An Internship Report on

"Research and Design for a Prosthetics Arm "

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In partial fulfillment of requirements for

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In

Electronics Engineering

By

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Certificate

This is to certify that the internship report titled, **Research and Design for a Prosthetics Arm at All India Council for Technical Education** submitted by **Pranav Belgaonkar** (GR NO. 11810395) is a record of bonafide work carried out by him under the guidance of Industry **mentor and College mentor Prof. Shripad Bhatlawande** in partial fulfillment of the requirement for the award of the Degree of Final Year Bachelor of Technology in **Electronics Engineering.**

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Pranav Belgaonkar Date: January 2022

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ABSTRACT

A prosthetic is a device that is used by amputees as a replacement for partial or entirely lost biological limbs due to accident, injury, illness, or congenital defect. They come in many different designs, sizes, depending on who is going to be using them. Since a prosthetic is used to mimic a human limb it has the same functionalities and the same type of joints. A prosthetic may be cosmetic, functional, or both. The cost for the prosthetic and the materials depend on the type of functionality that is required.

In this project, we have performed research on multiple designs for a prosthetic arm, designed two types of prosthetic hands, a prosthetic wrist and a prosthetic elbow taking into account multiple constraints that affect prosthetic hands that are used in the world. The design has been implemented in SolidWorks.

CHAPTER 1 - Structure of Human Arm

Hands have a very delicate and complex structure. This gives muscles and joints in the hand a great range of movement and precision. The different forces are also distributed in the best possible way. Thanks to this structure, you can do a wide range of things with your hands, such as grip objects tightly and lift heavy weights, as well as guide a fine thread through the tiny eye of a needle.

Hands are also quite vulnerable, though: Tendons, nerve fibers, blood vessels and fairly thin bones are all positioned right under the skin and are only protected by a thin layer of muscle and fat. Only the palm is protected by a strong pad of tendons (aponeurosis), enabling a powerful grip. Our hands are put through quite a lot every day and often come into contact with potentially harmful objects. As a result, hand injuries and problems due to wear and tear are very common.

The right and left hands are each controlled by the opposite side of the brain. Usually, one hand is preferred for carrying out fine and complex movements, so we often say people are either right- or left-handed.

Bones and joints

The human hand is made up of a total of 27 individual bones: 8 carpal bones, 5 metacarpal bones and 14 "finger bones" (also called phalanges) are connected by joints and ligaments. About one-quarter of all our body's bones are found in our hands. The hand can be divided up into three different areas based on the joints:

- Carpus (wrist bones)
- Metacarpus
- Fingers

Figure 1- bones in a human hand

Wrist

The wrist is made up of two parts of a joint that work as one functional unit. It allows us to flex (bend) or extend (stretch) our hands. We can also tilt our hands sideways, towards our little finger or thumb.

Carpus

The eight carpal bones are held together tightly by ligaments, and are more or less fixed in place. They are positioned in two rows of four carpal bones each. Together with the radius bone in the forearm, two of the carpal bones (the scaphoid bone and the lunate bone) form the lower part of the wrist joint, which is very important for hand movements. The ulna bone in the forearm is separated from the carpal bones by a cartilage disc. The other part of the joint is located between the two rows of carpal bones.

Metacarpus

After the second row of carpal bones comes the metacarpus. This middle part of the hand consists of five long metacarpal bones. You can feel them quite clearly on the back of your hand. One of the carpal bones and the long thumb bone come together to form the basal joint of the thumb. Known as the carpometacarpal joint, it enables the thumb to be particularly flexible.

Fingers

The freely movable part of our hand is made up of five digits (four fingers and one thumb). Each finger has three individual bones, and the thumb only has two. The fingers have three joints each, which can only be bent and stretched in one direction. The thumb is the only digit that can twist, thanks to the saddle-shaped carpometacarpal joint.

Muscles

There are over 30 muscles in the hand, working together in a highly complex way. Movements of the hand are mostly started by muscles in the forearm. Only the thin tendons of these muscles are found directly in the hand: the extensor tendons used for stretching the hand run through the back of the hand to the tips of the fingers, and the flexor (bending) tendons run through the palms to the fingers.

Short muscles of the hand

There are short muscles between the individual metacarpal bones of the hand. They allow us to spread our fingers (abduction) and then pull them back together (adduction). They also help to bend and stretch the fingers.

The thenar eminence and the hypothenar eminence muscles

Two groups of more powerful muscles in the hand itself make up the thenar eminence (at the base of the thumb) and the hypothenar eminence (controlling the movement of the little finger). Among other things, the thenar muscles enable the thumb and the tips of the four fingers to touch each other (opposable thumb). A separate muscle (the adductor pollicis) is used to pull the thumb towards the palm. The hypothenar eminence muscles are mainly used for sticking out the little finger and pulling it inwards again, and for tightening the skin that covers the hypothenar eminence.

Lumbricals

The lumbricals of the hand are four thin, worm-like muscles that help bend the metacarpophalangeal joints and extend the fingers.

Connective tissue and tendons

Some parts of the long flexor and extensor tendons of the forearm muscles are surrounded by protective layers called tendon sheaths. Tendon sheaths contain a fluid that acts as a lubricant. This allows the tendons to slide smoothly through the sheaths, without friction.

Muscle tendons, nerves and blood vessels running from the forearm to the hand pass through a tunnel-like passageway on the palm side of the wrist. Known as the carpal tunnel, this passageway is made up of strong connective tissue and carpal bones.

The wrist joint is formed by:

- **Distally** – The proximal row of the carpal bones (except the pisiform).
- **Proximally –** The distal end of the radius, and the articular disk (see below).

The ulna is not part of the wrist joint – it articulates with the radius, just proximal to the wrist joint, at the distal radioulnar joint. It is prevented from articulating with the carpal bones by a fibrocartilaginous ligament, called the articular disk, which lies over the superior surface of the ulna.

Together, the carpal bones form a **convex** surface, which articulates with the **concave** surface of the radius and articular disk.

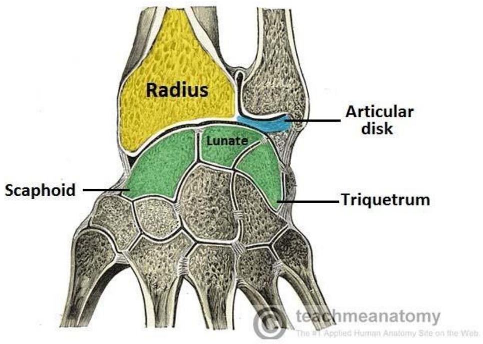

Fig 2 – Articular surfaces of the wrist joint.

Joint Capsule

Like any synovial joint, the capsule is dual-layered. The fibrous outer layer attaches to the radius, ulna and the proximal row of the carpal bones. The internal layer is composed of a synovial membrane, secreting synovial fluid which lubricates the joint.

Ligaments

There are four ligaments of note in the wrist joint, one for each side of the joint

- **Palmar radiocarpal** – Found on the palmar (anterior) side of the hand. It passes from the radius to both rows of carpal bones. Its function, apart from increasing stability, is to ensure that the hand follows the forearm during supination.

- **Dorsal radiocarpal** – Found on the dorsum (posterior) side of the hand. It passes from the radius to both rows of carpal bones. It contributes to the stability of the wrist, but also ensures that the hand follows the forearm during pronation.

- **Ulnar collateral** – Runs from the ulnar styloid process to the triquetrum and pisiform. It acts to prevent excessive radial (lateral) deviation of the hand.

- **Radial collateral** – Runs from the radial styloid process to the scaphoid and trapezium. It acts to prevent excessive ulnar (medial) deviation of the hand.

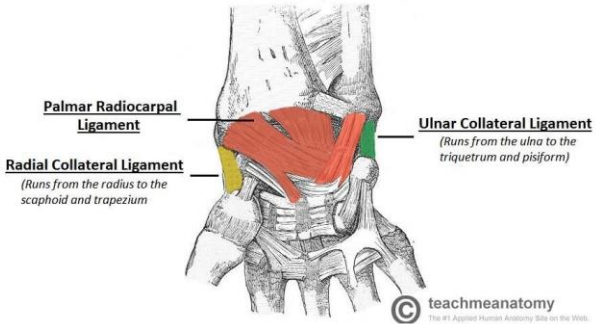

Fig 3 – Palmar view of the ligaments of the wrist joint.

Neurovascular Supply

The wrist joint receives blood from branches of the dorsal and palmar carpal arches, which are derived from the **ulnar** and **radial** arteries (for more information, see Blood Supply to the Upper Limb)

Innervation to the wrist is delivered by branches of three nerves:

- **Median nerve** – Anterior interosseous branch.
- **Radial nerve** – Posterior interosseous branch.
- **Ulnar nerve** – deep and dorsal branches.

The muscles in the **anterior compartment of the forearm** are organized into three layers:

- **Superficial**: flexor carpi ulnaris, palmaris longus, flexor carpi radialis, pronator teres.
- **Intermediate**: flexor digitorum superficialis.
- **Deep**: flexor pollicis longus, flexor digitorum profundus and pronator quadratus.

This muscle group is associated with pronation of the forearm, **flexion** of the wrist and flexion of the fingers.

