ENGINEERING DESIGN AND INNOVATION

Project: Bionic Hand
FINAL REPORT

Group 33

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Executive Summary

This report contains this design team's solution for the Project 'Bionic Hand'. The problem defined for this project was to construct a robust, and aesthetically pleasing prosthesis for transradial amputees to ease the tasks of modern daily living. The apparatus must be capable of crucial hand functions. The design must be simplistic and easy to understand, for ease of maintenance. Additionally, it should be able to receive and act on Bluetooth signals, cost no more than $150 to produce, primarily use EMG signals to act and must be battery powered. Required functions include input numbers into a number pad by receiving a Bluetooth signal.

The final design scheme integrates 5 subsystems to fulfill the design requirements. These include; surface electrode bipolar configuration, amplification, high pass and low pass filtering, a five-digit servo string system, and Radio Frequency Identification (RFID). The fluent interfacing of the following systems and the independent tasks which they undertake ensures the device performs well.

The advantage of this design solution is that there is a smooth interfacing between frameworks as the internal subsystems guarantee every framework works in synchronization to accomplish the outlined objective while also ensuring flexibility. Also, the use of a five-digit servo string system is advantageous as it most accurately reflects the physiological structure, function and versatility of the human hand.

The results of prototype and final testing indicated:

- The reliability and capability of the internal circuits to acquire and harness an appropriate EMG and Bluetooth signal.
- The power, speed and structural features of the servo string five-digit mechanical system was not properly accounted for, limiting the design's ability to grip objects in certain situations.
- The design possessed innovative and aesthetically pleasing characteristics which distinguished it from its competition.

Further refinement and cross-checking of the integrity of the mechanical systems at play is required to produce a successful design solution.

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1 Introduction

This document presents the work undertaken by Group 33 for the Project Bionic Hand part of The Introduction to Engineering Design and Innovation course ENGG1000, most specifically, the results of prototype testing, final testing and proposals for additional development. The problem to be addressed included to construct a robust, and aesthetically pleasing prosthesis for transradial amputees, with the capability of successfully picking up objects of variable size and entering a 3-digit pin into a number pad via the reception of a Bluetooth signal. Additionally, the design had to cost no more than $150 to produce, primarily use electromyographic signals to act and had to be battery powered.

Construction of the final design incorporates the use of electromyography, electrical amplification and filtering controlled by an Arduino microcontroller and a servo-string five-digit 3D printed mechanical system to effectively replicate crucial skeletal and muscular systems for crucial hand function to ease the tasks of modern day living. Additionally, the design includes Radio Frequency Identification (RFID) and various other modular components, customisation options, and a built in digital LCD time keeping device.

To achieve one of the main design goals of producing an innovative yet simplistic prosthesis, several inherent key problems arose which would challenge the design's capabilities and the proposed solutions to the design brief:

- Incorporating the use of electromyography would require extensive amplification, conditioning and filtering processes due to underlying biological factors governing the nature of action potentials. This would also involve prior analysis of surface electrode placement based on fat, hair and microparticle density on the outer surface of the target muscle of the operator in regard to unwanted signal noise and impedance.
- In order to accurately replicate the skeletal and muscular mechanics of the hand, the team would have to implement a five-digit mechanical system which would be complemented with the appropriate time for strength and integrity testing and refinement to ensure proper design performance.
- The implementation of several innovative features including a digital LED time keeping device and other modular components would have to be included as to ensure all other integral electrical and mechanical components could be easily included in the internal housing of the device despite having cost and size restraints.

This report will begin with discussion of this team's final design scheme with respect to how the mechanical, biomedical and electrical sub-systems interface to address the design challenges. This will then follow with a thorough analysis of final testing in relation to the inherent key challenges stated above, including discussion, evaluation and recommendations to improve the design based on how successfully it had performed during assessment.

2 Final Design and Implementation

2.1 Mechanical Design

Overview and design evolution

In order to create a useful myoelectric prosthetic, it is important to have a design that mimics the functionality of the human hand as close as possible. The main factors that need to be considered with the mechanical design are namely: the forces present upon activation of the hand, and the method in which joints are activated to be of use. The bionic hand presented can easily be manufactured using computer aided design (CAD), 3D printing and basic methods of assembly.

The final mechanical design consists of a 5-digit prosthesis, mimicking that of the human hand. This was chosen not only to be sellable and aesthetically pleasing, but also to maximise efficiency and functionality, with the aim to implement modular components that can easily interface with modern technology. In our goal to create a hand which is "efficient for daily living", the 5-digit design was the basis for our modular prosthesis, where various components are interchangeable allowing for an experience tailored to the user. As a result of our goal, highlighted by the problem statement, our priority was not to create a hand that could perform physical manoeuvres and tasks that the human hand couldnt, but instead, to create a functioning hand that supplement itself with technology that makes life easier to live for amputees.

Component design

All components of the hand were designed using Autodesk Fusion360 Computer aided design and printed using PLA, through Zeal: Professional printing services. For each component, see Appendix A for construction procedure

Flexion/Extension of the fingers:

In our design, the flexion of the fingers was implemented through a string and servo system. Each finger consists of a proximal and a distal component. Sites of attachment are on the distal finger, for both the extensor elastic and the flexor fishing wire(which attaches to the servo motors). The fingers are designed to accommodate 1 degree of freedom and 2 joint contractions when flexed, which was a simplistic, yet efficient way of designing digits. This mechanism is depicted in Fig. 2.1 and Fig 2.2

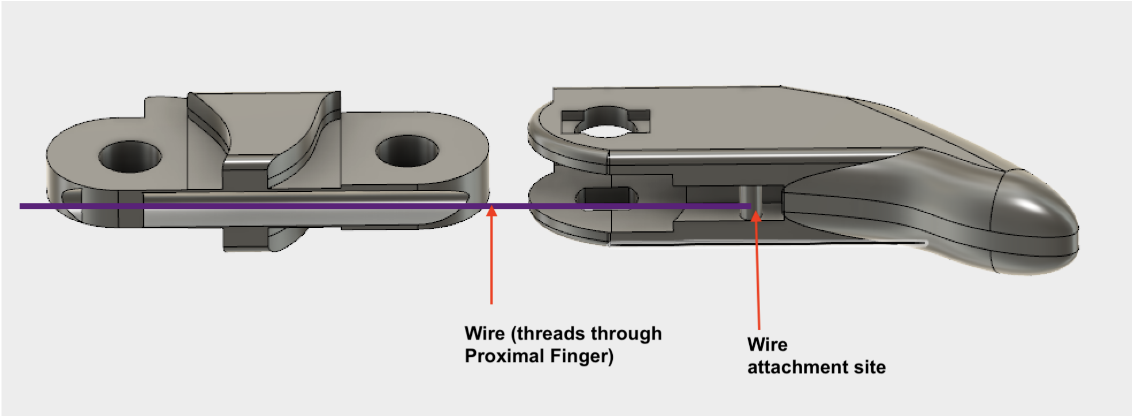

Figure 2.1: Underside view of proximal and distal finger: Wire flexion mechanism.

A large, metal geared servo pulls on the fishing wire resulting rotational forces, causing the finger to bend; the degree to which it bends depends on how much the wire is pulled, which is determined by the rotation of the servo head. The extension of the finger utilised the elastic property of rubber bands to straighten the fingers when the strings loosen up. The finger's function is to apply force in two areas, effectively gripping an object. Braided fishing line is used as there is minimal stretching, which would cause a lack of tension over time- a looser grip. Tendons in the body work in a similar way and were the inspiration for this method. However, there are numerous tendons attached to one bone, which allows for more precise control of the fingers.

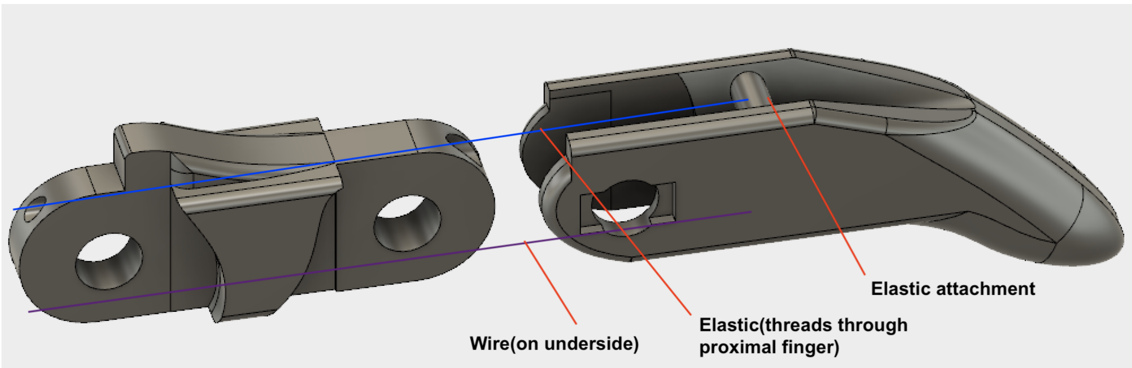

Figure 2.2: Top view of proximal and distal finger: Elastic extensor mechanism

Both the prototype and the final design utilised this system but the prototype design only incorporated one motor for four fingers with the thumb static and elastics were not used to straighten the fingers. Challenging problems included gripping smaller objects such as a coin and the lack of individual finger control makes it hard to grip objects of various sizes. This was resolved in the final design which incorporated three servos to all fingers making it more versatile and stronger in holding objects.

