# HUMAN ROBOTIC ARM AS EXTENSION OF BODY

Student Name: Kumar Rishav
Roll Number: 2021159

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on April 26th, 2024

**BTP Track**: Engineering Track

**BTP Advisor**
Dr. Sayan Basu Roy
Dr. Kalpana Shankhwar

Indraprastha Institute of Information Technology
New Delhi

# Student's Declaration

I hereby declare that the work presented in the report entitled Human Robotic arm as extension as extension of body submitted by me for the partial fulfilment of the requirements for the degree of *Bachelor of Technology* in *Electronics and Communication* at Indraprastha Institute of Information Technology, Delhi, is an authentic record of my work carried out under guidance of Dr. Sayan Basu Roy, and Dr. Kalpana Shankhwar Due acknowledgements have been given in the report to all material used. This work has not been submitted anywhere else for the reward of any other degree.

**............................**
Kumar Rishav

**Place & Date: IIIT Delhi, April 26th, 2024**

# Certificate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

**............................**
**Sayan Basu Roy**

**Place & Date: IIIT Delhi, April 26th, 2024**

## Abstract

The project delves into the development of a bio-mimetic mechatronic hands aiming to overcome the limitations of current bionic hand technologies. Traditional prosthetic hand often exhibits restricted movement and functionality, hindering users to experience natural movement and perform intricate tasks. To address this challenge, we propose an approach utilizing open-source hand tracking to mimic human hand movements with 27 degrees of freedom using similar to a natural human hand. Our focus lies on creating a bionic hand such that it can emulate real human-like movement, and fluidity.

By leveraging cable operated hand concept with servo mechanisms and integrating feedback systems within the knuckles and other joints, our project seeks to replicating the complexity of human hand with precision using secondary feedback. Drawing inspiration from anatomical and biomechanical principles of tendon and bone movement.

The methodology followed here encompasses conceptualization, integration of human hand tracking to capture movement and adding the model and rapid prototyping through cad design and 3D printing.

***Keywords:*** Biomimetic Mechatronics, Bionic Hands, Prosthetics, Image Tracking, Feedback Systems, Degree of Freedom, Anatomical Principles, Biomechanical Principles, CAD Design, Motion Capture, Precision Movement

# Acknowledgments

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# Work Distribution

All the work mentioned in this report has been done in the Winter Semester (2024).

# Contents

# Chapter 1

# Introduction

## 1.1 Motivation

This Project stems from the recognition of the limitations of current prosthetic hand technologies in replicating the intricate movements and functionalities of the human hand. Traditional prosthetics, while providing basic functionality, often lack the fluidity and dexterity necessary for individuals with limb differences to perform daily tasks with ease and precision. By developing a biomimetic mechatronic hand, we aim to bridge this gap and empower users to regain greater independence and functionality in their daily lives and can be used in places where human hand precision is required in the fields of military, medical and many other fields.

## 1.2 Problem Statement

Current bionic hand technologies in achieving biomimetic movement and motion fluidity. Existing prosthetic hands often struggle to replicate the natural range of motion, speed, and dexterity of the human hand, limiting users' ability to perform complex tasks. Additionally, the reliance on conventional control methods, such as myoelectric technology, poses challenges in achieving intuitive and responsive control of prosthetic limbs. Addressing these challenges requires innovative approaches that integrate principles from biomechanics, robotics, and control systems to design a bionic hand capable of real human-like movement.

## 1.3 Stakeholders

The stakeholders of this project include individuals with limb differences who rely on prosthetic hands for daily activities, healthcare professionals involved in prosthetics and rehabilitation, researchers and engineers in the field of biomechanics and robotics, and potential users of advanced prosthetic technologies.
By addressing the needs and challenges faced by these stakeholders, our project aims to contribute to the advancement of prosthetic hand technology and improve the quality of life for individuals with limb differences.
By providing modification to the project can be used in Military organizations have a vested interest in advanced prosthetic technologies not only for injured soldiers but also for broader applications such as integrating robotic or prosthetic limbs into combat or operational scenarios. This includes reducing casualties and enhancing operational capabilities.

Beyond prosthetics, advancements in robotics and biomechanics have implications for surgical procedures and rehabilitation techniques. Surgeons, physical therapists, and occupational therapists could benefit from innovations in robotic technologies for precise surgeries and personalized rehabilitation.

In space exploration, such as missions to other planets or space stations, advanced robotics and prosthetics could be essential for astronauts to perform complex tasks in challenging environments. The development of prosthetic technologies can have applications in space for both human and robotic missions

## 1.4 Methodology

The methodology of the project involves a multidisciplinary approach that integrates principles from biomechanics, robotics, control systems, Python scripting, 3D motion capture, and electronics implementation The methodology follows the following steps for the implementation of the project.

- Understanding Human Hand Dexterity and Movement:
  The project begins with a deep dive into the biomechanics and movement capabilities of the human hand. This foundational research is crucial for informing the design and functionality for the bionic hand.

- Simulation with Blender 3D and Media pipe/OpenCV:
  Using Blender 3D, Media pipe, and OpenCV, we try to simulate and capture hand movements from video input. The integration of these tools allows for real-time hand recognition and motion capture, which is a crucial step in understanding and replicating natural hand movements.

- Implementing Hand Recognition Algorithm:
  Leveraging the Media pipe Hand library and OpenCV, we developed a robust hand recognition algorithm. This algorithm is key to accurately tracking hand movements and translating them into digital data for further analysis and replication.

- Motion Capture and Armature Integration:
  The captured hand motions are integrated into a digital armature within Blender 3D. This step involves translating the recorded movements into a format that can be applied to a virtual or physical prosthetic hand model.

- CAD Design and Hardware Implementation:
  Moving beyond simulation, we design a physical prosthetic hand using Computer-Aided Design (CAD) software. The inclusion of a pulley mechanism driven by servos and potentiometer feedback adds a layer of precision control to the hardware implementation.

- Mathematical Modelling and Control System:
  The project relies upon the mathematical model to ensure precise control and adjustment of the prosthetic hand's movements. This involves the control algorithms that utilize feedback from the camera feed as primary input and potentiometers to adjust the hand's position and grip as the secondary input.

- Python Scripting for Control Systems:

Python scripting plays a central role in implementing control algorithms and integrating various components in the project, such as camera feed to angle generation for the primary input, electronics control using libraries as pyfirmata, and adding addons to the CAD software.

# Chapter 2

# Functional Anatomy and Biomechanics of Human Hand

In order to define clear parameters for the operation of the bionic hand, it is necessary to examine the anatomy behind a functional hand which allows it to move in the way that it does.
The aim of this project is to produce a bionic hand capable of replicating movement of the hand as closely as possible, so the actual structures of the hand are a very important.
The human hand has 27 degrees of freedom: 4 in each finger, 3 for extension and flexion and one for abduction and adduction; the thumb is more complicated and has 5 DOF, leaving 6 DOF for the rotation and translation of wrist. There are 17 bones with 36 articulations and 39 active muscles. Most Prosthetic / bionic arm have a limited DOF due to limitation to the designs considering power, space, weight and control, but as biomimetic mechatronic hand, we aim to imitate hand as closely as possible

