# DESIGN OF AFFORDABLE

# MYOELECTRIC PROSTECTIC ARM

**A Project report**

**Submitted by**


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# CHAPTER – 01 INTRODUCTION

It could be argued that the most valuable possession to any human being is their body. Replacing a missing human limb, especially a hand, is a challenging task which makes one truly appreciate the complexity of the human body. Until recent times the design of prosthetic limbs has progressed relatively slowly. Early innovations such as the wooden leg can be thought of as simple prosthetic devices. History shows that for a long-time prosthesis have remained passive devices that offer little in terms of control and movement.

Recent times however have given way to enormous advancements in prosthetic devices. Focus is not only on the physical aspects of a device but also the control and biofeedback systems. Slowly we are approaching an advanced trans-human integration between machine and body. Perhaps sometime in the future prosthetic devices will be faster, stronger and maybe even healthier than our biological limbs.

This project aims to revolutionize the field of prosthetics by designing and manufacturing a low-cost, 3D printed myoelectric prosthetic arm. Unlike traditional prosthetics, which are often expensive and inaccessible to many, this design leverages the rapid advancements in 3D printing technology and myoelectric control systems to offer a more affordable and accessible solution. The design focuses on mimicking the natural movements of the human arm, offering users a range of motions and controls that closely resemble those of their biological limbs.

## 1.1 TYPES OF PROSTECTIC LIMBS

There are several different categories of prosthetic devices. They are generally grouped by the way in which the device is controlled, including

**A. Passive Prosthetics**

Passive prosthetics are simple, non-moving devices that aim to restore cosmetic appearance and basic functionality to an amputee. A simple wooden ‘pirate’ peg leg is an example of a simple passive prosthetic.

Fig 1. Prosthetic toe made from leather and wood found on an ancient Egyptian Mummy, dating between 950-710 B.C. (courtesy Museum of Egyptian Antiquities in Cairo)

### B. Mechanical/Body Control Prostheses

Body powered prosthetics are controlled via a harness connected to the user. They are generally a simple device such as a mechanical hook which is linked to elbow/shoulder movement. Although these devices are relatively simple, they remain the most popular type of prosthesis today.

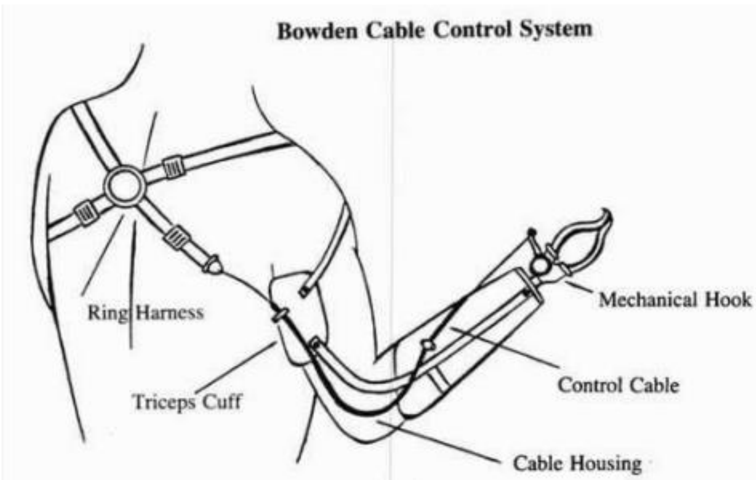


Fig 2. Body powered hook (courtesy Digital Resource Foundation for the Orthotics and Prosthetics community)

### C. Myoelectric Controlled Prostheses

Myoelectric prostheses measure electromyography (EMG) signals generated from the contraction of muscles near an amputee's residual limb. These signals are measured through electrodes placed on the surface of the skin or embedded directly into muscles. These signals are then amplified and sent to a microcontroller which analyses this information and controls the internal actuators. Myoelectric devices allow for far greater amounts of control than mechanical devices.

Fig 3. – Advanced DARPA myoelectric prosthetic arm

### D. Direct Brain interface

The most cutting-edge type of control is a direct brain neural interface. A surgical procedure places electrode arrays on the surface of the brain which are attached to pedestals implanted into the patient's skull. As the patient thinks of motion signals detected on the pedestals are used to control the movement of a robotic arm. This type of technology is still in its infancy but has already demonstrated disabled people controlling bionic devices with their thoughts alone.

Fig 4. Paraplegic woman uses her thoughts to guide a robotic arm

### 1.2 The Problem

**Physical Design**

- Complexity of mechanical and electrication design
- Mimicking ability is directly propotional to dexterity

**Control Scheme**

- Easy and natural to control
- Should be easily able to mimic basic hand structure such as grasping and holding

**Practicality**

- Benefit people with diabilities
- Providing affordable solution to amputees

**Affordable**

- Keeping material cost as low as possible
- Estimated cost for this project will be under $350.

### 1.3 Plausible Solution

The journey of prosthetic technology has been one of hope and resilience for those grappling with limb loss. It's been a path from basic replacements barely scratching the surface of functionality to the marvels of myoelectric arms, mirroring the intricate motions of real limbs. Yet, amidst this progress, there's a harsh reality: the staggering costs, rendering these transformative devices out of reach for so many who yearn for normalcy. It's within this stark reality that our project takes root, driven by the simple but profound mission of making advanced prosthetics not just a luxury, but a right for all who need them.

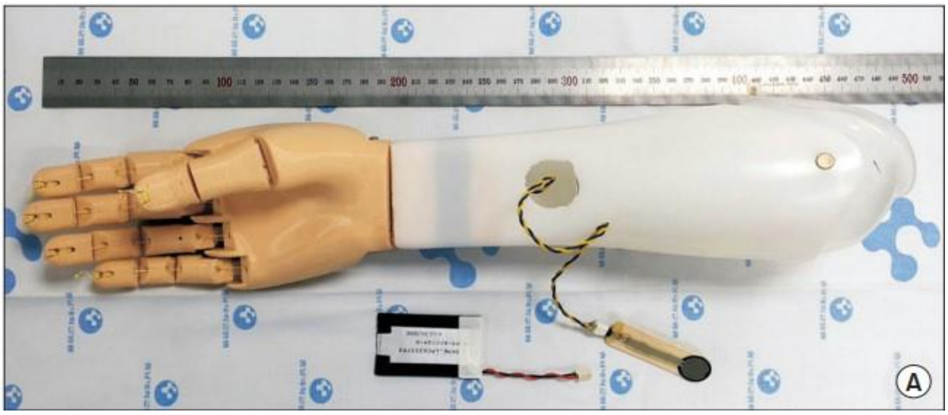



Fig 5. Basic Ideation of Project [1]

This undertaking seeks to redefine the landscape of prosthetic hands through the development of a low-price, 3D printed myoelectric prosthetic arm. At the pivot of our initiative lies the integration of 3-d printing technology with the myoelectric systems. By this integration we can make this prosthetic technology available to everyone making sure that financial constraints no longer prevent individuals from reclaiming their independence and functionality.

# CHAPTER-02 MARKET RESEARCH

The current market for prosthetic limbs is characterized by high costs, with advanced myoelectric prosthetics often ranging between $20,000 and $40,000. Such prices place these life-changing devices out of reach for many, especially in developing countries. Recent advancements in 3D printing technology have begun to challenge this, with projects across the globe demonstrating the potential for more cost-effective solutions [2]. However, most of these initiatives have focused on mechanical devices, lacking the sophistication and functionality of myoelectric prosthetics. Our research indicates a significant demand for affordable, functional prosthetic arms that can perform a wide range of motions and tasks.

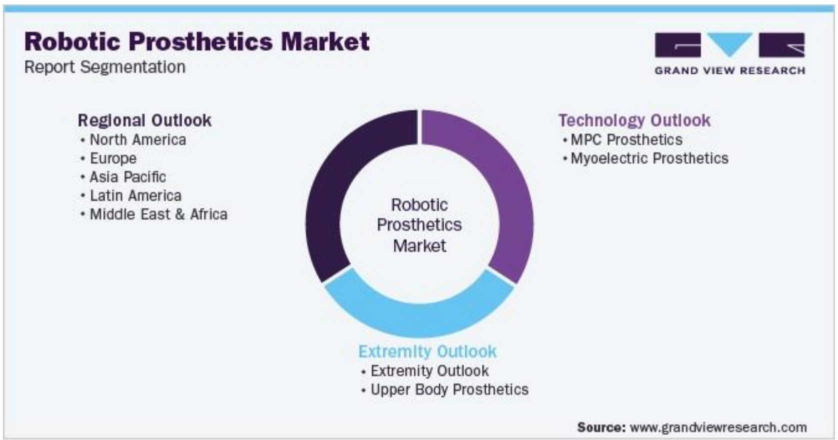



Fig 6. Market share of prosthetics technology and countries.

## 2.1 Current Market Scenario

- **Össur and Otto Bock** are leading companies known for their innovation in myoelectric prosthetics, offering devices like the Bebionic arm and the Michelangelo Hand. These products provide advanced functionality, such as individual finger movement and a natural grip pattern, but come at a high cost, often ranging from $25,000 to over $75,000 depending on customization and technological features.

- **Touch Bionics (now part of Össur)** produces the i-limb, a highly advanced series of prosthetic hands with individual finger control, offering nuanced movements. The cost for an i-limb hand can exceed $100,000 for the most advanced models, making it inaccessible to a significant portion of the population in need.
- **Advanced Arm Dynamics and Hanger Clinic** are notable for their comprehensive prosthetic services, including custom fittings and patient training. Their offerings include both mid-range and high-end prosthetics, with costs varying widely based on the level of technology and customization involved.

# CHAPTER-3 LITERATURE REVIEW

Several arms such as the Bebionic 3 and i-Limb are myoelectric controlled robotic arms commercially available to the public. Numerous more prosthetic arms exist in research labs around the world which are usually developed as prototypes to test advanced designs and concepts. Research prosthetics are generally more complex in terms of mechanical design and control and monitoring systems but are inferior to commercial devices in terms of practicality, cost and robustness.

## 3.1 DIMENSION EXTRACTION FOR HUMAN HAND

The human hand comprises of at least 27 bones (depending on the individual), more than 30 individual muscles and over 100 named ligaments, nerves and arteries. Prostheses aim to replicate the functions of the human body and return functionality to persons with missing extremities. No current prosthetics can match the dexterity, flexibility and fluidity of the human hand.

