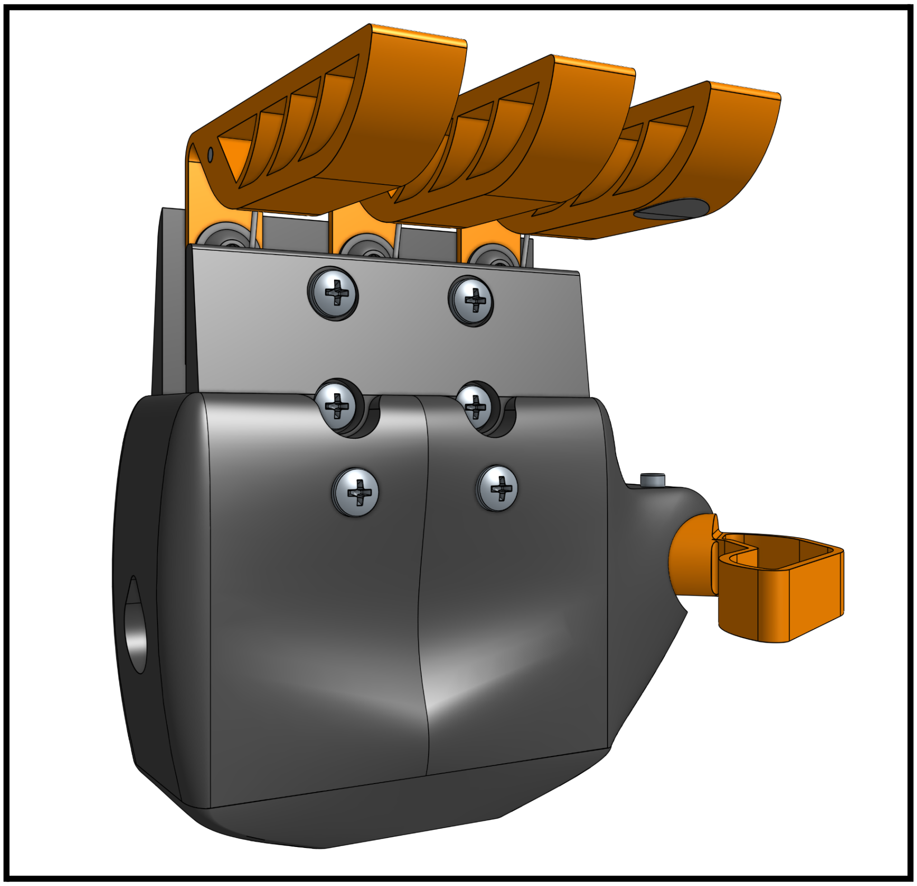
BEN 363: Instrumentation
Closing Report



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Executive Summary

Increasing accessibility and ease-of use should be the ultimate form of customer service. Developing a device to regain the ability to play an instrument, as well as being used to help teach anyone how to play the device is vital. To accomplish this, a previously developed prosthetic was remodeled to work as a practice hand for anyone to use, encouraging new musicians to learn how to play the trumpet. Then, a pressure sensor analysis was performed to give tactile feedback to the user, allowing them to know when alignment may be altered. Finally, two different musical feedback instrumentations were explored, a metronome and a tuner, to help advance individual practice sessions and performance.

The practice device was modeled after a pre-existing prosthetic hand that played the trumpet, named Hand-et. One of the major modifications to the prosthetic was changing the angle of the fingers to lay them flat, allowing for more direct force to be applied to the trumpet's valves. The thumb of the prosthetic was also modified to better support the trumpet and be more versatile to any trumpet the user might have access to. Finally, stronger solenoids were implemented to overcome the force of the valves. A pressure sensor was implemented to inform the user of their prostetic's alignment to the instrument. This pressure sensor translated the force applied to a voltage which could be used to tell if the valve attempting to be depressed was fully depressed or not. A calibration curve was generated to convert the voltage output of the pressure sensor to a force value using known forces. It was found that the minimum amount of force needed to completely compress the valves was 2.45 N. If this threshold is broken a LED on the hand is illuminated to indicate a proper valve depression. If not, the user knows the hand is misaligned as the LED grows brighter. If no light is shown the user will know the hand has malfunctioned.

A visual metronome was programmed using Python and a light-emitting diode (LED) to help the user stay in the correct tempo/inform them if they had changed their timing. This metronome was tested both against itself at different tempos and against a pre-existing audio metronome, *Smart Metronome & Tuner*. Both tests showed evidence that the LED metronome worked effectively and could be used as a learning technique. One LED will be used for both the pressure sensor and the metronome. To distinguish between a pressure sensor alarm and the metronome the brightness will indicate alignment accuracy.

Finally, the application of a real-time digital tuner was explored for users to maintain the correct pitch. This device utilized the voltage dependent input from a microphone and interfaced with the backend of a graphical user interface (GUI). This was programmed in Python, utilizing the fast Fourier transform algorithm to convert the raw signal into a frequency response. This conversion was effectively done in real time, allowing for continuous computation. However, the final implementation of the device was deemed unsuccessful at the present time. More focus on the development of this device would allow for a successful end product.

Overall the project was successful as a prototype was developed with integrated learning features that could withstand all appropriate tests. The only failure of the developed prototype was its inability to fully compress the valves of the trumpet. To solve this problem it is recommended that solenoids with a greater stroke length or better, servos are implemented to provide the pulling force. Also in future work a more sophisticated microcontroller could be implemented to increase the quality of feedback from the tuning device.

Introduction and Background

Mental health is becoming increasingly more well-renowned. In amputees, 84% have reported they've experienced psychiatric disorders, including depression, post-traumatic stress, and (Sahu, 2016). This likely is amplified disruption of body image, loss of sense of self due to physical impairment(s), and self or societal stigmas (Cruz, 2020). Regaining the ability to practice hobbies, specifically of music, has proved to increase physical and psychological well-being (Pressman, 2009 & Aalbers, 2017). Innovating on devices to increase the accessibility of hobbies is important in changing the mental health crises (Pressman, 2009). A prosthesis capable of aiding learning the trumpet can help increase the mental health status of amputees and new musicians.