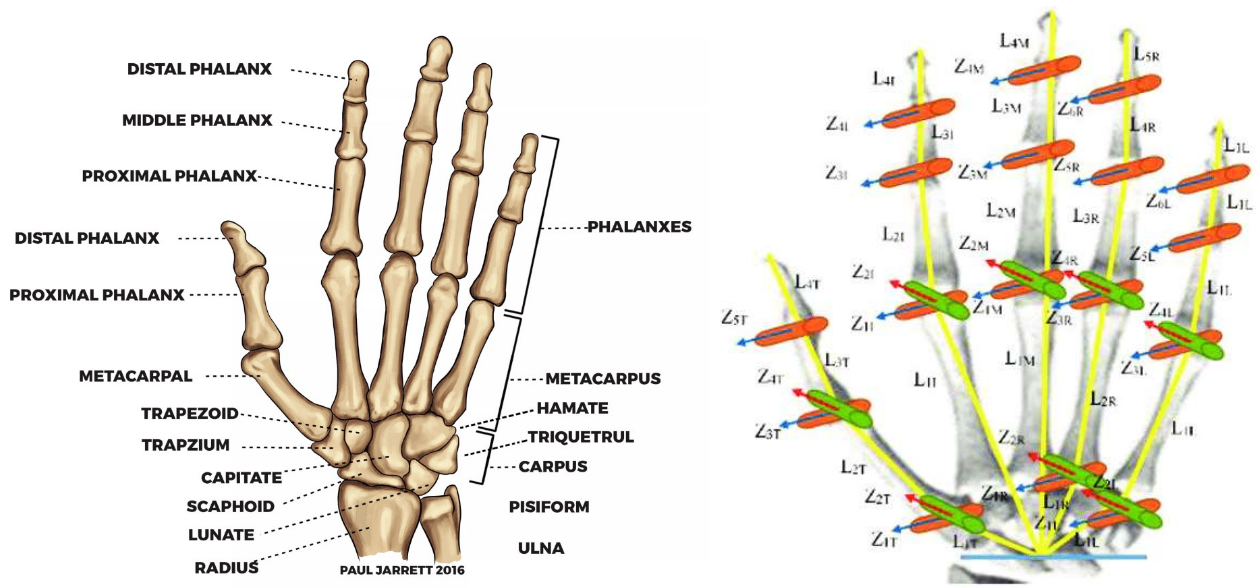


*Figure 2.1(a left) Bones of the hand and wrist, (b right) degree of freedom of a Human Hand*

Each finger present in human hand except thumb consists of four bones which include phalanges: distal, middle, and proximal which are visible as protrusion from the palms, and the metacarpal bones which are present in the palm. Much of hands actuation originates from muscles in the forearm, which move using tendons attaching to various bones of the hand, these are referred to as extrinsic muscles.

## 2.1 Fingers

The fingers have several tendons which allow for flexion (bending motion which decreases angle between bones) of each segment, as well as tendon which allow them to extend (increasing angle between bones). There are a total of nine extrinsic extension muscles in the hand, three of which extend the fingers,
These are:

- The extensor digitorum which extends all fingers from the distal phalanges, then the wrist
- The extensor digiti minimi which extends only the little finger
- The extensor indicis which extends the index finger

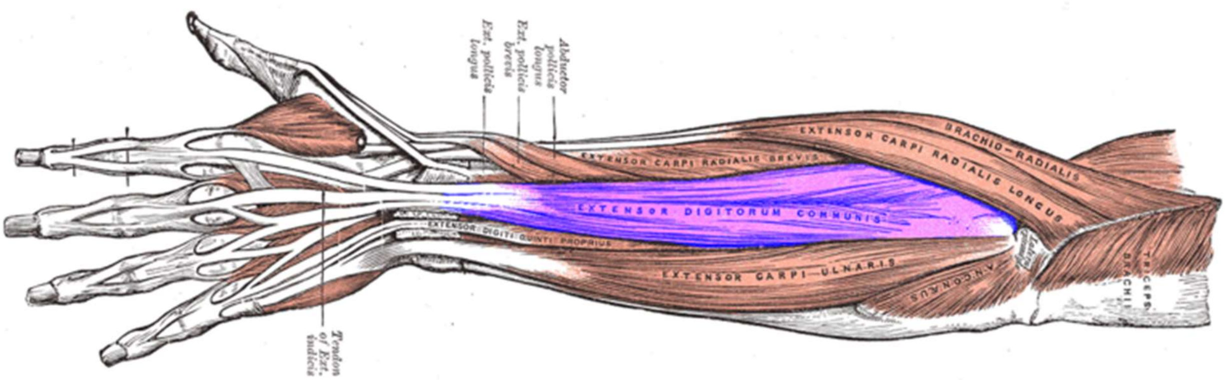


*Figure 2.2 Posterior surface of the forearm, extensor digitorum muscle labelled in purple*

The complexity of finger motion involves a sophisticated interplay of muscles, tendons, and ligaments that govern various degrees of freedom in the hand. Key aspects include the ability of only the index and little fingers to extend independently, with each finger capable of extending approximately 40° from the back of the palm. Flexor Digitorum Profundus (FDP) and Flexor Digitorum Superficialis (FDS) muscles play pivotal roles in finger flexion, with FDP extending to the distal phalanx and passing through the FDS tendon without obstruction. Lumbrical muscles, situated in the palm, enable independent flexion of the proximal phalanx. Sequential joint flexion is driven by tendon mechanics, where the FDP tendon influences flexion across all finger joints due to its arrangement and interaction with ligaments which can be referenced from Häggström, Mikael (2014) with Figure2.2. The Metacarpophalangeal (MCP) joint, a complex condyloid joint as shown in Figure 2.3, permits lateral rotation of the proximal phalanx by up to 15°, enhancing precision grip capabilities. Notably, the proximal phalanx can rotate up to 30° around the MCP joint and subtly twists inward during full extension. Unique finger manoeuvres, such as opposing the thumb at a 180° angle with the little and ring fingers, are facilitated by lateral movement of the proximal phalanges. This intricate biomechanical system underscores the challenges of replicating natural hand movements and highlights the importance of understanding these mechanics for advancements in prosthetic and robotic hand technologies.

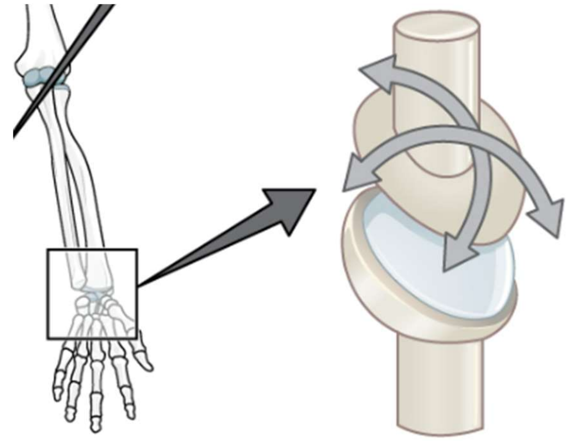

Figure 2.3 Condyloid Joint

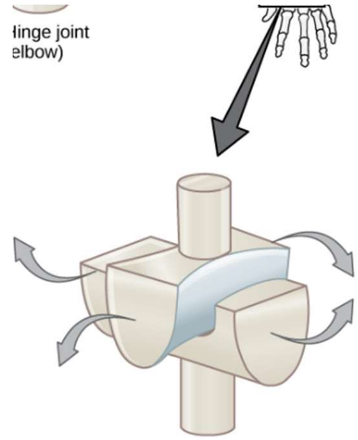

Figure 2.4 Saddle Joint

## 2.2 Thumb

The thumb, despite having one less joint than the fingers, exhibits remarkable mobility due to its unique carpometacarpal (CMC) joint. This joint connects the thumb's base to the carpals above the wrist and is described as a saddle joint, allowing two degrees of freedom akin to a condyloid joint. The CMC joint facilitates a semi-circle shaped range of motion about the palm, providing crucial dexterity. Although it lacks axial rotation, the thumb's movement can be perceived as rotating about its origin at the CMC joint during its range of motion. The complex thumb joint involves 9 muscles and 16 ligaments that dictate and stabilize its movement, emphasizing the challenge of replicating its mechanics accurately. The metacarpophalangeal joint of the thumb, similar to those in the fingers, allows flexion of the proximal phalanx up to approximately 70° and lateral motion over a range of about 30°. Lastly, the interphalangeal joint of the thumb functions as a pure hinge joint, offering around 90° of flexion and up to 80° of hyperextension in some individuals (Yoshida et al., 2003).