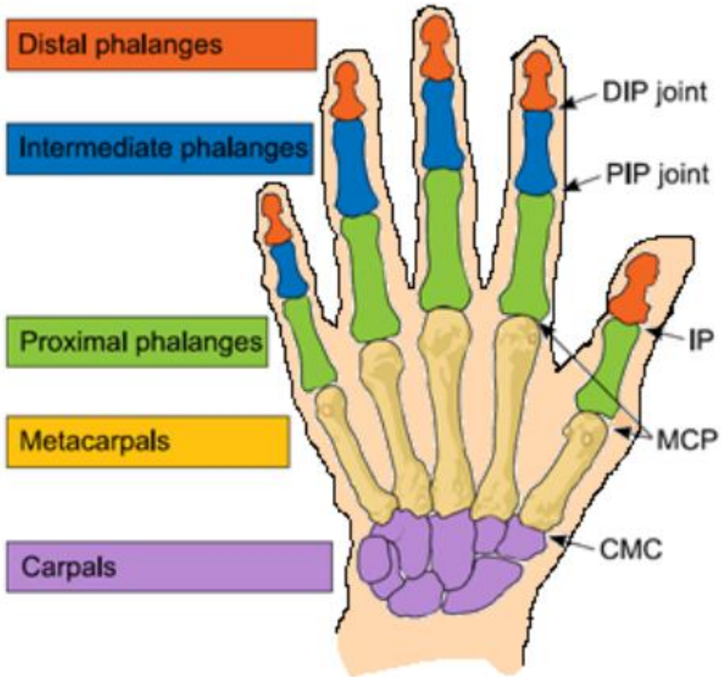



Fig 7. Major Bones in the human hand (image courtesy Dexmart)

**Human fingers contain 3 joints, distal, intermediate and proximal (knuckles).**

Before any further discussion, let us briefly explain the meaning of a degree of freedom (DOF) for a reader with a non-engineering background.

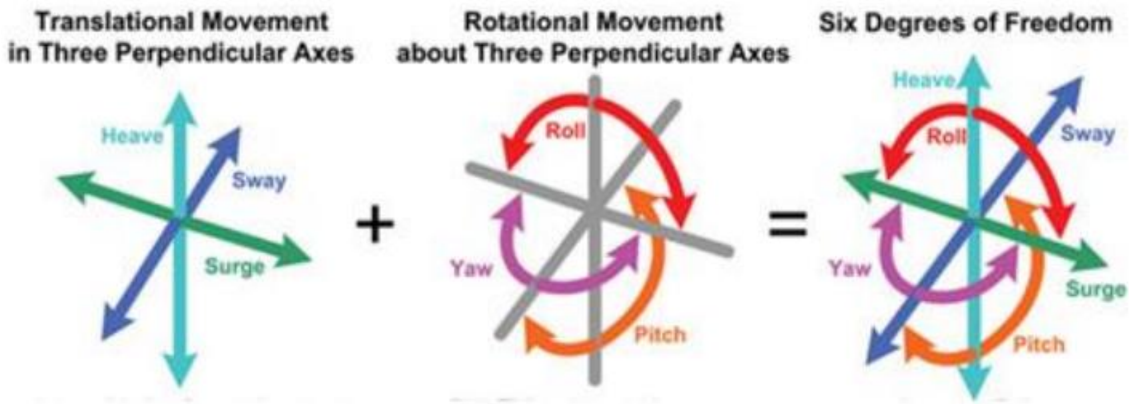



Fig 8. Degrees of freedom at a single point (courtesy Ben Nelson, 2013)

Looking at the above image, imagine a point in space. From this point we can translate (move) along 3 different axes, i.e. we can move forward/backward, up/down and left and right. At the same point we can also rotate around 3 different axes. The human neck for example has 3 degrees of rotational freedom – we can look left/right, up/down and tilt our head sideways. So, in total a single point can have a maximum of 6 degrees of freedom (3 translational, 3 rotational).

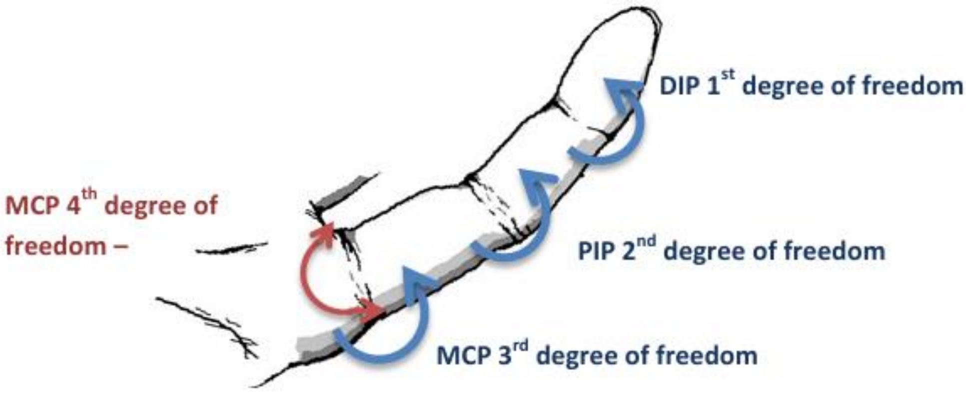
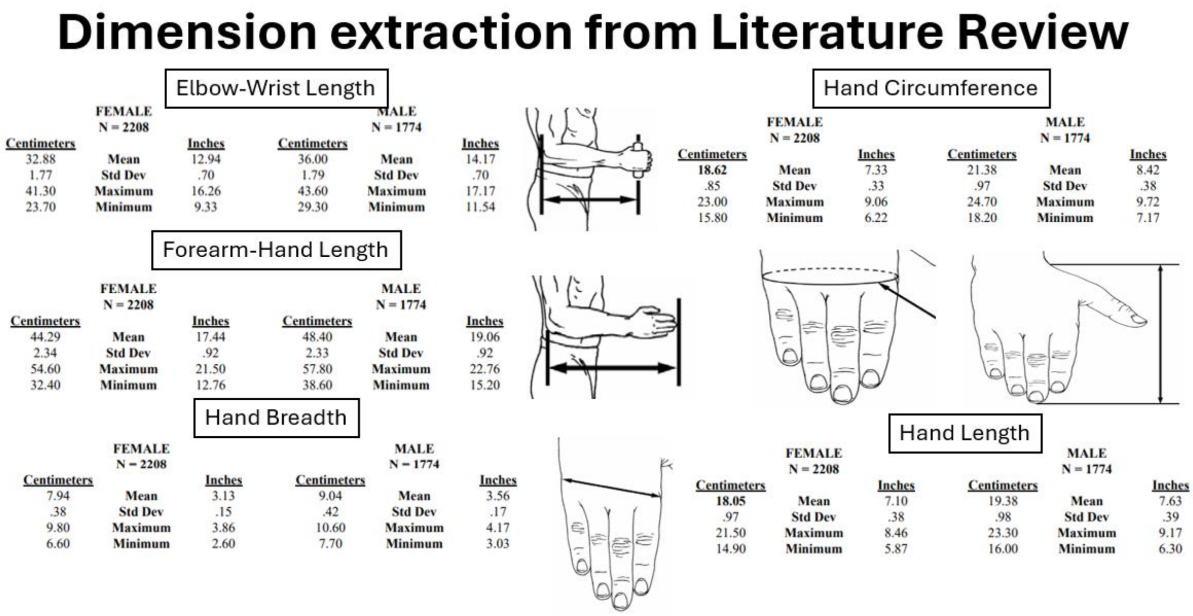



Fig 9. Depiction of the degrees of freedom in a human finger

The human finger in total has 4 degrees of freedom. Three of these are the rotations of each joint (DIP, PIP, MCP) which combine to control flexion and extension of the finger. The knuckle (MCP joint) also allows for abduction/adduction (wiggling the finger from side to side). In the thumb the lower CMC joint also allows for abduction/adduction – which gives 5 DOFs in the thumb. Fingers, and all joints in the human body are actuated (moved) via contraction of muscles and tendons.



## Dimension extraction from Literature Review

**Elbow-Wrist Length**

| FEMALE N = 2208 Centimeters | | Inches | MALE N = 1774 Centimeters | | Inches |
|---|---|---|---|---|---|
| 32.88 | Mean | 12.94 | 36.00 | Mean | 14.17 |
| 1.77 | Std Dev | .70 | 1.79 | Std Dev | .70 |
| 41.30 | Maximum | 16.26 | 43.60 | Maximum | 17.17 |
| 23.70 | Minimum | 9.33 | 29.30 | Minimum | 11.54 |

**Forearm-Hand Length**

| FEMALE N = 2208 Centimeters | | Inches | MALE N = 1774 Centimeters | | Inches |
|---|---|---|---|---|---|
| 44.29 | Mean | 17.44 | 48.40 | Mean | 19.06 |
| 2.34 | Std Dev | .92 | 2.33 | Std Dev | .92 |
| 54.60 | Maximum | 21.50 | 57.80 | Maximum | 22.76 |
| 32.40 | Minimum | 12.76 | 38.60 | Minimum | 15.20 |

**Hand Breadth**

| FEMALE N = 2208 Centimeters | | Inches | MALE N = 1774 Centimeters | | Inches |
|---|---|---|---|---|---|
| 7.94 | Mean | 3.13 | 9.04 | Mean | 3.56 |
| .38 | Std Dev | .15 | .42 | Std Dev | .17 |
| 9.80 | Maximum | 3.86 | 10.60 | Maximum | 4.17 |
| 6.60 | Minimum | 2.60 | 7.70 | Minimum | 3.03 |