However, although trumpet-playing can increase mental health, there are multiple physical factors that must be considered which can increase the difficulty of accessibility (Kula, 2015). Some examples include muscle strength, volume, speed, coordination, consistency, and finger positioning, pressure, and acceleration (Kula, 2015). By transforming a previously designed prosthetic hand into a learning device for playing the trumpet, the benefits apply to not just amputees, but to anyone interested in how to play the trumpet. Thus, the main objective was to prototype a trumpet-playing device with integrated learning features and feedback devices, including alignment, rhythm and tone to improve mental health, optimize individualized practice sessions, and lower the barrier of learning a new instrument. To accomplish this, four things were investigated. First, a past prosthetic design was innovated on. Then, a pressure sensor was used to create a calibration curve to give alignment feedback to the user. Next, a visual metronome was developed. Finally, the implementation of a real-time tuner was investigated.

The prosthetic chosen to modify was named Hand-et. Hand-et, Figure 1, was designed and developed in 2022 by three students studying biomedical engineering at the University of Maine. The purpose of the device was to allow amputees the ability to continue to play the trumpet through a 3D printed prosthetic. Hand-et included three solenoid actuated fingers to press down the trumpet's valves, as well as one thumb to help hold and support the trumpet. This design will be slightly altered to allow for a more efficient use as a learning device for all.

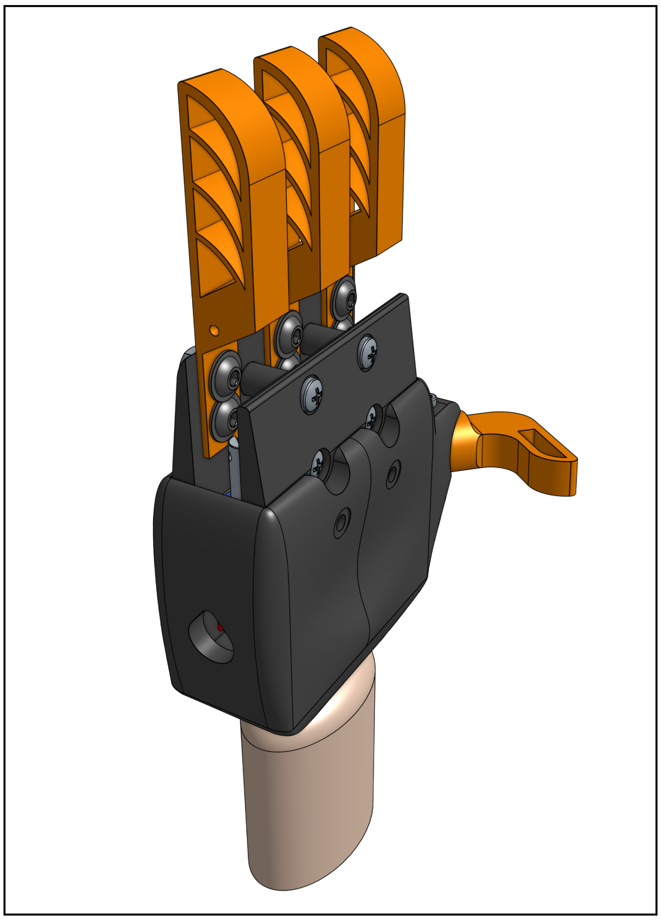

Figure 1: Lowered isometric view of "Hand-et" prosthetic hand attached to modeled partial forearm as represented by the pale pink fileted cylinder.

One of the main goals for this practice device was to implement assistive learning features. It has been found that when used together, kinesthetic and visual feedback methods allow for better mechanical analysis (Vidal, 2016). Thus, a pressure sensor was placed on the index finger of the device to allow feedback if the device fully compressed the first valve to monitor the alignment of the prosthetic. The pressure sensor was then used to formulate a calibration curve using varying known forces to the sensor and recording the corresponding voltage outputs. This calibration curve was then used to help program the user interface to give feedback to the user as to how well the device was functioning.

The other main goal for this prosthetic was to incorporate practice techniques to help aid musicians. One of the most common struggles for musicians when they practice their instruments is to keep a consistent tempo and pace (LaBach, 1965). A current method to help keep musicians in time is an audio-based metronome. These metronomes hold a consistent tempo with a constant speed and make a sound at every individual beat, allowing musicians to keep track of and correct their timing (Selek, 2020). For this implementation, a visual metronome was created using a raspberry pi, a light-emitting diode (LED), and through Python coding to allow for a real-time automatic timer for practicing musicians to get feedback from. The LED "blinks" the inputted tempo, just as a modern audio metronome would make sound. This metronome works as an individual device, allowing it to be implemented into the training hand or being functional on its own. On the hand, the LED can be found underneath the thumb to face the user, allowing them to see the beats as they play. On the practice hand's user interface, it was designed to allow the user to choose the tempo, as well as if they wanted to use the metronome or not (thus if practicing in large groups with a conductor acting as the metronome, the LED could be turned off to avoid distraction). Once built, the LED metronome was tested both against an audio metronome, *Smart Metronome & Tuner*, and against itself at different tempos, to ensure proper timing was achieved.

The most common struggle within trumpet playing is staying in tune (Chen, 2017). This is because as musicians play different pitches they must change their lip aperture, which increases the difficulty to maintain pitch (Grosshauser, 2015; Montenegro, 2012). A common current solution is to play with a tuner, allowing the user to see if they are maintaining the correct pitch and adapt their instrument and embouchure (Chen, 2017; Montenegro, 2012). Currently, real-time pitch recognition through computer applications are uncommon for trumpet, as it has unique spectral ranges (Montenegro, 2012; Chen, 2017).