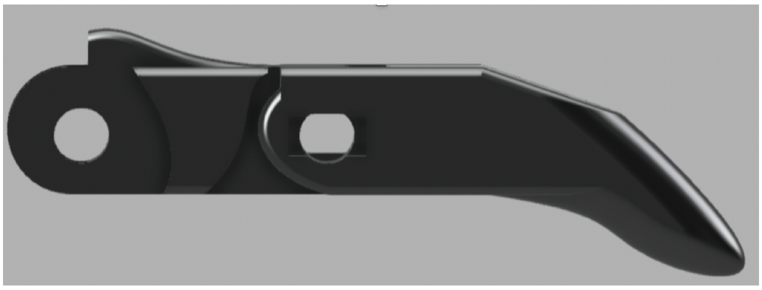

Figure 2.3: Side view of finger

Drive System:

The overall idea for joint activation is to use a string servo system to create hand movements. The advantage of this method is that it enables a smoother transition between hand states, due to the use of passive elastics that automatically induce finger extension, in comparison to gear systems which need to be controlled for both opening and closing movements. Hinges are used as joints for the hand as they restrict the movement of the fingers, which is a more simplistic joint type for the purpose of the task. The string servo system uses the pulling motion of the strings to create hand movements. The default state of the hand is open. The servo motor turns to an extent where the hand is able to hold on to an object tightly or to the maximum possible range for the fingers. When the motor returns to the default state ie. starting position, the fingers return to its original position with the help of elastics. The drive system is shown below in Fig 2.4

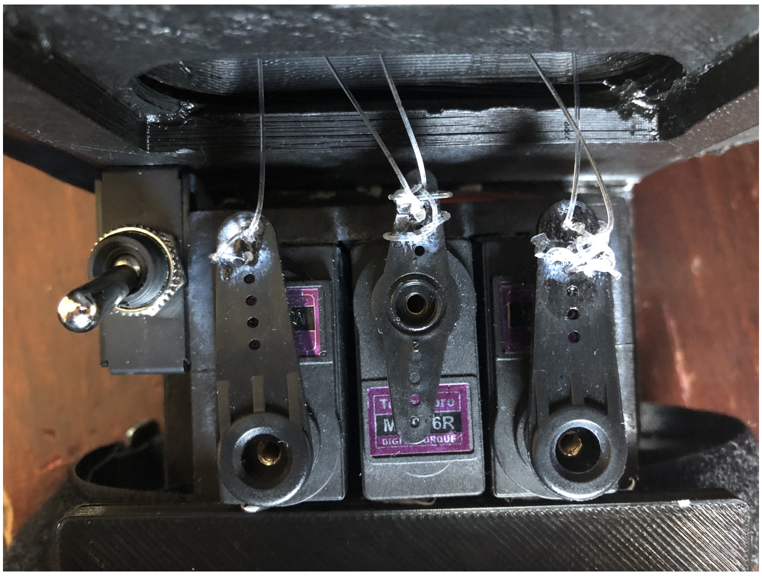

Figure 2.4: Birds eye view of motor drive system

The fishing wire requires to be pulled 8cm for the fingers to achieve complete flexion. Since:

Length = (n°/360°) x 2πr. Where r is the radius of the servo head (4cm), and length = 8cm

It can be found that the servo needs to rotate 115° to completely close the fingers.

Furthermore, The MG996R servo used has an operating speed of 0.15sec/60°. Hence the maximum time to close each finger would be: (0.15/60°) x 115 = 0.29s

<u>Hand Frame:</u>

In order to imitate a human hand, the fingers are required to be attached via hinges to a hand frame which serves to house the strings that are used for flexion and the elastics for extension. By separating the fingers from the hand frame, each finger becomes more manageable due to the easier access to individual fingers.

The basic design of the hand frame was a rectangular prism made of wood with hinges for attachment. However, it was found that a cylindrical shape was stronger structurally, so the final design incorporated a rounder shape which also makes the design less bulky and more aesthetically pleasing. Other problems included the lack of direction for the strings and to resolve this the final design had holes that directed the string in a certain direction allowing for better management and a smoother extension of the fingers due to the strings not getting tangled. Moreover, the final design had designated attachment sites for the elastics as well as support frames attached to the wrist, which overall made it more robust. This mechanism is detailed in fig 2.5 with additional diagrams in Appendix A

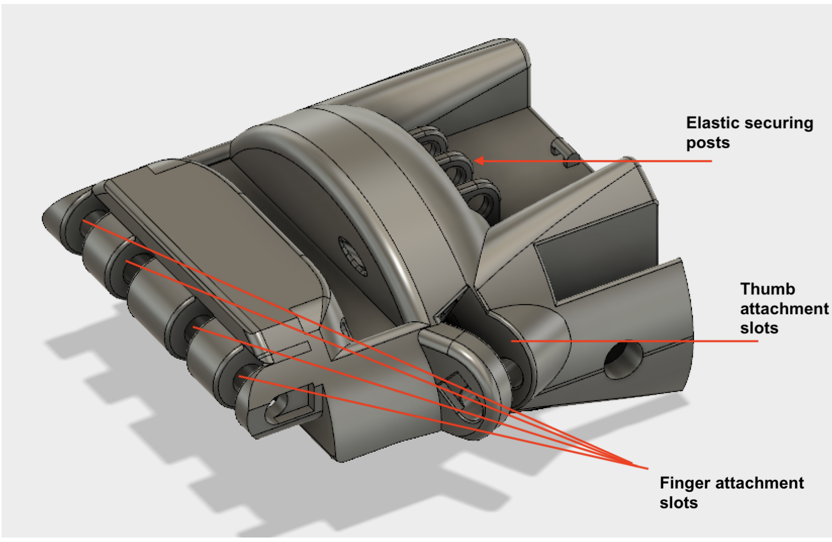

Figure 2.5: Front three-quarter view of hand

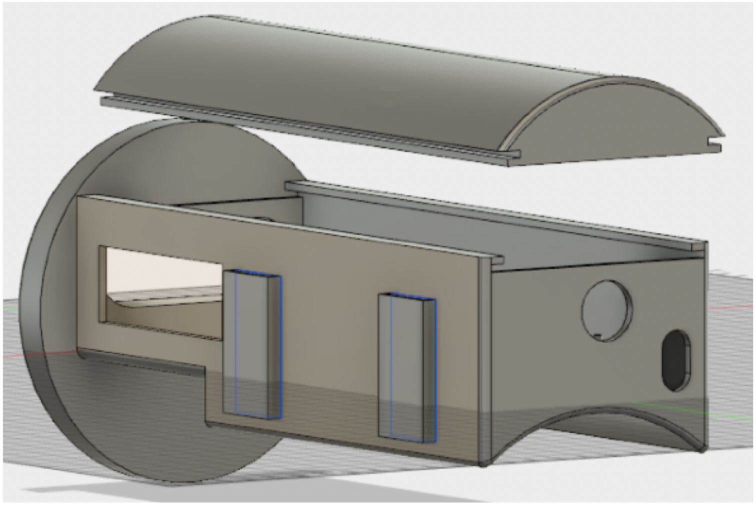

Figure 2.6: Rear view of wrist compartment

Wrist Gauntlet:

To house the circuitry and servos required for the hand's function a wrist gauntlet shell had to be designed. This compartment is attached to the hand via hinges and also acts as a place for attachment onto the forearm.Initially, the prototype was a rectangular prism with a slot at one side for the string to come through and hinges for attachment. It also included slots for the motor and LCD screen. Challenges included an uncomfortable attachment base and risk of circuitry falling out. The final design was a 3D printed wrist with the base rounded out increasing surface contact between the forearm and the wrist and allows for comfort and a more stable attachment. A sliding lid was added for easier access to the circuitry and it prevented them from falling out.

Keypad Input

An additional design requirement of the hand included an autonomous keypad input function which acted on Bluetooth. This component was separate to the hand and was designed to input a three-digit code onto a keypad with an actuating force of 100 ± 30g.

Initially, various methods of this function were conceived which utilised the fingers including the incorporation of sideways movement for one of the fingers or utilising three fingers and different degrees of bending for each number on the keypad. However, due to the size of the fingers, these methods were not viable and therefore, design looked for a separate contraption for keypad input. Again, various methods were thought of, one of which was a piston system. However due to the manufacturing challenges and complexity of that idea, the system of servos in the final design was used which in contrast was much more simpler and easier to implement. The final design positioned five micro servos attached to a PLA shell, where the servo heads were aligned with the keypad numbers, and each servo being able to press one to two number buttons. (Fig 2.7)

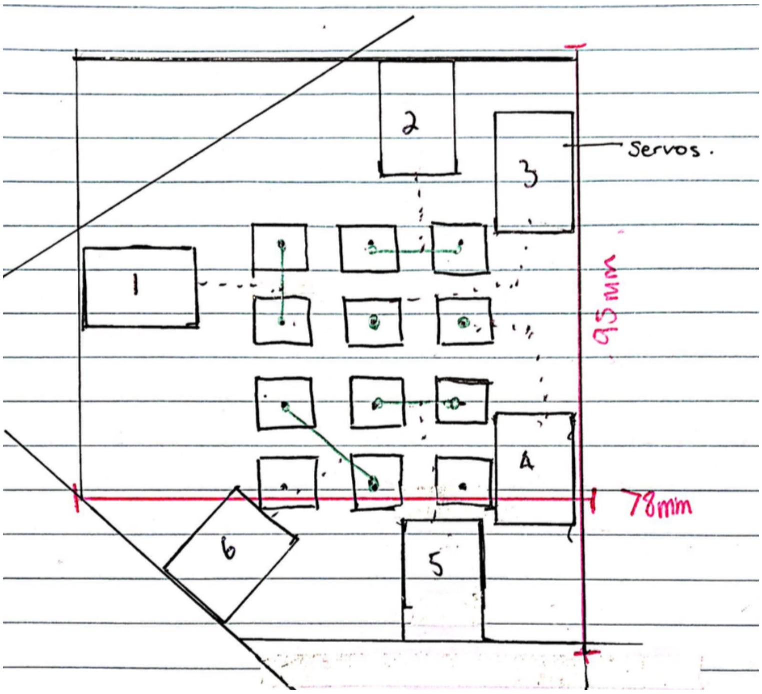

Figure 2.7: Blueprint of servo shell. The green lines perpendicular to the servos designate the keys responsible for that servo.