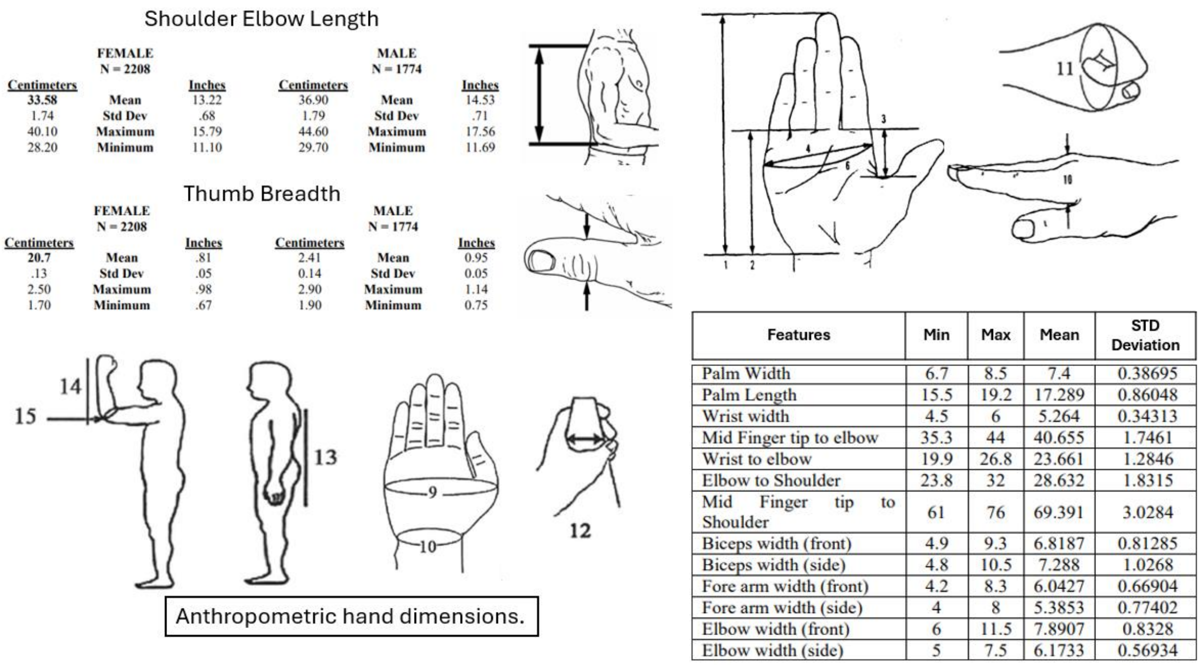
**Hand Circumference**

| FEMALE N = 2208 Centimeters | | Inches | MALE N = 1774 Centimeters | | Inches |
|---|---|---|---|---|---|
| **18.62** | Mean | 7.33 | 21.38 | Mean | 8.42 |
| .85 | Std Dev | .33 | .97 | Std Dev | .38 |
| 23.00 | Maximum | 9.06 | 24.70 | Maximum | 9.72 |
| 15.80 | Minimum | 6.22 | 18.20 | Minimum | 7.17 |

**Hand Length**

| FEMALE N = 2208 Centimeters | | Inches | MALE N = 1774 Centimeters | | Inches |
|---|---|---|---|---|---|
| **18.05** | Mean | 7.10 | 19.38 | Mean | 7.63 |
| .97 | Std Dev | .38 | .98 | Std Dev | .39 |
| 21.50 | Maximum | 8.46 | 23.30 | Maximum | 9.17 |
| 14.90 | Minimum | 5.87 | 16.00 | Minimum | 6.30 |

Fig 10. Lateral Dimension for human like Hand Part-1




Shoulder Elbow Length

| Centimeters | FEMALE N = 2208 | Inches | Centimeters | MALE N = 1774 | Inches |
|---|---|---|---|---|---|
| 33.58 | Mean | 13.22 | 36.90 | Mean | 14.53 |
| 1.74 | Std Dev | .68 | 1.79 | Std Dev | .71 |
| 40.10 | Maximum | 15.79 | 44.60 | Maximum | 17.56 |
| 28.20 | Minimum | 11.10 | 29.70 | Minimum | 11.69 |

Thumb Breadth

| Centimeters | FEMALE N = 2208 | Inches | Centimeters | MALE N = 1774 | Inches |
|---|---|---|---|---|---|
| 20.7 | Mean | .81 | 2.41 | Mean | 0.95 |
| .13 | Std Dev | .05 | 0.14 | Std Dev | 0.05 |
| 2.50 | Maximum | .98 | 2.90 | Maximum | 1.14 |
| 1.70 | Minimum | .67 | 1.90 | Minimum | 0.75 |

| Features | Min | Max | Mean | STD Deviation |
|---|---|---|---|---|
| Palm Width | 6.7 | 8.5 | 7.4 | 0.38695 |
| Palm Length | 15.5 | 19.2 | 17.289 | 0.86048 |
| Wrist width | 4.5 | 6 | 5.264 | 0.34313 |
| Mid Finger tip to elbow | 35.3 | 44 | 40.655 | 1.7461 |
| Wrist to elbow | 19.9 | 26.8 | 23.661 | 1.2846 |
| Elbow to Shoulder | 23.8 | 32 | 28.632 | 1.8315 |
| Mid Finger tip to Shoulder | 61 | 76 | 69.391 | 3.0284 |
| Biceps width (front) | 4.9 | 9.3 | 6.8187 | 0.81285 |
| Biceps width (side) | 4.8 | 10.5 | 7.288 | 1.0268 |
| Fore arm width (front) | 4.2 | 8.3 | 6.0427 | 0.66904 |
| Fore arm width (side) | 4 | 8 | 5.3853 | 0.77402 |
| Elbow width (front) | 6 | 11.5 | 7.8907 | 0.8328 |
| Elbow width (side) | 5 | 7.5 | 6.1733 | 0.56934 |

Fig 10.b Human hand extraction Part-2

# CHAPTER-4 DESIGN AND SIMULATION

## 3.1 Basic Ideation Design

To create a useful myoelectric prosthesis, it is necessary to have a well-designed mechanical system which mimics the functionality of the human arm as best as possible. Among many other things mechanical design involves how joints are actuated, and the types of forces present in the system. After researching several actuation methods for prosthetic arms an artificial tendon design was chosen. As seen commercially available devices like Shadow Hand, UB Hand and InMoov; artificial tendons are a viable way of actuating bionic hands. The tendons can be any high strength line which does not stretch when tensioned. These lines connect to the fingers and are tensioned by motors in the forearm. Pulling on the tendons cause the fingers to open and close.

The electric motors driving these tendons must be completely housed inside the device to make it portable and attachable to an amputee. Ideally, we would like these motors placed as closely to the fingers as possible, however due to their relatively large size we cannot house the motors used inside the palm section. Instead, the motors housed within the forearm. The choice to use standard servo motors to drive the tendons was made very early. Servo Motors are geared DC electric motors which can be controlled to rotate to specific angular positions.

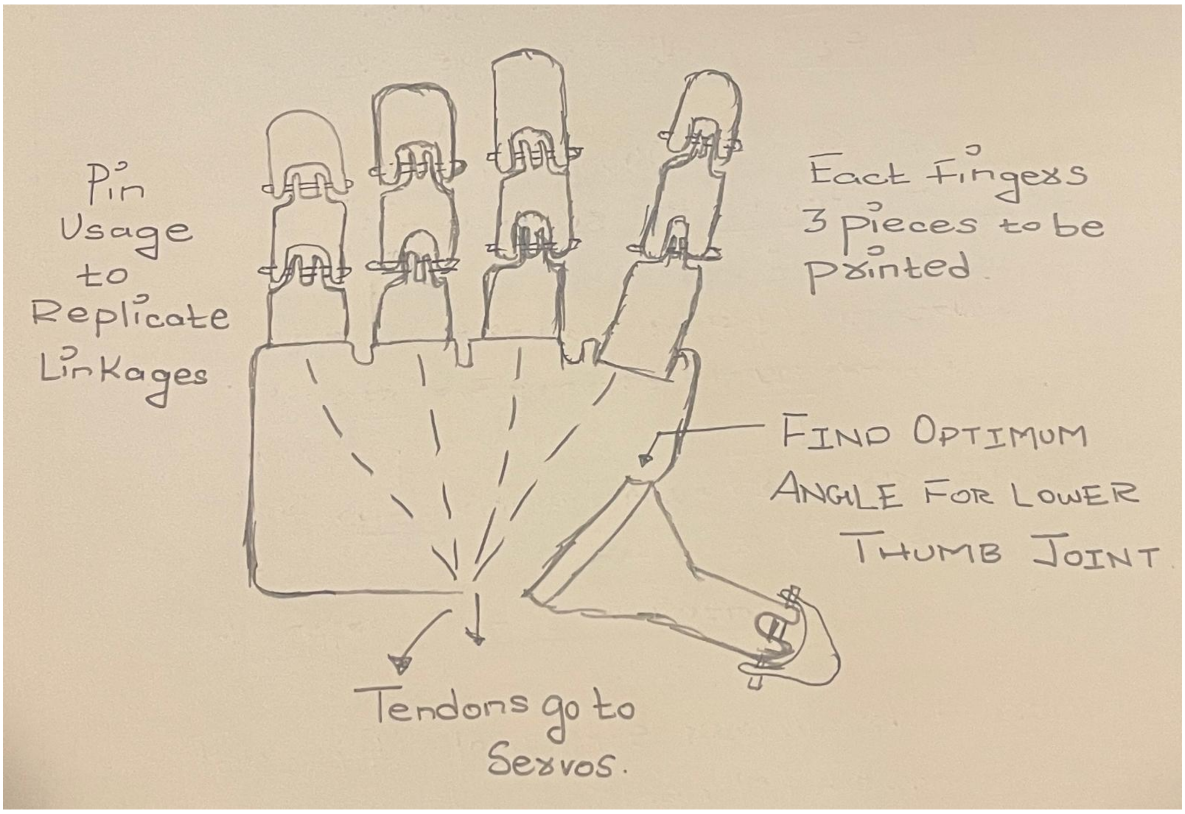



Fig 11. Semi Detailed Drawing for Geometry definition.

The above image shows the assembly of individual mechanical components of the hand. The below image shows some rough calculations for a geared wrist rotation design. Rough sketch like these is key to developing a solid design foundation. The final model still incorporates several of these early design features however many key design points have changed such as servo positioning and the use of guide pulleys.

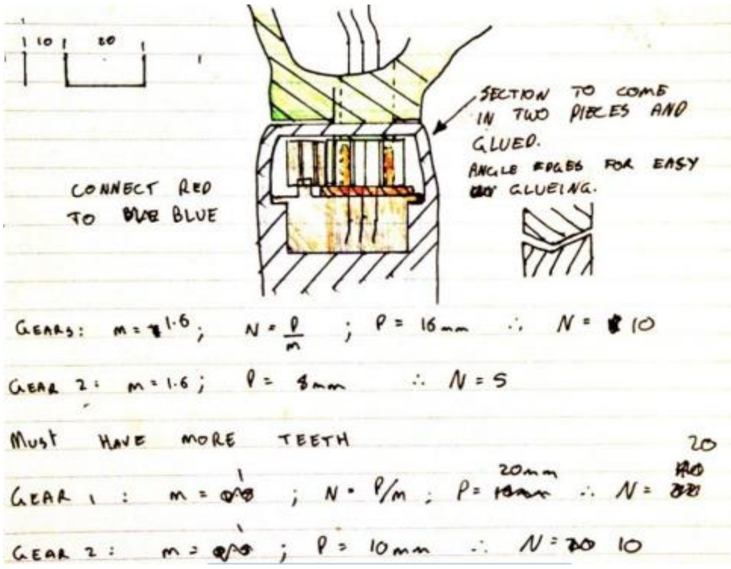



Fig 12. Early design of wrist rotation mechanism

### 3.1.1 Ergonomics

Ergonomics is the interaction between humans and machines. The field of prosthetics is interesting as it deals with ergonomics between prosthetics and amputees such – physical attachment to the body and sensory feedback. Ergonomics must also be considered for the interaction between a person's prosthesis and other people. An ideal prosthesis is physically comfortable for the amputee to wear, easy and natural to control, provides useful sensory feedback and interacts well with its environment.