Thus, the second learning device explored for this application was an electronic tuning device to allow the user to analyze their pitch accuracy while they play. To do this, an electret microphone was used as a transducer, a Raspberry Pi as a microcontroller and a fast Fourier transform (FFT) to convert signals in a digital signal processing program. Electret microphones, on average, can transduce between $1.0\text{x}10^{-3}$ Hz to $2\text{x}10^{8}$ Hz, which is within the 168.4 Hz to 932.2 Hz range that the average trumpet player performs within (Sesseler, 1973). The Raspberry Pi was chosen as a simple microphone signal interpreter. To interpret, first a Python program utilizing computational analysis algorithms was used to baseline the input voltages from the microphone. Then, the Fast Fourier Transform algorithm (FFT) was used to relate the time domain to the frequency domain. This process can be broken into multiple steps. First, the Discrete Fourier transform (DFT) was utilized as a mathematical technique that relates the time domain to the frequency domain while processing signals that vary throughout time. The mathematical definition can be seen within equation [eqn.1], where a sequence of N complex numbers with a wavenumber, k, can be transformed into another discrete series of complex numbers. Utilizing Euler's Formula, shown in equation [eqn. 2], the latter term can be substituted for sine and cosine functions, producing equation [eqn. 3]. Segments of data can be sampled over a finite period of time and passed into the substituted DFT function to output a sequence of sine and cosine functions that collectively make up the complex signal, thus, when the frequency components of each sine function is graphed, it converts the signal into the frequency domain.

Discrete Fourier Transform	$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{\frac{-i2\pi}{N}kn}$$	[eqn. 1]
Euler's Formula	$$e^{ix} = cos\, x + i \cdot sin\, x$$	[eqn. 2]
Substituted DFT	$$X_k = \sum_{n=0}^{N-1} x_n \cdot \left[cos\left(\frac{2\pi}{N}kn\right) - i \cdot sin\left(\frac{2\pi}{N}kn\right)\right]$$	[eqn. 3]

This series of calculations need to happen simultaneously as the signal is being recorded. This proves to be an issue with allocation of processing power within the microcontroller that automates the hand. This issue, however, was resolved in the way that the FFT function takes place. FFT factorizes the DFT matrix which reduces the factors significantly (from N^2 to $N \times logN$, where N is the size of the data set). This increases the speed of the computation significantly allowing for a near-instantaneous output. Additionally, FFT is more accurate than collectively calculating the individual DFT functions due to round-off errors. Due to the sheer size of data sets within DFT, an error is magnified, as it is present within each data point. Factorizing the set reduces this inherent error. This computational method was used to analyze the input from the microphone.

Results and Discussion:

The prosthesis was manufactured via 3D printing as it is an up-and-coming economical alternative to traditional custom manufacturing methods used in prosthetic development (Silva, 2015). The 3D printed prototype was manufactured with multiple materials and few geometric constraints which aids in the functionality and realism of the device while allowing for modifications to be easily accessible. In Figure 2, the realistic and organic shapes of the hand elements can be seen. Figure 2 also displays all modified components of Hand-et v2 such as the modified digit components, solenoid support plates, and thumb. The dimensions of the new design replicate the dimensions of a larger adult hand (D'Amour, 2020).

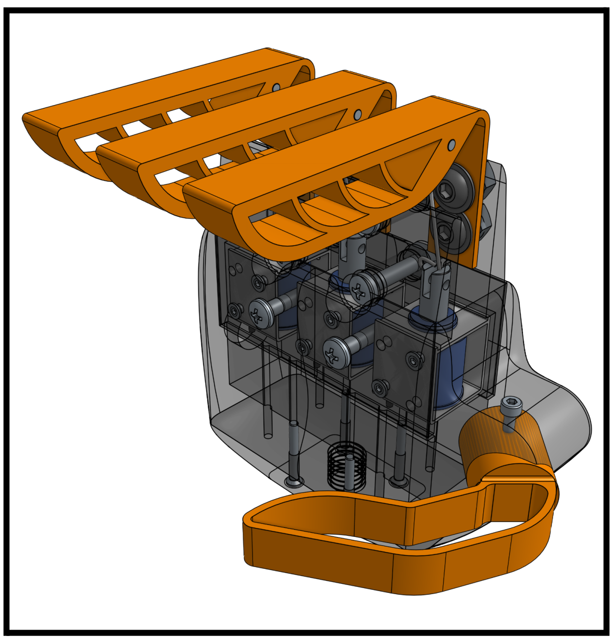

Figure 2: Perspective isometric view of Hand-et v2.

The digits of the prosthetic hand are powered using 20N solenoids that nest inside the outer hand casing as seen in Figure 3. The solenoid's force will be transmitted using strings run between the digits and solenoids. The string attachment point on the digits was placed closer to the tip of the finger to generate a greater lever arm to reduce the load on the solenoids.

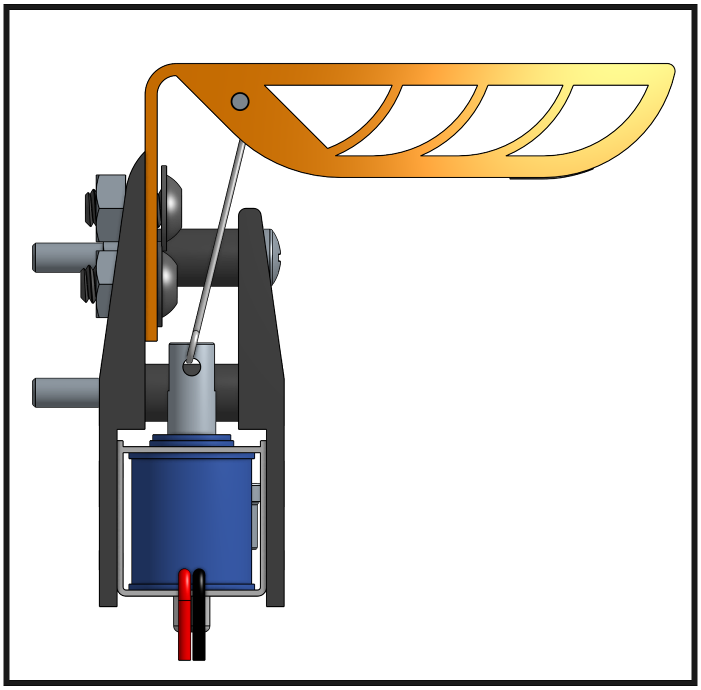

Figure 3: Side view of actuation components. The pressure sensor can also be seen as the thin black outline on the tip of the digit.