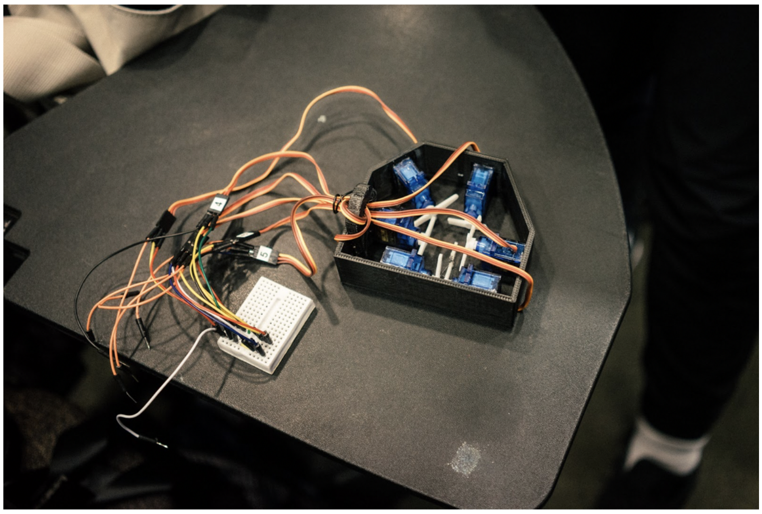

Figure 2.8: Servo shell before attachment to arm.

Assembly

Initial assembly proved to be a challenging task, with multiple components needing to be remodelled and altered through manual means (as there was not enough time to reprint parts). This was due to the fact that some components such as the wrist needed to be printed in sections, in order to minimise cost (from an external printing company). In a manufacturing environment, the size of the print wouldn't matter. Sanding, cutting and adhering parts to each other proved to be quick fixes to some minor problems on the design- that we could only account for after the model was printed. However, once the main assembly was complete, the modular component attachment proved to be quite simple, as intended for the target market. This includes threading strings through and securing wires and elastics. All can be done in under 1 hour. The assembly guide in the appendix provides basic instructions on how to assemble the hand.

2.2 Signal Acquisition

Details of all passive component final circuit values can be found Appendix B

In order to actuate the motors, a signal from the muscles must be acquired and processed first. Once the signal has been analysed by feeding it into an oscilloscope, voltage cut offs for the motor function can be determined and utilised. A flow chart of steps to create a fully functional EMG prosthetic can be seen below:

Myoelectric user input → Control circuitry → Motors → Flexion of the prosthetic fingers

The Biomedical component of the design focused on creating a reliable EMG signal using appropriate acquisition, filtering and amplification processes. The signal was acquired by flexing target muscle accompanied with appropriate surface electrodes and alligator clips. Due to various underlying biological factors, electromyographic signals are of the order 10-3 volts, insufficient to power the various electrical and mechanical parts of this team's design solution. As such, the signal upon acquisition was first amplified by an op amp electrical circuit. As well as this, filtering was required to alleviate the distortion and lowering of the amplitude of the signal due to internal cross talk, local electromagnetic activity and other underlying factors. To extract the signal a bipolar configuration was used. A bipolar configuration utilises two surface electrodes placed on the belly of the target muscle, with the signal between the electrodes being differentially amplified with respect to the reference electrode [1]. Employing the use of this configuration reduce unwanted signal noise induced onto the signal produced from internal crosstalk, hence its inclusion in the design scheme.

Bipolar Configuration:

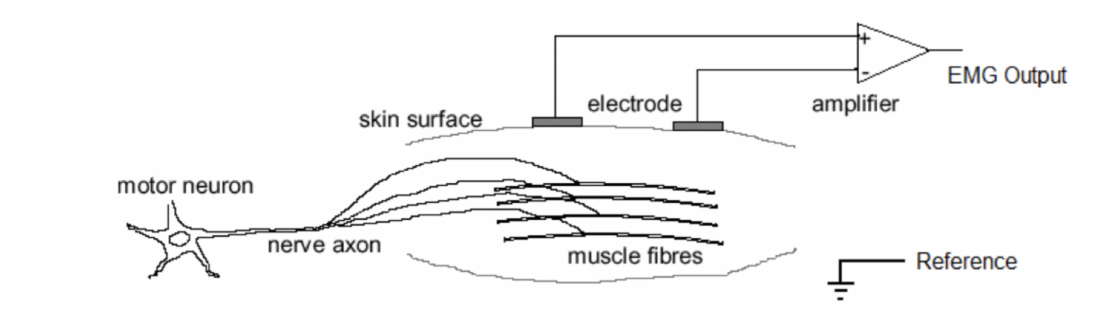

Figure 2.9: Bipolar electrode configuration

Reducing Impedance:

Other than utilising a Bipolar configuration, there are many other factors that can reduce the amount of signal noise in the acquired EMG signal. The amount of body hair and fat in between the surface electrodes and the target muscle will induce impedance and therefore create signal noise. This was considered when choosing the operator for the bionic arm, thus a person with minimal body hair and relatively low body fat percentage was chosen as the operator. Moreover the wires that connect to the EMG pads should be lock on and not clip on, to avoid external noise from being detected.[2]

Once a suitable source for the EMG signal has been determined, it is now time to pass the signal through to a microprocessor, such as an Arduino, which is able to control the motors in a specific way through the use of the EMG Signal. The simple way to understand how this works is to picture the EMG signal as an on/off switch. When the person is flexing, the signal is on, and when the muscle Is relaxed, the signal is off. Now when the signal is on, the Arduino will instruct the servo motors to rotate, contracting the fingers, and when there is no signal, the motors will rotate to their initial, relaxed state. A flow chart of the sub systems of the circuitry that achieves this can be seen below.[3] Electrodes Amplification High pass filter Low pass filter Rectification Arduino

Electrodes → Amplification → High pass filter → Low pass filter → Rectification → Arduino

However, upon the construction of such circuit, one must keep in mind that the EMG signal is fairly weak and with unwanted noise. Hence, producing voltages of only 10-3 V – an insufficient amount of voltage when operating the hand. Thus, an EMG amplification circuit must be made in order for use in EMG applications with ranges from 1 to 10 millivolts. [4] Since the EMG signal's amplitude lies between 1-10mV, an amplification circuit is necessary to determine a suitable cut-off to trigger the motors. Initially, the amplification circuit was constructed using 3 LM741 Operational amplifiers, to mimic an instrumentation amplifier which was not available.