They are mostly innervated by the **median nerve** (except for the flexor carpi ulnaris and medial half of flexor digitorum profundus, which are innervated by the ulnar nerve), and they receive arterial supply from the ulnar artery and radial artery

Superficial Compartment

The superficial muscles in the anterior compartment are the flexor carpi ulnaris, palmaris longus, flexor carpi radialis and pronator teres.

They all originate from a common tendon, which arises from the **medial epicondyle** of the humerus.

Flexor Carpi Ulnaris

- **Attachments:**
  - The flexor carpi ulnaris has two origins. The humeral head originates from the medial epicondyle of the humerus with the other superficial flexors, whilst the ulnar head originates from the olecranon of the ulnar.
  - The muscle tendon passes into the wrist and attaches to the pisiform bone, hook of hamate, and base of the 5th metacarpal
- **Actions:** Flexion and adduction at the wrist.
- **Innervation:** Ulnar nerve.

Palmaris Longus

This muscle is absent in about 15% of the population.

- **Attachments:** Originates from the medial epicondyle, attaches to the flexor retinaculum of the wrist.
- **Actions:** Flexion at the wrist.
- **Innervation:** Median nerve.

Flexor Carpi Radialis

- **Attachments:** Originates from the medial epicondyle, attaches to the base of metacarpals II and III.
- **Actions:** Flexion and abduction at the wrist.
- **Innervation:** Median nerve.

Pronator Teres

The lateral border of the pronator teres forms the medial border of the cubital fossa, an anatomical triangle located over the elbow.

- **Attachments:** It has two origins, one from the medial epicondyle, and the other from the coronoid process of the ulna. It attaches laterally to the mid-shaft of the radius.
- **Actions:** Pronation of the forearm.
- **Innervation:** Median nerve.

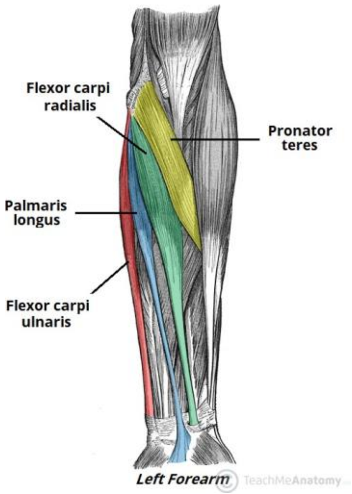

Fig 4 – The superficial muscles of the anterior forearm.

Intermediate Compartment

The **flexor digitorum superficialis** is the only muscle of the intermediate compartment. It can sometimes be classed as a superficial muscle, but in most individuals, it lies between the deep and superficial muscle layers.

The muscle is a good anatomical landmark in the forearm – the **median nerve** and **ulnar artery** pass between its two heads, and then travel posteriorly.

- **Attachments:** It has two heads – one originates from the medial epicondyle of the humerus, the other from the radius. The muscle splits into four tendons at the wrist, which travels through the carpal tunnel, and attaches to the middle phalanges of the four fingers.
- **Actions:** Flexes the metacarpophalangeal joints and proximal interphalangeal joints at the 4 fingers, and flexes at the wrist.
- **Innervation:** Median nerve.

Deep Compartment

There are three muscles in the deep anterior forearm: flexor digitorum profundus, flexor pollicis longus, and pronator quadratus.

Flexor Digitorum Profundus

- **Attachments:** Originates from the ulna and associated interosseous membrane. At the wrist, it splits into four tendons that pass through the carpal tunnel and attach to the distal phalanges of the four fingers.
- **Actions:** It is the only muscle that can flex the distal interphalangeal joints of the fingers. It also flexes at the metacarpophalangeal joints and at the wrist.
- **Innervation:** The medial half (acts on the little and ring fingers) is innervated by the ulnar nerve. The lateral half (acts on the middle and index fingers) is innervated by the anterior interosseous branch of the median nerve.

Flexor Pollicis Longus

This muscle lies laterally to the FDP.

- **Attachments:** Originates from the anterior surface of the radius and surrounding interosseous membrane. Attaches to the base of the distal phalanx of the thumb.
- **Actions**: Flexes the interphalangeal joint and metacarpophalangeal joint of the thumb.
- **Innervation**: Median nerve (anterior interosseous branch).

Pronator Quadratus

A square-shaped muscle was found deep to the tendons of the FDP and FPL.

- **Attachments:** Originates from the anterior surface of the ulna and attaches to the anterior surface of the radius.
- **Actions:** Pronates the forearm.
- **Innervation:** Median nerve (anterior interosseous branch).

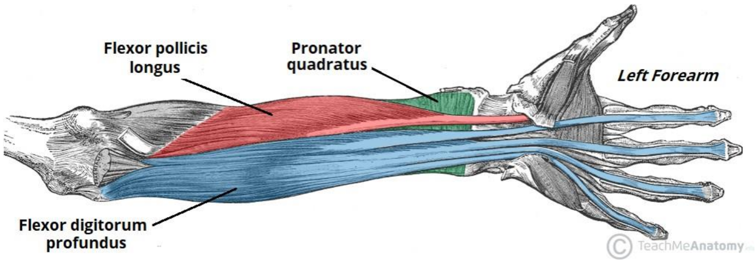

Fig 5 – Deep flexor muscles of the anterior forearm.

Prosection Image

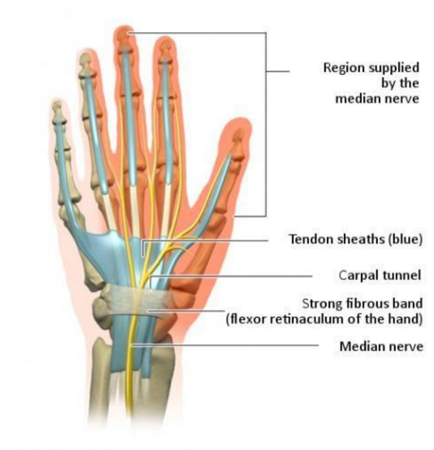

Figure 6 - The carpal tunnel (seen from the palm side of the hand)

The function of the muscles: Power, touch and precision

Our hands can grasp and move objects in two different ways: with a power grip or precision grip. The object's size, shape, weight and ease of handling determines which of these two approaches is used. The power grip is better suited for large, heavy objects, and the precision grip is used for small, delicate objects.

Power grip

The power grip is used to do things like carry heavy bags or hold on to a handle. In the power grip, the object is held in the palm of the hand, and the long flexor tendons pull the fingers and the thumb so that they can tightly grasp the object. This grip is made possible by the four other fingers flexing (bending) and, most importantly, the ability of the thumb to be positioned opposite the fingers. With the hand in this position, larger objects such as a stone or a heavy bottle can be held and moved in a controlled way. The heavier the weight and the smoother the surface is, the more strength is needed to hold and move the object.

Precision grip

The precision grip is important for moving small and delicate objects, for example when writing, sewing or drawing. When using the precision grip, the thumb and the index ("pointer") finger work like tweezers: The thumb is opposite one or more fingertips, allowing the hand to grip.

The **elbow** is the joint connecting the upper arm to the forearm. It is classed as a hinge-type synovial joint.

Structures of the Elbow Joint

Articulating Surfaces

It consists of two separate articulations:

- Trochlear notch of the ulna and the trochlea of the humerus
- Head of the radius and the capitulum of the humerus

Note: The proximal radioulnar joint is found within the same joint capsule of the elbow, but most resources consider it as a separate articulation.

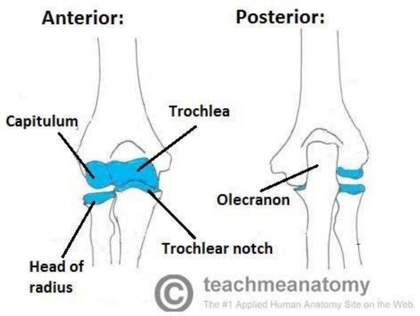

Fig 7 – Anterior and posterior views of the articulations of the elbow joint

Joint Capsule and Bursae

Like all synovial joints, the elbow joint has a capsule enclosing the joint. This in itself is strong and fibrous, strengthening the joint. The joint capsule is thickened medially and laterally to form collateral ligaments, which stabilize the flexing and extending motion of the arm.

A bursa is a membranous sac filled with synovial fluid. It acts as a cushion to reduce friction between the moving parts of a joint, limiting degenerative damage. There are many bursae in the elbow, but only a few have clinical importance:

- **Intratendinous** – located within the tendon of the triceps brachii.
- **Subtendinous** – between the olecranon and the tendon of the triceps brachii, reducing friction between the two structures during extension and flexion of the arm.
- **Subcutaneous (olecranon) bursa** – between the olecranon and the overlying connective tissue (implicated in olecranon bursitis).

Ligaments

The joint capsule of the elbow is strengthened by ligaments medially and laterally.

The **radial collateral** ligament is found on the lateral side of the joint, extending from the **lateral epicondyle**, and blending with the annular ligament of the radius (a ligament from the proximal radioulnar joint).

The **ulnar collateral** ligament originates from the **medial epicondyle and** attaches to the coronoid process and olecranon of the ulna.

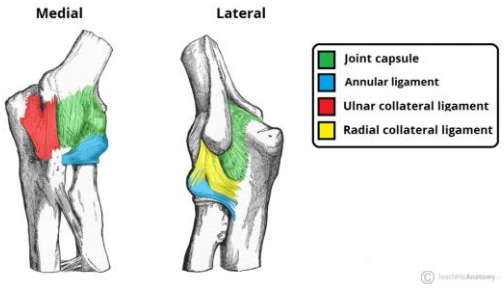

Fig 8 – Ligaments of the elbow joint.