Polylactic acid (PLA) was used to print the base of the device and thermoplastic polyurethane (TPU) was used to print the finger pads. PLA and TPU were chosen because they are accessible and cost-efficient while maintaining reliable strength and fatigue behaviors (Liacouras, 2017 & Afrose, 2016). The finger digits profiles and infill were specially designed to promote a realistic and beneficial response when they are put into contact with the trumpet support and valves. The digits possess a scalloped infill pattern in the bulk of the digit. This pattern, as seen in Figure 3, along with the TPU material allows the digit to flex and respond similarly to how true finger pads respond to normal forces. The thumb is designed similarly but with no inner layers at all, as seen in Figure 2. The lack of inner layers allows the thumb to flex and bend around any trumpet thumb support. This allows the thumb component to be universal and accessible.

All printed components remained functional and retained all mechanical properties even at high stress points throughout testing. There were no visual signs or wear such as stress cracking, material thinning, or any other deformation. While the design held up against all testing conditions, it was ultimately unsuccessful as it was unable to fully compress the trumpet valves. While the modifications previously described overcame the force threshold for compression

Along with physical device modifications for more efficient use, another main goal of the project was to implement assistive learning features into the prosthetic hand. It was found that when visual and kinesthetic feedback mechanisms are combined, users are most accurately able to identify the state of the prosthetic system while in use (Vidal, 2016). Therefore, a pressure sensor was implemented on the pad of the index digit as seen in Figure 4. This feature allows the device to track if the prosthetic successfully compresses the first valve each time it is triggered to do so. With this data, a visual light indicator is illuminated on the hand to notify the user of misalignment or device failure. If the pressure sensor system detects misalignment the LED will get brighter. If the system is receiving no data from the pressure sensor the light will turn off completely. This feedback, along with the minor forces pushing the arm down in response to valve compression, will allow the user to monitor the prosthetic's alignment while utilizing the majority of their attentional resources for playing.

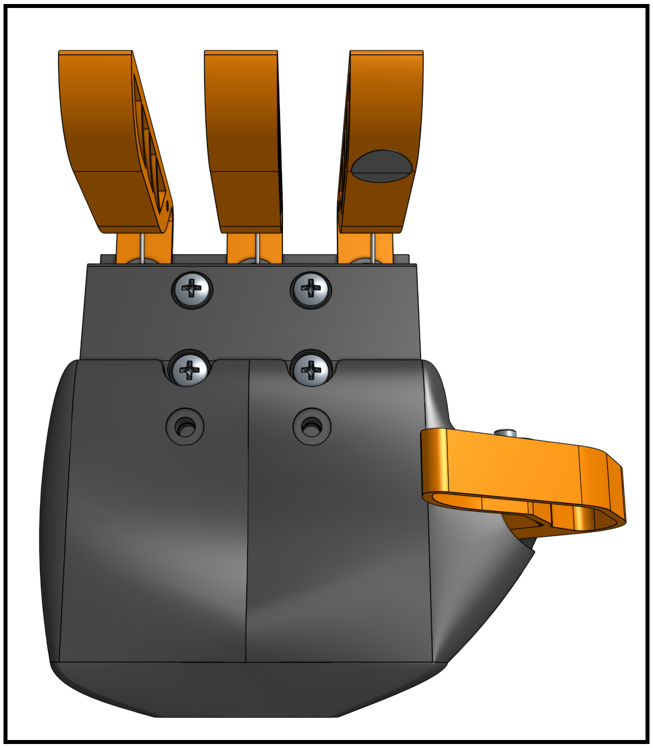

Figure 4: Angled front view of Hand-et V2 with pressure sensor on rightmost digit.

A test circuit for the pressure sensor was designed in order to produce a calibration curve. The output voltages across the pressure sensor were measured as known forces were applied to the sensor. Objects of known mass were placed on top of the sensor, and the applied force was calculated using the following equation, [eqn. 4], where *m* represents the object's mass, and *g* represents the acceleration due to gravity.

Applied Force	$F = m * g$	**[eqn. 4]**
Mass	m [kg]	**[var. 1]**
Force of Gravity	$g = 9.8$ [m/s^2]	**[var. 2]**

These measurements were taken on an Analog Discovery 2 Oscilloscope with the scope probe attachments at points *A* and *B* in the following schematic, Figure 5.

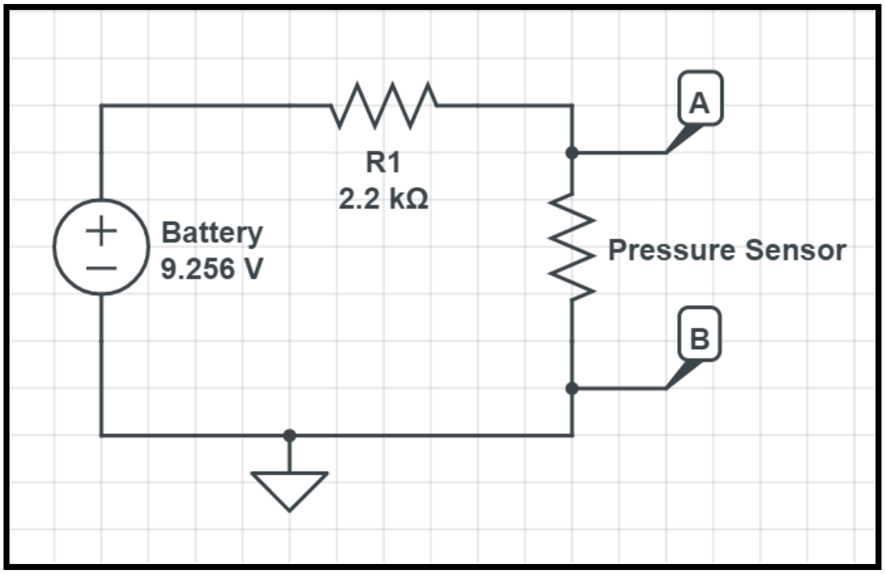

Figure 5: Schematic of the circuit used to create the calibration curve for the pressure sensor.

