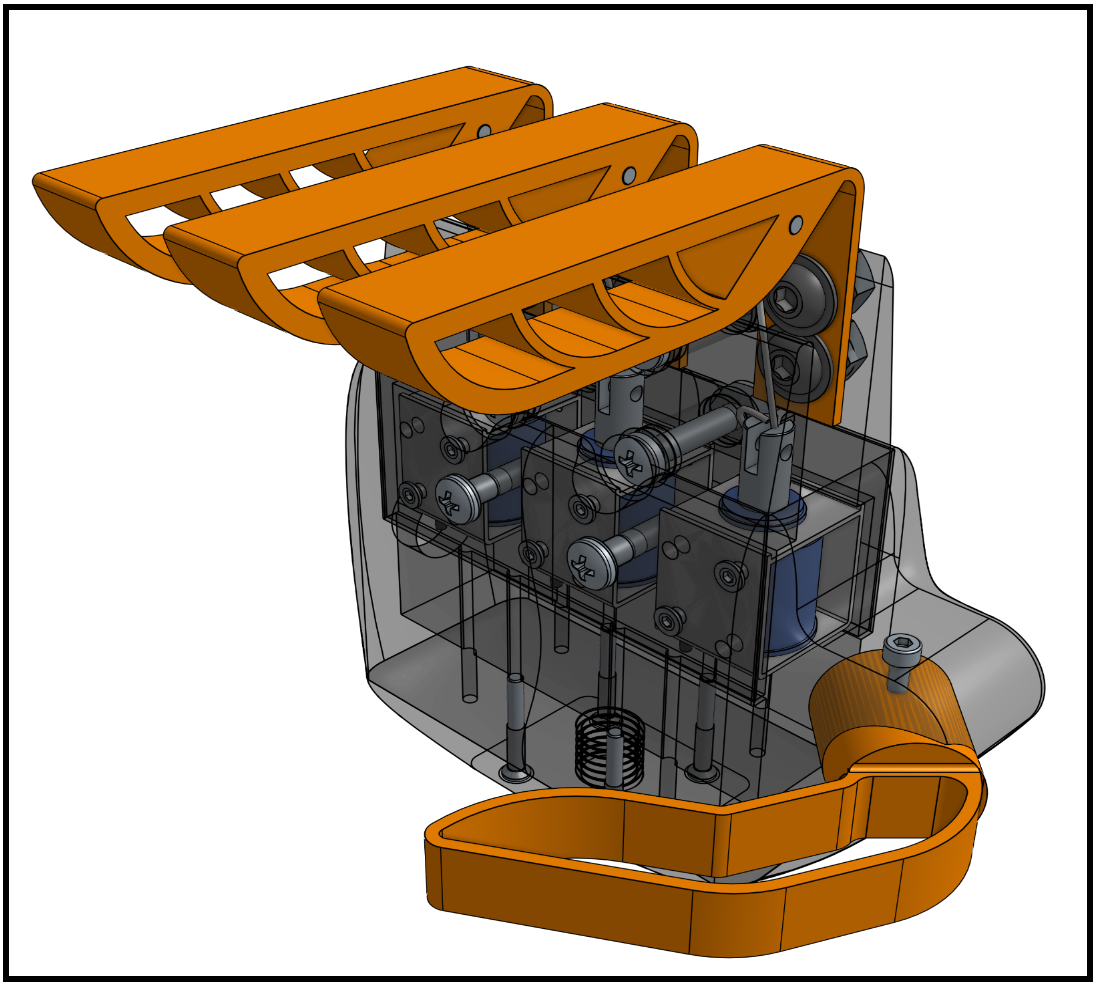

BEN 363: Instrumentation Proposal Report

By Anna Johnson, Emily Hanscom, Zoe Vittum

Problem Statement

The percentage of amputees who experience psychiatric disorders such as depression, post-traumatic stress, and anxiety is reported to be up to 84%, significantly higher than the general public (Sahu, 2016). These disorders are brought on by 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, especially music-related hobbies, is shown to increase physical and psychological well-being dramatically (Pressman, 2009 & Aalbers, 2017). Therefore, making hobbies accessible is an important first step in bettering the mental health crises among amputees (Pressman, 2009). However, not all amputees can perform important activities with their prosthetics, as affordable prosthetics are typically structured to have no tactile feedback and limit movement (Legro, 2001; Silva, 2015). Therefore, if a prosthesis capable of aiding the user to learn how to play the trumpet is developed, amputees can learn a new hobby, helping increase their mental health status.