Neurovasculature

The arterial supply to the elbow joint is from the **cubital anastomosis,** which includes recurrent and collateral branches from the **brachial** and **deep brachial** arteries.

Its nerve supply is provided by the **median**, **musculocutaneous** and **radial** nerves anteriorly, and the **ulnar** nerve posteriorly.

Movements of the Joint

The orientation of the bones forming the elbow joint produces a hinge type synovial joint, which allows for extension and flexion of the forearm:

- **Extension** – triceps brachii and anconeus
- **Flexion** – brachialis, biceps brachii, brachioradialis

Note – pronation and supination do not occur at the elbow – they are produced at the nearby radioulnar joints.

CHAPTER 2 - Introduction

2.1 Introduction to myoelectric Prosthetic arm

A myoelectric Prosthetic Arm consists of an ElectroMyoenciphelogram or EMG sensor. Electromyography (EMG) measures muscle response or electrical activity in response to a nerve's stimulation of the muscle. The test is used to help detect neuromuscular abnormalities. The sensors are non-invasive. i.e they do not have to be inserted into the body and can be applied on the arm. You control this type of prosthesis through muscle contractions in your residual limb. These muscle contractions are caught with electrodes integrated into your prosthetic socket. This control system allows you to vary the intensity of your grip force as well as speed and control your hand position and wrist joint. The prosthetic arm that an amputee purchase depends on the condition of his/her arm. A prosthetic elbow will be purchased only if the residual limb is cut above the elbow. Wrists with multiple degrees of freedom are available but such as flexion-extension and pronation - supination, but the cost increases with complexity. Finally, the hand can have a gripper that can only open and close. These types of grippers are similar to robotic grippers which are used for pick and place. Has can also have complex functionality like individual finger movement where the person is able to control each finger but they are many times more expensive than grippers due to their highly complex nature.

1.1 Types of Prosthetic Limbs

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

Passive Prostheses

Passive prosthetics are simple, non-moving devices that aim to restore the cosmetic appearance and basic functionality to an amputee. A simple wooden 'pirate' peg leg is an example of a simple passive prosthetic. Prosthetic toes have even been found attached to ancient Egyptian mummy's as shown in the image to the right.

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 that is linked to elbow/shoulder movement. Although these devices are relatively simple they remain the most popular type of prosthesis today.

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 analyzes this information and controls the internal actuators. Myoelectric devices allow for far greater amounts of control than mechanical devices.

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 is 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.

2.1 Problem Statement

The Problem statement includes designing a prosthetic arm that can be implemented into the real world.

2.2 Objective

- Researching papers and documents to find out how prosthetics are created
- Researching the design for prosthetic grippers and implementing them
- Researching the design for prosthetic fingers and implementing them in the least complex way possible.
- Researching the design for prosthetic wrists and providing it with the most degrees of freedom as possible.
- Researching the design for prosthetic elbows and making sure that they are capable of lifting the entire load of the hand and the payload.
- contacting prosthetic hand suppliers and requesting quotations for purchasing prosthetic limbs.

2.3 Scope

- Creating documentation that will support the design that will be realized
- Creating a prosthetic arm design in CAD that can be implemented and used.

2.4 Project Output

- Documentation that contains designs used by the industry for making prosthetic limbs
- Two CAD designs can be used for implementing prosthetic arms.

CHAPTER 3 - Research

Wrist

Wrist Design Objectives though varied in design and appearance, most wrist devices seek to achieve similar objectives. Namely, devices should be designed to provide spherical rotational motion, meaning that the axes of rotation of a multi-DOF wrist should intersect, or the distance between axes should be minimized. Linear movements of the end effector are generally accomplished via proximal joints in the arm system. Generally, weight and rotational inertia should be minimized as well, as wrists are often located near the distal end of the arm. Minimizing mass and inertia often involves minimization of the total size of the wrist (especially length along the forearm axis), although this objective is more critical in prosthetic and mobile robots than in industrial robots.

Active Serial 1-DOF

Active 1-DOF wrists are often found in both prosthetic and robotic applications. Within the field of prosthetics, these are generally used with myoelectric (EMG) systems that enable a user to control rotation through muscle signals. Active wrists may be standalone units integrated into a prosthetic hand or integrated into the forearm within larger prosthetic arms. In robotics applications, single DOF units are commonly used but rarely discussed due to their simplistic nature. Like the passive wrists, active 1 DOF units may also be categorized into rotators and flexors. Active rotators are the most common powered units in wrist prostheses. Standalone devices include the Motion Control (MC) Electric Rotator and the OB Wrist Rotator (Fig. 4c), both of which have been designed for compatibility with many terminal devices, leading to relatively widespread use. The non-commercial standalone design employs pronation about an axis skewed from the forearm longitudinal axis, with the authors claiming rotation about this axis leads to better manipulation performance when compared to other 1-DOF devices. As powered rotators are much less compact than their passive counterparts (due to motor and drive

train packaging), some rotators are incorporated directly into a terminal device to shorten the overall length of the prosthetic system. Both the OB Michelangelo Hand and TB i-Limb Quantum utilize compact rotators, namely Axon Rotation and Supertwist (Fig. 4d), respectively, which fit within the prosthetic socket and lower palm of the respective hands. Some devices incorporate a small motor and spur gear pair into the base of the hand are used to impart wrist rotation with few components. The MANUS Hand utilizes an ultrasonic motor and a low reduction gear train to achieve compact packaging as well as a hollow channel to pass wiring from socket to hand through the wrist. Active flexors also tend to be incorporated into existing robotic hand or terminal device systems. The wrist flexion mechanism and rotary actuators can also be located within the body of the hands.

B. Parallel 1-DOF

As single-DOF wrists are kinematically equivalent to a single rotational joint, parallel mechanisms generally are not used as single-DOF wrist devices. The mechanical simplicity of serial devices compared to parallel devices appears to outweigh the potential benefits of using a single-DOF parallel mechanism, such as a 4-bar linkage. However, single-DOF parallel mechanisms often find use in other devices, such as ankle prostheses. For example, a four-bar linkage with compression springs as links serves as a passive single-DOF ankle prosthesis. This device stores and releases energy in the compression springs to provide powered push-off during gait. A four-bar mechanism is also used in an active ankle prosthesis, with an electric motor injecting power during gait. In both cases, the customizable kinematics and increased load-bearing capacity of four-bar mechanisms were reasons for incorporating them over simple revolute joints. Single-DOF wrist prostheses with similar requirements may be suitable candidates for using 1-DOF parallel mechanisms in their design. The clearest theme within single-DOF wrists is that most of the devices are passive prostheses with serial mechanism architecture. As these have been the standard wrist prosthesis for most of the last century, it is not surprising they are the most prevalent in this category.

Compared to their passive counterparts, active single-DOF wrists tend to incur significantly greater length in their designs, especially with rotators. By the content of this review, it may seem that active 1-DOF wrists are either standalone wrist prostheses or additional features in hand designs, but the commonality of 1-DOF units in all fields minimizes discussion on devices outside of these applications. Improvements to the torque production, strength, and compactness of active 1-DOF rotators will allow for increased manipulation capabilities for both amputees and mobile robots. These units currently do not match the capabilities of the human wrist in terms of torque production, strength, and compactness. This limits the manipulation capabilities of amputees as well as for robotic systems (e.g., mobile humanoid robots).

Active Serial 2-DOF

Active serial 2-DOF wrists are the point at which prosthetic and robotic systems begin to overlap. Similar designs may be employed between transracial/transhumeral prostheses and the arms of humanoid robots. Like passive 2-DOF wrists, some active designs simply place two active 1-DOF units in series with one another. Prosthetic wrists are composed of pronation and a flexion unit placed together in some way. Two motors can be placed directly next to each other within the forearm volume and use slightly different gearing systems to actuate their DOFs (internal ring gear vs bevel gear). However, the flexion motor can be placed directly on top of the pronation motor, resulting in an uncomplicated yet large design, occupying the forearm volume.

Notably, this wrist could generate torques comparable to that of a healthy adult, though achievable speeds are difficult. As 2-DOF motion cannot fully replicate the capabilities of the human wrist, some wrist designs have implemented coupling between the flexion and radial deviation DOFs. The forearm portion of the notable DEKA Arm prosthesis uses coupled flexion/deviation in series with a powered pronation unit. The RIC Arm, a research transhumeral prosthesis designed to be within the form factor of a 25th percentile female arm, makes use of orthogonal cycloidal drives housed within the forearm to impart pronation and flexion to the terminal device. The ToMPAW, a research device designed to be a modular prosthetics testing platform (especially for myoelectric control systems), utilizes similar pronation and flexion configuration. The arms of humanoid robots are often similar to trans-humeral prostheses, though their applications may determine the size and additional functionality required in their design.

Alternatively, the DLR TORO humanoid features an arm design, similar in size to the human arm, as its primary applications are related to manipulation tasks. The wrist of this robot consists of a pronation and flexion unit in series with one another. As compliant manipulation is a particular application of this robot, both DOFs were designed to be variable stiffness actuators, and thus employ two motors each (to control both position and stiffness at each joint). To eliminate the necessity of constant holding torque, the wrists can also use worm gearing in their pronation and flexion mechanisms, rendering both DOFs in each wrist non-back drivable.