Understanding the detailed biomechanics of the thumb's joints underscores the intricate nature of hand functionality and the complexities involved in developing prosthetic or robotic hands that can emulate natural thumb movements effectively. The combination of joint structures, muscle interactions, and ligament stability contributes significantly to the thumb's exceptional range of motion and precision grip capabilities, posing challenges for bionic hand design that require empirical observation and advanced engineering solutions.

## 2.3 Palm

The palm contains many muscles and supports many tendons which pass through it, but its motion is very limited. The top of the palm appears to move as the proximal phalanges flex, but this is actually loose skin on the other side of the knuckles. The fourth and fifth metacarpals (ring and little fingers) however do flex and extend very slightly about the carpometacarpal joint as controlled by the bundle of muscles around the base of the little finger. This movement allows these last two fingers to more severely oppose the other fingers and thumb, and also allows the palm to more intimately grip round objects. The displacement of the metacarpals varies considerably, but as a rough estimate the fifth metacarpal moves 30° about an axis in the centre of the third metacarpal, and the fourth metacarpal moves 20°. The shape of the palm is also influenced by movement of the thumb

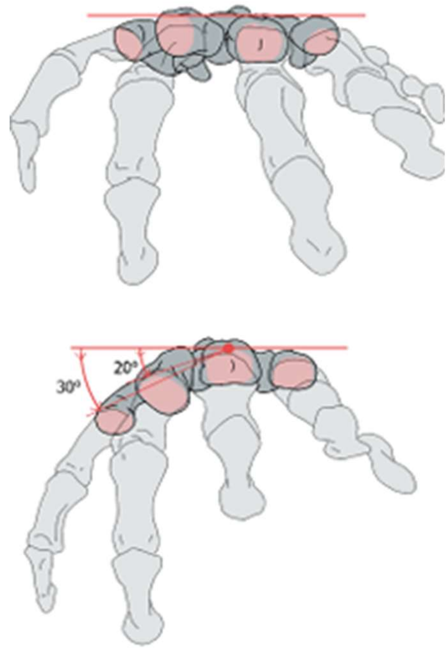


Figure 2.5 Movement of the metacarpals as viewed from the front of the hand

## 2.4 Wrist

At first glance the wrist may appear to act as a simple ball-socket joint, but up close it is apparent that it is much more complex. There are 8 carpal bones which make up the wrist joint morphologically; it can be divided into 2 separate joints – proximal and distal. The proximal wrist joint connects the hand to the radius and ulna in an extremely complex interaction permitting flexion/extension and lateral deviation. For the purposes of this project, it is simplest to think of the wrist as a condyloid joint like the MCP joints of the fingers and thumb. Axial rotation of the wrist is achieved via the radius and ulnar bones of the forearm the ulna bone remains stationary while the radius moves around it, and both bones are fixed relative to each other by ligaments in the forearm.

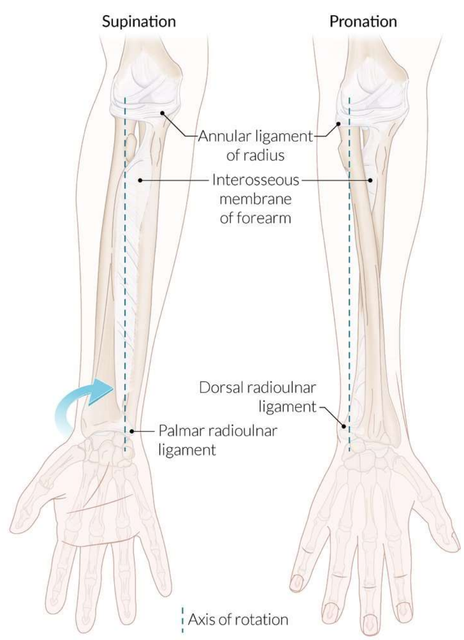


*Figure 2.6 Axial rotation of wrist via radius and ulnar bones of the forearm 4*

## 2.5 Movement Terms

The intricacies of replicating the precise movements of the human hand in bionic prosthetics present a significant challenge, especially when considering the multitude of muscles, tendons, and neural pathways involved. This complexity raises questions about how to best optimize the design of bionic hands to achieve biomimetic functionality while balancing factors such as weight, complexity, and control options.

In conventional bionic hand designs, designers often simplify motion patterns by using a single actuator to control multiple finger movements, even though this contrasts with the intricate control of individual tendons in the human hand. While this approach reduces complexity, it may not fully capture the natural movement patterns of the hand. However, attempting to replicate every muscle and movement pattern of the human hand within the scope of a project is impractical.

Given the limitations of current myoelectric technology, which relies on detecting nerve signals for control, it may not yet be feasible to directly emulate the complexity of human hand movements in bionic hands. Instead, this project aims to use camera as input and capture real time movement from, focusing on achieving biomimetic movement through thoughtful design rather than mechanically or electronically linking every joint and movement path. Some movements, such as the slight flexion of metacarpal bones to facilitate opposition between the little finger and thumb, can be mechanically linked in the bionic hand to reduce the number of actuators required. Similarly, simplifying the lateral movement of proximal phalanges to a single actuator can streamline the design while still achieving functional versatility.

In cases where replicating complex biological joints is impractical, such as the saddle joint of the thumb's CMC joint, simplifications can be made without compromising functionality. For instance, modelling the joint as a simple ball and socket joint allows for easier implementation at the expense of physical endpoints within the joint's design. Furthermore, considerations for the speed of motion in the biomimetic mechatronic hand are crucial for user satisfaction. While prosthetic hands should contract within one second to meet user expectations, a biomimetic mechatronic hand should aim to be faster and more responsive, approximately twice the speed specified for prosthetic hands. Drawing from anatomical data, biomechanical principles, and empirical observations. These visual representations serve as valuable reference points for optimizing the design of the bionic hand to achieve biomimetic kinaesthetic function.

# Chapter 3

# Review of Previous Works

Bionic hands are already widely available as prosthetics, and highly biomimetic hands have also been developed but have not yet been made available commercially. Prosthetic hands generally have a very limited number of degrees of freedom, largely due to the limitations of myoelectric technology (detecting signals from the nerves and using these to control bionics), but some designs are much closer to human hands than others. Some works have also attempted to design a control glove alongside a bionic hand (as this project will), while other projects have looked at designing a control glove independently of a bionic hand, to be used in PC simulations. Only a very small number of projects have specifically tried to create a biomimetic hand alongside a control glove as a single project, so it will be useful to examine other projects as well as these specific ones.

## 3.1 DLR-HIT

The DLR-HIT hand, a collaborative effort between the Harbin Institute of Technology and the German Aerospace Centre, represents a significant advancement in bionic hand technology. While visually lacking in biomimetic appearance, the hand boasts remarkable mobility and functionality, featuring three identical fingers and one thumb, each equipped with four joints and discreetly integrated actuators. Its successor, the DLR-HIT hand II, exhibits a more lifelike appearance with all four fingers and a realistic structure, while maintaining the same degrees of freedom in a smaller and lighter form factor. Commercially available, these hands find application in telemanipulation, offering users precise control and manipulation capabilities. The original DLR-HIT hand, weighing approximately 2.2kg, features a lightweight metal skeleton and a minimalist exterior plastic shell. Actuation is achieved through commercial brushless DC motors integrated into the fingers and palm, controlled via a PC software platform. Hall effect sensors are utilized to detect joint angles, providing accurate positioning feedback to the controller. Despite its precision, the hand is capable of moving all joints at a maximum speed of 180 degrees per second. The second iteration of the DLR-HIT hand builds upon its predecessor's success with refinements in design and performance. It boasts increased speed and fingertip force, while being significantly lighter, weighing only 75% of the original. With these enhancements, the DLR-HIT hand II sets a new standard for bionic hand technology, offering users improved functionality and usability in a sleeker and more efficient package.