The dimensions of a large male hand have been used for design proportions. A universal goal in prosthetic design is to achieve shapes and sizes that match an average female physique. It is much easier to scale a design up in size rather than shrink it down to fit a smaller person. Scalability has been kept in mind throughout the design process. Components can be easily rescaled in computer modelling software and printed relatively fast. This allows for various size prototypes to be developed with ease.

## 3.2 CAD Geometry formation

### 3.2.1 Fingers

Each finger consists of three individual printed components linked together with polypropylene pins. The artificial tendon loops around the inside tip of the finger to create a tendon locking point. This tendon runs through channels inside the finger to form an enclosed loop. When the tendon is pulled, rotational forces are applied to all the joints and the finger curls up.

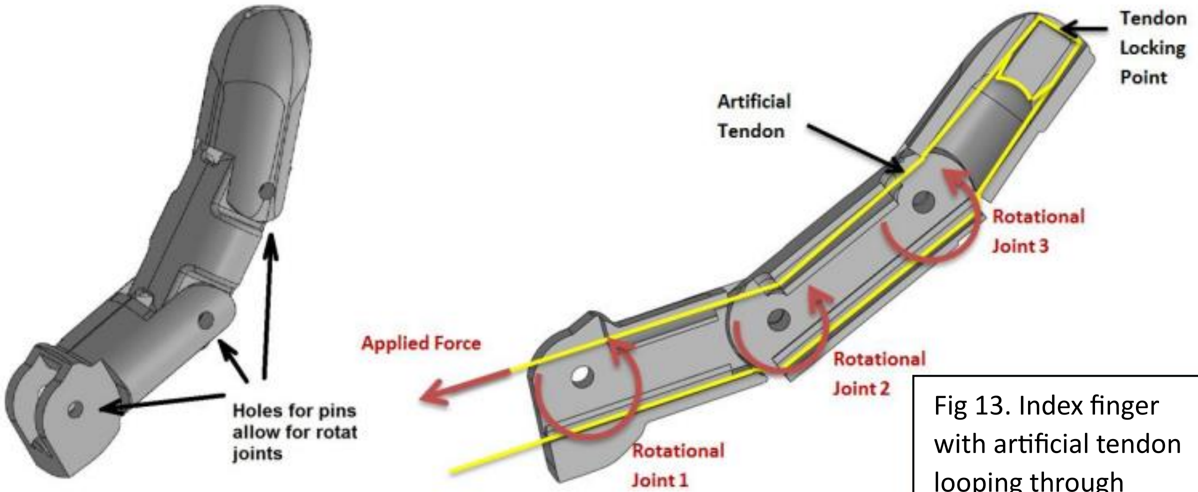



Fig 13. Index finger with artificial tendon looping through

The tendon locking point is essential so that when the tendon is tensioned it pulls the tip of the finger and causes all joints to rotate. If the tendon did not lock it would just slip when tensioned and the finger would not move. To open the finger from a closed position tension is applied to the other end of the tendon.

High quality braided fishing line has been used as it offers minimal stretch when tensioned. Nylon fishing line would stretch over time leading to a loss of tension which would negatively affect finger movements. Tendons in the biological human hand work in a similar way, however there are far more biological tendons attached to different bones – allowing for more precise control of the fingers.

### 3.2.2 Thumb

High quality braided fishing line has been used as it offers minimal stretch when tensioned. Nylon fishing line would stretch over time leading to a loss of tension which would negatively affect finger movements. Tendons in the biological human hand work in a similar way, however there are far more biological tendons attached to different bones – allowing for more precise control of the fingers.

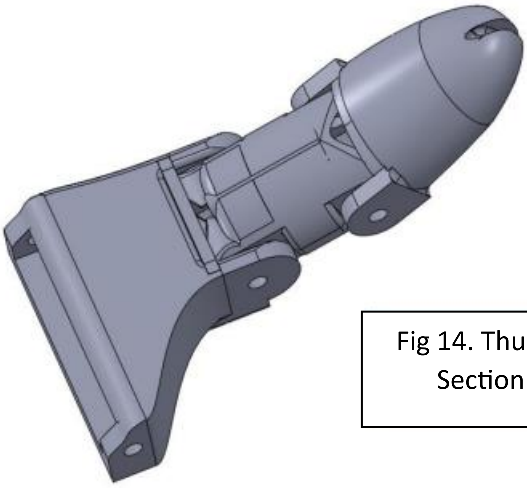


Fig 14. Thumb Section

### 3.2.3 Palm

Each finger connects to the palm by polypropylene pins. The bottom of the palm incorporates part of the wrist rotation mechanism discussed on the following page.

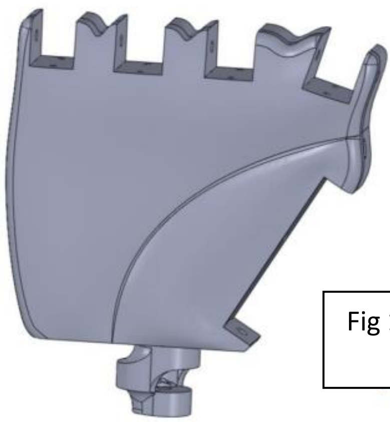


Fig 15. Palm with optimized connector

### 3.2.4 Wrist

Initially a gear driven system was implemented to control wrist rotation. A small gear was 3D printed and pressed onto a servo shaft which would then drive a larger gear connected to the palm section.

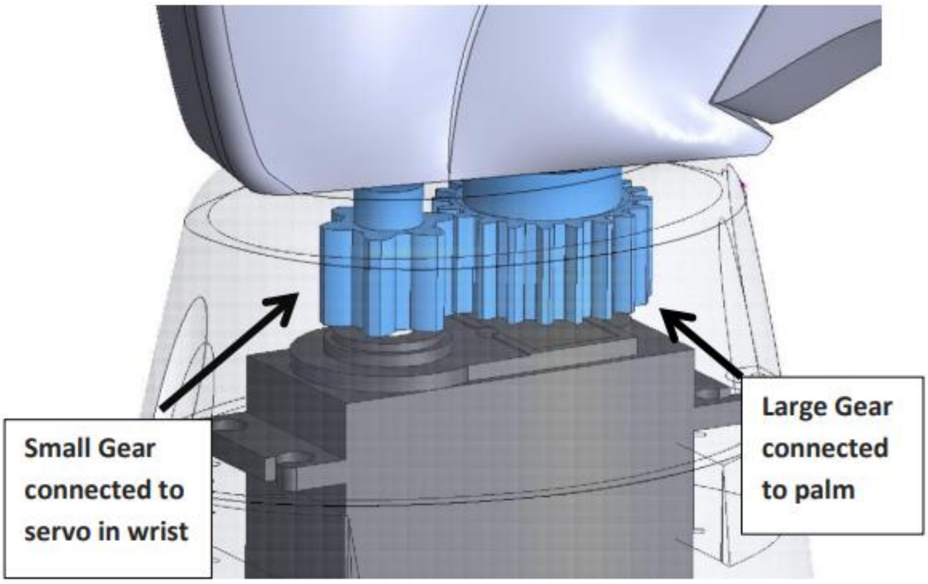



Fig 16. Initial gear-based design for wrist rotation

Unfortunately, the gears did not rotate in a smooth manner. This is because 3D printers produce components which are slightly warped from their original design – this is especially noticeable when printing in ABS plastic. The teeth or the gears warped ever so slightly which resulted in poor meshing and rotation of the gears.

To avoid these problems, it was decided to drop the gear system and instead press fit the palm section directly onto the shaft of the servo in the forearm as shown below. The images on the previous page show a wrist model which snapped during testing as it was too weak. The latest model operates on the exact same principle but includes far more material around the base to increase the component strength and prevent fractures occurring at this point. A small horizontal ridge around the outside of the small cylinder helps transfer lateral loads to the outer forearm shell.

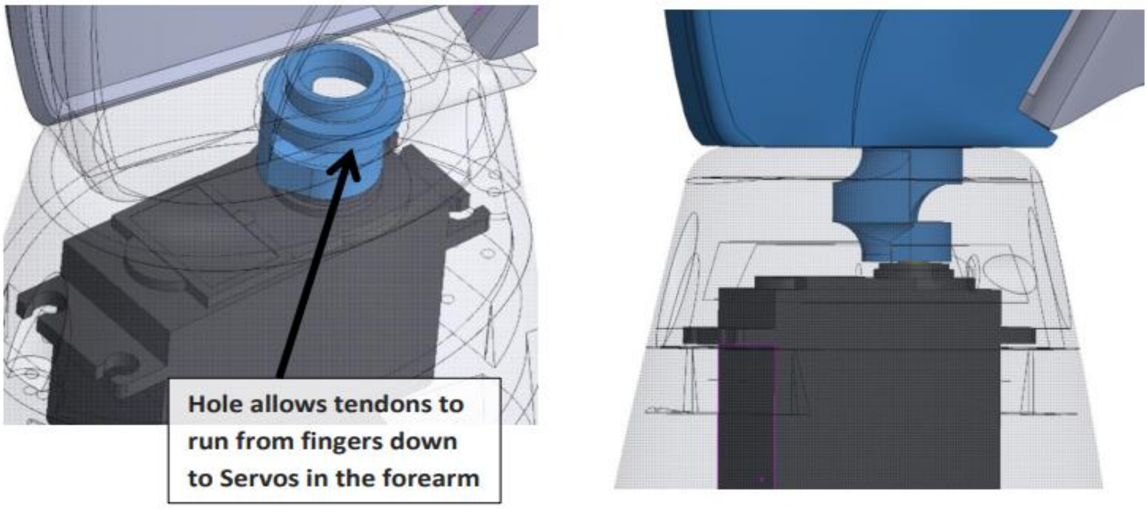



Fig 17. Improved Wrist Rotation Mechanism

### 3.2.5 Forearm

Although the forearm section contains no moving components its design is still somewhat challenging as this section needs to house five servo motors, lithium polymer (LiPo) battery and allow for assembly. After the complete forearm section was designed it had to be split into separate components which could then be assembled with screws. If the forearm was 3D printed as a single large component, then there would be no way of assembling the motors and tendons inside the arm.