By transforming the prosthetic hand into a practice and learning device for playing the trumpet, the accessibility and benefits apply to not just amputees, but to anyone interested in learning the instrument. In trumpet playing, multiple physical factors must be considered, including finger positioning, acceleration, and pressure, along with muscle strength, air consistency, volume, speed through embouchure, and coordination (Kula, 2015). One current musician practice tool is a metronome. Oftentimes tempos and pace become unsteady and vary when musicians of any level practice alone (LaBach, 1965). A metronome plays at a consistent tempo with a constant speed, assisting musicians to correct their timing (Selek, 2020). It also allows the user to develop a deeper understanding of pace and could be used as an evaluation tool to see how accurately players are keeping tempos (LaBach, 1965; Selek, 2020). Implementing a visual metronome into a practice device will allow musicians to have an accurate automatic timer that can give real-time feedback, allowing them to improve their techniques.

Similar to how it is difficult to keep a consistent tempo, it is also difficult to apply constant pressure on the trumpet's mouthpiece. In order to reach higher notes, musicians tend to increase their lip pressure and, conversely, tend to decrease it when reaching lower notes (Grosshauser, 2015). By changing the aperture of the lips, airflow varies, allowing sound pitch to be altered, playing different notes, which can be classified through pitch recognition (Grosshauser, 2015; Montenegro, 2012). Although this variability is expected, it can be difficult to effectively accomplish while staying in tune; it is the most common challenge for practicing musicians (Chen, 2017).

Some musicians can accurately recognize pitch and rhythm, allowing them to tune themselves, but not everyone can do this accurately or in real-time while playing (Kula, 2015). By having a tuner, the musician can gauge if they are accurately maintaining the correct pitch and allow them to adapt the instrument, or their embouchure, as they play (Chen, 2017; Montenegro, 2012). However, real-time pitch recognition programs using computer applications are uncommon, as the trumpet has unique spectral ranges, thus, developing a tuner on a practice device specified for the instrument is imperative to improving practice techniques (Montenegro, 2012; Chen, 2017). On top of this, attention spans are limited, which can result in a pitch or tempo change, making it imperative to take breaks after 20 minutes of practice to strengthen techniques (Downs, 2018).

To assist new and experienced players to develop proper techniques, a previously developed prosthetic will be mechanically modified to properly play the trumpet while simultaneously providing real-time feedback to the user. The prosthetic shown in Figure 1 will help to enhance the practice and learning of the instrument. It will be tested with pressure sensors on one finger of the device, allowing automatic feedback to ensure the positioning of the prosthetic to the instrument, as well as if the pressure being applied, is adequate. The pressure sensors will ensure the trumpet is accurately lined up with the learning tool, while the new implementations will allow for real-time feedback during a practice session to improve trumpet performance. To integrate the assistive learning features, the tuner, visual LED metronome, and user interface will be capable of playing through the piece before the user plays with all visual cues. Thus, the prosthetic will still serve its original purpose of aiding an amputee with regaining the ability to play the trumpet but have the added function of being an aid or practice tool for learning how to play the trumpet itself, which could be of benefit to all regardless of physical capability.

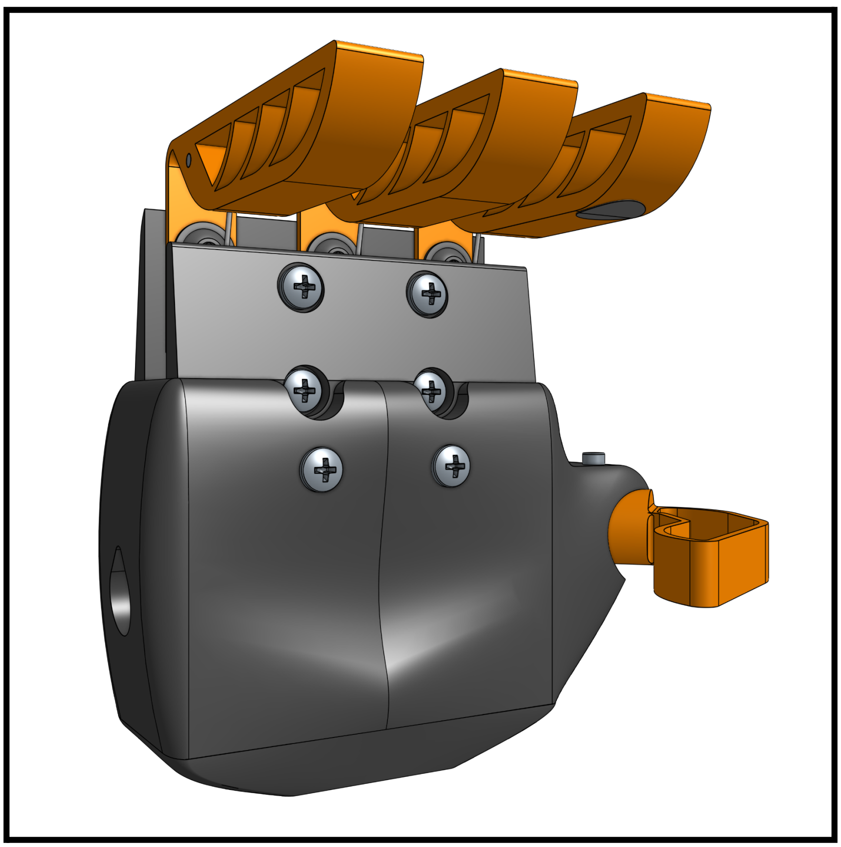

Figure 1: The prosthetic hand, “Hand-et V2”, was developed and designed to aid in amputee use of playing the trumpet. It was engineered by students at the University of Maine in 2022. The prosthetic automates the fingers to press down the trumpet’s valves in tempo through actuators and a user-friendly computer interface.