*Figure 3.1 (a) DLR-HiT version1 and (b) version2*

## 3.2 Biomimetic bionic hand project, Todorov and Xu (2016)

In their biomimetic bionic hand project, Todorov and Xu (2016) embarked on an ambitious endeavour to replicate the intricacies of the human hand through innovative design and fabrication techniques. Their approach involved closely mimicking the anatomical structures of the human hand, including artificial joint capsules, crocheted ligaments and tendons, laser-cut extensor hoods, and elastic pulley mechanisms. By leveraging advanced imaging technologies such as laser and MRI scanning, they meticulously examined the bone structures of the hand and 3D printed detailed replicas to serve as reference points for building crocheted tendons and ligaments.

*Figure 3.2 Biomimetic bionic hand project, Todorov and Xu*

The actuation of the hand was achieved using 10 Dynamixel servos located in the forearm, which moved the hand via Spectra string tendons. Control was facilitated through a data glove described in Xu's previous work (2015), enabling precise measurement and manipulation of finger movements. Through rigorous testing, including trajectory analysis and object manipulation tasks, the hand demonstrated its ability to replicate human-like motion and manipulate a wide variety of objects with finesse. While Todorov and Xu's project set a high bar in terms of replicating human hand motion with remarkable fidelity, it also faced challenges related to budget and timescale. As such, direct replication of their work may not be feasible within the constraints of this project. However, their approach serves as a valuable reference point for exploring alternative methods of achieving biomimetic functionality. For instance, while the use of advanced medical scanning capabilities may not be available, software simulations and alternative actuation methods can still yield comparable results. Additionally, while the incorporation of artificial ligaments for joint capsules is feasible, mechanical simplifications of joint surfaces may be preferred for greater robustness and ease of fabrication.

While Todorov and Xu's project represents a pinnacle of biomimetic bionic hand design, this project aims to draw inspiration from their work while exploring innovative approaches tailored to the available resources and constraints. By leveraging advanced engineering techniques and creative problem-solving, we endeavour to develop a bionic hand prototype that achieves biomimetic functionality while remaining practical and accessible.

## 3.3 IN-Moov

The In-moov hand is a groundbreaking open-source project that has revolutionized the field of prosthetics and robotics. Developed by French artist and engineer Gael Langevin, the IN-moov hand is a fully articulated robotic hand designed to replicate the movements and functionalities of the human hand. Named after its creator's online alias, IN-moov, the project aims to provide accessible and customizable solutions for individuals with limb differences and robotics enthusiasts alike.

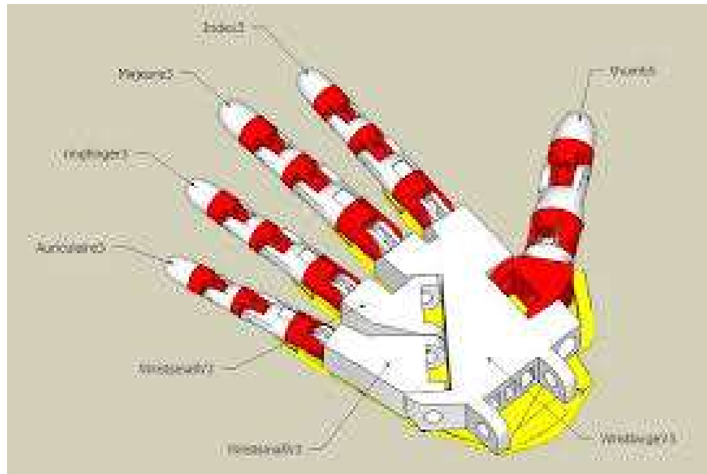

*Figure 3.3 IN-Moov hand Prosthetic*

At its core, the In-moov hand is built upon the principles of open-source hardware and software, allowing users to access and modify the design freely. The hand is constructed using 3D-printed components, making it cost-effective and easily reproducible. This democratization of technology enables individuals around the world to create their own prosthetic hands or robotic projects using the In-moov design. The In-moov hand features a sophisticated system of servo motors and tendons, which mimic the movements of human fingers and thumbs. By utilizing servo motors and pulley systems, the hand can achieve a wide range of movements, including grasping, pinching, and pointing. The design also incorporates sensors and feedback mechanisms to enable intuitive control and interaction with the environment. One of the key strengths of the In-moov hand is its modularity and scalability. Users can customize the hand to suit their specific needs and preferences, whether it's adjusting the size and shape of the fingers or integrating additional sensors for enhanced functionality. This flexibility makes the In-moov hand suitable for a variety of applications, from prosthetic devices for individuals with limb differences to educational projects and research endeavours in robotics. Moreover, the In-moov project has fostered a vibrant online community of users and contributors who share their experiences, ideas, and improvements. This collaborative approach has led to continuous innovation and refinement of the In-moov design, with users around the world sharing their adaptations and enhancements to the original concept.

# Chapter 4

# Hand Tracking and Integration

Hand tracking using Media pipe and OpenCV is a powerful technique for detecting and tracking the movement of hands in images or video streams. Media pipe is an open-source machine learning framework developed by Google that offers pre-trained models for various tasks, including hand tracking. OpenCV, on the other hand, is a popular computer vision library that provides tools for image processing and manipulation.

The combination of Media pipe and OpenCV enables developers to build robust hand tracking applications with ease. Here's how it works:

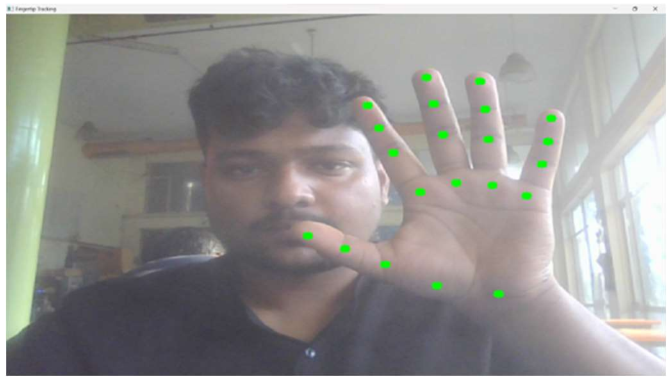

*Figure 4.1 Hand Tracking Implementation*

## 4.1 Hand Detection with Media pipe

Media pipe provides a pre-trained model called the "Media Pipe Hands" model, which is capable of detecting and localizing hands in images or video frames. This model is based on convolutional neural networks (CNNs) and is optimized for real-time performance. It works by analysing the pixels in the input image to identify regions that are likely to contain hands.

## 4.2 Integration with OpenCV

Once the hands are detected using Media Pipe, the detected regions can be further processed and analysed using OpenCV. OpenCV provides a wide range of tools and functions for image processing, such as filtering, thresholding, and contour detection, which can be used to refine the hand detection results and extract additional information about the hand's position, orientation, and movement.

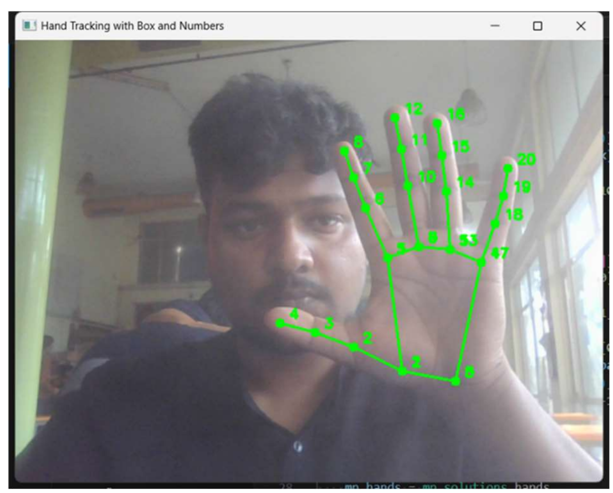


*Figure 4.1 Hand Tracking Implementation with computer Vision*

## 4.3 Hand Tracking and Gesture Recognition

With the detected hand regions, developers we have implement hand tracking algorithms to track the movement of the hands over time. This allows for real-time tracking of hand gestures and movements, which can be used for various applications such as gesture-based interaction, sign language recognition, and virtual reality (VR) control.