Moreover, as these are both trans humeral prostheses, the wrist actuation motors occupy the forearm volume. To reduce the weight or mechanical complexity of wrist designs, some systems employ hydraulic or pneumatic actuation. Though these may achieve the goals, additional reservoir systems, pumps, or compressors are needed in tandem with these devices, leading to additional equipment that must be transported by the user. Constrained S joints may be used for powered 2-DOF motion. One such example is the RSL Steeper BeBionic Wrist. The unconstrained DOF is actuated by a single motor, and via a button press, may be changed from flexion to radial deviation by the user. A bevel gear differential can be used to create a wrist with pronation and flexion motors placed obliquely to the forearm longitudinal axis. While this design places more mass distally, the compact design occupies less forearm volume, making it more suitable for amputees with distal amputations. A similar differential design can be employed in the transradial prosthesis design though motors are placed within the forearm volume and a tendon drive is used to actuate the input bevel gears. In both cases, both motors may contribute to actuating the same DOF, potentially allowing for greater mechanical power input to each DOF, though only actuated one at a time.

Other tendons driven serial 2-DOF wrists have been designed for a variety of applications, such as transradial prostheses, anthropomorphic robotic arms, surgical robots, and solar tracking systems. The wrist of the transradial prosthesis can utilize Bowden cables to actuate a constrained S joint (resulting in a U joint). Though three motors were required for 2-DOF actuation, the motor could be placed in a way to reduce loads on the elbow or outside the forearm (due to the use of Bowden cables). Like transradial prostheses, anthropomorphic robotic hands attempt to replicate the capabilities and appearance of the human hand. The anthropomorphic University of Bologna IV hand (UB-Hand IV) contains a wrist composed of two R joints offset by a small distance with perpendicular axes, with each R joint driven by an antagonistic tendon pair. Tendons that actuate the hand pass through channels in line with the wrist axis, causing no net torque on the wrist due to hand actuation. The tendon driven surgical robotic wrists are examples of the EndoWrist instruments for use with the da Vinci surgical system produced by Intuitive Surgical.

Utilizing a tendon drive system allows for the actuators to be placed in a separate housing away from the wrist, and the tendons routed to the wrist through a long shaft, thus the wrist need only be large enough to route tendons. However, the size and drive system make these wrist devices exceedingly prone to friction and wear, thus requiring replacement after one to ten operations. One such solar tracking system utilizes two tendon drive systems to actuate the DOFs of a U joint, allowing a solar panel to track the sun optimally. Motors with pulleys route and actuate the tendons, and each tendon attaches to the panel underside on each end via a tension spring, maintaining tension even when the panel is buffeted by the wind. B. Parallel 2-DOF

Excluding planar linkages, much of parallel mechanism research and design focuses on creating mechanisms with two or more DOFs. When these mechanisms are nonplanar, either by implementing 3-DOF translational motion or 2-DOF rotational motion, these mechanisms may be called spatial linkages. The subsequently presented parallel mechanisms are all active devices. While it is likely passive parallel mechanisms find their uses in other cases, within wrist devices, only active wrists appear to have incorporated such mechanisms.

Serial vs. Parallel

A great number of differences exist between serial and parallel wrist mechanisms. Notably, serial mechanisms tend to be longer than their parallel counterparts when comparing across devices with the same number of DOFs, though the use of tendon drives and bevel gear differentials may alleviate this issue, due to some freedom conferred in actuator placement. If differential couplings are not used, only a single actuator is responsible for an output DOF. Though this only allows power input from a single motor, it is much simpler to introduce compliance or measure loads than it would be in a parallel counterpart. With serial mechanisms, range of motion and torque specifications are often simply determined by actuator selection (in the case of active devices) and basic shape geometry and are not configuration dependent. Moreover, the use of fewer components can potentially lead to greater robustness, though loads must be transferred through the entire wrist mechanism.

Parallel mechanisms often have many more architectures and geometric design parameters that can affect the producible torque. However, this additional complexity allows greater freedom in the design process. For example, collocating axes of rotation may be feasible and actuators may be placed proximally to reduce the inertia of the device. Passive constraints, such as a central universal joint can be used to bear loads away from actuators and increase the stiffness of the mechanisms. However, issues that are not present in serial wrists, must be addressed in successful implementations of parallel wrist designs. These issues become more difficult to deal with as the desired workspace of a mechanism grows larger, indicating a trade-off between a range of motion and stiffness. This trade-off not only serves as a major difference between serial and parallel mechanisms but within parallel mechanisms themselves. In most parallel wrist mechanisms, motion along an arbitrary DOF requires the tandem actuation of multiple motors. This coupling allows multiple actuators to contribute to a single motion. However, in some configurations, actuators may work in opposition to one another, or the wrist may be in a singular configuration, unable to actuate in a particular direction. Singular configurations also exist in serial wrists, such as in the roll-pitch-roll configuration when the pitch is neutral, but other configurations such as roll-pitch-yaw only experience a singularity when either pitch or yaw reaches 90°. The singularities are much more predictable, and mechanisms are easily designed for singularities to lie outside of the desired workspace. The variety of architectures within parallel mechanisms leaves much room for wrist development within the subfield, especially when compared to serial mechanisms. Within serial wrist mechanisms, only a few types of architectures are possible, though improvements to the actuation systems (motors, transmission, etc.) in terms of size, reliability, and power density still may be made. Though the architectures of many parallel mechanisms, and specifically spherical mechanisms, have been described exhaustively and indexed in atlases, physical implementations remain scarce. Part of this may be attributed to the difficulty in creating the successful physical implementation of a parallel mechanism. Small manufacturing errors can lead to over constraints and large increases of internal forces. Difficulty can also arise in the software and method used to control the mechanism as the forward kinematics are difficult to solve. For some redundantly actuated parallel mechanisms, mitigation of internal forces requires additional sensors and sophisticated control methods.

Compound Thumb Design

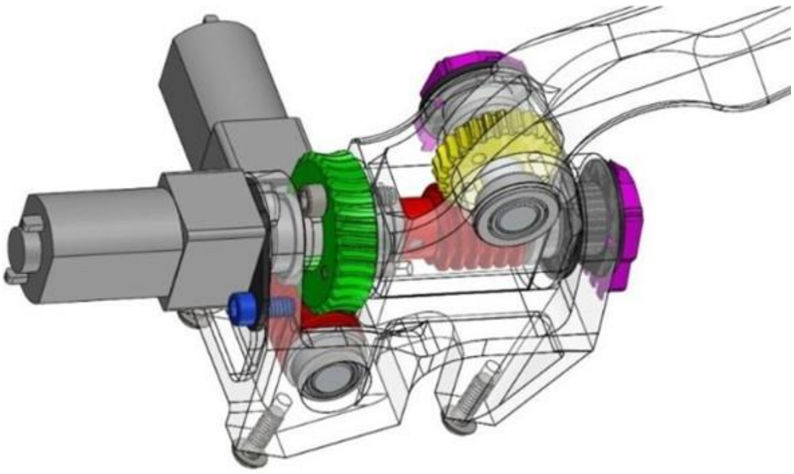

Figure 24 Final Compound Thumb Gearbox Solution

Fig 9 - Compound Thumb Gearbox

I found a very interesting design for a complex thumb. The gearbox was described as a “compound wo gearbox”. The basic principle used to design this was to use the input shaft from the thumb flexing join as the structural pivot for allowing the thumb to roll. The same components were used once again from the main finger gearboxes to keep the design as simple as possible. The design is explained more clear by the colours of the individual components in these figures. The thumb itself is pinned directly to the reused 24 tooth brass worm gear in the exact same way as the main fingers with the again reused 1/16” COTS alloy dowel pins. The simple Delrin gearbox has the same ball bearings pressed into it used in t rest of the fingers, with another 7075 aluminium shaft. The same potentiometer (purple) reads the posi of the thumb flex, although the 1/32” thin Delrin potentiometer mount has been slightly modified for w routing purposes.

The (green) 30 tooth brass worm gear is used to provide the novel thumb roll rotation. The gear is pinned with alloy steel dowel pins to transfer torque to the thumb flex gearbox body, and it is attached to that body with two 2-56 cap screws. The gear is pressed over a boss of the gearbox to ensure concentricity and not put additional loading on the dowel pins. The (green) gear is not attached in any way to the aluminium shaft which passes through its bore. The gear is co-axial with the (red) input worm which drives the flex motion, but the gearbox rotates on more of the same ball bearings used throughout the design. In order to read the rotation angle of the thumb roll, a unique Delrin pot shaft adaptor was designed which serves as both a plain bearing for the end of the aluminium shaft and also has an ear with a bolt hole for mounting on the side of the thumb flex gearbox. The pot adaptor has the necessary D-shaft profile for the potentiometer design. This piece is separate from the thumb flex gearbox in order to make the entire system able to be assembled.