Design Approach and Schematic

To manufacture the prosthesis, 3D printing will be utilized as it is an up-and-coming economical alternative to traditional custom manufacturing methods used in prosthetic development (Silva, 2015). By 3D printing a prototype, the device can be 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 1, the realistic and organic shapes of the hand elements can be seen. Figure 2 displays the overall dimensions of the fully assembled prosthetic hand; these dimensions replicate the dimensions of a larger adult hand (D'Amour, 2020). The digits of the prosthetic hand will be powered using 20N solenoids nested inside the outer hand casing. CAD drawings for the outer hand casing can be found in Figure A-1. The solenoid's force will be transmitted using strings run between the digits and solenoids.

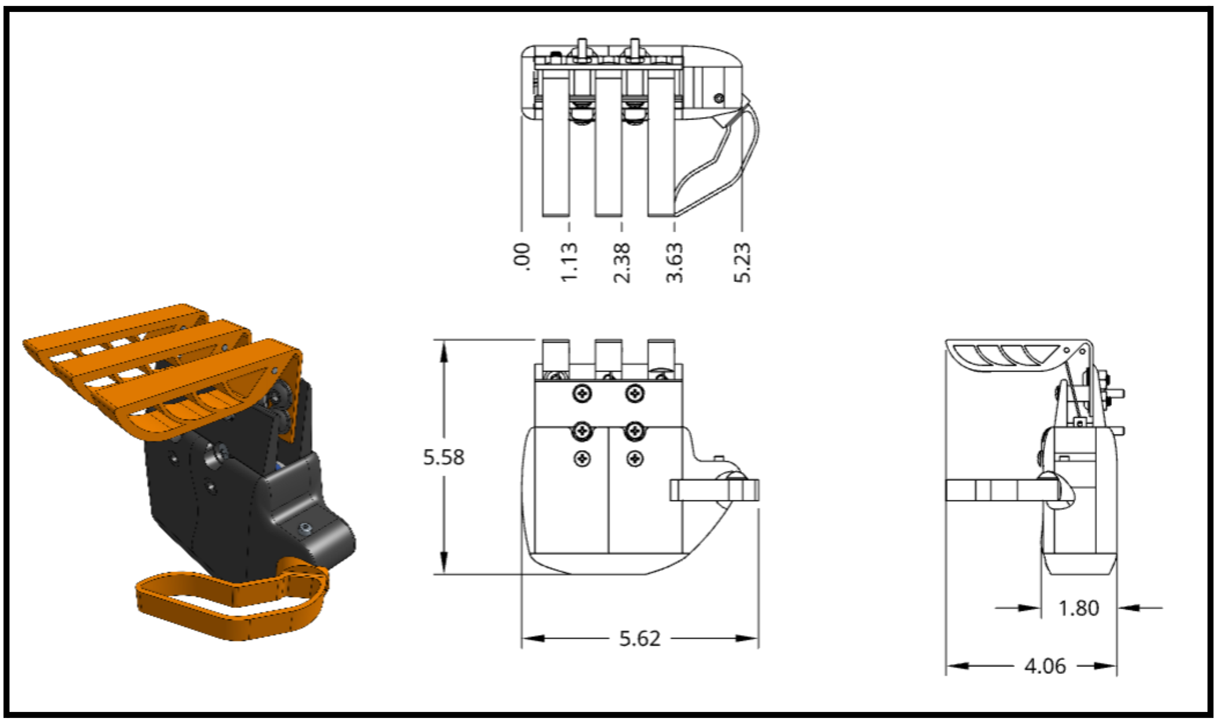

Figure 2: Top, side, front, and isometric views (clockwise listing) of the assembled prosthetic are shown above with the overall dimension of assembly in the resting position. Dimensions are inches and indicate an average to large-sized hand.

Polylactic acid (PLA) will be used in the base of the device and thermoplastic polyurethane (TPU) will be used in 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). 3D printed nonuniform TPU can be used to absorb energy in loading conditions, which will be applied in response to finger pressure absorption (Bates, 2019). The thumb and 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 design feature also increases the surface area of the interface between the digit and the valve while playing. The thumb is designed similarly but with no inner layers at all, as seen in Figure 4. The thumb component is not required to support any physical load as the left hand supports the weight of the trumpet while playing. Therefore, the role of the thumb is purely alignment making its ability to allow proper alignment most important. The lack of inner layers is to allow the thumb to flex and bend around any trumpet thumb support. This allows the thumb component to be universal and accessible. Figure 5 shows the overall and key dimensions of the thumb design.