Fig 18. Exploded view of forearm assembly

The two large sections of the forearm could be 3D printed as a single piece without affecting the assembly of the device. However, the UP 2 is simply not large enough to print an object of this size. The two pieces were printed separately and then secured together with super glue. The Gear section seen in the image above is part of the elbow rotation mechanism. It is crucial that the quality of this gear be as dimensionally accurate as possible. Printing the gear separately produces a printed gear of higher quality. This gear was then pressed into a groove in the forearm and glued into position.

### 3.2.6 Elbow

The elbow actuator must always move the weight of the forearm on top of any additional load. The minimum required torque to lift the forearm with no load is roughly 13.5kg-cm (see calculations). The TowerPro servo being used provides 10kg-cm of torque. In order to lift the arm using a single servo a gear system had to be implemented. Gears allow us to generate more torque (turning force) at the cost of speed. A small gear pressed onto the bicep servo drives a larger gear section connected to the forearm. The designed gear system increases the torque from the servo by a factor of 2.10.

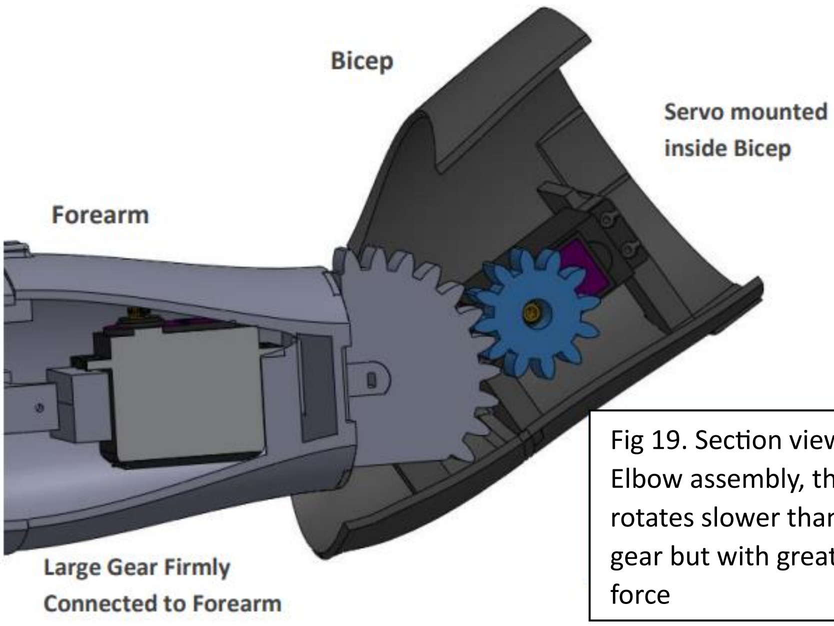



Fig 19. Section view of the Elbow assembly, the large gear rotates slower than the small gear but with greater turning force

This Elbow has been designed to provide 110 degrees of rotation. This allows for a straight orientation and a right-angle bend. With the addition of the gears the servo now must rotate the small gear by 290O to completely bend the elbow. As previously mentioned, a standard servo can only rotate through 180 degree so modifications had to be made to increase the servos rotational range.

### 3.2.7 Full assembly

The final design consists of 35 individual 3D printed components. The large bicep section took the longest amount of time to print at 25.6 hours.

Fig 20. Entire Full arm assembly

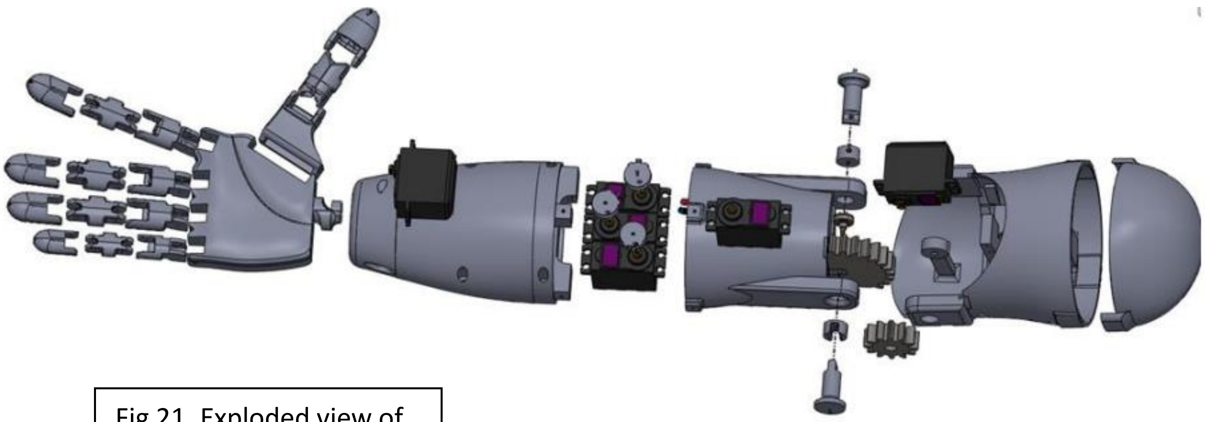


Fig 21. Exploded view of assembly

## 3.3 Discussion of Simulation Results

The kinematic analysis for carried out by creating the kinematic model of the hand, the equations of motion of the finger model must be obtained. Finger anatomy consists of cylindrical and spherical structures. DIP, PIP and MCP connections can be thought of as a single degree of freedom rotary connection. In the finger model in the figure, the MCP joint was accepted at the origin point, while the DIP joint was accepted as the fixed limb.

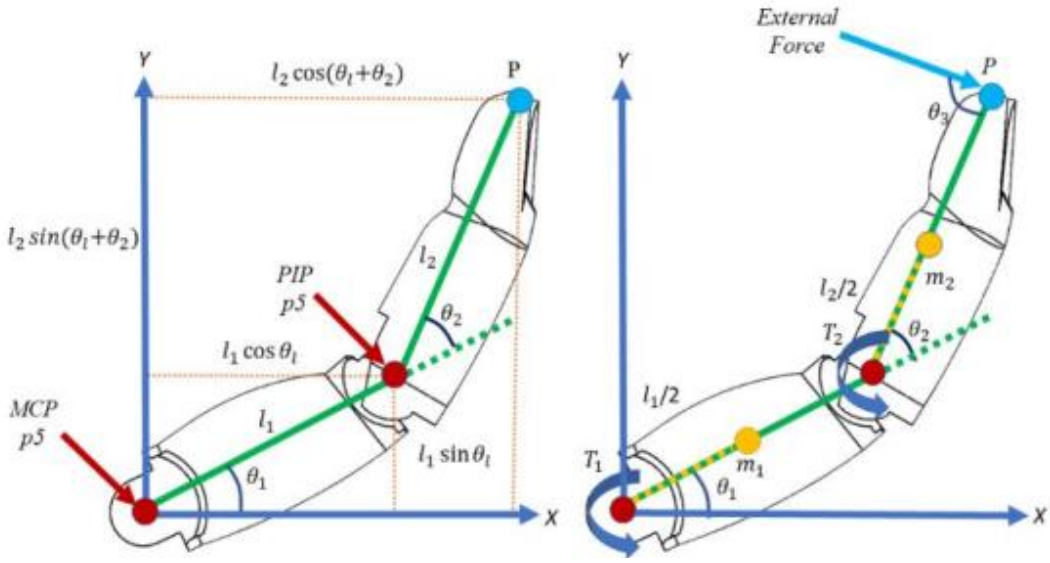



Fig 21. Kinematic Modelling of Fingers.

It is important for the stress values and distribution in the structure of the finger limb that remains under force. Firstly, CAD geometry was created for static analysis. A mathematical model was created from the CAD geometry created afterwards. Resin material, linear elastic isotopically, the mechanical properties of the material were introduced to the package program, and the degree of freedom limitations and forces were applied.

After these steps, the analysis was run, and the results shown in Figure below were obtained. The mathematical model used is 10 nodes for each element. In the Solidworks simulation program, the most sensitive solution network was created with 10-node element structure. The total number of nets used is 162139. The percentage of the item with an aspect ratio of less than

3 is 99.5%. Solid mesh is used as the mesh type. The real pin element is not used in the analysis model. This is to reduce the number of contacts and networks.

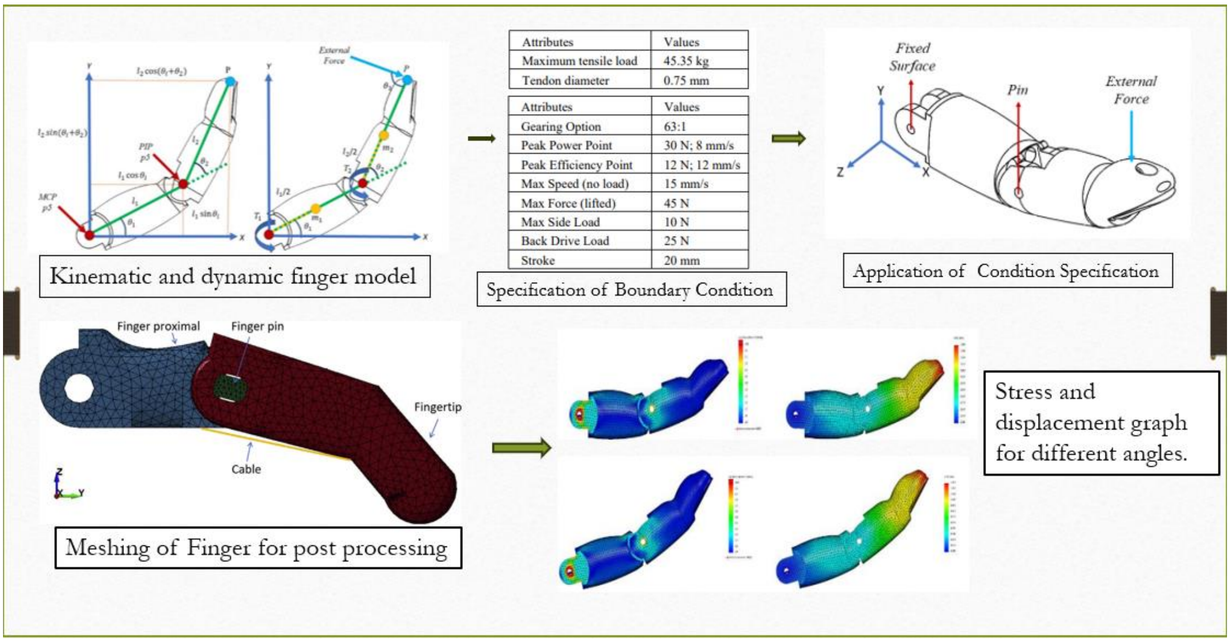



Fig 22. Static Structural Analysis Setup.