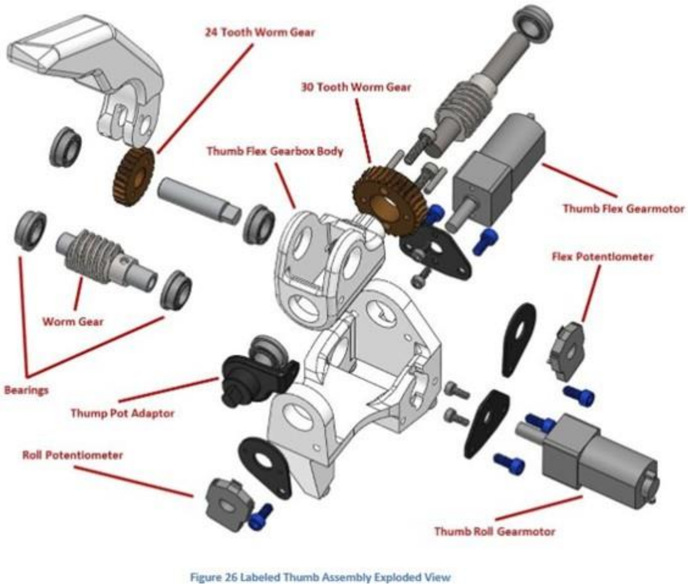

Figure 10 - Labeled Thumb Assembly Exploded View

Case study - Bebionic Hand

Finger

The Bebionic hand features individually powered, articulated digits each driven by and linked to its own 6V actuator. The actuators are positioned within the palm to provide a beneficial solution for weight distribution.
The actuators are assembled with individual separately programmed PCBs with onboard microprocessors. These are coded to constantly track the placement of each digit and provide precise control. This ensures accurate grip sequences and digits performing synchronized movements together every time.

An aluminium lead screw nut attaches the actuator to its individual finger proximal through carefully designed foldaway links. Made of nylon (Technyl A218V30) these foldaway finger links allow the fingers to flex freely and naturally, as well as allow the user to push up to 90kg through the hand to aid in standing from a seated position, a feature especially useful for the bilateral amputee. In the event of mechanical overload, it is important to protect the unit. The design accomplishes this with a shear pin fitted as part of the finger linkage. The shear pin is made from peek and is designed to fracture under a predetermined extension load, thus preventing damage to the finger and motor. The shear pin can be replaced locally by the clinical team.

Thumb Design

The thumb also utilizes its own actuator and can be manually placed in one of two positions, opposed or non-opposed to the fingers. Located at the base of the thumb motor is a nylon (Delrin AF) trunnion nut which fits directly into the aluminum (AL-LM25TF) thumb bracket. A wishbone link, made from silicone brass, attaches the back of the bracket to the actuator to provide stability and allow movement towards and away from the palm. The thumb bracket is attached to the chassis base through a fitted lower cam, mounting bolt and spring assembly.

This robust assembly allows for continual manual movement of the thumb with a 68-degree range of baseline adjustability. The cam design allows the thumb to lock into an opposing or non-opposing position. This prevents the patient from wasting time aligning the thumb and allows for a fast selection of grip patterns through the feedback loop (reed switch). Also, when the thumb is locked it cannot back away under load, for example, if the finger object is hitting off-centre.

Chassis Architecture

The rear chassis provides attachment of the thumb through the bracket, lower cam, mounting bolt and spring assembly. The selected bebionic wrist type is attached to the base of the rear chassis and held in place with three M3 x 8 SKT cap screws. The chassis is uniquely designed to conform to the shape of the palm PCB which is slid in and held in place with an M2 x 6 PAN POZI thread forming screw.
The front chassis design conformably houses the four-finger actuators and a gear cover, while providing attachment and placement for the knuckles. The gear cover (ABS material) protects the finger actuators from dust particles while also providing a shield for the palm PCB and wiring. Attachment of the front chassis to the rear chassis is done in three places. An M3 16 PAN POZI thread forming screw located in the outer palm of the front chassis attaches it directly to the rear chassis. An M3 x 16 SKT head cap screw below the first finger on the front chassis attaches it from "MEC 11 Raising the Standard,"
through the rear chassis thumb bolt. This also holds the thumb bolt/bracket assembly in place. The third connection point is located on the back of the hand and includes a chassis link, T-bolt and M3 x 12 SKT head cap screw assembly that also contributes to further stabilizing the palm

PCB.

The top chassis, or back cover, provides final enclosure and easy access to the finger actuators and palm PBC. An RFID tag is placed on the inside of the cover to provide easy identification of each hand. At the top of the cover are three pins designed to slide into adjacent holes located on the front chassis beneath the back of the knuckles. The base of the cover is secured directly to the rear chassis with two M2 x 10mm trimet thread forming screws.

Program Switch

Located on the back of the hand is a membrane switch that utilizes flexible PCB tracks to connect directly to the palm PCB. The tactile design allows the user to easily locate it beneath a glove. The switch has four functions and is integrated with selectable bleep and vibrate switch indicators, which can be activated through the be balance software.

Electronic Monitoring of Digit Position

The code sets a starting point for the counter when the hand is first powered up. The number of revolutions of each actuator is counted to monitor the placement of individual motors. This provides accurate and repeatable grip patterns.

Auto Grip Feature

Auto Grip is a selectable electronic feature that can be enabled or disabled through the bebalance software. It functions only with the thumb opposed and in Tripod or Pinch Grips. Once enabled, auto Grip is activated by the user providing three consecutive close signals and deactivated when the hand is opened. The rotation of the finger actuators is monitored every 50ms. The movement or slippage of a held object is detected by motor rotation. The appropriate motors are driven to prevent this movement from occurring by changing finger position/grip force and therefore automatically providing a more secure grip.

The hand is programmed using Bebalance software developed by RSLSteeper. Information is transmitted wirelessly to and from the system. A radio frequency transmitter/receiver module is incorporated within the hand. The software allows control parameters such as hand speed, grip force and grip selection to be individually optimized, set, and stored. It also provides a range of control methods using one or two electrodes, or other inputs. The software provides real-time analysis including adjustment of user signals and allows the user to practice using visual feedback. The software also allows a hand to be ‘read’ to determine its existing program setting

CHAPTER 4 - Overview

The control system for the prosthetic arm is as shown. There are seven servo motors in design that have individual finger movements and 3 servo motors with gripper designs. The below diagram shows it for the one with seven motors. The EMG sensor will detect the movement of the arms and send the signals to a signal processor. The processor will then perform signal processing to clean the data and interpret it for the microcontroller. The microcontroller will then read those signals and command the servo motors to move in the desired direction. The Battery and the battery management will take care of the powering needs. Since the motors are servo motors, they have the capacity to provide feedback to the microcontrollers and will be used as hard limits.

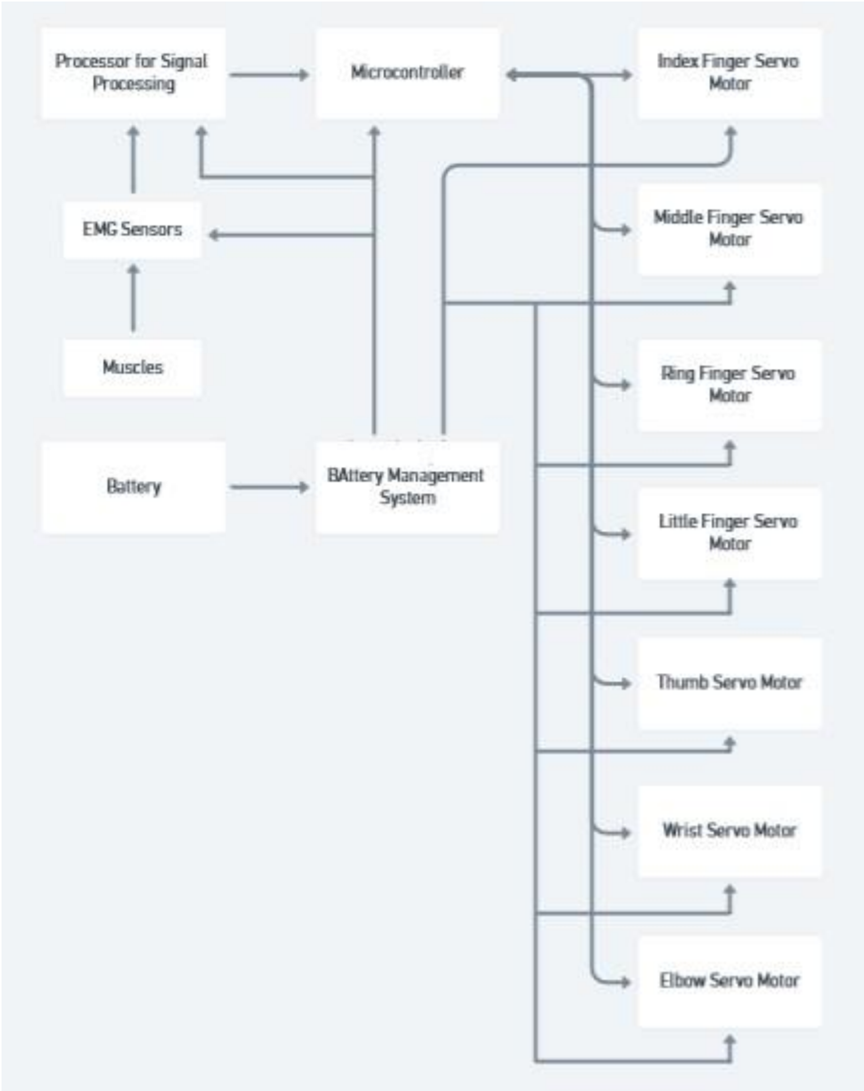

Fig 11 : Block diagram of the Prosthetic Arm

CHAPTER 5 - Design

5.1 Prosthetic Finger

Fig 12 - design for prosthetic finger

The fingers that will be used for the gripper have to mimic the hand so they need to have three sections and the same type of movement. The three different sections were connected to each other using linkages. The original design did not contain pins for the links to be attached to the sections, so that had to be added. The finger shown in the above figure was used for demonstration purposes. The Triangular part is attached to the first section through the hole at one end. The two extensions/pins are connected to the worm gear through a link and the second section is connected to the furthest pin of the next section respectively.