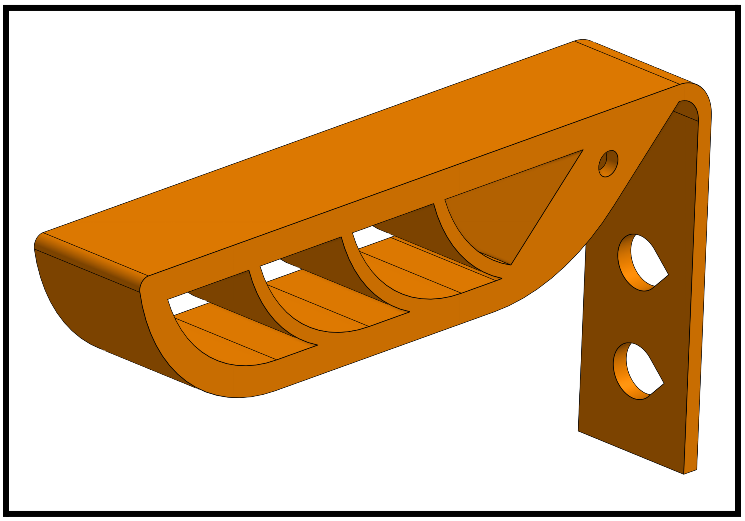

Figure 3: Isometric view of TPU digit design. Tear drop-shaped clearance holes can be seen, these holes allow for printing of the digit on its side while maintaining wall structure and print quality.

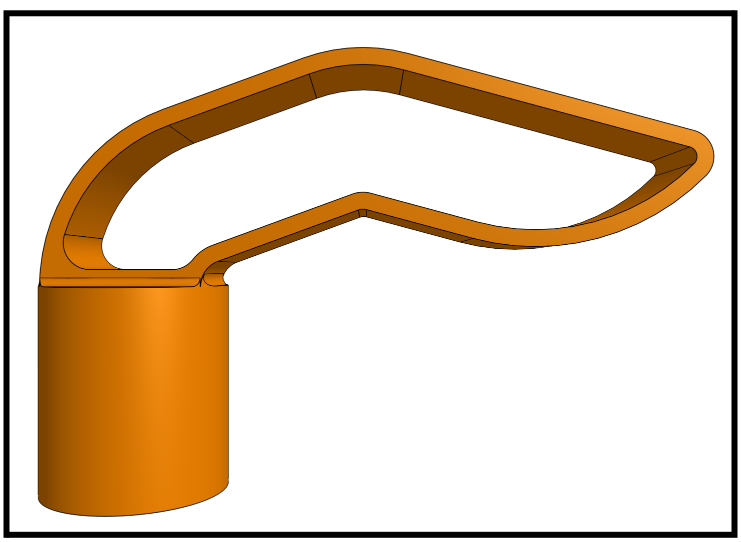

Figure 4: Tilted side view of the thumb component. The round base that allows for rotational adjustment once placed within the hand case can be seen.

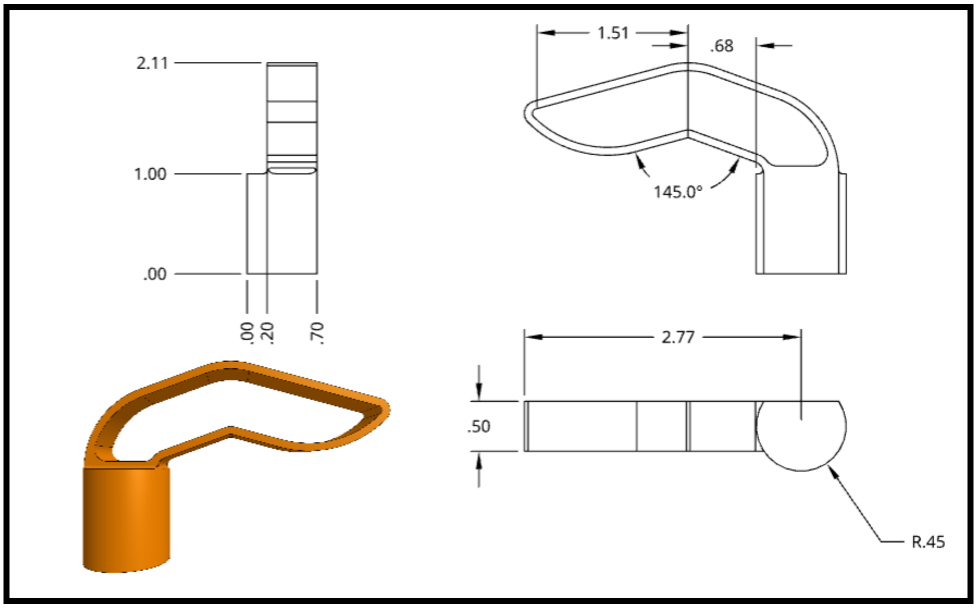

Figure 5: Front, side, bottom, and an angled 3D view of the thumb component are shown with overall dimensions in inches and key angles in degrees.