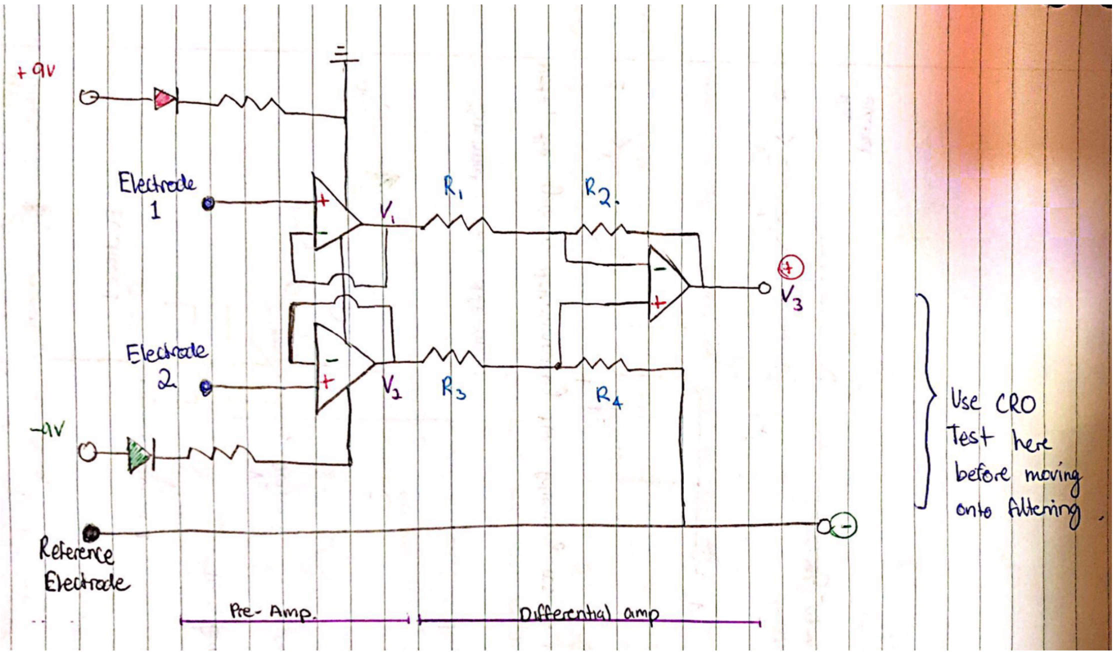

Figure 2.10: Stage 1 amplification draft circuit 1

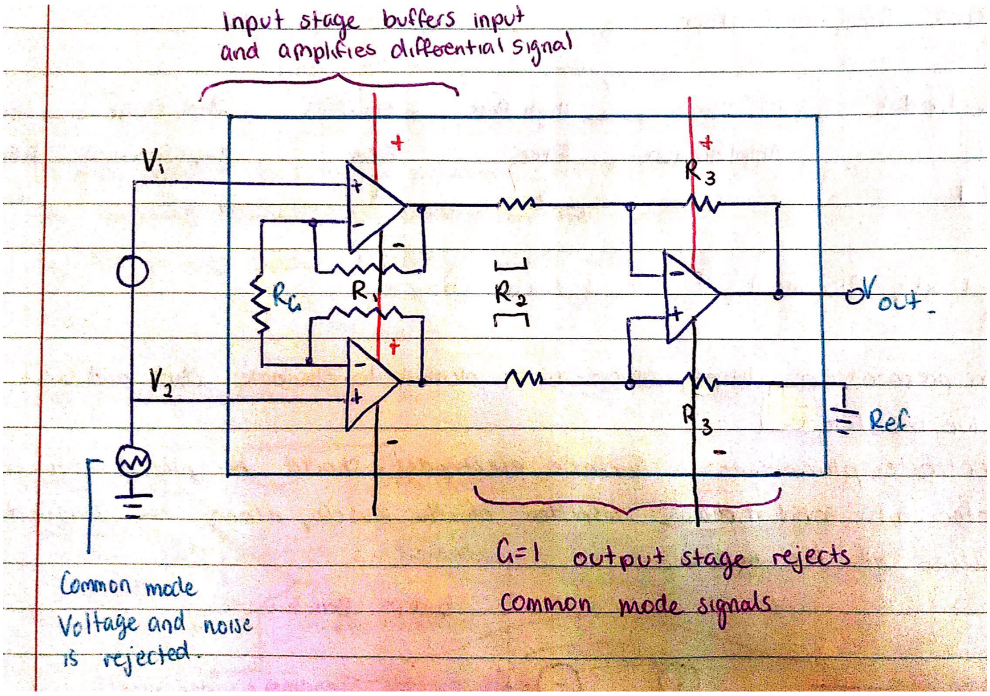

Figure 2.11: Stage 1 amplification draft circuit 2

Circuits in figure 2.10 and 2.11 both attempt to harness EMG signals through the use of differential amplification, where the circuit overall should have a high impedance input and a low impedance output. From diagram 2.10, the input stage is comprised of a two-op amp configuration in adjustable gain and provides very high input impedance on both inverting and non-inverting inputs. The output stage consists of a difference amplifier composed with 4 accurately matched resistors and a single op amp that rejects common mode voltage and noise; which is referred to ground. (N.E. Cotter, D. Christensen, K. Furse, pg.7)[5][6]

This circuit was later improved and simplified to diagram 2.11, by removing some passive components, such as the resistors along the pre-amps, resulting in a more efficient circuit. A resistor Rg was introduced, which will ultimately determine the amplification value of the EMG signals.

Using the formula: Gain=(1+(2R1)/Rg)(R3/R2)
Make all resistors equal except Rg
R1=25kΩ and Gain=10
Gain=(1+(50)/Rg)
Rg= 6kΩ (1 sig. fig.)

Thus, for a gain of 10, Rg must be set to approximately 600Ω.

Despite the functioning circuit, the simplicity of the system seemed to be compromised as there were too many components to monitor. Hence if a passive component was by any chance broke, it would be a tedious task to find and replace it. We aimed to make this system as simple and as user friendly as possible, in order to uphold our modular prosthetic goal, so that users could attach new electronic components with ease. As a result of this, an instrumentation amplifier package was purchased and used to replace stage 1 amplification. Moreover, since a stage 2 amp was not being used (to avoid failure in circuitry), the gain for the stage 1 amp was set to approximately 1500. [7] This reduced the space used on the breadboard and made room for an extensive filtering circuit which provided a highly accurate sequential EMG detection system.

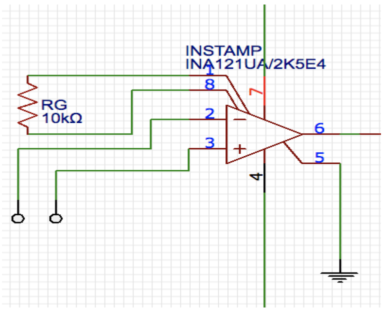

Figure 2.12: Final stage 1 Instrumentation amplification circuit

FILTERING

During the first stage of amplification, both EMG signals and noise harnessed from the muscles were intensified. However, the operation of the bionic arm with noise will obstruct fluid hand motion; implementing a high pass and low pass filter can alleviate this issue.[8]

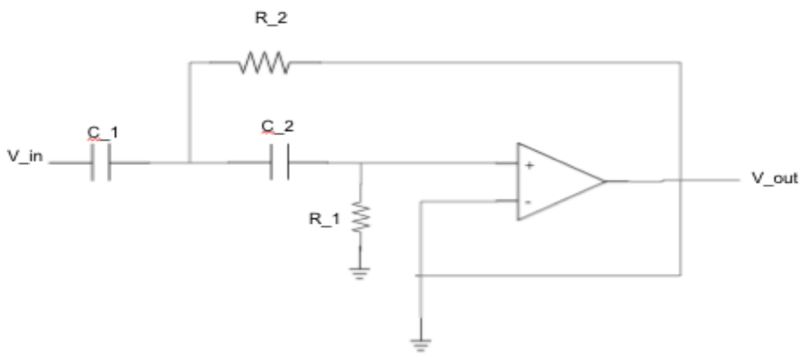

Figure 2.13: Second order sallen-key high pass filter

Figure 2.13 presents such high pass filter, which is responsible for the removal of low frequency components from the amplified signal. Implemented after the first amplification circuit, the design uses a second order sallen-key op amp filter. The utilisation of active components isolates the filter from the rest of the circuitry, providing a roll off of 40 db/dec. (Roll off is the slope at which the filter reaches its cut off.) [9]

The capacitance and resistance of the passive components were chosen in such a manner that the frequency cut off would be 48Hz ie. Everything below 48Hz would be cut off. However in manufacturing a customised prosthesis, these values should be tested and chosen according to the operator's optimal cut off rates.

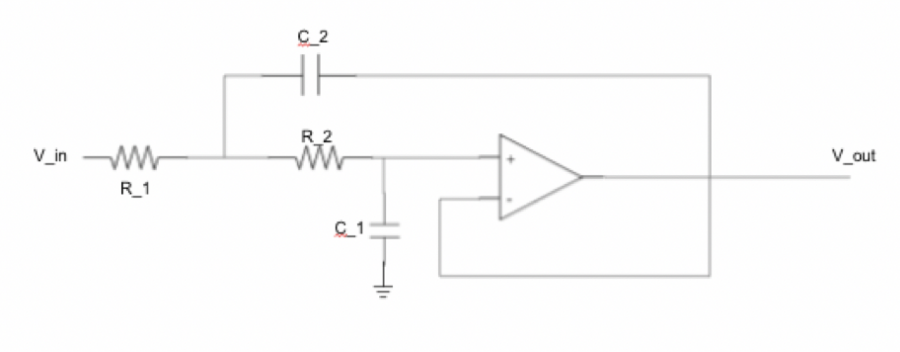

Figure 2.14: Second order sallen-key low pass filter

In a similar manner, the low pass filter allows low frequencies to pass and cuts off high frequency noise. This cutoff was chosen to be 185Hz. These values were chosen according to the formula:

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

These values are optimal as the EMG signal is most intense between 50-150Hz in the bicep brachii, and noise from electrode-skin interface is around 20Hz, while common mode noise exists in the 50-60Hz range. [10]

RECTIFICATION

Up to this stage, the circuit amplifies the EMG signal and filters it, producing a neat wave function when visualised on a CRO. However, when this signal is fed into the Arduino, the microprocessor converts it into a digital signal, by converting the voltage output into bytes. Hence a voltage between 0-5v is converted into data from 0-1023 bytes. Since there can be no negative voltage in this conversion, sections of negativity in the signal will be set to 0 bytes, leaving gaps in the wave. Rectification is an important step as it converts alternating current to direct current. Through the use of 2 diodes, all values are flipped to positive voltage and a continuous wave is acquired. [11]

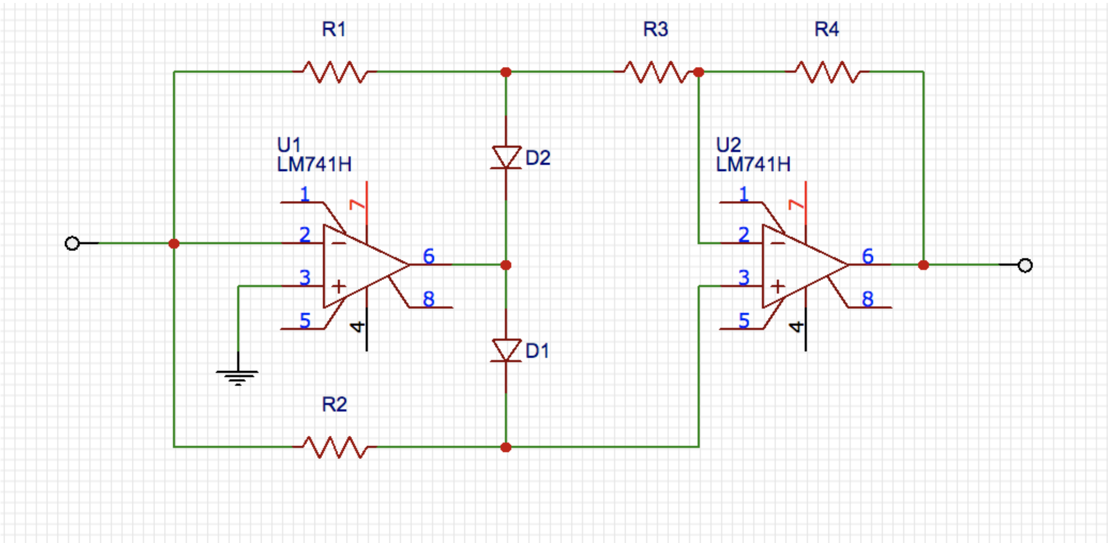

Figure 2.15: Rectification circuit

Assembling the circuit

The complete circuit shown in fig 2.16 implements all the above discussed components, and uses an INA121 instrumentation amplifier, and an LM324 op amp, which has 4 op amp packages. This quad package amplifier significantly minimises space used on the circuit and also makes handling and changing components much easier. Prior to the installation of these packages, the circuit was very inconsistent, with multiple disturbances in the output. The output of this final circuit provides a raw voltage between 0.8V- 3.2V (relaxed to flexed) on the tested operator's arm.