## 4.4 Add-On Development for Blender

Using the combined capabilities of Media pipe and OpenCV, developers can build a wide range of applications that leverage hand tracking technology.
Hand tracking using Media pipe and OpenCV offers a powerful and flexible solution for detecting and tracking hand movements in images or video streams. By leveraging pre-trained models and advanced image processing techniques, developers can create immersive and interactive experiences that respond to the movements of the user's hands in real-time.

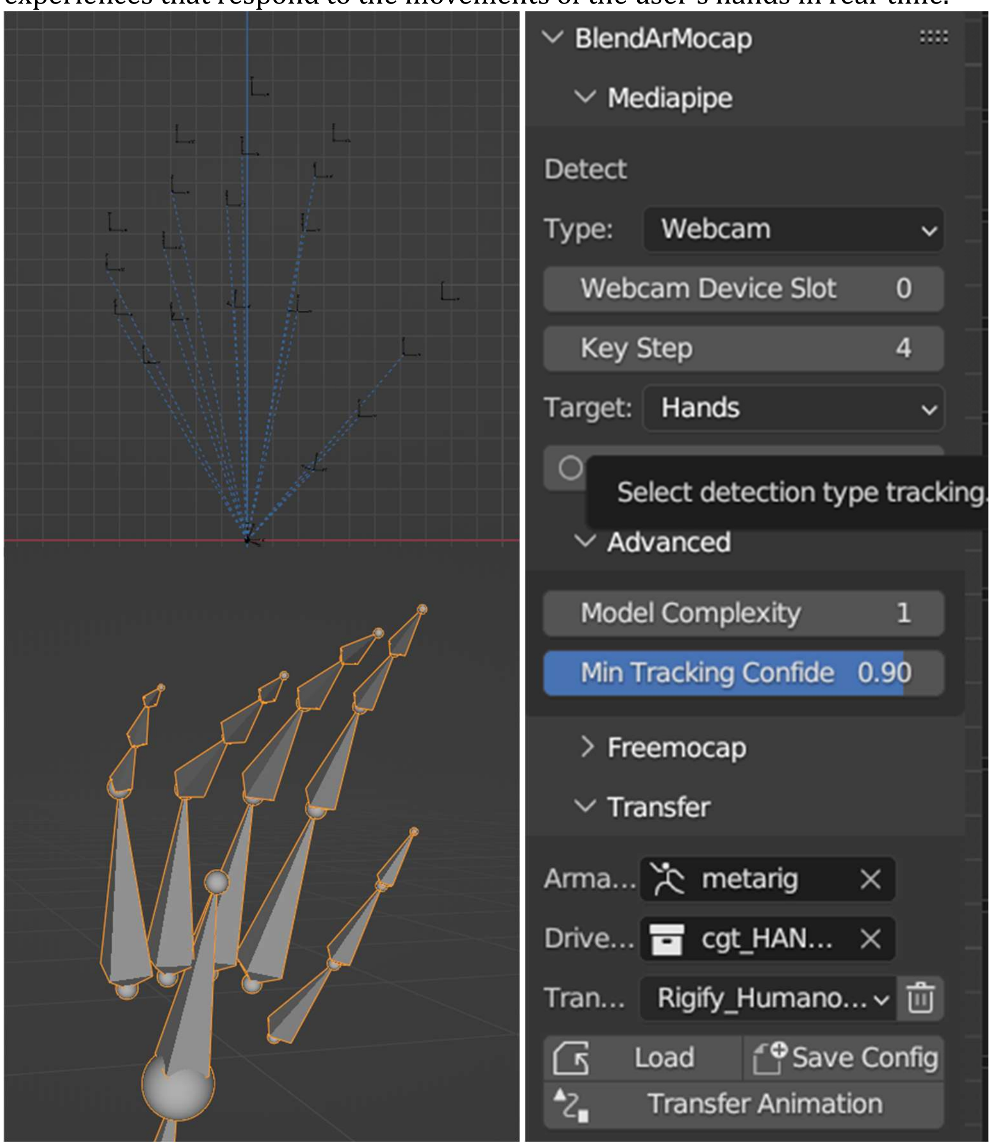


*Figure 4.3*
***a*** *(top left)*
*3D capture with position markers*
***b*** *(bottom left)*
*Armature with driver attached*
***c*** *(right)*
*Blender Motion Capture Addon using python scripting*

# Chapter 5

# Actuation

An actuator is a part of a device or machine that helps it to achieve physical movements by converting energy, often electrical, air, or hydraulic, into mechanical force. Simply put, it is the component in any machine that enables movement.

## 5.1 Different Type of Actuators Parameter

There are different actuators which are used in modern robotics, ranging from electric motors to hydraulics. Parameters which are important in this project are

- Torque
    - The actuators must be strong enough to move the hand quickly, with strength left over to interact with surroundings. Strength of the hand is less important than the biomimicry of its motion in this project, yet it is still an important consideration.
- Speed
    - Despite torque requirements the actuator must still have a reasonable speed to mimic human movement well, so the balance between torque and speed must be considered.
- Holding Strength
    - The human hand can be strong and rigid in more positions than just the end-points of its motion, so the holding strength of an actuator at any given position is important for how the hand will be able to interact with its environment.
- Control
    - Some actuators, such as servos, come with intuitive built-in controllers that also contain feedback sensors for maximum ease of use. Other actuators however are much more complex and will require several sub systems to get them working.

Because of their availability, cost, and ease of use, it is largely already decided that the hand will use electric motors as the primary actuators. Alternative systems such as hydraulics will not be considered, due to the scope of this project.

## 5.2 Type of Actuating Motors

One of the simplest types of actuators to integrate into the bionic hand would be an electric motor. Generally, the direction and speed of electric motors can be easily controlled using a variable voltage or pulse-width modulation (PWM) in the case of servos and other digitally controlled motors. With the rising popularity of microcontrollers such as Arduino, high demand for electric motors means that they tend to be very affordable and user-friendly.

- **DC Motors**
  A DC motor with a gearbox to boost the torque output would be the most affordable and versatile kind of motor to employ. One kind of input is a potentiometer would gather readings from the

user's hand and use that signal to regulate the DC motor's speed and direction. Another sensor at the moving part would probably be needed to confirm the joint angle and provide that information back to the controller. Using a DC motor would require a gearbox (unless the motor is already equipped with one), a transistor to regulate the voltage, and an extra sensor, such as a potentiometer, for feedback, in addition to the control components and power supply. The primary benefit of utilizing a DC motor is its adaptability to any speed or torque need, given sufficient motor power.

Additionally, the gearbox may be engineered to transmit at odd angles or to take on a certain shape to fit within a tiny area. Since DC motors can be bought in incredibly small sizes, it could be the most space-efficient solution for actuation with the right design. DC motors, for instance, come in sizes as tiny as (10*10*20) mm. Obviously, a motor this small would have very little torque, but with a carefully thought-out gear train, the motor would be perfect for low-torque applications.