The digit component was designed to rest at 90 degrees from the typical resting state of fingers to generate the proper extension to reach the values while limiting the vertical movement needed to flex the digit from the resting position to compressing a valve. This resting state also allows the actuation attachment point of the string, as seen in Figure 3 as the small hole penetrating the bulk of the digit, to be moved to generate a greater lever arm and amplify the solenoid stroke length. This is crucial as the solenoids used to actuate the digits have a shorter stroke length than the vertical stroke of the valves. The digit design can be seen in Figure 3. The overall and key dimensions of the digit design and actuation point can be found in Figure 6.

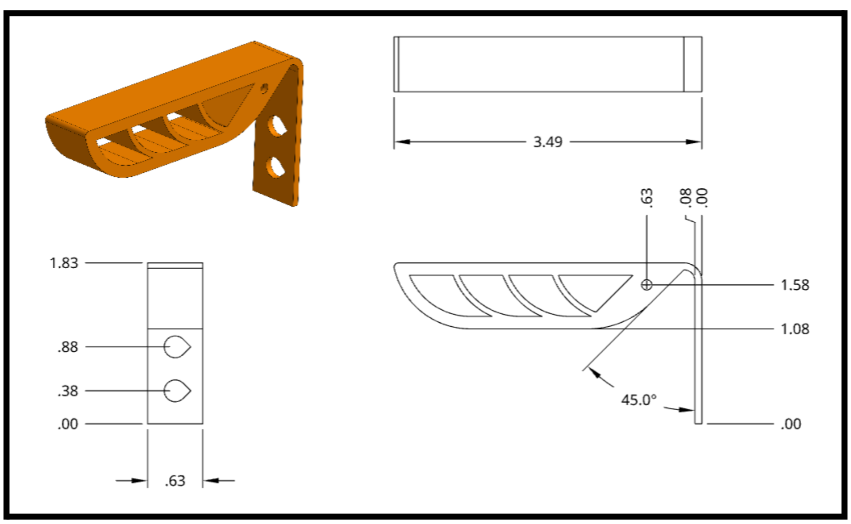

Figure 6: Top, side, front, and isometric views (clockwise listing) of the digit are shown with overall and key dimensions, in inches, in the resting position.

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 will be implemented on the pad of the index digit. This feature will allow 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 can be illuminated on the hand to notify the user of misalignment or device failure. 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. In Figure 1 the pressure sensor can be seen on the pad of the index digit. The force-sensing resistor will be used as it has plastic adhesive built into the sensor making attachment, maintenance, and replacement easy.

Another visual feedback and learning tool that will be integrated into the prosthetic to improve on the previous design is a light-emitting diode (LED) based metronome. To do this, an LED light will sit on the prosthetic and blink in tempo, like a modern metronome would make a sound to the tempo. To accomplish this, Python code will be used with a 4 beat count-in.The tempo will be interpreted from the musical instrument digital interface (MIDI) converter, which is already available in the device and user interface.

An electronic tuning device integrated within Hand-et V2 is the final integrated learning tool and it will allow the final user to analyze their pitch accuracy while they play. In terms of hardware, an electronic tuner would require two pieces of equipment: a transducer and a microcontroller. A transducer is an electronic component that converts energy from one form to another, such as the energy within acoustical signals to electric potential. An electret microphone would be suitable for this conversion, as these components have excellent frequency response over a large range. The typical trumpet player performs within the range of E3 to Bb3 on the scale, with frequencies varying from 168.4 Hz to 932.2 Hz. This falls well within the 1.0×10^{-3} Hz to 2×10^{8} Hz range that the average electret microphone can transduce (Sesseler, 1973).

To interpret the signals from the microphone, a microcontroller is needed. A Raspberry Pi will be used for the purpose of this rapid prototype. The microphone will be connected to the analog input pins on the Raspberry Pi, allowing for it to act as an oscilloscope, recording the signal within the time domain. To convert this signal into the relative trumpet notes, the frequency response would first need to be calculated. This can be done within a Python program, utilizing computational analysis algorithms.

Discrete Fourier transform (DFT) is 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 DFT function to output a sequence of sine and cosine functions that collectively make up the complex signal, thus, when graphed, converts the signal into the frequency domain.