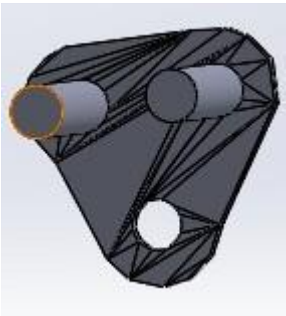

Fig 13 - attachment for the first section

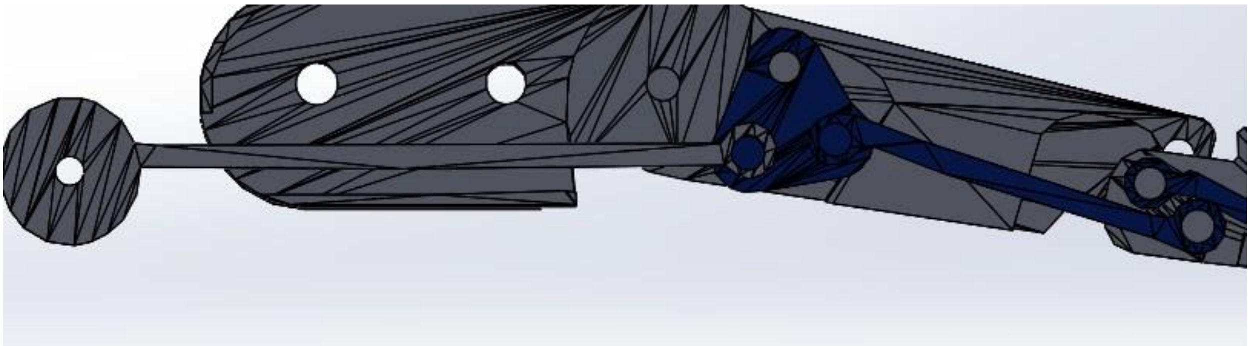

Fig 14 - first section connected to the second section

The first pin from the middle section is used to connect to the final section of the finger. The movement of the finger occurs because when the worm gear pulls the first link towards itself the triangular section rotates and pulls the second link. This second pulls the second section and the clockwise motion generated rotates the third section as well.

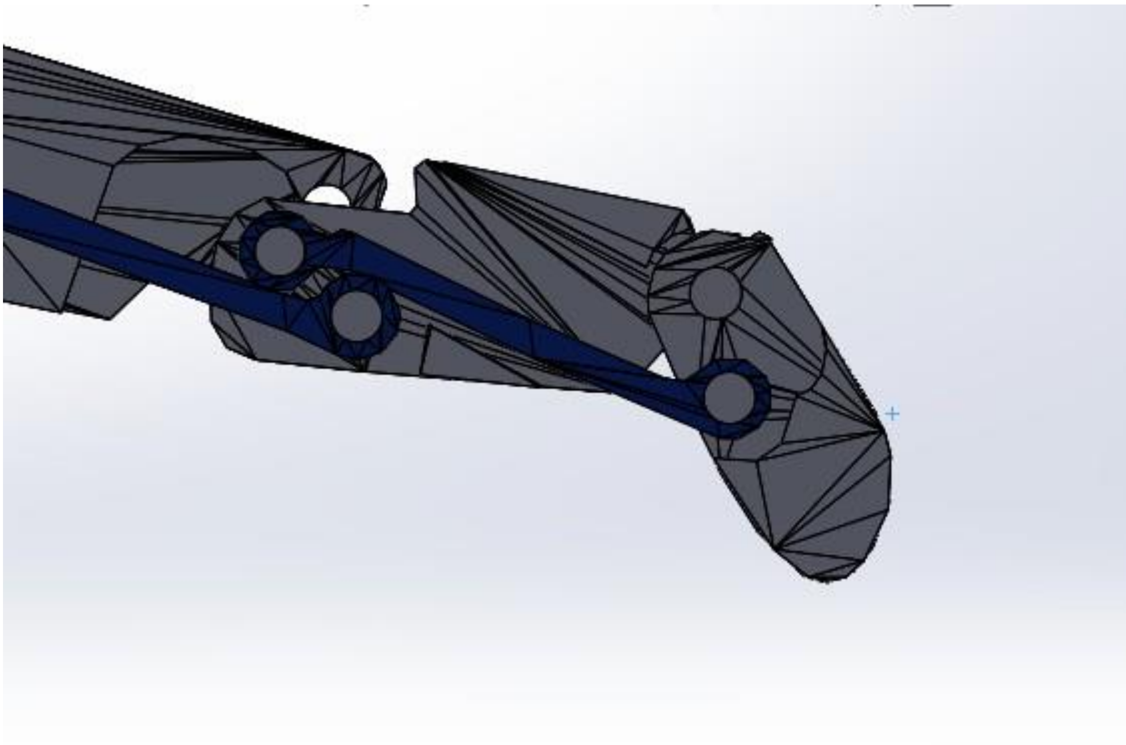

Fig 15 - the tip of the finger

The actual finger looks like the figure shown below. The finger is connected to the palm as the third section is connected to a ‘knuckle section’ that has a hole in it. The knuckle can be connected to the backplate using screws.

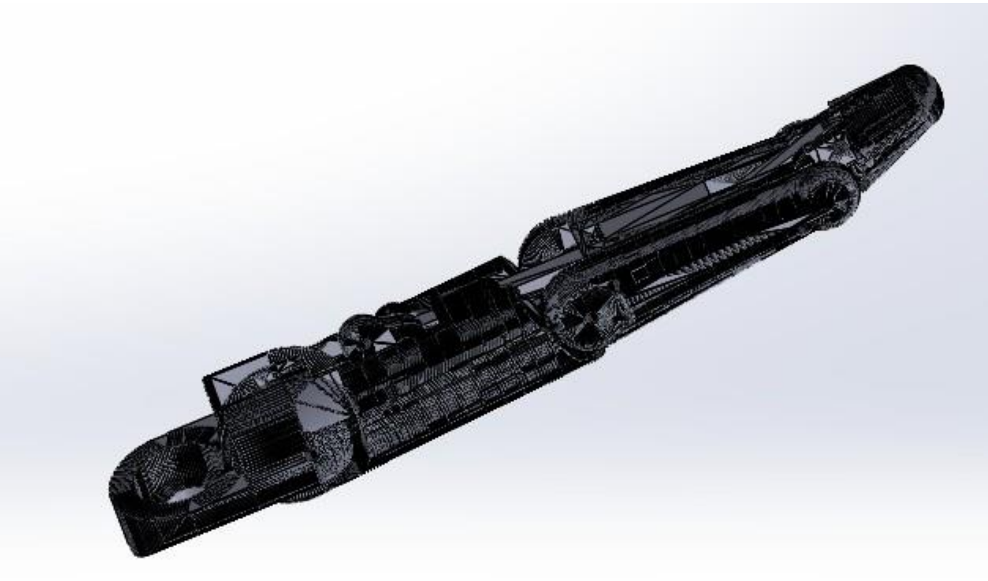

Fig 16- the actual finger from below

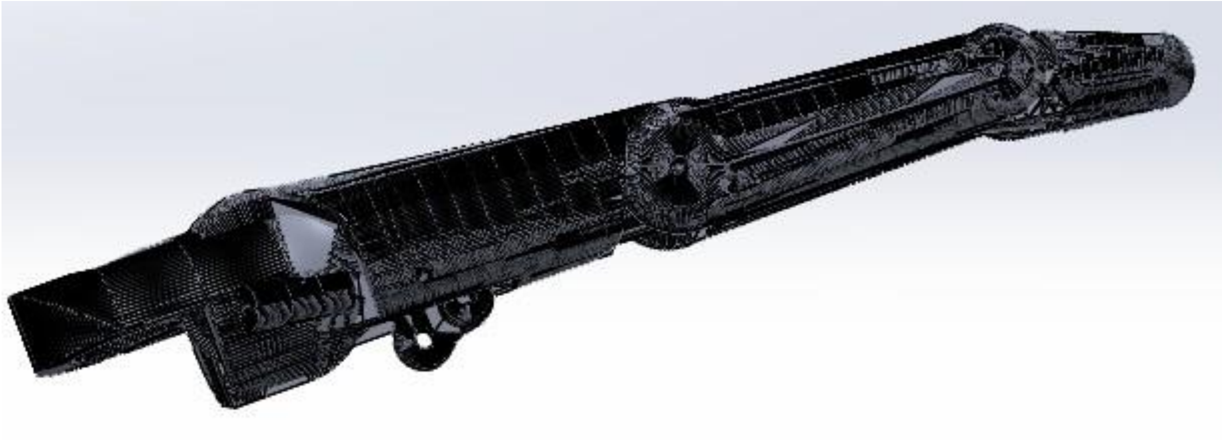

Fig 17 - The finger from above

The finger link at the start of the finger would be connected to a worm gear that will be driving it. The mechanism is similar to the gripper mechanism shown in Figure 2. The major advantage to having a worm gear is that it will be locked in any position unless the user wants to move it. They are also low maintenance and are used in situations that require a low gear ratio resulting in more torque. The dimensions that can be used for the worm gear are approximate.
worm - 48 pitch, 3/16” bore, 5/16” outer diameter
gear - 24 gear, brass, 3/16” bore
A list of commercially available worm gears has been compiled.