## 3.4 Design of Drive system

The tendons wrap around custom 3D printed servo horns creating a closed loop shown below. As the servo motor rotates one way it pulls on the tendon and closes the finger. To open the finger the motor is rotated in the opposite direction.

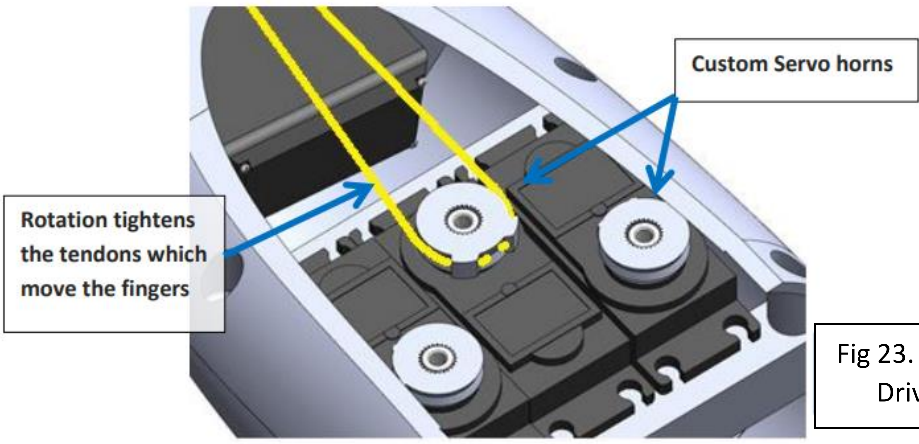



Fig 23. Designing of Drive system

The image below shows the artificial tendon drive for the index finger. All other tendons have been omitted for clarity. The thumb, index and middle fingers are connected to individual servo motors. Because the interior space of the arm is limited the ring and Pinky fingers have both been tied to the same servo, meaning they open and close in tandem.

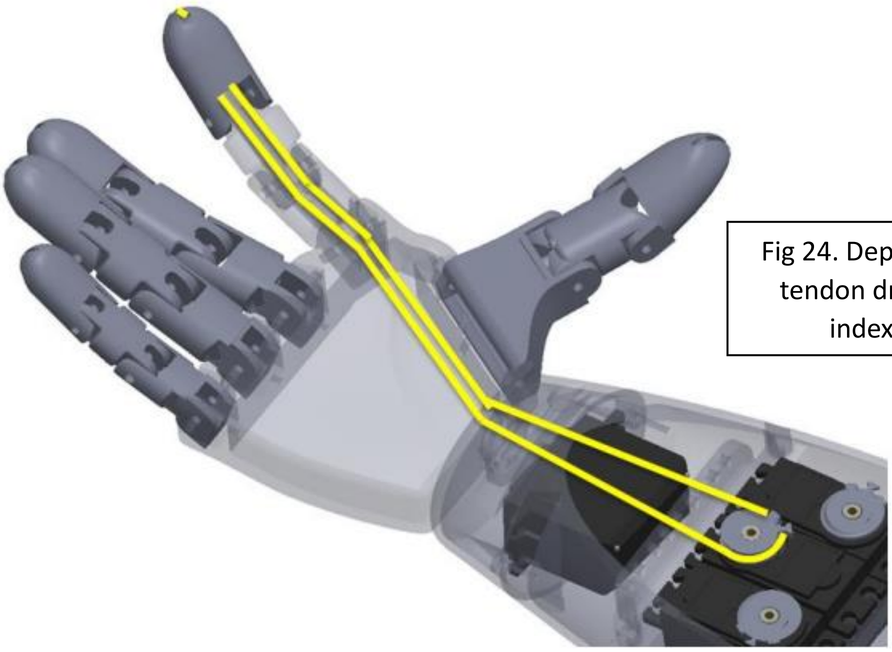


Fig 24. Depiction of the tendon drive for the index finger

## 3.5 3D Printing prototype

All mechanical components have been produced using an Tiertime x5 – a fused deposition modelling 3D printer. This type of 3D printer produces what is known as support material which provides support to horizontal planes during printing. Care must be taken when removing this support material as to not damage the component. All the pins used within the device, such as at the finger joints, have been 3mm diameter polypropylene filament. After printing these pin holes were drilled with a 3mm bit to improve dimensional accuracy. The Tiertime x5 provides its own development environment which allows for fine tuning of the printer options. Several features have been experimented with such as print speed, layer resolution and extrusion temperature to produces high quality printed components.

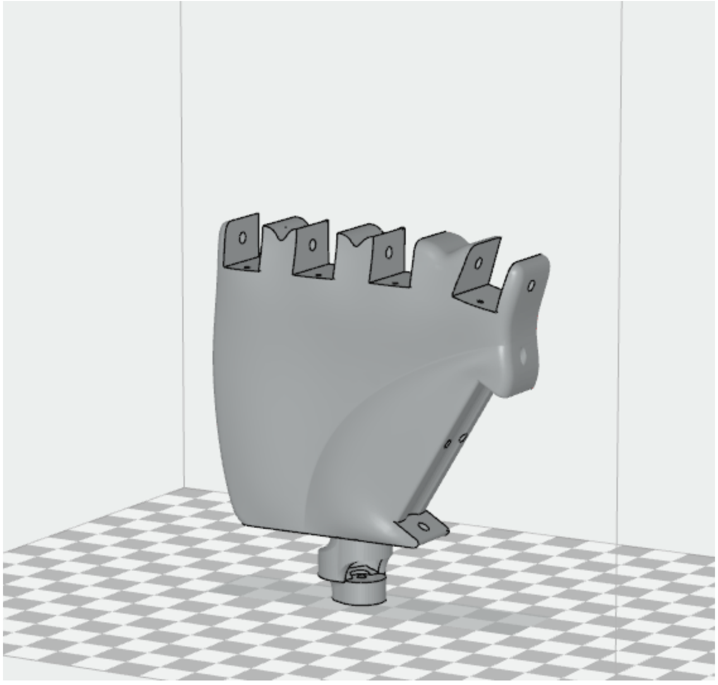


Fig 25. .STL file of the palm model displayed in the printing environment

# CHAPTER 4 ELECTRICAL DESIGN & CONTROL

The prosthetic arm employs servo motors as part of its actuation mechanism to control the movement of the fingers and thumb. Servo motors are selected based on their precision, reliability, and compatibility with electronic control systems. The fingers are activated through artificial tendons constructed from nylon fishing lines, simulating the function of biological tendons to facilitate controlled movement. The electrical design of the prosthetic arm features an electromyography (EMG) sensing system, microprocessors, and power management components, all of which play crucial roles in the overall functionality of the prosthetic arm.

The figure below illustrates the electrical design with a circuit diagram. The EMG sensing system captures electrical signals from muscle contractions in the user's residual limb, utilizing surface electrodes placed on the skin. The amplified signals are then sent to the microcontroller for processing.

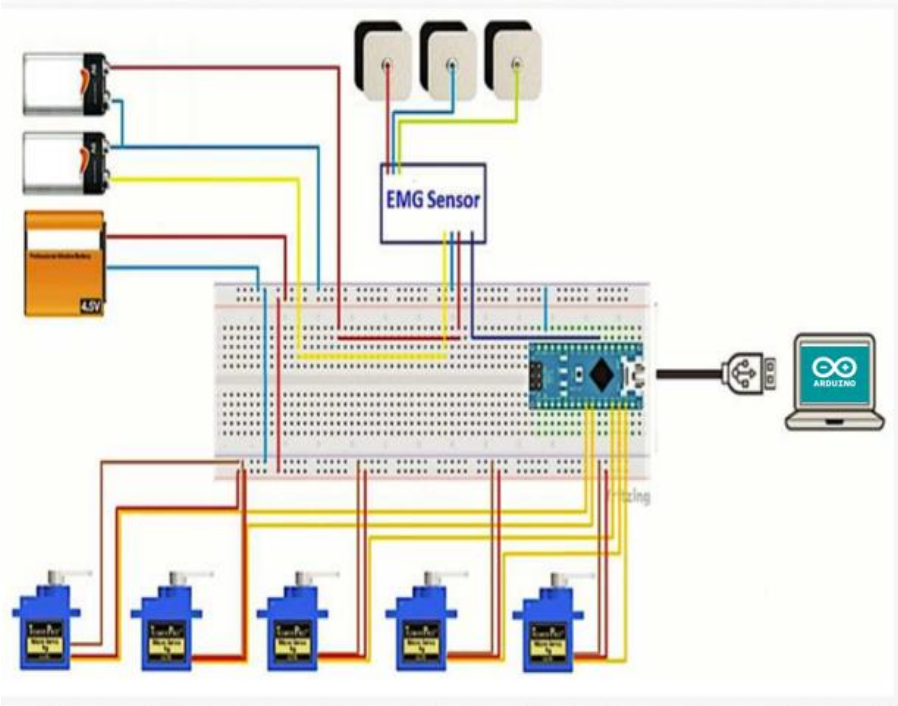



Fig 26. Electrical design with circuit diagram

The prosthetic arm's design allows modular configurations to accommodate various types of amputations, ensuring customization to suit individual needs. For instance, the thumb and wrist components are adjustable to provide a personalized fit and improved comfort. The movement of the prosthetic arm is controlled by servo motors, which receive signals from the microcontroller. Each servo motor is linked to an artificial tendon, translating the rotational motion of the motor into linear movement of the fingers, allowing for precise control of finger movements to perform tasks requiring fine motor skills. The actuation system includes geared wrist and elbow mechanisms to enhance the range of motion and functionality.