Discrete Fourier Transform

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{\frac{-i2\pi}{N}kn} \quad \text{[eqn. 1]}$$

Euler's Formula

$$e^{ix} = cos\, x + i \cdot sin\, x \quad \text{[eqn. 2]}$$

Substituted DFT

$$X_k = \sum_{n=0}^{N-1} x_n \cdot \left[cos\left(\frac{2\pi}{N}kn\right) - i \cdot sin\left(\frac{2\pi}{N}kn\right)\right] \quad \text{[eqn. 3]}$$

To utilize this mathematical method within a digital signal processing program, an algorithm called fast Fourier transform (FFT), shall be applied. FFT factorizes the DFT matrix which reduces the factors significantly (from N^2 to N×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.

Before displaying the final frequency to the end-user, noise and distortion should first be factored out of the signal. During the initialization of the device, a sample signal shall be recorded as a baseline. This signal will be processed by the FFT algorithm and subtracted out of the subsequent data in order to ensure an accurate display of note frequencies.

A visual will be designed to display the final note frequency along with its accuracy to the closest note. This graphic will be incorporated into the graphical user interface (GUI) to display the instantaneous frequencies for use in tuning the instrument as well as note accuracy analysis during a performance. Figure 7 shows the progression of the analysis to the display of the recorded signals.

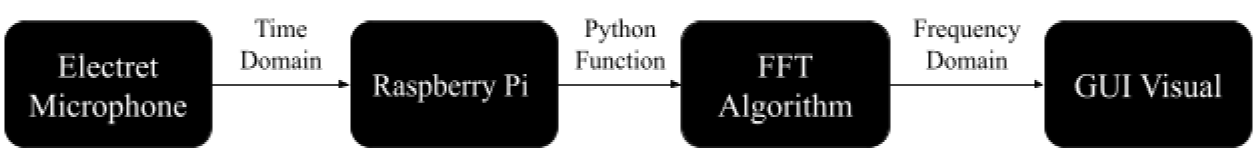

Figure 7: Hardware integration flowchart for electronic tuning device.

Experimental Plan

The previously discussed integrated learning features of the prosthetic hand will be tested individually and holistically. The first feature of the device to be tested will be the pressure sensors and digit actuation. The digits will be tested for a range of motion by powering the solenoids for short periods of time. If the range of motion test does not pass physical and mechanical issues will be investigated as well as the voltage and amperage throughout the circuit. Once the range of motion is confirmed the force required to compress a trumpet valve will be measured by gradually increasing the amount of water within a vessel on top of the valve. When the valve compresses, the vessel's mass will be measured. This mass will be converted to force using the acceleration of gravity. Next, the amperage to the solenoid will be adjusted until the force generated is greater than the force needed to compress the valve. The hand will then be held against the trumpet to test the force of the solenoids. If the solenoids compress the valves easily without being overly forceful or aggressive the range of motion and force tests will be considered to be passed. If the solenoids are "slamming" or forcing the valves down the amperage to the solenoids will be adjusted downward until a suitable speed is achieved.

After the prosthetic is proven to be functional, the pressure sensor will be calibrated by applying varying known forces to the sensor and recording the resistance outputs. Once the calibration curve is generated, a "compressed" range of resistance will be determined using a 95% confidence interval on the calibration curve. The positive compressed cases and negative compressed cases will be tested during mock practice sessions. To perform the positive compression test a mock practice session will be run but the index digit will be compressing a hard stop that has been manually aligned. If the practice run is successful and all pressure readings are within the accepted range the positive compression test will pass. If the hand is not interacting with anything else and the "No Valve Compression" message is displayed on the user interface the no compression test will pass.

Next, the tuning device will be tested. In order to test and accept the final tuning device, a series of tests will be conducted. The converted frequencies will be compared to known values. Statistical analysis will be performed to determine the accuracy of the device. Based on these tests, a calibration can be done to reduce any direct current (DC) offset present within the measured signals.

Finally, to test and evaluate the prosthetic and learning feature holistically, the prosthetic will be offered up to the brass ensemble at the University of Maine for a round of testing. We will record how many times the players restart, how long it takes them to play a song successfully with no prior exposure to the device, their comfortability with the device, and their final thoughts. If the trumpet players can successfully play a song by the end of the hour session, it will be concluded that players can adapt to successfully use the prosthetic. This would be "successful", as it would not take more than a practice session or two to adapt or transition to the prosthetic hand—helping to eliminate a large learning curve. Also, if the feedback and ease of use of the trumpet are overall neutral or positive, the device would be deemed successful.

Safety

When printing, be sure to be in a room that is well-ventilated to circulate the air, as small particles and chemicals may be emitted by the printer. Do not touch the 3D printer while it is running. The extruder gets very hot and can cause burns. Locate the nearest fire extinguisher, exit, and power source. Be sure hair is pulled back to avoid it getting caught by the motors, into the print, or tangled with the extruder. TPU granules can be a slip hazard, adequate ventilation is required when using this material (Americanortho, 2017). PLA is not classified as dangerous (Printparts, 2017).