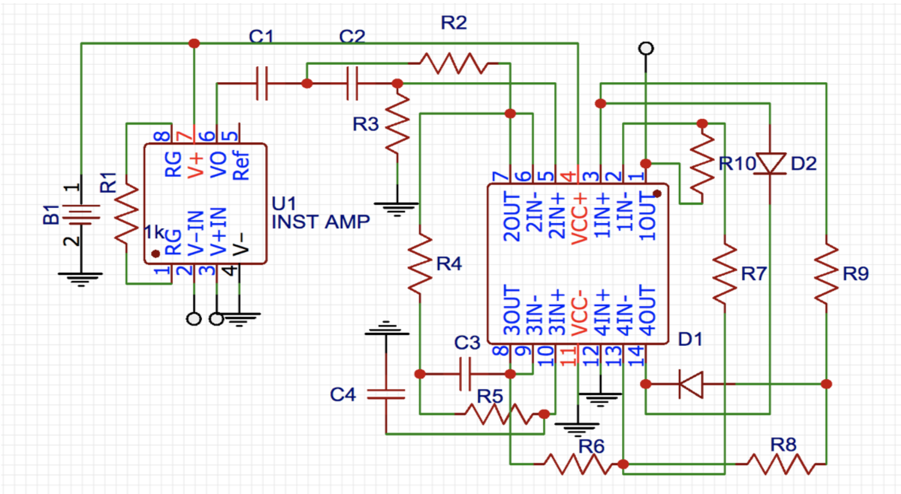

Figure 2.16: Final circuit schematic displaying the pin-outs of the INA121 (left) and LM324(right)

Creating a fully functional EMG circuit took 8 weeks, which included research as well as construction. Under manufacturing conditions, a PCB would be easier to create and distribute. The PCB for the final circuit is shown below:

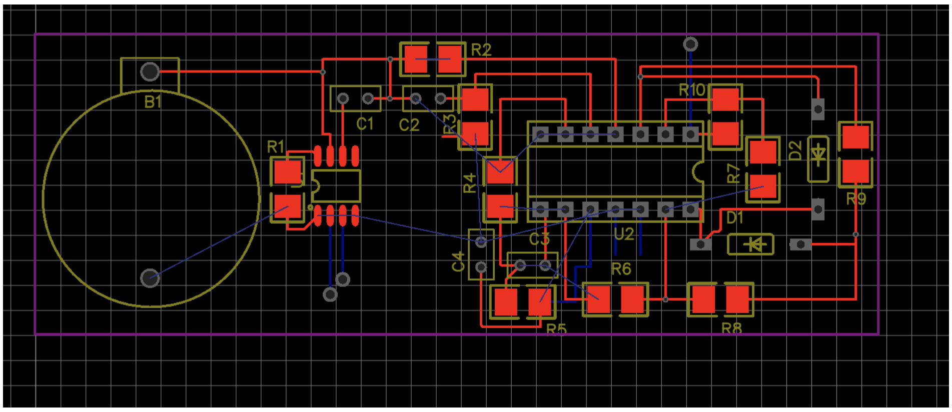

Figure 2.17: PCB Schematic using easyEda PCB maker

2.3 Utilising the Signal

Arduino Program Summary

The annotated code can be found in the appendix.

The EMG circuit program reads in the EMG signal, and once the signal passes a chosen threshold, activates the servo motors to rotate to a desired angle. The threshold should be chosen to accommodate the operators bicep flexion, which can be determined through testing. This program also smooths the signal, by constantly calculating the average of points, and using that value as a peak detector for the signal. In this manner, there will be no spikes in the signal, making the contractions of the hand very fluid under all EMG signal values. The Arduino serial plotter was used to gather information and determine thresholds using this code, prior to physically attaching the motors.

Attaching Motors

A very simple motor circuit was created, separate to the EMG circuit, which powers all the motors with a single 9v battery (Fig 2.18). The only problem with this component, is that it uses a single a battery, which could be replaced by a more reliable lithium ion battery. This circuit can be constructed on the same breadboard or PCB to minimise space used and cost of production. It is important that the motors are ordered correctly and assigned to the correct Arduino pin. Details can be found within the annotated code in the appendix.

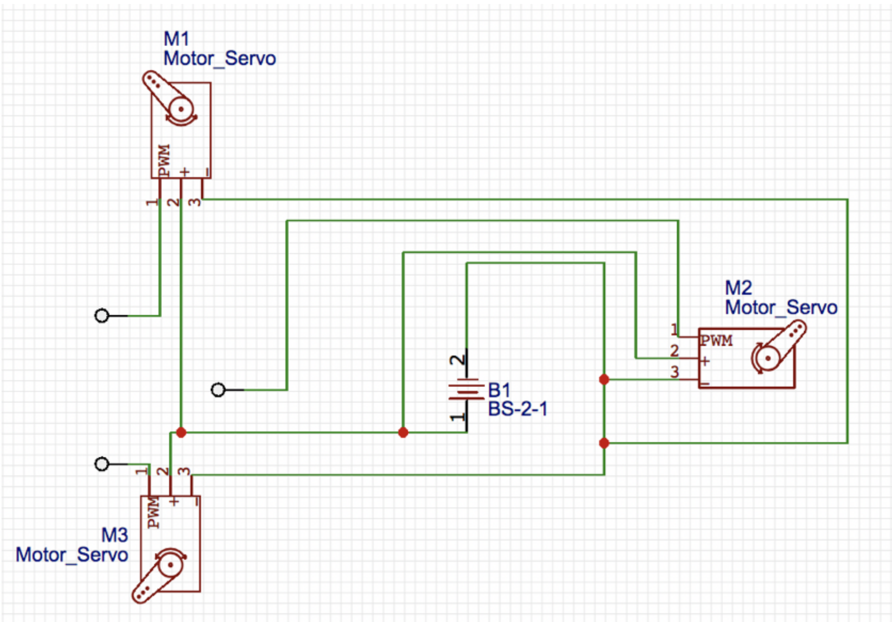

Figure 2.18: Motor circuit consisting of 3 servo motors in parallel

2.4 Expenses and Product Viability

This design was very well planned and involved a large amount of research in order to source the best solution for our problem statement. Due to the extensive revisions and simulations of both the CAD files as well as the Myoelectric circuit, our this prototype may be the basis for an effective, innovative and aesthetically pleasing prosthesis, one that could easily be utilised to an amputee and integrated into society. Due to its already low production cost, detailed in Table 2.1 few adjustments involving higher quality materials as well as fine tuning functionality, would truly allow it to make it's user's lives efficient for daily living. However, as most prototype require, this design requires a great deal of revision and improvements until it can be easily manufactured and integrated within society. Reasons for the changes needing to be implemented are discussed further in the analysis of testing and recommendations section, additionally with a review of the project's viability for manufacturing and distribution.

Item	**Amount**	**Cost**
PLA	1 kg	$20
Elastic bands	5	$2
Fishing wire	5 metres	$0.50
Breadboard	1	$8
Batteries	6	$15
Small electrical components (including resistors, capactiors,wires, etc.)	Approx 10 resistors, 5 capacitors, 25 wires, 1 in-amp and op-amp	$15
Wood	0.2 cubic metres	$20
Superglue	20 mL	$4
	Total Cost	$85

Table 2.1: Total expenditure of project

3 Analysis of Testing and Recommendations

When assembling our final design, we had several aspects of the performance in mind in order to maximise the success of our prosthetic.

3.1 Subjective Analysis

Our prosthetic prevailed in the styling and aesthetic aspect of the design. We prioritised the similarity between a prosthesis and real-life appendages, in order to allow the amputee to be more comfortable with their prosthetic. To do so, we utilised tools such as CAD and 3D printing, allowing us to gain accuracy with respect to the form of the design. This turned out highly successful, as signified by our 5/5 in the Aesthetic section, as we were able to fairly accurately represent a human arm.

Our design process aimed to prioritise functionality and innovation over simplicity. We knew that it would be near impossible to create a perfect hand that can physically perform every act a human can, however, we aimed to compensate for this by making a prosthetic that was "efficient for daily living". This lead us to aim to implement certain modular components such as a clock, RFID, fingerprint module and some others.

Additionally, in order for the prosthetic to function similar to, or even superior to a human arm, we needed to retain many similar functionalities. We integrated five fingers onto our hand, which not only assisted our aesthetic appeal, but additionally aimed to augment the exact functions of a human hand. We also integrated three motors into our hand, two of which were attached to a pair of forefingers, and one attached to the thumb. This innovative yet intuitive design would allow us to accurately mimic the muscular system of the human arm, leaving the user familiar with its functionality. We also ensured that each segment of our hand (i.e. finger, palm, wrist) were modular and easily attached/detached. This significantly increases the ease in which our prosthetic could be improved. The integration of these various innovative aspects of our design, such as the modular nature of the design, evidently awarded us with a 5/5 in the Innovation section.

There was slight compromise in our design, as there commonly is, where we prioritised innovation, functionality and practicality over simplicity. Due to the integration of our thorough muscular system replication, we had to involve several actuators (three motors as mentioned above). This resulted in a 3 /5 in our Simplicity section, our lowest mark in all four sections. However, practicality and usability are far more important than simplicity. A simplistic design may be quicker to design, but will often lead to reduced functionality, which cannot be sold or distributed to any amputees, as they are a much higher priority.

