation involved writing a composition to showcase its potential. By intentionally attempting to make certain sounds we had a clear understanding of what was and was not possible. Overall we were able to produce at least 11 distinct sounds for one actuator, each of which received its own octave of midi keys used to control power. Despite this, countless other sounds beyond the 11 were also created but were not deemed musically useful for our purposes.

Dynamic Range

Because the drum hits rely on gravity pulling the actuator an inch down, with an additional optional force from the voice coil, the stroke length and maximum force impose limits on the minimum and maximum decibels produced by a hit. Though the exact values are not yet tested, it is likely that the minimum requirement was reached and achieved. This occurs during a light drum roll which a human would find difficult to play as softly as the actuator. The maximum hit velocity was unlikely to be reached as a human could easily play louder than the actuator with a hard stroke. This did not pose a problem while composing, as the drums felt overpowered compared to the other instruments in a medium sized room. If the drum's were microphoned, they most likely could be used for a live performance. Additional work experimenting and programming could yield results that an even quieter sound can be achieved but we are unlikely to produce a louder hit without a higher powered motor controller or design revision.

Drum Hit Speed

The requirements previously outlined that 13 hits per second was a benchmark for success in terms of the actuator's maximum velocity. It was extremely difficult to verify the maximum frequency precisely, but it is known that at least 13 hits per second was achieved. By controlling an actuator hit in an ableton midi track and slowly increasing the speed to a max of 999 BPM, it was clear that the actuator surpassed what we thought was possible but differences were difficult to hear past 700 BPM. By playing with various dynamics and timing, a low-power drum roll was programmed that seemed to surpass the forced stroke speed. The maximum frequency of this is known to be at least greater than 40Hz as a definite pitch is produced by the drum's surface well within the range of human hearing. We are not confident that either of the determined values are the limit but more work is needed to program better control methods.

Visual Aesthetics

The aesthetics of the system as a whole played a large role in the progression of the designs. It is generally difficult to quantify the success of aesthetic choices and design solutions but there were clear visual accomplishments and challenges. With the "jellyfish" concept image in mind, LED strips, each with addressable control, were mounted to the base of the snare drum.

Despite cable management attempts, there were far more wires visible in the final version than initially intended. The lights however were able to be programmed in sync with the actuators leading to a synthesis between what an audience member is hearing and seeing. This could be further extended by adding LEDs around the bassdrum and on top of the actuators so they can be seen in low-light. A large improvement involved moving the arduino to the ground and changing all of the wires connecting the drums to the same color in bundles. This made debugging quite difficult but was worth the slightly cleaner looking result. Another visual success was the design of the actuator which offered cutouts in the cylinder to view the shaft and coil moving. While this was intended for ease of manufacturing and heat dissipation, it offers a look into the inner mechanism and makes the performance feel more alive. The entire system satisfied our requirements but could have been executed much neater which can be addressed in future revisions.

Results

Qualitative Musical Characteristics

When the driver is fixed to the aluminum rod, above the drum, and the distance from the bottom of the rod to the drum face is adjusted well, everything is ready to make sound. When the end surface of the shaft hits the drum surface, the vibration that occurs on the drum surface is transmitted through the air inside the drum, producing a loud drum sound. In particular, the shaft is placed vertically above the drum face, and the drum face as well as the drumsticks have elasticity, so the shaft will bounce back to the original position after it hits on the face. Therefore, theoretically, when we control the movement pattern of the shaft, we can control the amount of sound the drums make and the time between each strike to achieve different musical effects. For example, the actuator can achieve the drum roll effect. When the shaft hits the face, without countroling, it will rebounce to hit the face again quickly and repeatedly, until the potential energy fully transfers into the kinetic energy and stops on the surface. However, during this process, if we program the actuator to power the shaft, the shaft will continually hit the drum face and also manage the force on the shaft to control the repeated note to sound even. Besides that, the actuator could be programmed, so that it can be controlled to produce different voice volume by varying the force of the strike.

Comparison to Solenoid

The components of voice coil actuator consist of a permanent magnet, ferrous steel, and a coil assembly. When the device is connected to the power supply, current flows through the coil around the body and interacts with the magnet field. Therefore, a force will be generated in the direction which is perpendicular with the current flowing. And the force direction could be reversed by changing the direction of the polarity of current going through the coil. The force generated depends on the current and the magnet flux in the magnetic field. The principle of working of the voice coil actuator determines whether the coil or the magnet can be used individually as the moveable part, which means that the weight of the moving parts can be optional by selecting which part to move.

The solenoid actuator has steel housing, spring and a moveable slug. When the current flows through the coil, the electromagnetic field will be generated, and its intensity will affect the amount of force generated. When the solenoid connects to the power, the plunger will move forward driven by the force and then back to the position by the elasticity from the spring.