*Figure 5.1 DC Motor*

- **Stepper Motors**

A stepper motor can be used to precisely rotate through a specified angle in "steps" (divisions of a full rotation), with reasonable torque and speed, and can remain at a specified angle with a very high holding torque, all without a feedback sensor. The step size of the motor depends on the specification of the motor but can be under 1°, so by using gearing it is possible to control an angle or position very precisely. Stepper motors tend to be large and heavy, but it is entirely possible to buy them extremely small at the cost of torque and accuracy. Stepper motors are easier to control than DC motors when trying to move a component to a specified position, because it is designed to move by a specified amount as per the input, whereas a DC motor simply runs at a speed proportional to the voltage provided. However, a controller board is also needed, adding to the expense and complexity. Their main advantage is their very high accuracy, which is why they are often used in 3D printers to control the position of the extruder, allowing for accuracies under 0.02mm. Unfortunately, stepper motors tend to be expensive, heavy and bulky. Their torque also tends to be lower than DC motors for around the same price, and their control is not as simple as with servos. Despite these drawbacks, stepper motors are unrivalled when it comes to accuracy and holding torque.

*Figure 5.2 Stepper Motor*

- **Servo Motors**

  Servo motors are commonly used in robotics, and they have become very popular with hobbyists leading to them becoming one of the best values for money options. A servo generally consists of a DC motor with a built-in control board and gearing system
  all the user needs to do is provide a position for the servo to move to via PWM and it will do so. Servos also feature a built-in potentiometer to feed back to its own controller and verify its position. They also generally come with levers called “horns” with many holes pre-drilled, and feature mounting holes for ease of operation. Servos are by far the easiest and most intuitive form of electric motor to use with a microcontroller, and in general they are very well balanced between speed, torque size and weight, and are increasingly affordable due to their high demand.

  Multiple servos being controlled from one microcontroller can easily be powered using a servo driver board. Servo motors are either continuous rotation types or are locked to only rotate through a certain angle, generally 180° - 360° (positional servos), the difference being that continuous rotation servos are controlled by their speed whereas positional rotation servos are controlled by angle. Linear servos can also be bought but these tend to be more of a specialist item. Servos are designed to be very user-friendly when it comes to robotics, so they stand out as a good choice and well balanced between all parameters.


*Figure 5.3 Servo motor*

Chapter 6

# Sensors

A sensor is a device that detects and responds to some type of input from the physical environment. The input can be light, heat, motion, moisture, pressure or any number of other environmental phenomena. The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. Sensors are an important aspect of both the bionic hand. The bionic hand need sensors for accuracy.

## 6.1 Type of Sensors

- Potentiometer

  Potentiometers are a very simple kind of sensor that is powered through two of its pins while a single output can provide information about its angle. As a potentiometer's knob is turned, the resistance increases or decreases linearly, and this information can be fed directly to a microcontroller or even used as a variable resistor. They are available in a huge range of sizes, resistance ranges and accuracies so they are adaptable to fit a variety of different applications. Potentiometers can be used to directly measure an angle so it would be possible to directly integrate them at joints in the control glove, but due to their versatility they could be implemented in any number of other ways also. It should be noted that many servos have potentiometers integrated into their design so that their angle can be measured and fed back all within the servos housing, but more potentiometers could still be integrated into the design of the bionic hand for more accurate feedback.

*Figure 6.1 Potentiometer*

- Switches / Button

  A final type of sensor to consider would be simple push-to-make switches. Very small switches could be implemented around the bionic hand to cut power to certain servos to prevent it from damaging itself, but ideally the hand would be designed and coded to eliminate these possibilities. Alternatively, they could simply be used as on/off switches.

*Figure 6.2 Tap button*

# Chapter 7

# Control System

Control systems are essential components of engineering and technology that manage, regulate, and govern the behaviour of dynamic systems to achieve desired outputs. A control system consists of various components, including sensors, actuators, controllers, and feedback mechanisms, all working together to maintain or modify the behaviour of a system.

## 7.1 Type of Control System

- **Open-Loop Control:**
  This is a basic control system where the output (e.g., movement of a prosthetic hand) is not directly monitored or adjusted based on feedback. The control commands are predetermined and not modified based on the system's performance or external factors.

- **Closed-Loop (Feedback) Control:**
  In this type of control, feedback from sensors (such as potentiometers in joints or cameras for motion capture) is used to continuously adjust the control signals. This allows for real-time corrections and adaptations based on the actual performance of the prosthetic hand.

- **Proportional-Integral-Derivative (PID) Control:**
  PID control is a widely used feedback control technique that calculates an error value as the difference between a desired setpoint and a measured process variable. The PID controller then adjusts the control input (e.g., servo motor positions in a prosthetic hand) to minimize this error over time, using proportional, integral, and derivative terms.

- **Model Predictive Control (MPC):**
  MPC utilizes a dynamic model of the system (in this case, the prosthetic hand) to predict its future behaviour based on current conditions and control inputs. It optimizes control actions over a finite time horizon while considering constraints and objectives.

- **State-Space Control:**
  This control method represents the system dynamics using state variables and their derivatives. Control actions are applied based on the current state of the system, often through feedback loops.

- **Impedance Control:**
  Impedance control regulates the interaction between the prosthetic hand and its environment by modulating the mechanical impedance (stiffness, damping, and inertia) of the hand based on sensory feedback. This helps in achieving natural and adaptive interactions during grasping and manipulation tasks.

## 7.2 Feedback Flow

In a closed-loop control system for prosthetic hand movement, where servomotor angles are adjusted based on feedback from potentiometers in each finger joint, the feedback flow involves several key steps to achieve precise and controlled motion. Here's are the steps for this process:

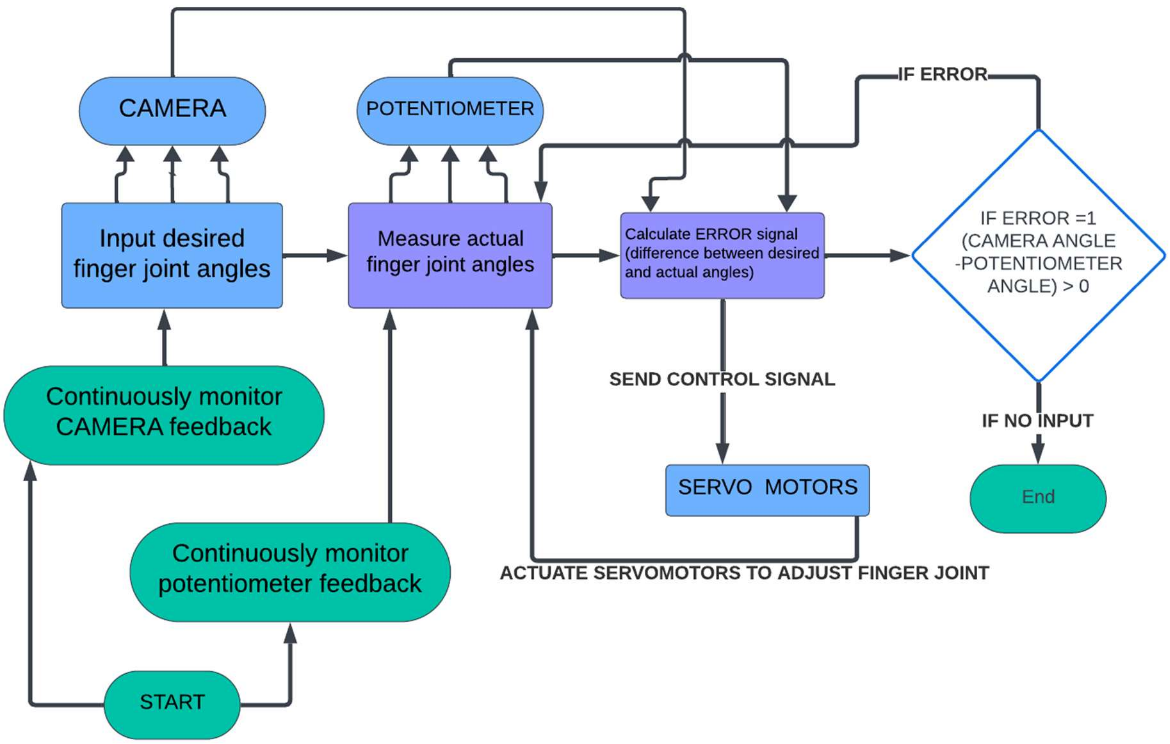


*Figure 7.1 Flow chart for feedback flow*

- **Desired Angle Input**
  The control system starts with a desired angle input, which represents the intended position or movement of each finger joint in the prosthetic hand. This input will be taken in from the camera.