Our team also had robustness in mind while creating this design. While it is difficult to ensure absolute robustness in a prosthetic, especially one which has integrated electronic and mechanical movements, our design maximised robustness while not compromising any other aspects. We 3D printing each aspect of our arm, which means they were consisting of several tightly packed layers of PLA. It is quite difficult to fracture these pieces; however it is possible with large amounts of force. Aside from simply rupturing the individual pieces, the only other delicate part was the elastics holding the fingers at an equilibrium position. If these are hyperextended, they may snap and prevent the fingers from adjusting back. These could simply be replaced by a more robust elastic material, preventing this issue entirely. Our prosthetic was awarded a 5/5 for robustness since it was fully functional following the 'drop test', showing its ability to sustain a significant force.

An intricate design such as ours is not easy to largely manufacture. We used breadboards for the electronics, which need physical labour to make, instead of computer-generated assembly. We additionally 3D printing all physical aspects of our arm, which can vary in time taken by a large margin. However, this method of design does not need to be completely automated, as each individual amputee will need a specific prosthetic tailored to them, due to size and bodily differences. The most optimal improvement would be the implementation of a printed circuit board (PCB) instead of a breadboard since all electronics will be created the same.

3.2 Physical Testing

Considering two separate aspects of our design - the physical and electrical components - we had varying success.

Our electrical circuit was extremely reliable, being able to function consistently after repeated use, and even after a large force was imparted on it. The only significant maintenance that is required for the electrical component is the replacement of the batteries, which are easily accessed due to the physical containment method of our arm.

This electronic component was a great success and contributed to a significant portion of our groups positive results. This was due to the extensive amount of time and focus spent on creating a sensitive, yet accurate EMG circuit. Throughout testing, the prosthesis activated with ease and did not malfunction even once. It also had a 100% success rate in activation when the operator flexed during testing. Due to its simplistic design, using only 2 active components, as well as possessing a switch and indicator lights, the circuit component was extremely robust and reliable.

Our physical component was the main reason why we did not fully succeed in our final testing. While all aspects of our hand were theoretically correct, including the manner in which our prosthetic would manoeuvre, we overlooked a significant aspect of the design.

Since we opted to have our design 3D printed, this process takes a long time to collate and assemble. This resulted in us not having any time for physical testing, and instead relying on CAD and mental simulations to see how it would manoeuvre and pick up certain objects, due to a shortage of time. However, we did not take several physical aspects into account while doing these calculations.

1. We did not account for the speed and power at which our fingers would contract. This made it very difficult to pick up any standing objects as they were simply knocked over, such as the water bottle.

2. We did not align the thumb with any of the forefingers. This made it near impossible to hold anything too small for the palm, such as a coin or paperclip.

3. We did not have any form of friction between the fingers. Due to it being made of PLA, any object simply slipped out after it was picked up, such as the water bottle and glasses, due to lack of friction.

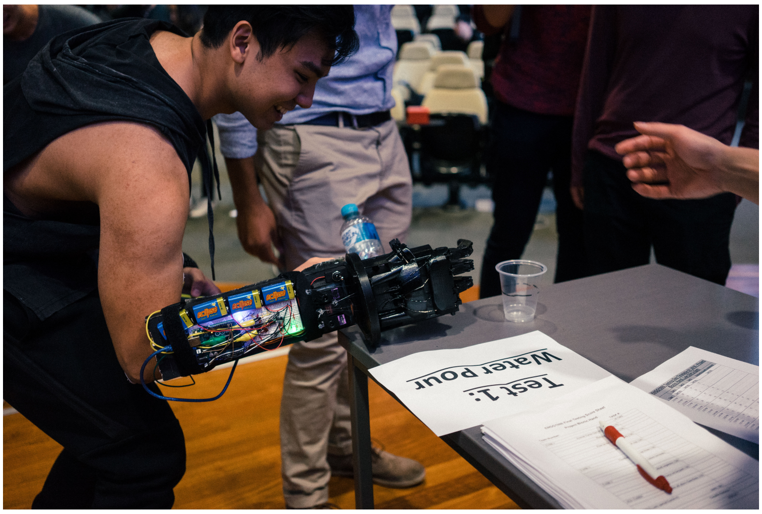

Figure 3.1: Prosthesis failing to pick up water bottle

Figure 3.2: Operator attempting to pick up pineapple during testing

In order to fix these problems in the future, we would more thoroughly test the strength and speed of the contraction and make it a lot slower. We would also ensure to align the thumb so that it can pick up any smaller objects. Finally, we would implement a material which has a high friction coefficient such as silicon or rubber, to assist with the gripping.

These fixes are easily changed though, due to the modular nature referred to earlier. In order to replace any elastics, we could simply detach the finger, replace the elastic, and reattached the finger. If we needed to replace the fingers due to a part not being designed completely correctly, this is easily done so as its maintenance and replacement will not interfere with any other part of the prosthetic. This allows a high degree of fine tuning and minor adjusting, given more time to complete and test the design.Some additional minor changes that could be made include:

- Replacing fishing wire with an automatically attaching hook of some capacity, allowing easier attachment and detachment to the prosthetic.
- Replacing elastic bands with more reliable, stronger and more flexible materials that could be specifically manufactured for our design.
- Replacing super glue with a more intricate and elegant securing method, such as custom fittings designed in CAD.
- Refining the electrical circuit to incorporate all five motors into the hand.
- Refining the Arduino code with the capacity to control all five fingers separately.

3.3 Design Evolution

Taking a very wide look at our initial design proposal and our final implementation, there were not many features that were altered. This initial design proposal followed through up until our Acceptance Testing, where we observed a few flaws in our design. However, after revising through our mistakes during acceptance testing, we altered our design to compensate for these flaws, to our best ability.

Our initial design proposal had five motors powering a finger each. Initially, this seemed like a sound proposal, as it would be able to intricately and accurately control each separate finger and function very much like a human hand. We also planned on being able to contract each finger separately, allowing complete control over the prosthetic, just like a natural arm.

As we approached Acceptance Testing, we had to implement these ideas. The idea of contracting each finger separately at different times was quickly discarded. This was due to the fact that our current EMG set up was using a bipolar input, making it very difficult to implement five different triggers for separate contraction.

The idea of having each finger powered by a separate motor was discarded just before the Acceptance Testing. After configuring our final electrical circuit, we attempted to integrate all five motors. However, since motors draw a very high amount of current, it caused a large amount of interference with our interpretation system. This lead us to slightly adjust the circuit and only integrate three motors into the final design, to limit interference.

After our Acceptance Testing, we realised that we would not be able to effectively input the Bluetooth code with the prosthetic fingers. Thus, we designed a modular component to input the Bluetooth input onto the keypad. This involved setting up 6 servos in a hexagonal settings to fit around the keypad, and turn according to which button needed to be pressed.

This Acceptance Testing played a major role in us gaining a large portion of our successful marks in Final Testing. However, there were still several issues with our design, some of which we have already discussed.

Most, if not all of our design flaws were present in either the Acceptance or Final testing. This would allow for a future team to conduct further research and adjust the prosthetic in order to optimise it, where they would know all the major flaws they needed to adjust.

In retrospect, the biggest flaw in our design was our lack of physical testing. Every electrical component was tested thoroughly and worked almost flawlessly, so that part did not require much adjustment at all. However, optimally, we would have started 3D printing much earlier, in order to ensure that we had ample time to test, adjust, and reprint certain parts of our prosthetic for more efficient handling. This would have been a simple task as well, due to the modular nature of our prosthetic, allowing these adjustments to be made swiftly and accurately.

The overall design analyses were quite accurate, where we prioritised functionality and practicality over simplicity for the pure reason of being able to realistically utilise this prosthetic for everyday life. If we had sacrificed any aspect of this functionality, and instead made a more simplistic design, it would have defeated the purpose of creating a replacement prosthetic, as it would not be able to accurately perform many intricate daily tasks that a prosthetic should be able to.

3.4 Reflection of Testing and Final Design

After this thorough analysis of the results of final testing and overall performance of our prosthetic, we were able to observe the most optimised parts of our design which should be retained in all future iterations, as well as our major flaws which should be researched and replaced for future implementation and manufacturing.

Our design was able to fulfill a plethora of initial requirements made by the client, due to several pivotal choices we made along the way.

We were able to stay within the $150 budget due to several things, including; using cost-efficient yet thoroughly effective parts such as fishing wire and elastic bands, utilising 3D printing which was relatively cheap for the small amount we printed, using a conservative amount of electrical components when testing and designing our electrical circuit. We were able to use fingers of a human hand as “grippers of some sort”, and were able to contract these fingers using EMG connected with a bipolar input to the biceps of the user. This EMG circuit was fully designed by our electrical team and effectively detects and interprets the electrical signal. We were able to take a Bluetooth input, in this case a 3-digit code. This was then interpreted by our Arduino code and furthermore, we designed a modular component to reliably input this code.

However, there were certain aspects of the design process that were not carried out to their finality. Despite this, we have analysed and proposed possible solutions for a future system based around this one.

- To combat the issue of lack of friction, some form of high friction surface must be added to the fingertips and possibly the palm. This will aim to replicate human skin and allow for various objects to be picked up more effectively.
- Due to the inability to pick up small objects such as a coin, the alignment of the fingers must be adjusted. Future teams may have to conduct research into how the CAD may be effectively altered, however a simple solution is aligning the thumb to come into contact with one of the forefingers.
- To combat the fragility of the elastic bands, they must be replaced with a superior material. While there are no such materials available to us in this small time frame and this limited budget, a future development team may have access to more resources and utilise a more flexible and reliable material.
- To prevent any chemical corrosion of the plastics as well as increase the overall rigidity of the prosthetic, the superglue would ultimately be replaced. By designing a series of fittings and holes in the CAD files, it may be able to stay together purely by mechanical means.
- To optimise the flexibility of the system, there are two major adjustments:
  - Integrate five motors into the circuit, each attached to their own finger. This will require an altered electrical circuit, one that can deal with the interference of five motors.
  - Alter the code to interpret and implement the individual movement of each finger. This may be difficult with a bipolar EMG input, so that may also need research and revision.