A user flexing generates an analogue signal which is amplified, rectified and smoothed by the EMG sensor board. The microcontroller uses this analogue signal to generate a pulse width modulated signal. This drives servo motors which tension the tendons causing the fingers to curl up. Appendix-1 contains details regarding components setup and related images and sensors used.

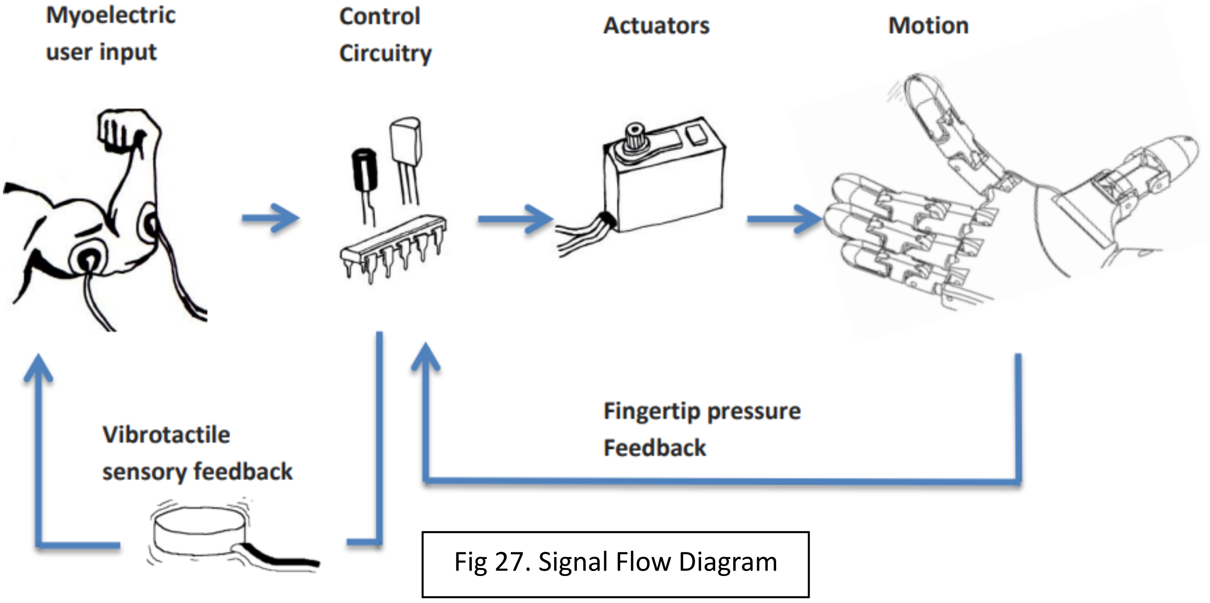



Fig 27. Signal Flow Diagram

## 4.1 Insights on system design

| System Properties | Description |
|---|---|
| System Weight | 710g |
| Material | PLA |
| Tendons | Nylon Fishing Line |
| Power Source | 2 9v Battey |
| Microcontroller | Arduino Uno R3 |
| EMG Sensors | Myowave 2.0 Sensor |
| Servo Voltage Regulator | AP1117 – 5V output, maximum current 1A |

Table No 1. Components usage and system insights

## CHAPTER-5 ASSEMBLY AND TESTING

The final system is a bionic arm offering six degrees of freedom and the ability to be controlled through myoelectric signals. The total design consists of thirty-six individual 3D printed components. The thumb, index and middle fingers each move independently, and the ring finger and small finger move in tandem. The wrist allows for 180 degrees of rotation and the elbow allows for 110 degrees of bending. A user can control the motion of the arm through a set of EMG electrodes placed on their forearm and/or bicep. At these stage two electrodes sets allow for rudimentary control of the arms range of motions.

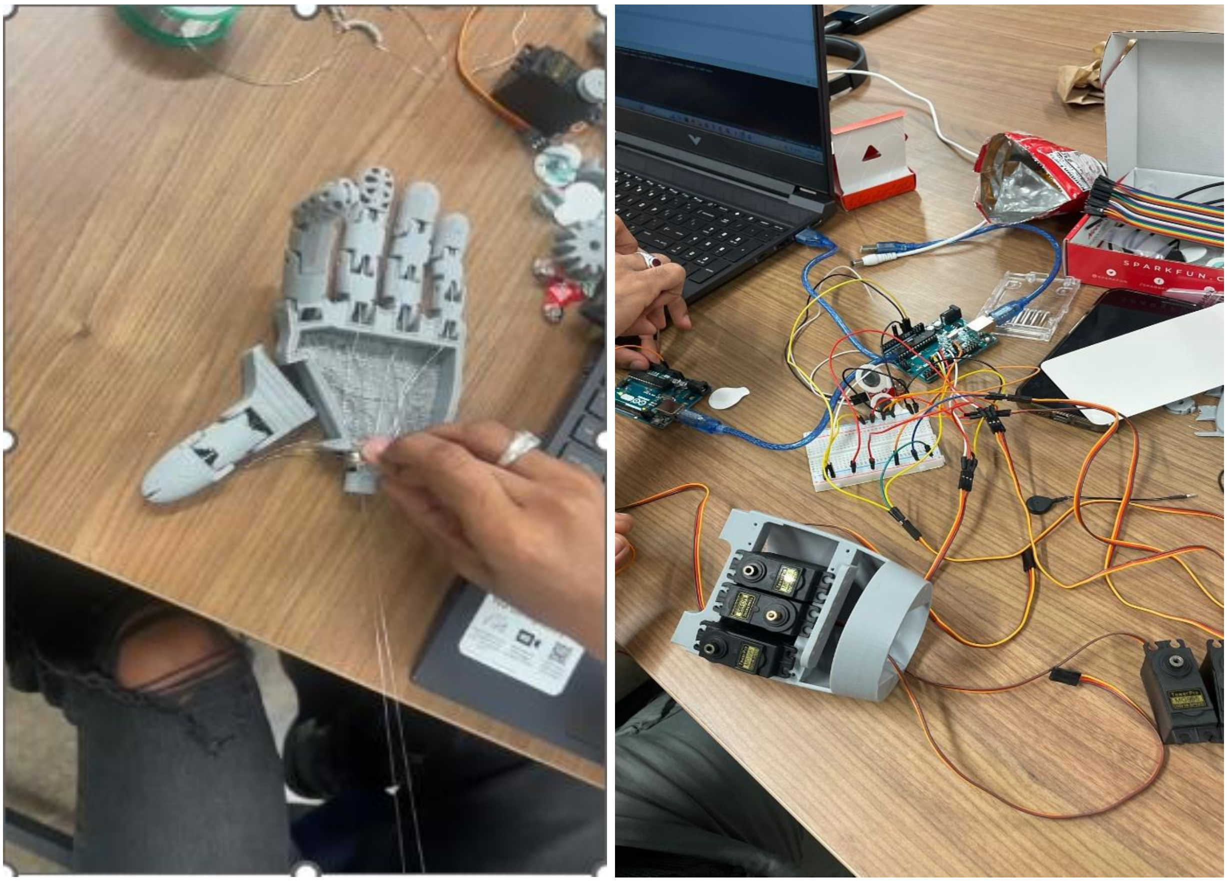


Fig 28. Tendon actuation and electrical assembly control.

Proportional control of the fingers worked well – the harder the user flexed the more the fingers would close. However, this proportional control caused the fingers to start shaking when trying to close – which was due to noisy signals being used to control servo positions.

# CHAPTER 6 BUDGET FOR THE PROJECT

| Materials | Item/Description | Estimated Cost (USD) | Notes | Links |
|---|---|---|---|---|
| Prices are subject to change on different Websites (We have order all things from Amazon) (Links are Pasted here for Verification. | | | | |
| 3D Printing Material | PLA filament | $24 | For printing the prosthetic parts | Product Link |
| Electronic Components | Servo motors (6 pcs) | $27 | For finger movements | Product Link |
| Tendon Connectors | Nylon cables | $6 | For tendon replication | Product Link |
| Cables and Connectors | Jumper Wire for Arduno Connections | $7 | For electrical connections | Product Link |
| Electric Circuit Components | Arduino Board | $26 | For Hand Movemrnt Replication | Product Link |
| Bluetooth Module | HC-05 Bluetooth Module | $10 | For EMG Connections | Product Link |
| | | | | |
| | Total Budget:- $100 | | | |

Table 2. Budget for building prototype

## Concluding Remarks

The primary objective of this research was to design a prosthetic arm that balances performance with affordability. By utilizing 3D printing technology, we significantly reduced the manufacturing costs associated with traditional prosthetic limbs. The mechanical design was optimized for 3D printing, resulting in durable and lightweight components. Using PLA material not only provided a cost-effective solution but also ensured the sustainability of the prosthetic arm. The electrical design incorporated advanced myoelectric sensing technology, enabling the prosthetic to respond accurately to muscle contractions. The integration of servo motors and artificial tendons provided precise control of finger movements, allowing for improved dexterity and functionality. The Arduino-based control system processed the EMG signals efficiently, ensuring responsive and intuitive operation. Performance evaluations demonstrated that the prototype prosthetic arm significantly improved dexterity and user comfort compared to traditional prosthetics. The testing procedures, including dexterity tests and user comfort assessments, highlighted the practical benefits of the design. Our project not only addresses a critical gap in the current prosthetic market but also demonstrates the potential for innovative technologies to create meaningful social impact.

# References


1. Hand Functions of Myoelectric and 3D-Printed Pressure-Sensored Prosthetics: A Comparative Study by Kyu Ho Lee, MD, MS, Hobeom Bin, BS, KeunBae Kim, MD, So Young Ahn, MD, PhD, Bong-Ok Kim, MD, PhD, and Soo-Kyung Bok, MD, PhD [NCBI Paper Link].
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3. Bray JJ. University of California Los Angeles. Prosthetics-Orthotics Education Program.: Prosthetic principles, upper extremity amputations : fabrication and fitting principles. Los Angeles: Prosthetics-Orthotics Education Program, Division of Orthopedic Surgery, University of California, Los Angeles; 1970 [ Google Scholar].
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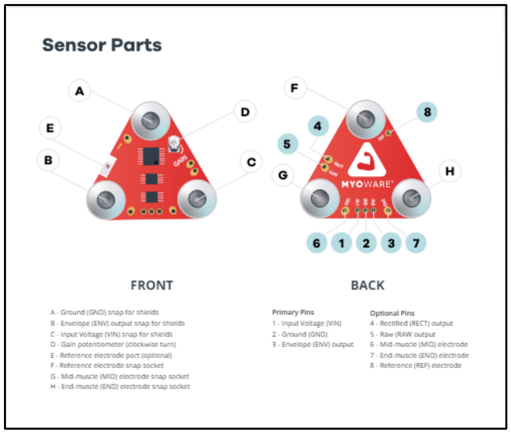
8. Mathematical modelling and production of semi-active hand prosthesis from clear resin by Mehmet Kayrici , Yusuf Uzun, Onur Gok and Huseyin Arikan [Paper Link].
9. New developments in prosthetic arm systems by Ivan Vujaklija, Dario Farina, Oskar C Aszmann [Paper Link].