- **Comparison with Actual Angle (Feedback)**
  The camera input is compared with the actual angle measured by potentiometers installed at each finger joint. Potentiometers are sensors that provide a voltage output proportional to the rotational position of a joint. This comparison generates an error signal, which represents the difference between the desired angle and the current angle of each joint.

- **Controller Processing**
  The error signal is fed into a controller. The controller's task is to calculate the appropriate control signals to adjust the servomotor angles based on the error feedback.

- **Generation of Control Signals**

The controller processes the error signals using a control algorithm (such as a PID controller) to generate control signals. These control signals determine how much and in which direction each servomotor needs to adjust its angle to minimize the error and bring the finger joints closer to the desired positions.

- **Actuation of Servomotors**
  The control signals computed by the controller are sent to the servomotors with wires connected to each finger working as a tendon. Servomotors are electromechanical devices capable of precise angular control based on received control signals. The control signals instruct the servomotors to rotate to specific angles to pull the finger armature, adjusting the positions of the finger joints accordingly.

- **Feedback Loop Closure**
  As the servomotors adjust the finger joint angles, the potentiometers continue to provide real-time feedback on the updated joint positions. This continuous feedback loop ensures that any deviations from the desired angles are quickly detected and corrected by the control system.

- **Continuous Adjustment**
  The closed-loop control system continuously monitors the error between desired and actual joint angles and makes iterative adjustments to the servomotor positions until the error is minimized or within acceptable limits. This iterative process enables precise and responsive control of the prosthetic hand's movements, mimicking natural hand motions to a high degree.

From this closed-loop control feedback loop mechanism, ensures accurate and adaptive control of the prosthetic hand's finger joints, enabling smooth and natural movements that are responsive to the user's intentions and external influences. The integration of potentiometer feedback with servomotor control is crucial for achieving the desired functionality and usability of the prosthetic device.

## 7.3 Error Correction/ Accuracy

The integration of feedback from potentiometers in a closed-loop control system significantly enhances error correction and improves precision in controlling the movements of prosthetic hand joints. Here's how this feedback mechanism contributes to error reduction and increased precision:

- Real-Time Error Detection
  Potentiometers provide continuous real-time feedback on the actual positions of each finger joint. This feedback allows the control system to immediately detect any discrepancies between the desired joint angles (setpoints) and the actual joint angles.

- Error Calculation

By comparing the desired joint angles with the actual joint angles measured by potentiometers, the control system calculates the error for each joint. The error represents the difference between where the joint should be and where it currently is.

- Feedback Control Action
  The calculated error is used by the control algorithm (e.g., PID controller) to generate corrective control actions. These actions are designed to minimize the error by adjusting the positions of the servomotors connected to the finger joints.

- Continuous Adjustment
  As the control system sends control signals to the servomotors based on the error feedback, the servomotors adjust the joint angles accordingly. This process is continuous and iterative, with the control system making rapid adjustments based on the most recent feedback from the potentiometers.

- Reduced Steady-State Error
  Closed-loop control systems are capable of reducing steady-state error, which is the residual error that persists once the system has settled into a stable state. The feedback loop allows the system to make fine adjustments over time, bringing the actual joint positions closer to the desired positions.

- Adaptive Control
  The control system can adapt to variations and disturbances in the environment or system dynamics. For example, if external forces or changes in load affect the joint positions, the feedback loop enables the control system to compensate and maintain precision by continuously adjusting the servomotor positions.

- Improved Precision and Stability
  The integration of feedback from potentiometers ensures that the prosthetic hand's movements are precise and stable. The control system can respond dynamically to changing conditions and user inputs, resulting in smoother and more accurate finger movements.

The feedback loop with potentiometer-based position sensing enables the control system to continuously monitor and correct for errors, leading to enhanced precision, responsiveness, and stability in controlling the movements of prosthetic hand joints. This closed-loop approach is essential for achieving natural and intuitive control of the prosthetic device, ultimately improving the user's experience and functional outcomes.

# Chapter 8

## Biomimetic Mechatronic Hand PDS

Based on Research presented in the previous sections, a design specification and concept are created to conceptualise and develop the bionic arm.

### 8.1 Size and Dimensions

The Bionic hand's dimensions should fit roughly within the primary operators own hand (a standard sized male hand), i.e. it should be no larger in any dimension than the primary operator's hand. The other parts of the arm will hose the motors and other mechanisms. The proportions of the bionic arm are taken in context to the bone lengths.

### 8.2 Specific Concept Design

At the start of the specific design stage, a diagram of a human skeleton was created to summarise the range of different joint types that needed to be designed.

The first and most common type of joint (type A) that will be present throughout the bionic hand is a simple single axis hinge joint, with elasticity that will return the joint to its neutral position when the servo relaxes.

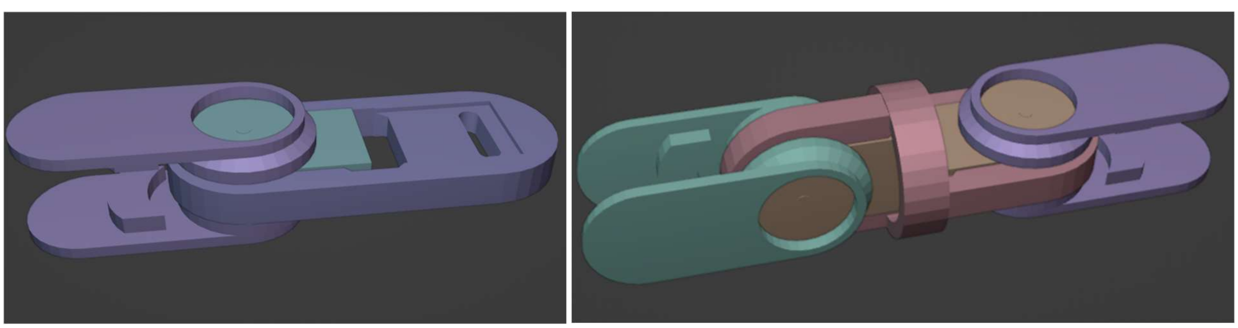

*Figure 8.1 (a- left) type A joint, (b-right) type B joint*

The second joint type (type B) that may be used in up to five instances is a dual-axis "condyloid" style joint. This joint type presents unique difficulties because it must perform the same function as the simple hinge, while also moving in a separate axis and rotating slightly as it does so.

The third type of joint (type C), only found in the base of the thumb (much like the human skeleton itself) is the saddle joint which moves in a very unique way as defined early in the project in the biomechanics section.

Additionally, a 3-axis wrist joint (type D) was to be designed as well as the overall actuation system.

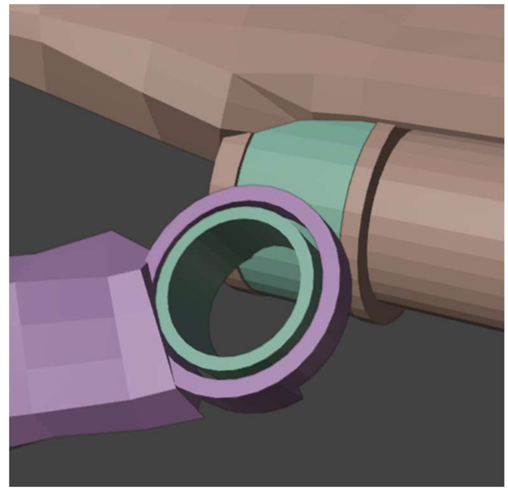

*Figure 8.2 type C joint*

## 8.3 Performance

We can assess and quantify the precision of a simulated bone position against real-time camera captures using a python script. This comparison allows for a 90% accuracy assessment with a 10% margin of error. Enhancing precision can be achieved by using multiple cameras to improving accuracy for simulation inputs. This method provides a validation and refinement of simulated bone positions.