4 Conclusion

To conclude, this team's design solution served as a replication of the human hand using 3D printed material, servos and elastics to emulate the flexion and extension of the fingers. Several subsystems operate in cohesion to achieve the hand's primary function, to grip and hold objects. These subsystems include a surface electrode bipolar configuration, amplification, high pass and low pass filtering, a five-digit servo string system, and Radio Frequency Identification (RFID).

For the project 'Bionic Hand', this teams design showcased an excellent style and aesthetic which would allow amputees to feel more comfortable with their prosthetic during day to day life. However, due to many of its physical features, the design failed to appropriately grip and lift objects of variable size in certain situations. Therefore, for it to be properly integrated into society, the device would require several revisions. A future design would employ a high friction surface for attachment on the fingertips and palm to simulate human skin. This would allow for various objects to be picked up more effectively. Also, due to the design's inability to pick up small objects, the alignment of the fingers must be adjusted. Research would have to be conducted into how the CAD may be effectively altered by future teams, however a simple solution could be implemented involving the re-alignment of the thumb to meet one of the forefingers.

While our design is not perfect, it is still an exceptional prototype serving as an innovative and aesthetically pleasing prosthetic. The recommendations specified above could be easily implemented in the future with proper planning and time allocation to maximise the design's potential.

5 REFERENCES

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6 APPENDICES

6.1 APPENDIX A

CONSTRUCTION USING FUSION360

Since there is no way to accurately describe the procedure used to design the components on CAD, all .stl files have been uploaded to a google drive as well as github for non-commercial use and expansion. We hope to further improve this design to one day make a prosthesis truly efficient for daily living.

The modelling workspace was of main use in Fusion360, as it provided a basis for the solid shapes that comprised our design. All designs started off with rectangular sketches, and eventually were sculpted into the intricate models seen below.

ASSEMBLY INSTRUCTIONS:

Materials needed:

- Superglue 20g
- Tweezers
- 76 x 1.5mm elastic bands
- Scissors
- Clamp
- Braided fishing wire reel

Components:

- 5 x Distal finger
- 5 x Proximal finger
- 4 x Distal hinge
- 1 x Proximal hinge
- 1 x Thumb hinge
- 1 x Hand
- 1 x Wrist hinge
- 1 x Wrist
- 1 x Lid

1. The first step once everything is printed, is to attach the proximal fingers to the distal fingers using the distal hinges.

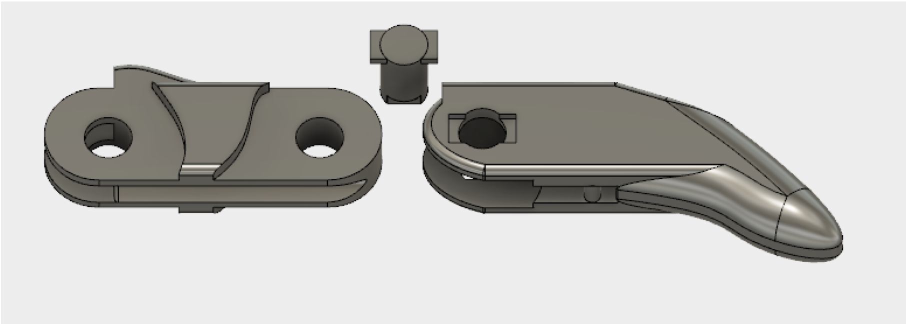


Figure 6.1: Proximal finger(left) Distal finger(right) Distal hinge(centre)

2. Now use superglue to adhere the wrist to the hand, ensuring that the wrist hinge slot aligns with both components. Use a clamp to fixate the pieces while they dry, and insert the wrist hinge.

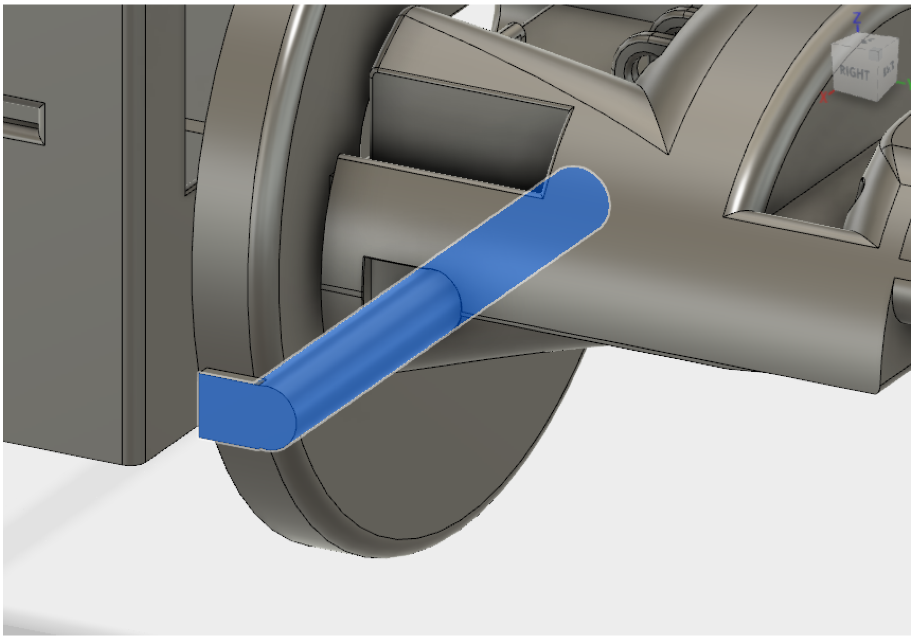


Figure 6.2: Wrist hinge placement

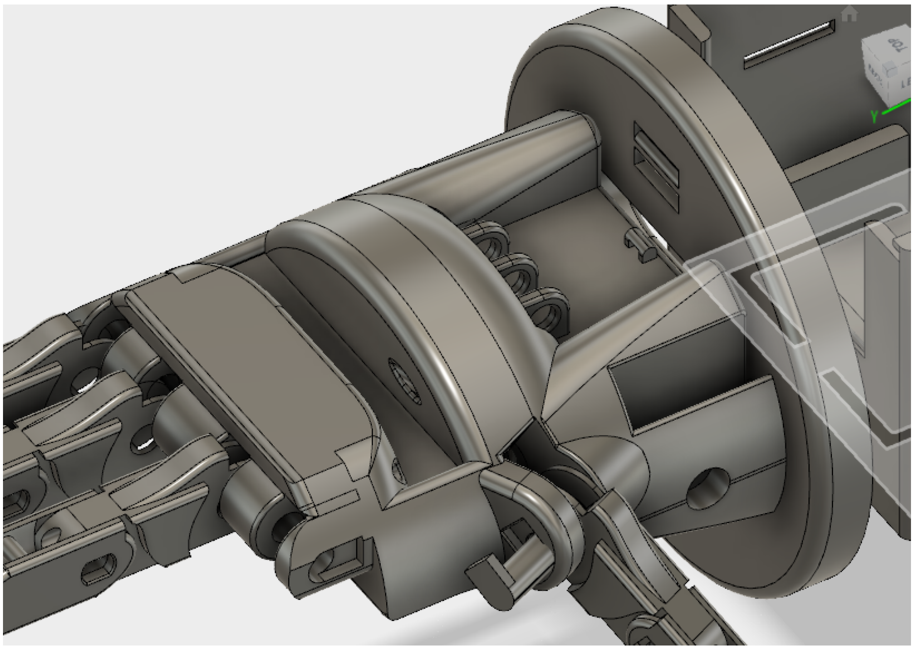


Figure 6.3: Hand attachment to wrist

3. Cut an excess of fishing wire and thread it through the underside of the proximal finger and distal finger, securing it to the bottom crossbar of the distal finger. A simple fishing knot works quite well in this case. (fig 2.1)
4. Connect each finger to the hand component and thread the other side of the wire through each finger's respective hand wire tunnel and through to the wrist compartment. Attach each finger to the hand using the Proximal hinge, and the thumb hinge(fig 6.4),(fig 6.5)