The print should be cooled to room temperature before being removed from the printer's bed. This protects a finger from getting burned by the plastic or the nearby extruder if something moves. When removing the print, be cautious, as the spatula is sharp. If removing filament, be sure that the power is off so stepper motors don't come in contact with fingers while running. Make sure the printer also has no power when taking it apart. When using the printer, be sure it is plugged in completely and there are no fire hazards present.

Do not touch sharp operating machinery or ingest food or metal pieces. Avoid breathing adhesive fumes. Never carry sharp tools in a pocket and handle them with care while transporting. Proper care and maintenance of equipment should be observed, so thoroughly inspect tools before use. Only operate tools as per manufacturing instructions. Never operate power tools or perform risky operations alone.

Schedule of Tasks

The following Gantt chart, Table 1, has been constructed to help visualize the progression of the instrumentation development by the A2Z Team. Tasks listed in bold are assignments with specified due dates as per the syllabus. All members have continuous access to the chart, allowing for the content to be reviewed at the beginning of each week's meeting in case adjustments are needed. In the case of an edit, all present members will collectively decide on how to adjust. The Gantt chart documents an outline of attainable, step-by-step goals to ensure the team does not fall behind and completes individual tasks in a timely manner. This Gantt chart begins with determining a plan for sensor integration into the prosthetic, includes all major systems engineering milestones, and ends with the final presentation and closing report. The goal of the Gantt chart is to outline and assign, step-by-step goals to ensure they are completed in a timely manner. This will keep the design team on time and on track to completing the project. There are three different sections on the Gantt Chart: Theoretical development (planning and design modification), Physical construction (printing, coding, and implementing the device), and Testing/Troubleshooting (analysis, modification, and presentation preparation).

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+	174.14 grams	$0.02	$3.48
SainSmart TPU	24 grams	$0.04	$0.96
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	1	$0.25	$0.25
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			**$144.56**

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. **Hand Casing Drawing with Key Dimensions**

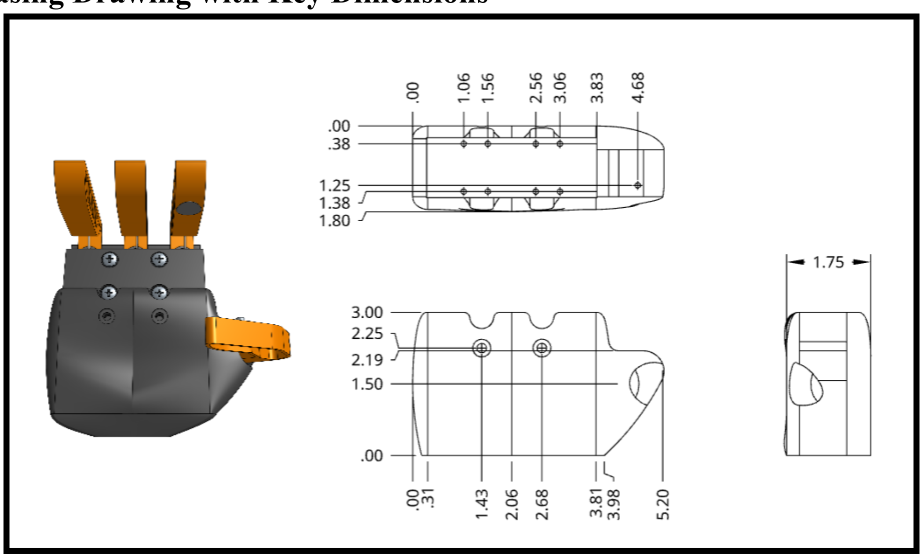

Figure A-1: Top, side, front views (clockwise listing) of the outer hand casing along with a front 3D view of the prosthetic assembly are shown. Overall and key dimensions are displayed in inches.

References

Aalbers, Sonja et al. *Music therapy for depression.* The Cochrane database of systematic reviews vol. 11,11 CD004517. 16 Nov. 2017, doi:10.1002/14651858.CD004517.pub3

Afrose, M.F., Masood, S.H., Iovenitti, P. et al. *Effects of part build orientations on fatigue behaviour of FDM-processed PLA material.* Prog Addit Manuf 1, 21–28 (2016). https://doi.org/10.1007/s40964-015-0002-3

Amazon. Amazon.com. spend less. smile more. (1995, July 16). Retrieved March 8, 2022, from https://www.amazon.com/

Americanortho.com. (2017). Retrieved 29 March 2022, from https://www.americanortho.com/assets/Uploads/Docs-SDS/SDS-Thermoplastic_Polyurethane_TPU_042415.pdf.