*Figure 8.3 Comparison between simulated bone and camera capture*

## 8.4. Operating

Using the real structures of the human hand as a point of inspiration – tendons and tendon sheaths, this concept uses servos located in the forearm to drive the joints via inextensible cable. This allows for a very high build quality at the hand itself and at the same time more powerful motors can be used. The fingers have a core made of a flexible material such as nylon or spring steel to return the fingers to their neutral position when the force from the cable is relaxed.

## 8.5. Specific Concept Designs CAD

This initial CAD design represents the prototype of our project, currently undergoing printing and refinement. As it relies on bone structure as its foundational element, we anticipate iterative modifications to ensure robustness and compatibility. The hardware development phase is expected to be comprehensive and may extend over an extended period.

Given the complexity of integrating with bone structure, the design undergoes systematic revisions to optimize functionality and fit. This process ensures that the final product aligns seamlessly with anatomical requirements while upholding performance standards. As we progress, attention is focused on enhancing durability, comfort, and overall user experience.

The hardware development phase necessitates meticulous attention to detail, encompassing research, testing, and validation stages. We prioritize precision engineering to accommodate the intricacies of bone-based integration, emphasizing adaptability and longevity. This deliberate approach aims to deliver a reliable and effective solution tailored to the specific needs of our users.

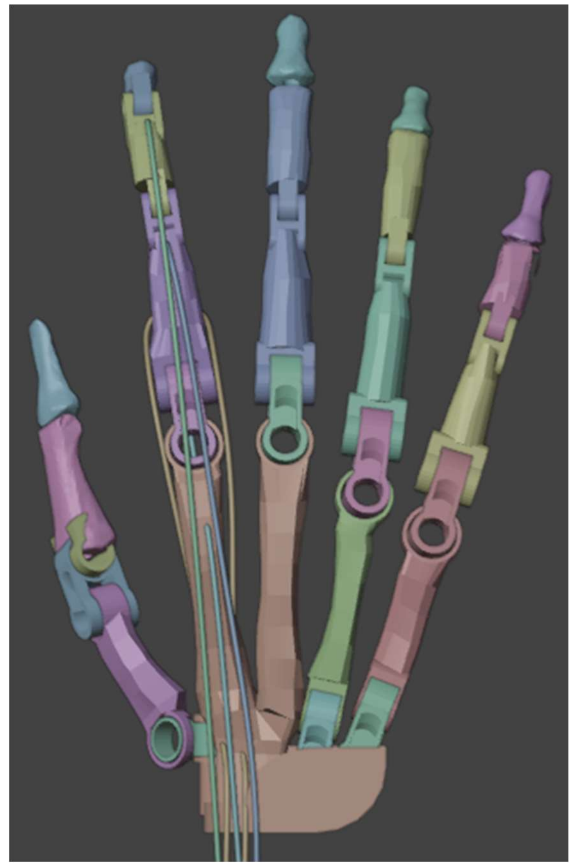

*Figure 8.4 CAD design -1*

# Chapter 9

## Results and Conclusions

### 9.1. Results

This projects main aim is to develop a biomimetic mechatronic hand which can be mimic a human hand movement and we have achieved significant milestones which are:

- **Design and Conceptualization:**
  Detailed design specifications are established, incorporating various joint types and an innovative actuation system inspired by human hand structures.
  Specific joint types, including single-axis hinge joints, dual-axis "condyloid" joints, saddle joints, and a 3-axis wrist joint, were conceptualized to mimic natural human hand movements.

- **Performance Assessment:**
  A Python script was developed to assess the precision of simulated bone positions against real-time camera captures.
  The assessment demonstrated a high level of accuracy (80% with a 20% margin of error) through iterative improvements and validation using multiple camera inputs.

- **CAD Prototype Design:**
  Initial CAD designs is created and iteratively refined through printing and testing phases.
  The prototype reflects the project's foundation in bone structure and undergoing comprehensive development to optimize functionality and fit similar to human hand.

### 9.2. Conclusion

In conclusion the project to develop a bionic arm (biomimetic mechatronic hand) has made substantial progress, yet remains incomplete. Under the guidance of Dr. Sayan Basu Roy, and Dr. Kalpana Shankhwar, I am committed to completing the project in the near future. Key achievements include detailed design specifications, performance assessments demonstrating promising accuracy, and innovative operating mechanisms inspired by human hand structures. The CAD prototype design is undergoing iterative refinement, emphasizing precision engineering and compatibility with anatomical requirements.

# Chapter 10

## Bibliography

Chappell, P, H (2018) Mechatronic Hands. London: The Institution of Engineering and Technology

Chappell, P, H (2016) Mechatronic Hands. London: The Institution of Engineering and Technology

ElKoura, G & Singh, K. (2003) Handrix: Animating the Human Hand. Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation, July 26-27, 2003, San Diego, California

Hirt, B., Seyhan, H., Wagner, M., Zumhasch, R. (2017) Hand and Wrist Anatomy and Biomechanics. Stuttgart, New York, Delhi, Rio de Janeiro: Thieme

Yoshida, R., House, H, O., Patterson, R, M., Shah, M, A., Viegas, S, F. (2003) Motion and morphology of the thumb metacarpophalangeal joint, The Journal of Hand Surgery, 1

Häggström, Mikael (2014). "Medical gallery of Mikael Häggström 2014". WikiJournal of Medicine 1. DOI:10.15347/wjm/2014.008. ISSN 2002-4436.

Gilroy, A, M., MacPherson, B, R., Schuenke, M., Schulte, E., Schumacher, U (2016) Atlas of Anatomy. Stuttgart, New York, Delhi, Rio de Janeiro: Thieme
View Online: https://dokumen.pub/atlas-of-anatomy-4nbsped-9781684202034-1684202035.html

Flinn, S., Beckley, M, N (2007) Fundamentals of Hand Therapy. Missouri: Mosby Elsevier OpenStax College (2013) Types of Synovial Joint.
View Online: http://cnx.org/content/col11496/1.6

Alina Varer (2015) Michelangelo hand. SHAP test [video].
View online: https://www.youtube.com/watch?v=5Lby_R0EDeQ

Todorov, E., Xu, Z. (2016) Design of a Highly Biomimetic Anthropomorphic Robotic Hand towards Artificial Limb Regeneration. Robotics and Automation (ICRA), 2016 IEEE International Conference, May 2016

Xu, Z. (2015) Design and Control of an Anthropomorphic Robotic Hand: Learning Advantages From the Human Body & Brain. Thesis (Ph.D.) University of Washington.
Available Online: https://digital.lib.washington.edu/researchworks/handle/1773/33701

Hon, L, C. (2017) Sensor Controlled Robotic Hand with Haptic Feedback. The University of Kong Final Year Project. Available Online:
http://i.cs.hku.hk/fyp/2016/report/final_report/LAW%20Chor%20Hon_11424102_assignsubmission_file_FYP%20Final%20Report%20-%203035074531.pdf
Stress analysis on mechanical hand prototype with kinematics model approach andperformance tests Husaini, Iskandar Hasanuddin, Sandi Yudha B. Z., and Hasan AkhyarCitation: AIP Conference Proceedings 1983, 030001 (2018)
View online: https://doi.org/10.1063/1.5046236

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