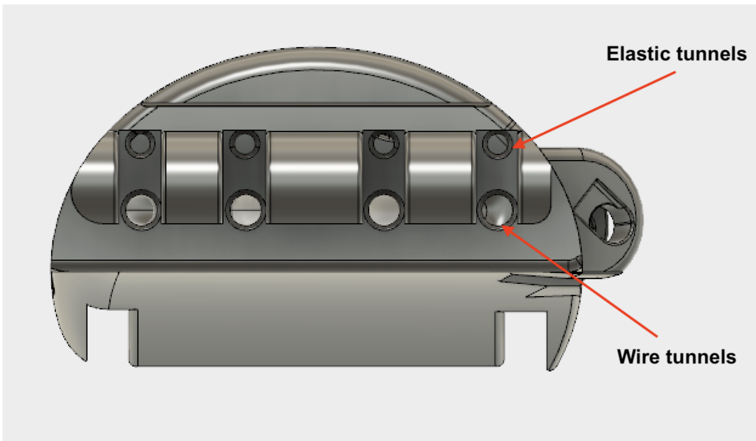


Figure 6.4: Front view of Hand

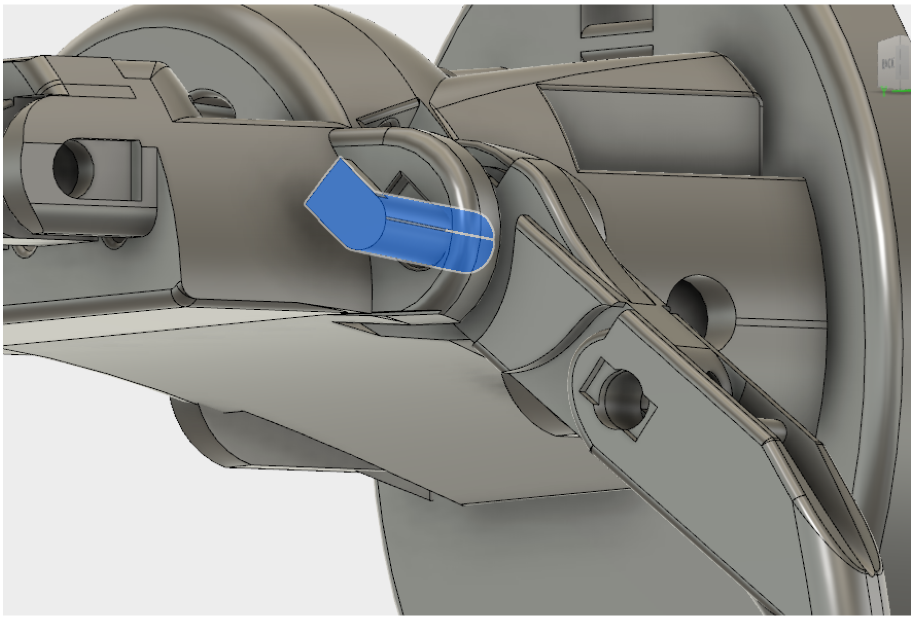


Figure 6.5: Thumb attachment

5. Cut the elastic bands and thread them through the top of the proximal and distal finger, tying them to the top securing post of the distal finger.(fig 2.2)
6. Use tweezers to pull the other side of each elastic through the respective hand elastic tunnel and secure them to the hand's securing posts.

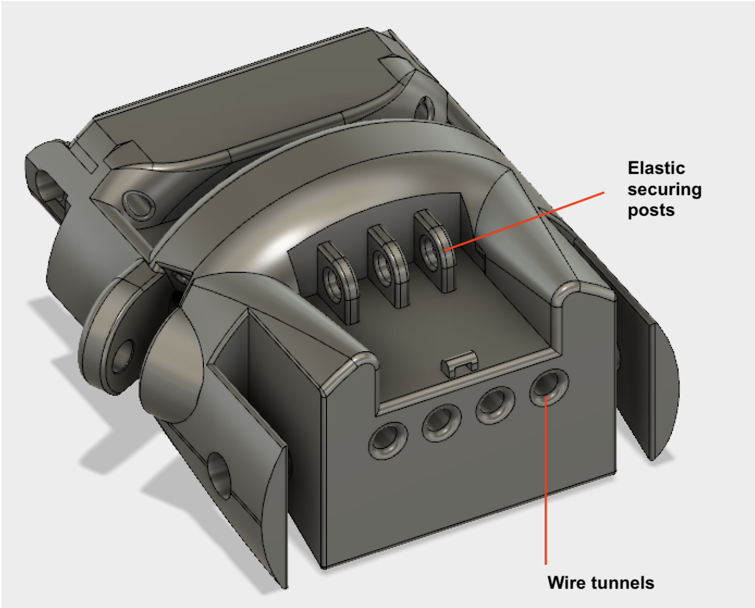


Figure 6.6: Rear 3/4 view of Hand

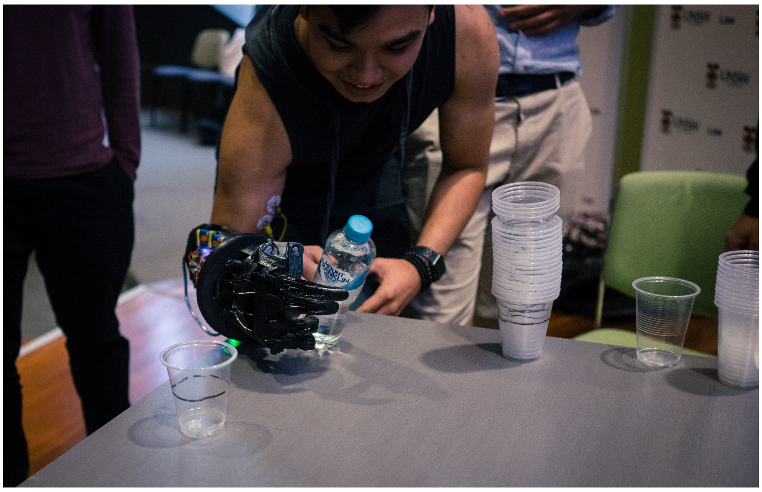
7. Once this is complete, attach the motors in the configuration shown in fig 2.4. Connect the fishing wires securely to the motors, ensuring that they are not connected loosely(this will result in the fingers not closing fully or tightly). The mechanics of the prosthesis is now complete, and circuitry is ready to be attached.

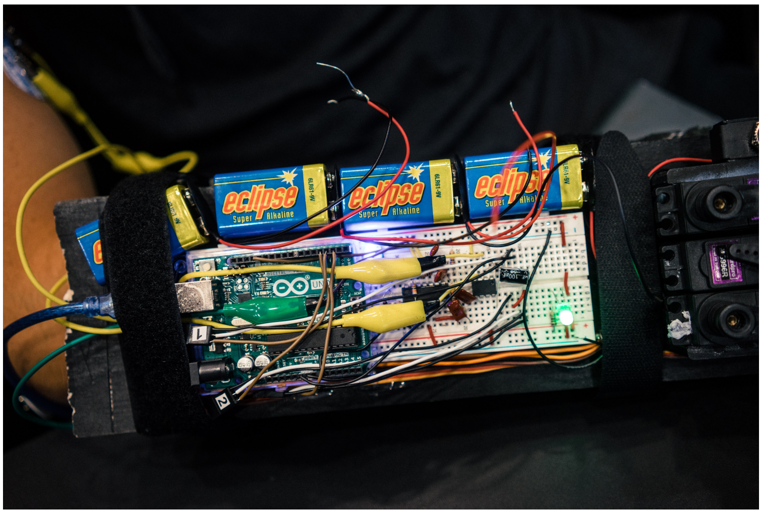
Figure 6.7: Final Product

Bluetooth Keypad Input Assembly

To assemble the keypad input mechanism, simply use the the blueprint (fig 2.7) to line up the servo motors, and superglue them in place. This position may vary according to the keypad used. Stock dual end servo horns can be used.

Additional Final Design Images




eclipse
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6.2 Appendix B

Final Circuit Passive Component Values

Stage 1 Amplification:

Rg = 33Ω
Gain = 1500

High pass filter:

Resistors(all) = 1.5kΩ
Capacitors(all) = 2.2μ
Fc = 48Hz

Low pass filter:

Resistors(all) = 390Ω
Capacitors(all) = 2.2μ
Fc = 185Hz

Rectifier:

Resistors(all) = 10kΩ

Arduino Sketches

Final Circuit Code

Final_Circuit_code §

```
#include <Servo.h>

const int x = 200; //Threshold
const int numReadings = 500;

//Naming the servos
Servo servo1;
Servo servo2;
Servo servo3;


int readings[numReadings];      // the readings from the analog input
int readIndex = 0;              // the index of the current reading
int total = 0;                  // the running total
int average = 0;                // the average

int inputPin = A0 ;

void setup(){
  Serial.begin(115200); //initialise comunication with arduino serial port

  servo1.attach(4); //assigning servos to arduino pins
  servo2.attach(3);
  servo3.attach(2);
  servo1.write(0);
  servo2.write(0);
  servo3.write(0);

// initialize all the readings to 0:
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
    readings[thisReading] = 0;
  }
}

void loop() {

  total = total - readings[readIndex];
  readings[readIndex] = analogRead(inputPin);
  total = total + readings[readIndex];
  readIndex = readIndex + 1;

  if (readIndex >= numReadings) {
    readIndex = 0;
  }

  average = 80*(total/numReadings) ; //determines average (value to display)
  Serial.println(average);
  delay(1);

//Close hand
  if(average> x){
    servo1.write(120);
    servo2.write(150);
    servo3.write(120);
  }

//Open hand
  else if (average< x){
    servo1.write(0);
    servo2.write(0);
    servo3.write(0);
  }
}
```

Figure 6.8: Final Circuit Code

Keypad Input Code

Servo_Serial

```
#include <Servo.h>

Servo servo1;
Servo servo2;
Servo servo3;
Servo servo4;
Servo servo5;
Servo servo6;
int input;

void setup() {
  Serial.begin(9600);
  servo1.attach(2); //Attaching servos to arduino pins
  servo2.attach(3);
  servo3.attach(4);
  servo4.attach(5);
  servo5.attach(6);
  servo6.attach(7);
  servo1.write(90); //Initialising position of head
  servo2.write(90);
  servo3.write(90);
  servo4.write(90);
  servo5.write(90);
  servo6.write(90);
}

void loop() {
  if (Serial.available() > 0) {
    input = Serial.parseInt();
    if (input == 1) {       //Assigning keypad numbers to respective servo rotations
      servo1.write(40);
    } else if (input == 2) {
      servo2.write(170);
    } else if (input == 3) {
      servo2.write(10);
    } else if (input == 4){
      servo1.write(130);
    } else if (input == 5) {
      servo3.write(110);
    } else if (input == 6) {
      servo4.write(0);
    } else if (input == 7) {
      servo6.write(10);
    } else if (input == 8) {
      servo5.write(50);
    } else if (input == 9) {
      servo5.write(140);
    } else if (input == 0) {
      servo6.write(170);
    }

    delay (1500);  //delay for stability
  }

  servo1.write(90); //Recalibrating servos
  servo2.write(90);
  servo3.write(90);
  servo4.write(90);
  servo5.write(90);
  servo6.write(90);
}
```

Figure 6.9: Bluetooth Keypad Input Code