Due to the difference of the principle, the solenoid actuator and the voice coil actuator have different performance. Under the same condition, the most difference between these two actuators is that: the voice coil has a longer stroke, the force it generates can be easily controlled to have dynamic range when it hits on the durm face, as well as the position precision. In addition, the voice coil actuator can generate constant force and the direction of the motion trajectory can be reversed too. In contrast, the only advantage of the solenoid actuator is that it is cheap to build.

Musical Usage

The software was implemented in such a way that a composer could use our actuator without knowledge of its inner workings or electrical control system. All composition occurs in Ableton where there is a full midi keyboard of octaves controlling two actuators, a snare and low tom acting as a bass. Within an octave, earlier keys starting at C correspond to lower powers while B corresponds to the highest power. These powers theoretically correspond to the minimum and maximum intensity of hits but in actuality can be overbearing in musical composition. Our team did not prepare for our second actuator being higher powered than the first despite having the same coil and magnet size. This leads to lower control over the bass drum. In addition, due to errors with the encoders located on the dampers they were not able to be implemented in time for the composition. It is likely that this would improve the musical composition experience for multiple reasons. One weakness of the current system is the requirement of providing power to lift the shaft. When it is unpowered, it falls and bounces, making sound. While we have programmed some hits to do full strokes where the shaft is immediately pulled up, this is not effective throughout an entire composition as the motor controllers may overheat and malfunction. The force of the damper could relieve the unwanted sound. In testing, it was also able to change the pitch of the snare drum which would add an extra dimension of variation for a composer to use. The actuator proved to have very low latency which made it easy to test and experiment with in real time using the midi-keyboard. While it is easy to use, it is difficult to access the full potential of the instrument without a strong understanding of how it functions. For this reason, more programming is required to make the composition process intuitive. Additional control could be implemented through Max in which each stroke timing pattern could be customized easily.

Reflection

In realizing the idea of a voice coil actuator next-gen percussion robot, the system that the team produced satisfied most of the requirements, with certain aspects exceeding expectations. The voice coil actuators were able to play at speeds much faster than the required 13 hits per second, and allowed for a very wide dynamic range and timbral variation. In achieving this, the team overcame many difficulties, from making the actuator itself, to the electronics, and the programming. Initially, the actuator of the first iteration is twice as long as the current design, this resulted in the coil wanting to remain in the center when charged, and does not move to either end unless an external force is exerted upon it, pushing it to one side. Our team came up with the solution of making the actuator housing half the length as before, and position it vertically so that gravity will always try to pull the coil down, and ensure that the start position of the coil is at one end. Another difficulty the team encountered was with electronics where the system was using too much current, and resulted in burning one of the microcontrollers. This was solved by installing a stronger permanent magnet, which can reduce the amount of current that is needed to charge the coil.

In comparison to the preliminary design and the motivation, there are a few areas that can be improved, such as better control programs and making use of a sensor. Initially, the version 3 of the VCA included a laser sensor that is pointed into the actuator to take readings and keep track of the position of the coil. This distance can be used to make a PID control loop, and in turn achieving control of greater precision. In addition, since the VCA allows for significantly more control options than a traditional solenoid, the controls and programs is another area that can be further explored. The first test of the actuator was refreshing because it validated our understanding of voice-coils and their potential in actuated percussion. The final iteration surpassed our initial expectations and we were surprised to see it behave the way we expected. As a team, we had fun exploring the sonic abilities of the instrument which ranged from a typical snare drum roll to comically fast sputters and slams. We look forward to future iterations where we will focus on ease of use, software design and minimalist wiring.

Future Directions

Due to the limited time that the team has available working on this project, there are many directions and potentials which could be improved upon. There are mainly three ways in which the robot can be enhanced: plug and play drumming, physical interface for performance, and adaptability with other sonic objects.

Plug and play is a feature that the team has come up with during the brainstorming phase of the project. In essence, an aux cable can be incorporated into the system to send audio frequencies, and the robotic system can automatically analyze the audio signal and play the drum beats along with the music. Alternatively, the system can be improved by adding more control options. For example, custom made physical buttons, dials and knobs can be added to turn the robot into a more advanced drum machine. An example could be a LaunchPad, where each individual pad can be programmed to perform a certain action of the drum robot, such as single hits, drum rolls, and damping. This can also increase the expersitivity of live performances with the drum robot. Finally, while the current system can only be mounted on drums, a universal mounting system can be designed so that the system can be used for other sonic objects such as cymbals, marimba, glasses filled with water, and any other pitched and unpitched percussion instruments.

Only a few possibilities are mentioned, but there are various other areas that can be improved. The team believes that with enough design iterations and improvements, the drum robot also has the potential to become a commercial product.