This allowed for the voltage drop across the pressure sensor to be measured. Resistor *R1* was used to amplify the change in the voltage as more force was applied to the pressure sensor to allow for more precise measurements. The measured voltages across the pressure sensor can be seen within Table 1. Ohm's law- shown in [eqn. 5] where V represents voltage, I represents current, and R represents resistance- can be utilized to calculate the internal resistance of the pressure sensor at variable forces. This is shown in the fourth column of Table 1.

Table 1: Measured voltages across the pressure sensor in relation to applied known forces.

Mass (g)	Force (N)	Voltage (V)	Resistance (Ω)
0	0	8.608	29224.69
36.53	0.357994	7.834	12120.11
103.53	1.014594	6.062	4175.45
170.74	1.673252	4.711	2280.35
233.59	2.289182	4.078	1732.64
278.31	2.727438	3.593	1395.83
250	2.45	3.73	1487.65

Ohm's Law	$V = I * R$	**[eqn. 5]**
Current	I [A]	**[var. 3]**
Resistance	R [Ω]	**[var. 4]**

The pressure sensor that was used in this design has an inverse relationship of applied force to internal resistance. As the applied force was increased, the internal resistance of the sensor decreased. The measured voltages were then plotted against applied force and a trendline was extracted. The relationship appeared to be linear as indicated by the high R^2 value, allowing for a first order equation to be produced. The generated calibration curve is shown in Figure 6.

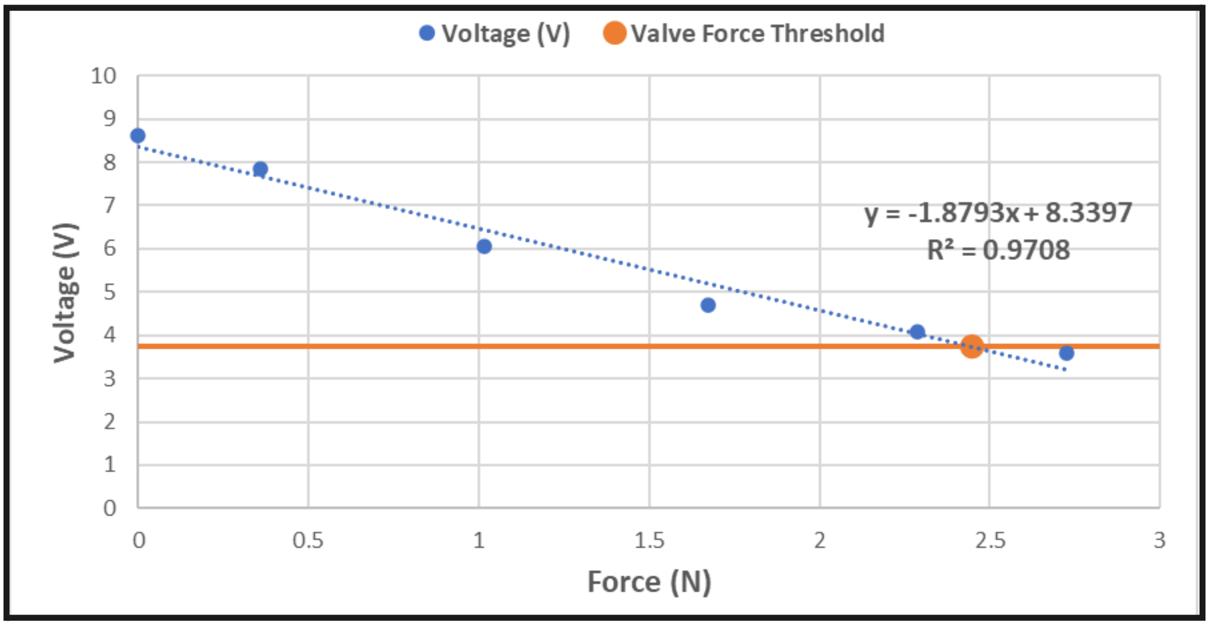

Figure 6: Calibration curve of measured voltage across pressure sensor vs applied force. The linear trendline, shown in light blue, represents the relationship between force and voltage and is represented by the equation shown at the top of the figure. The orange horizontal line represents the force threshold for fully compressing a valve.

A threshold force of 2.45N was determined to be the cutoff force to fully depress a trumpet valve. The force threshold value was generated by applying increasing mass to a valve on the trumpet until it compressed. The collected mass value was translated to a force value using equation 4. The force value was computed to be 2.45 N which is equal to a voltage output of 3.74 V when using the generated linear trendline, this cutoff is shown in Figure 6. This cutoff resistance value is shown in the highlighted last row of Table 1. During use, if this force is reached, then the alignment of the hand can be confirmed. The output of the alignment sensor does not need to be continuous as it is either properly aligned or misaligned. Therefore an LED may be utilized to represent the alignment. A circuit was designed to turn an LED on when the threshold voltage was reached. This would indicate proper alignments of Hand-et.

The 5V direct current (DC) voltage source that is integrated into the Raspberry Pi was used to power this circuit as it is already incorporated into the design. The LED that was chosen had an operational voltage of 2.1V. The internal cutoff resistance of the pressure sensor was used to calculate the new value of *R1* that is required to turn on the LED at the threshold force. This value was found to be 2.054kΩ. The final circuit is represented in Figure 7.