# APPENDIX-1- Description for Components

## A. Myoware 2.0 Muscle Sensor

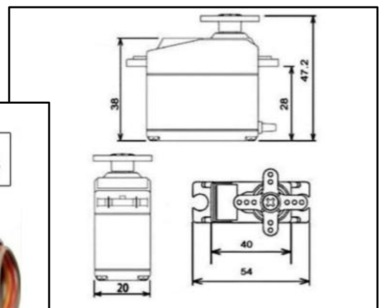
The Myoware 2.0 muscle sensor detects electrical activity from muscles, known as electromyography (EMG) signals. When a muscle contracts, the sensor generates a voltage signal proportional to the muscle activity. This signal can be read by a microcontroller, such as the Arduino UNO, to control other components.




- Specifications:
  1. Input Voltage: 3.1V to 5V
  2. Output Voltage Range: 0V to Vin
  3. Adjustable Gain
  4. Single-supply operation

## B. MG995 Servo Motors

The MG995 servo motors are responsible for the movements of the wrist and fingers. These high-torque motors are essential for the precise and controlled movements required for the prosthetic arm.

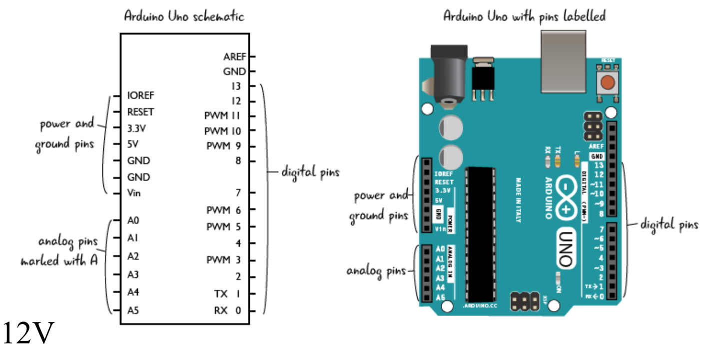




- Specifications:
  1. Operating Voltage: 4.8V to 7.2V
  2. Stall Torque: 10 kg/cm (at 6V)
  3. Speed: 0.20 sec/60 degrees (at 4.8V)
  4. Dimensions: 40.7 x 19.7 x 42.9 mm
  5. Weight: 55g

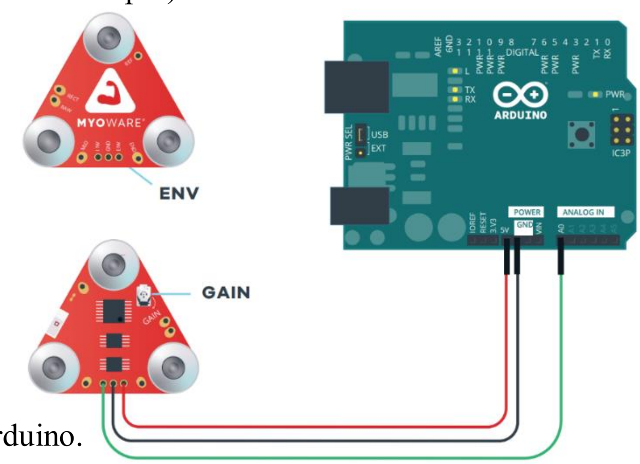
### C. Arduino UNO

The Arduino UNO is a versatile microcontroller board based on the ATmega328P. It processes the input signals from the Myoware sensor and generates the appropriate control signals for the servo motors.




- Specifications:
  1. Microcontroller: ATmega328P
  2. Operating Voltage: 5V
  3. Input Voltage (recommended): 7-12V
  4. Digital I/O Pins: 14 (of which 6 provide PWM output)
  5. Analog Input Pins: 6

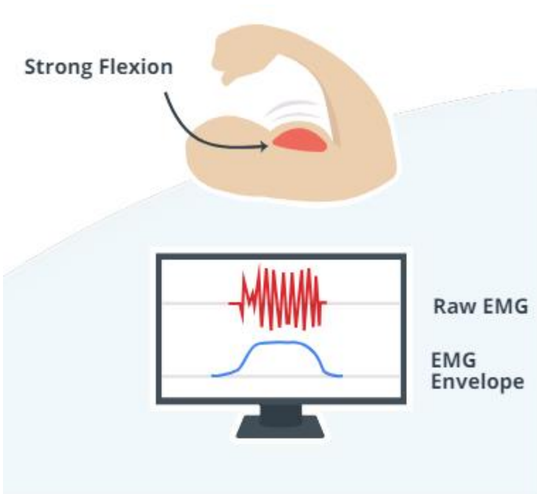
### D. Connection Diagram

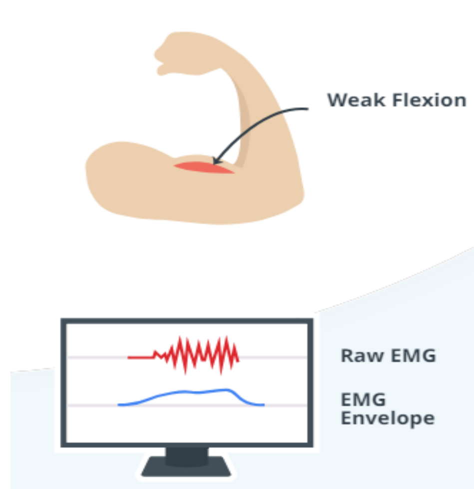



1. Myoware 2.0 Muscle Sensor:
   - VCC connected to 5V on Arduino.
   - GND connected to GND on Arduino.
   - SIG connected to Analog Input A0 on Arduino.
2. MG995 Servo Motors:
   - Wrist Servo Motor:
     - Signal Pin connected to Digital Pin 3 on Arduino.
     - Power and GND connected to an external power source (5-6V).
   - Finger Servo Motors (5):
     - Signal Pins connected to Digital Pins 4-8 on Arduino.
     - Power and GND connected to an external power source (5-6V).

### E. Calibrate the Sensor

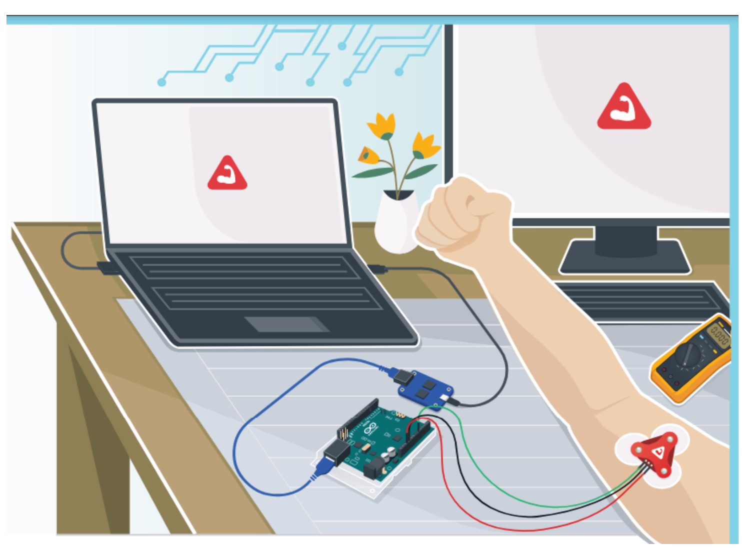
- Once the sensor is attached, you may need to calibrate it to ensure accurate readings. This can involve adjusting the gain settings on the Myoware sensor.
- Use the serial monitor in the Arduino IDE to read the sensor values and adjust the gain to achieve a range of values that correspond to the muscle contractions.




**F. Test the Sensor**

- Flex the muscle and observe the sensor's output on the Arduino serial monitor. Ensure the sensor detects muscle activity accurately and the readings are consistent.
- If necessary, adjust the placement of the electrode pads or the gain settings until you achieve reliable readings.



## G. Software Implementation

- The code reads the value from the Myoware 2.0 muscle sensor, processes it to determine the appropriate angle for the servo motors, and then moves the servos accordingly. If the sensor value is below a set threshold, the servos are set to a default position.

sketch_sep30a.ino

```
#include <Servo.h>

const int sensorPin = A0;  // Myoware 2.0 sensor is connected to analog pin A0
const int threshold = 50;  // Threshold for significant readings

Servo servo1;
Servo servo2;
Servo servo3;
Servo servo4;
Servo servo5;

void setup() {
  Serial.begin(19200);  // Initialize serial communication for debugging

  servo1.attach(3);  // Attach servo1 to pin 3
  servo2.attach(5);  // Attach servo2 to pin 5
  servo3.attach(6);  // Attach servo3 to pin 6
  servo4.attach(9);  // Attach servo4 to pin 9
  servo5.attach(10); // Attach servo5 to pin 10
}

void loop() {
  int sensorValue = analogRead(sensorPin);  // Read the raw sensor value

  // Debugging: print the raw sensor value to the serial monitor
  Serial.print("Raw sensor value: ");
  Serial.println(sensorValue);

  if (sensorValue > threshold) {
    // Map the sensor value to the servo angle range (0 to 180 degrees)
    int angle = map(sensorValue, threshold, 1023, 0, 180);

    // Control each servo based on the mapped angle
    servo1.write(angle);
    servo2.write(angle);
    servo3.write(angle);
    servo4.write(angle);
    servo5.write(angle);

    // Debugging: print the mapped angle to the serial monitor
    Serial.print("Mapped angle: ");
    Serial.println(angle);
  } else {
    // If the reading is below the threshold, set servos to default position (e.g., 90 degrees)
    servo1.write(90);
    servo2.write(90);
    servo3.write(90);
    servo4.write(90);
    servo5.write(90);

    // Debugging: print insignificant reading message
    Serial.println("Insignificant reading, servos set to default position.");
  }

  delay(10);  // Delay for a short time to allow the serial monitor to keep up
}
```