The design parameters for the prosthetic hand are
Weight - 450 - 500 g
Overall size - 185 to 200 mm long
- 80 to 90 mm wide
- 35 to 50 mm thick

Maximum Power Grip 16.8 ft-lbs(75N)
Maximum Tripod Grip 7.6 ft-lbs (34N)

Finger/Grasp Speed - 1.9 s (power grasp)
- 0.8 s (tripod grasp)
- 1.5–1.7 s (key grasp)

5.2 Prosthetic Gripper

Figure 2 shows the design for the gripper. It has the same working principle that is used to actuate the finger. The worm gear has 2 parts - a worm or a screw and a gear. The worm is rotated by the motor. The gear is inserted inside the grooves of the worm such that when the worm rotates, it rotates the gear. A potentiometer can be attached to the gear to measure its rotation to measure the angle of the gripper. The same motor that is used for the elbow can be used for the gripper.
These values were set as the target to achieve for grippers.
Opening span – 100mm

Speed - 110mm/s

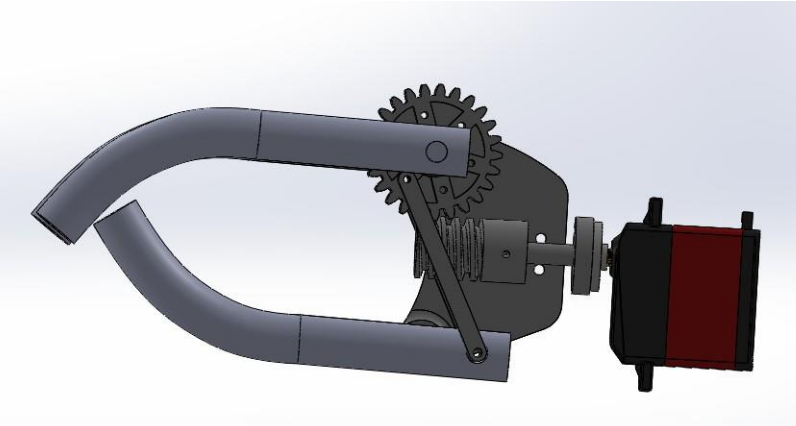

Fig 18- Prosthetic Gripper

5.3 Prosthetic Wrist

The prosthetic wrist has been designed so that it can rotate along the axis of the forearm thus mimicking the pronation- supination movement. The smaller gear is connected to the motor and is the driver gear. The larger gear is connected to the wrist and will be used to rotate the wrist. This design could have been improved by connecting the outer side of the wrist to a ball bearing to reduce friction during motion.

The design specifications for the wrist are as follows:
Mass <100 g
Speed ≥ 1.42 rad s^{-1}(13.5 rpm)

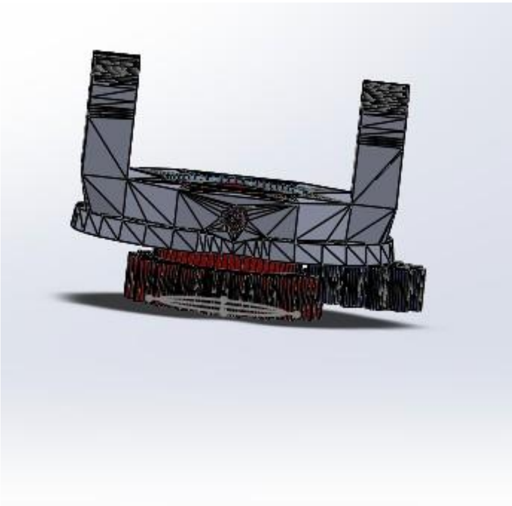

Fig 19 - upper part of the prosthetic wrist

Fig 20 - complete prosthetic wrist

5.4 Prosthetic Elbow

The elbow

There were not a lot of designs available for the elbow. One of the designs present on the internet had moving parts above the elbow, which was not a great design as not fit most of the amputees. 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. 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 has to rotate the small gear by 290 degrees to completely bend the elbow. As previously mentioned a standard servo can only rotate through 180 degrees so modifications have to be made to increase the servos rotational range. One potential solution is to remove the potentiometer from the motor and attach it to the driven gear. Thus, the potentiometer will rotate as the driven gear is rotated and not the driver gear.

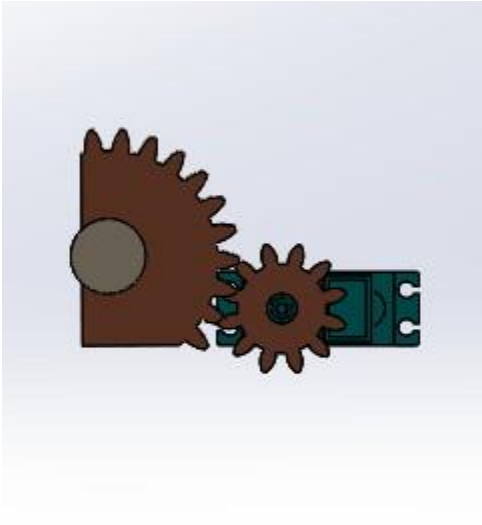

Fig 21 - the mechanism for prosthetic elbow

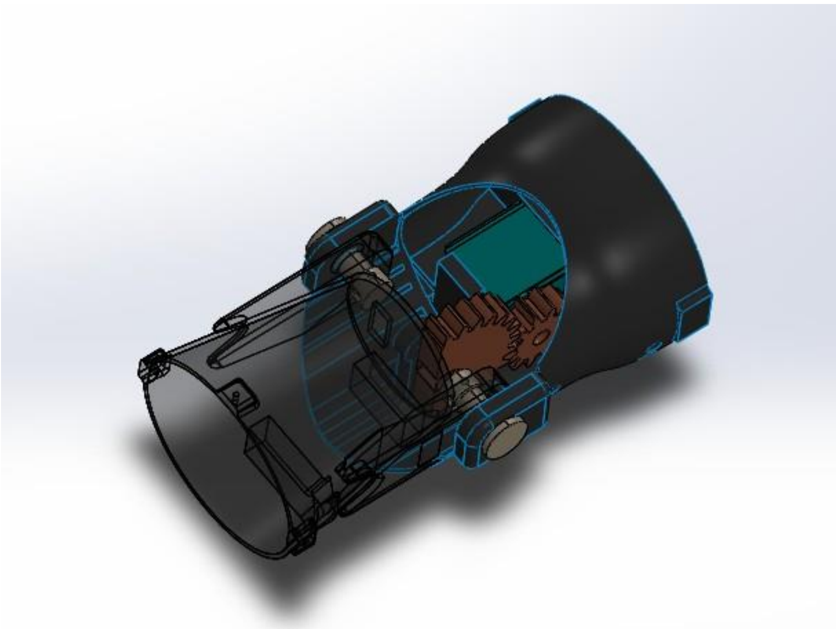

Fig 22 - complete prosthetic elbow

CHAPTER 6 - Electronics

Once the design for each and every part was finalized, I began looking for electronics that would be used to move the arm.

Motors for grippers
The elbow will lift the weight of the entire arm plus the payload so it requires a lot of torque. So a motor of that caliber was selected. The elbow will be able to provide 110 degrees of motion. This limitation can be removed if the potentiometer from the servo motor is removed and attached to the gear in the forearm. But doing so can result in a decreased angular resolution.

The calculation below shows the minimum torque required for a gripper

Speed: 110 mm/s

Total Torque= Jaw Length X Gripper Force + Jaw Length* X Part Weight X (Acceleration + 1G if Up and Down)

$$= 0.036 * 10 + (0.036 * 1 * (2 * 9.8))$$

$$= 1.06 \text{ Nm}$$

Hitec HS-805BB
Voltage: 4.8-6.0 Volts
Torque: 1.93/2.42 Nm. (4.8/6.0V)
Speed: 0.19/0.14 sec/60° (4.8/6.0V)
Rotation: 180°
Dual Ball Bearing Heavy Duty Nylon Gears 3-Pole Ferrite Motor D1 Heavy Duty Spline* 66 x 30 x 57.6mm Wire Length: 300mm
Weight: 152g

As can be seen from the calculations, the motor can handle more than the required torque and is about the right dimensions so it was decided that it will be used for the wrist as well as the elbow.

Motors for fingers

The Pololu DC brushed gear motors are a perfect fit for this application. They are very tiny, yet still quite powerful. They are convenient to work with by having 2 face mount screws, and a flatted output shaft. The best feature of these motors though is the fact that Pololu offers dozens of different gear reductions all in the same motor package size. This means that even after the entire hand has been built and tested, if it is discovered that there is too much friction in the system and more torque is needed, a new motor can simply be swapped in and nothing else on the design would have to change.