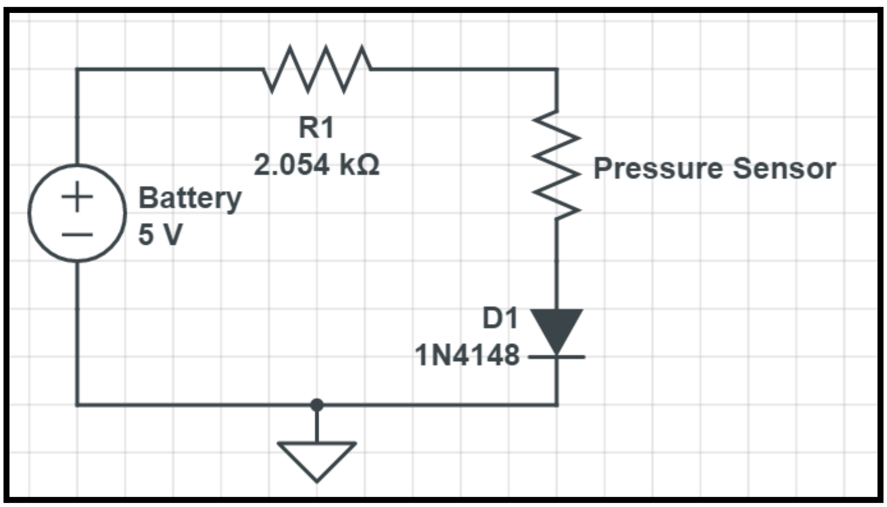

Figure 7: Schematic of the final pressure sensor circuit incorporating LED alignment indicator (1N4148).

This circuit was tested by applying the threshold force, 2.45N, to the pressure sensor and recording if the LED turned on. A digital multimeter was connected across the pressure sensor to measure the voltage difference at steady state and at threshold force. It was found that the light turned on when there was a voltage difference of 2.1V across the pressure sensor, which occurred when the threshold force was applied. These results indicate that this device was successfully implemented.

The second feedback mechanism implemented into Hand-et was the visual metronome. In order to test the visual metronome two different tests were performed. First, the metronome was tested against itself. Data points were taken every 0.5 seconds to record how many beats had passed at two different tempos: 60 beats per minute (bpm) and 120bpm. As seen in Figure 7, at 60bpm, there was one beat recorded every second, resulting in 15 beats within the recorded 12 seconds. For 120bpm, two beats were recorded every second, resulting in 30 beats in 15 seconds. This was the expected trendline. Thus, at 120bpm, double the timing of 60bpm, double the amount of beats recorded in the same time period. As the beats were recorded every 0.5 seconds and at 60bpm there was no signal until every full second, it resulted in a staircase shaped line, but the data shown was as predicted.

The second test was to test the visual metronome against a pre-existing audio metronome, *Smart Metronome & Tuner*. The audio and visual metronomes were tested at both 60bpm and 120bpm. As seen in Figure 8, the audio and visual metronomes at both tempos recorded the same number of beats at the same time, resulting in an overlap of the data points and the lines. Each test was done three times at multiple different tempos, two were just chosen for ease of conveying information in graphical format. Thus, it was concluded that the visual metronome worked and could be used as an effective practice device.

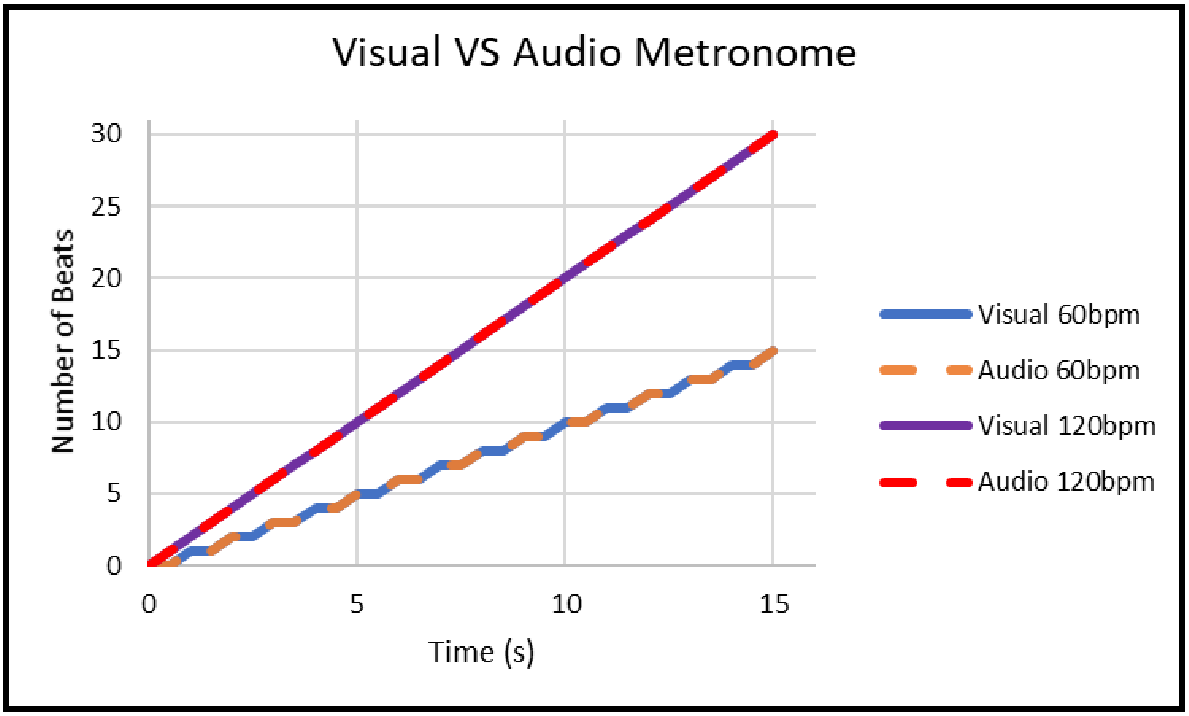

Figure 8: This graph compares an audio and visual metronome at 60bpm and 120bpm to verify how accurate the developed LED metronome works both at different tempos and in comparison to a pre-existing audio metronome.