Bates, S. R. G., Farrow, I. R., & Trask, R. S. (2019). *Compressive behavior of 3D printed thermoplastic polyurethane honeycombs with graded densities*. *Materials & Design*, *162*, 130–142. https://doi.org/10.1016/j.matdes.2018.11.019

Chen, Y. (2017). *Soprano Cornet: The Hidden Gem of the Trumpet Family* (Ph. D). The University of Georgia. "Playing Ranges of Instruments.", 2022

Cruz, Rena L J et al. "Advancements in Soft-Tissue Prosthetics Part A: The Art of Imitating Life." Frontiers in bioengineering and biotechnology vol. 8 121. 31 Mar. 2020, doi:10.3389/fbioe.2020.00121

D'Amour S, Harris LR. The perceived size of the implicit representation of the dorsum and palm of the hand. PLoS One. 2020 Mar 23;15(3):e0230624. doi: 10.1371/journal.pone.0230624. PMID: 32203552; PMCID: PMC7089569.

Downs, S. (2018). *Breaking Old Practice Myths*. Scholarly Commons. Retrieved 22 March 2022, from https://scholarlycommons.pacific.edu/researchday/2018/events/14/.

Grosshauser, T., Tröster, G., Bertsch, M., & Thul, A. (2015). *Sensor and Software Technologies for Lip Pressure Measurements in Trumpet and Cornet Playing - from Lab to Classroom*. Research-collection.ethz.ch. Retrieved 22 March 2022, from https://www.research-collection.ethz.ch/handle/20.500.11850/108609.

Kula, K., Cilingir, H., Eckert, G., Dagg, J., & Ghoneima, A. (2015). The association of malocclusion and trumpet performance. *The Angle Orthodontist*, *86*(1), 108-114. https://doi.org/10.2319/111214-812.1

LaBach, P. (1965). A Device to Facilitate Learning of Basic Music Skills. *Bulletin of the Council for Research in Music Education*, *4*, 7–10. http://www.jstor.org/stable/40375257

LaBach, P. (1965). A Device to Facilitate Learning of Basic Music Skills. *Bulletin of the Council for Research in Music Education*, *4*, 7–10. http://www.jstor.org/stable/40375257

Legro, M. W., Reiber, G. E., Czerniecki, J. M., & Sangeorzan, B. J. (2001). Recreational activities of lower-limb amputees with prostheses. *Journal of Rehabilitation Research and Development*, *38*(3), 319–325. Retrieved March 22, 2022, from rehab.research.va.gov/jour/01/38/3/legro.html.

Liacouras, P.C., Sahajwalla, D., Beachler, M.D. et al. *Using computed tomography and 3D printing to construct custom prosthetics attachments and devices*. 3D Print Med 3, 8 (2017). https://doi.org/10.1186/s41205-017-0016-1

McMaster-Carr. (2002). Retrieved March 7, 2022, from http://www.mcmastercarr.com/

Montenegro, C., Cabrera, A., Alcaide, A., & Selda, l. (2012). *A Study on Pitch Recognition for Trumpet. Jurnal Informatika*, *8*(2). Retrieved 22 March 2022, from https://ti.ukdw.ac.id/ojs/index.php/informatika/article/view/129/89.

Pressman, Sarah D et al. "Association of enjoyable leisure activities with psychological and physical well-being." Psychosomatic medicine vol. 71,7 (2009): 725-32. doi:10.1097/PSY.0b013e3181ad7978

Printparts.com. *PLA SDS sheet*. (2017). Retrieved 29 March 2022, from https://printparts.com/datasheets/PLA-MSDS.pdf.

Selek, H. (2020). Programmable Metronome for Percussion Instruments and an Application. *International Journal of Electronics, Mechanical And Mechatronics Engineering, 2*(1), 128-132. Retrieved 22 March 2022, from https://ijemme.aydin.edu.tr/wp-content /uploads/2020/04/ijemme_v2i1006.pdf.

Sessler, G. M., and J. E. West. *Electret Transducers: A Review*. The Journal of the Acoustical

Sahu, Anamika et al. "Psychological effects of amputation: A review of studies from India." Industrial psychiatry journal vol. 25,1 (2016): 4-10. doi:10.4103/0972-6748.196041

Silva, K., Rand, S., Cancel, D., Chen, Y., Kathirithamby, R. and Stern, M. (2015), *Three-Dimensional (3-D) Printing: A Cost-Effective Solution for Improving Global Accessibility to Prostheses.* PM&R, 7: 1312-1314. https://doi.org/10.1016/j.pmrj.2015 .06.438

Society of America 53, no. 6 (1973): 1589–1600. https://doi.org/10.1121/1.1913507.

Vidal, G. W., Rynes, M. L., Kelliher, Z., & Goodwin, S. J. (2016). *Review of brain-machine interfaces used in neural prosthetics with new perspective on somatosensory feedback through method of signal breakdown*. *Scientifica*, *2016*. https://doi.org/10.1155/2016/8956432