Name	Reduction	Voltage	RPM (no load)	stall torque in lbs	stall torque for 15 RPM	weight (g)
Pololu 250:1 HP	250:1	6 V	120	3.75	30	10

Battery
One single battery is supposed to give current to the entire arm, so the capacity should be high enough.
Battery Specifications

Weight	Capacity	Charging time (full charge)	Technology	Length	Voltage
65 g	900 mah	3.5 h	Lithium-ion	`2 3/4 in	6/7.2 Volt

CHAPTER 7 - Integration

All the individual components were now designed and ready to be compiled. I started with the gripper. While I was assembling the gripper, I saw that the finger was not properly designed. The finger had to pass through a narrow gap between the endplates after which it would be connected to the worm gear and I had not accounted for that. So I redesigned the finger.

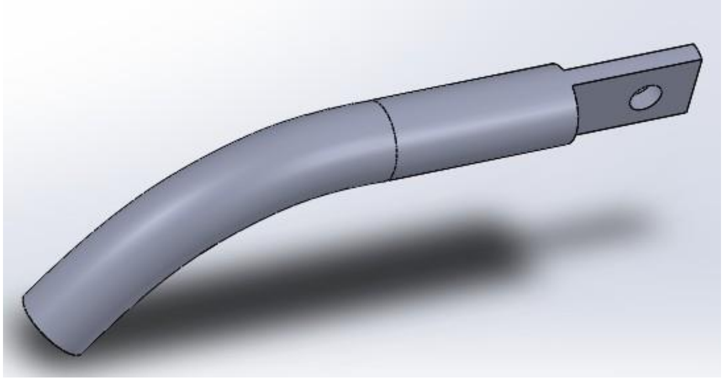

Fig 23 - redesigned finger

The Position where the thumb would attach to the worm gear was behind, as compared to the other fingers so that thumb was also changed a bit.
The overall look for the gripper looks like the figure below

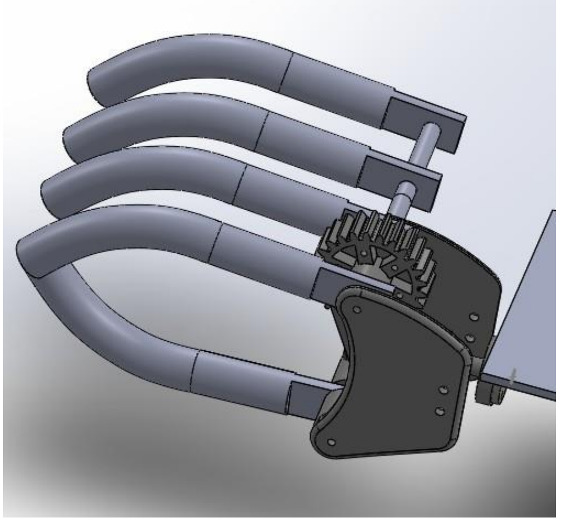

Fig 24 - new gripper design

In prosthetic hands that are manufactured, The ring finger and the little finger are not attached to the motor directly. They are not used for picking and placing and are just for aesthetic purposes. The same can be said for the two fingers in my design.

The next part that had to be designed was the backplate. It can be considered as the palm that holds together all the muscles and bones for the fingers and connects the wrist to the hand. The backplate will be attached to the gripper, it will hold the motor for the gripper firmly and connect to the wrist as shown.

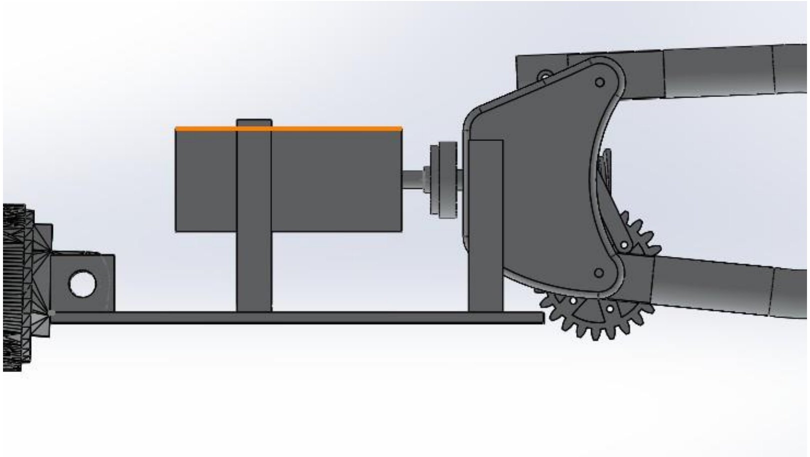

Fig 25 - gripper attached to the backplate

The worst is designed in such a way that it can be connected to the backplate easily. All the electronics components from the hand will be connected to the microcontroller present in the forearm through the wrist.

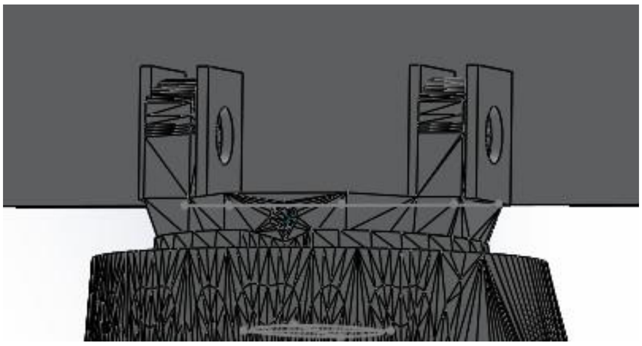

Fig 26 - backplate attached to the wrist

The forearm is designed so that it can be attached to the wrist and the elbow easily. The forearm will also hold the batteries, microcontroller and microprocessor so it has to be hollow from the inside. It should also be strong enough to hold the weight of the payload, hand, wrist, and electronics.

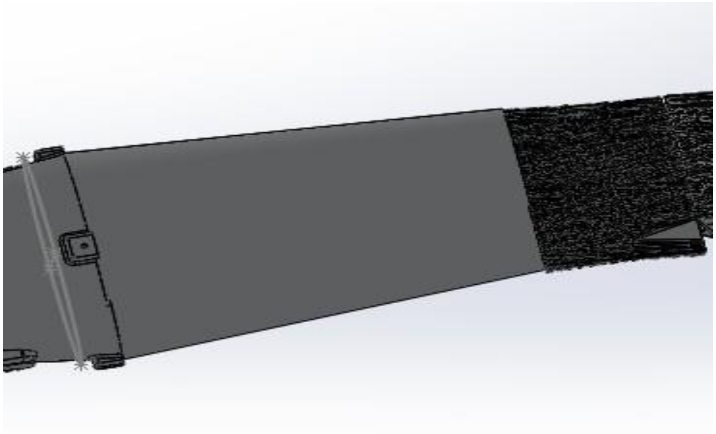

Fig 27 - forearm

CHAPTER 8 - Purchasing the prosthetic arm

1.1 Prosthetic Arm

One of the responsibilities for the internship involved finding a supplier who would provide us with a functioning prosthetic arm that we would use for research. There is a wide range of products available from mechanical / body-powered prosthetics to bionic prosthetics. I was told to find prosthetic arms that had 2 degrees of freedom and 3 degrees of freedom. 2 DOF includes movement of the hand gripper and movement of the elbow. 3 DOF includes movement of the gripper, rotation of the wrist, and movement of the elbow.

While I was searching for the arms, I noticed that the majority of the suppliers were available on IndiaMart. I went through all the products which looked reliable and selected suppliers that were in India and preferably near Pune. I had an additional constraint of finding an arm with the budget that was provided to me. I also provided IndiaMart with my number in case any supplier would like to contact me. I narrowed down products using the constraints and came up with a list of about 20 potential suppliers. In the following days, I contacted each and every supplier to ask them about their products and if they were willing to sell prosthetics to the college. Out of the 20 suppliers, a few said that they would not sell prosthetics for research purposes and a few actually did not sell the type of prosthetics that I wanted. Eventually, I narrowed it down to 7 suppliers. Most of the prosthetics I enquired about could lift up to 7 kg and more than that was not recommended. I was told that the time to deliver those prosthetic arms was two to three weeks as they are imported from other countries.

I arranged for a demonstration with the suppliers and the mentors so that they could see the prosthetic arm function in real-time. In the following weeks, we corresponded with the suppliers and asked them to provide us with quotations for 2 degrees of freedom and 3 degrees of freedom prosthetic arms. I compiled all the quotations to create a comparative for the institute.

All the quotations are given in the appendix.

Fig 28 - Suppliers for a prosthetic arm

CHAPTER 9 - Benefits and Future Scope

1.1 Benefits

- The design is practical enough to be realized and used
- The design is simple enough so that anyone can understand and repair it

1.2 Future Scope

The future scope for this project includes

- Designing a better thumb with more functionalities
- Reviewing a prosthetic arm and understanding it better
- creating a wrist with flexion-extension capabilities
- Integrating an EMG sensor

Conclusion and References:

Conclusion

The future of prosthetics is very bright. While researching to find out more about prosthetic arms I realized that there are a lot of people and organizations that want to provide affordable prosthetic arms to people around the world and the technology is such that it is possible.

I was able to research and create an extensive document that contains the designs and workings of the prosthetic arm. I also created two designs for prosthetic hands - one being a gripper and one with independent finger control. Along with designing prosthetic hands, I also designed a prosthetic wrist and an elbow.

A lot of further development can be done in this domain as shown in the Future scope.

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