The final feedback mechanism designed was a real time tuner. The original design of this tuner involved a 5.5V variable gain electret microphone that was connected to a general pin input/output (GPIO) on a Raspberry Pi. It was discovered that GPIO inputs on Raspberry Pi's only accept digital data. This means that the Pi could only interpret a binary signal from the microphone rather than a continuous, analog signal. While a microcontroller that interprets analog data could have been developed or sourced out, an internal microphone within a laptop was used instead as a time and budget conscious solution.

A Python library called PyAudio was used to control the internal microphone within the laptop. Segments of recorded audio were taken in 0.25 second intervals to be processed. This data was represented in values that ranged from 0 to 255, with 0 being no signal and 255 representing the maximum signal. To convert these values into a waveform in the time domain, the values were normalized, producing the output represented in Figure 9.

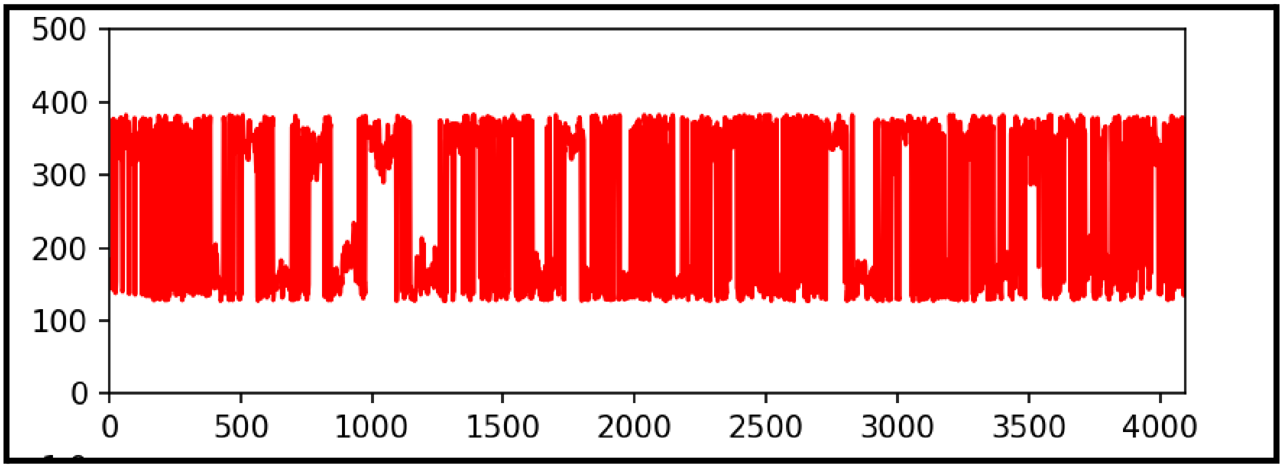

Figure 9: Microphone output interpreted and presented by Python program in the time domain.

The signal was then filtered for unexpected noise, but this was not successful. As shown in Figure 9, the signal was very noisy, and the signal did not appear to be a typical sinusoidal waveform. This was most likely due to audio clipping as a result of a low quality microphone. Because there were no regular sinusoidal signals present in the data, the FFT function was not able to output a frequency response. In order to produce a working real time tuning device, it was determined that a higher quality microphone would need to be utilized in conjunction with an analog microcontroller.

To determine the estimated functionality of a higher quality microphone, the electret microphone was connected to an oscilloscope to compare the output signal to that of the internal laptop microphone. The result is shown within Figure 10. This audio transducer outputted a much cleaner signal containing many sinusoidal functions that could have been transformed using the FFT algorithm to produce the frequency response that may have been incorporated into the GUI. Based on these measurements and the data shown in Figure 9 and Figure 10, it can be concluded that the concept developed could work for a real time tuning device if this project was provided a larger budget and more time for development.

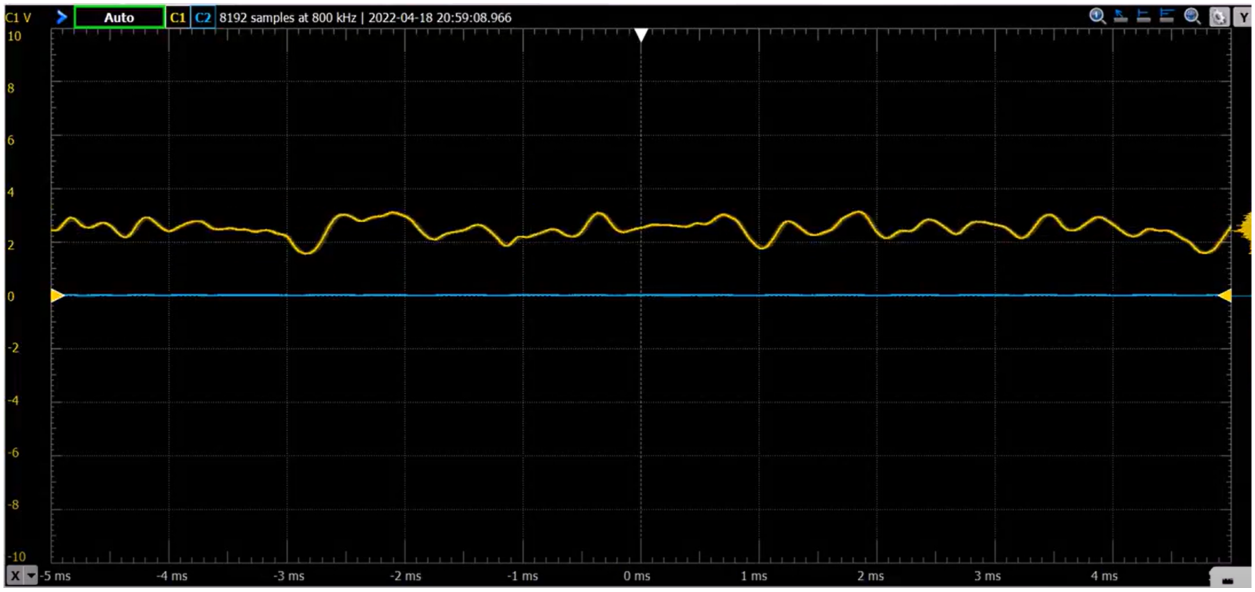

Figure 10: Oscilloscope output of electret transducer within the time domain. The y-axis represents the recorded voltage in volts and the x-axis represents time in milliseconds.

Cost Analysis

With all the new learning features and improved mechanical componentes the total material cost of the prosthetic hand device was \$137.54, as seen in Table A-1. \$46.39 of the total cost was mechanical components including the solenoids, filament, and fasteners, and \$91.15 was spent on electrical components. A full fasteners parts list can be found in Table A-2 and individual breakdowns of the PLA and TPU consumption can be found in Table A-3. While the total material cost was ultimately extremely low compared to marketed prosthetic hands, the cost of the prosthetic can be reduced by implementing custom power control boards (PCB). A custom PCB or microcontroller would reduce the cost of the electronics components as a Raspberry Pi is ultimately oversized and does not include some key functionalities, such as analog input, that are vital to this prototype. A custom PCB would be inexpensive and tailored to the application. This would also reduce the need for other circuit elements such as resistors and the Pi, reducing the greatest materials cost.

Conclusion and Recommendations:

Overall the goal of developing a prosthetics prototype with integrated learning tools was accomplished. The new prosthetic design showed great improvement over the initial design. The prosthetic prototype was able to partially compress the trumpet valve and hold at a consistent depression with a consistent force. However, this is not functional or optimal for true trumpet playing. Therefore, it is recommended that in the next version solenoids with a longer stroke length are implemented. Another alternative for this problem would be to alter the design to implement servors to supply a rotary force rather than the linear force of the solenoids. The motion of a servo would better align with the ideal motion of the prosthetic's digits for depressing the valves. While implementing servos would be an easy alternative to the solenoids they do pose three major downsides. First, they are costly. Implementing servos would over double the cost of the prosthetic hand. Second, servos possessing the power to actuate the digits of the prosthetic are often larger and heavier than the solenoids already used within the prosthetic design. This would make the device less wearable for the final user. Finally, servos are harder to control programmatically and often have a much slower response time than solenoids because of this. This would limit the end user in what tempos and time scales they can play in. Therefore, before another round of prototyping is conducted an analysis should be performed weighting the available solenoid and servo options to determine the best course of actions for continued development.

Two assistive learning devices were successfully implemented to the prosthetic developed. First, the visual metronome was also implemented successfully with great results showing no delay or miscounts between an off the shelf timing device and the consulted visual metronome. Second, the pressure sensor feedback system was successfully implemented and tested as discussed above. Both systems could be electronically simplified if a custom PCB or microcontroller were implemented.

While the development of a real time tuner was not successful, the concepts used had promising results. Based on the results previously discussed, in order to produce a fully functional tuning device, a microcontroller containing analog inputs shall be used. This would allow for the electret microphone to be utilized rather than an internal laptop microphone. This style of microphone is designed to have variable gain options to reduce audio clipping, which was the cause of the unstable signals recorded with the internal laptop microphone.

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Appendix

1. **Overall Equipment and Materials Cost List**

Table A-1 : Equipment and Materials List (Amazon, 1995)

Mechanical			
Name	**Quantity**	**Cost Per Unit**	**Cost**
Solenoid Actuator	3	\$11.39	\$34.17
Duramic PLA+	172.93 grams	\$0.02	\$3.46
SainSmart TPU	16.51 grams	\$0.04	\$0.66
Fasteners	See Table A-2		\$7.85
Electrical			
Tactile Button	1	\$1.00	\$1.00
Raspberry Pi 4	1	\$35.00	\$35.00
Resistors	10	\$0.05	\$0.50
LEDs	2	\$0.25	\$0.50
12V, 6A Battery	1	\$20.00	\$20.00
9V Battery	1	\$2.45	\$2.45
Jumper Wires	<50	~\$0.08	\$4.00
Single Output Relays	3	\$5.83	\$17.49
Pressure Sensor	1	\$6.95	\$6.95
Electret Microphone	1	\$6.95	\$6.95
Dual Output Relays	3	\$1.17	\$3.51
Total Materials Cost			**137.54**

2. **Table A-2 : 3D Fasteners Parts List (McMaster-Carr, 2002)**

Fastener Type	Quantity	Price Per Unit	Total Cost
10-32 x 1.5” Pan Head Machine Screw	4	$0.13	$0.52
10-32 Hex Nut	4	$0.02	$0.08
¼” - 20 x 0.5” Flanged Button Head Screw	6	$0.42	$2.52
¼” - 20 Hex Nut	6	$0.06	$0.36
M2 x 12mm Socket Head Cap Screw	3	$0.15	$0.45
M2 Thin Hex Nut	3	$0.82	$2.47
M3 x 25mm Flat Head Screw	4	$0.19	$0.76
M3 x 8 mm Socket Head Cap Screw	1	$0.09	$0.09
M3 x 5 mm Flat Head Screw	6	$0.10	$0.60
Total Fasteners Cost			**$7.85**

3. **Filament Itemized Weight List**

Table A-3 : 3D Printed Parts List

Part Number	Part Name	Quantity	Filament Type	Part Weight (grams)	Support Weight (grams)	Total Weight
BEN-A2Z-006	Digit	3	SainSmart TPU	10.54	0	10.54
BEN-A2Z-007	Thumb	1	SainSmart TPU	5.97	0	5.97
Total Grams of SainSmart TPU						**16.51**
BEN-A2Z-001	Front Solenoid Plate	1	Duramic PLA+	18.76	3.52	22.28

BEN-A2Z-002	Back Solenoid Plate	1	Duramic PLA+	21.51	3.78	25.29
BEN-A2Z-003	Outer Hand Case	1	Duramic PLA+	100.01	4.58	104.59
BEN-A2Z-004	Arm Attachment Component	1	Duramic PLA+	19.57	0	19.57
BEN-A2Z-005	Standoffs	4	Duramic PLA+	1.2	0	1.2
Total Grams of Duramic PLA+						**172.93**