A Project Stage-I Report on

BIONIC ARM

By

Mr. Shambhuraj Anil Mane.

Mr. Sukrut Sanjay Bhujbal.

Ms. Namrata Nitin Potnis.

Guide

Prof. Akshay C Kulkarni.

Department of Mechanical Engineering

Pune Vidyarthi Griha’s College of Engineering and Technology.

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Pune Vidyarthi Griha's College of Engineering and Technology, Pune.

C E R T I F I C A T E

This is to certify that **Mr. Shambhuraj Anil Mane, Mr. Sukrut Sanjay Bhujbal and Ms. Namrata Nitin Potnis**, has successfully completed the Project Stage – I entitled "**Bionic Arm**" under my supervision, in the partial fulfilment of Bachelor of Engineering - Mechanical Engineering of University of Pune.

Date:

Place:

Prof. Akshay C Kulkarni.

Guide **Internal Examiner**

Dr. Shivaji V Gawali. Dr. Yogesh P Nerkar.

Head of the Department **Principal**

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Shambhuraj mane
Sukrut Bhujbal
Namrata potnis

CONTENTS

List of figures

1.INTRODUCTION

1.1 Introduction to bionic arm

The human hand is a complex system, with a large number of degrees of freedom sensors embedded in its structure, actuators and tendons, and a complex hierarchical control. Despite this complexity, the efforts required to the user to carry out the different movements are quite small. The myoelectric arm works under the influence of Electromyography (EMG) signals extracted from skin surface. These Electromyographic signals are utilized to run various motors which enable the user (patient) to grip and move limbs in a much more effective manner. prosthetic hands are replication of the natural hand, with significantly reduced grasping capabilities and no sensory information delivered back to the user. Despite the significant impact of losing a hand, numbers of amputees requiring prosthesis are too small to push manufacturers to innovate their products, so both the control interfaces and mechanisms have barely changed in the past 40 years.

1.2 What are EMG signals

The Electromyogram signal is a neuro muscular signal that measures electric potential generated in muscles during their contraction and relaxation representing neuromuscular activities. The amplitude of the signal is in the range of 0-10 mV. Signal frequency range is above 12 Hz. These signals can be recorded from the lower elbow region of the arm for a certain set of gestures. These gestures can be rest, palm-up, palm-down, fist, hold, etc. Various features like average, L2-norm, kurtosis, skewness, etc. can be extracted from these recorded signals. With good analysis tools and algorithms, the EMG signals can be mapped with the control signals for the actuators in Bionic Arm with a high degree of accuracy.

1.3 Social relevance of the project

The outcome of this project is to create a cost effective less weight Bionic Arm that can mimic the hand gestures correctly. This will help lower elbow amputees by providing them a solution that will help them in their day to day tasks. This in turn will give them more independence and improve their quality of life. The study of problems perceived by the amputees was done. As our design is only specified for lower elbow amputees the study was only limited to problems perceived by lower elbow amputees. Recently development of myoelectric prostheses has mostly focused on increasing the number of

DoFs while increasing joint speed and torque. However, these devices achieve improved dexterity at the cost of increased weight, size, and complexity. There is trade-off between the dexterity of Bionic Arm and the weight, size of the Bionic Arm. In they have suggested that the weight of Bionic Arm should be around 500 grams.

R.F Weir et al consulted different amputees and has proposed following rules of thumb for design of prosthetic arm-

1. The total weight of prosthesis should be around 500 grams. A lighter prosthetic arm is always beneficial for amputees as they can easily use the device for carrying out daily activities without any hardships.

2. The Bionic Arms should incorporate main functional grasps like Power Grasp, Pinch Grasp and Lateral Grasp.

3. The design and control of Bionic Arm should be compliant enough.

4. Simple and robust finger kinematic design should be implemented.

5. The exact need of amputees should be mapped and then specified design for that person should be initiated. This approach gives a better design output which will be definitely compliant to the amputee

1.4 Objective of project

1. To study the human-arm anatomy with reference to different gestures.

2. To study the EMG signals related to lower arm/finger gestures.

3. To acquire the EMG signals from a healthy person (one subject) and create datasets for various pre-decided gestures.

4. To analyse the recorded signals and extract various features from them.
5. To create a machine learning model that can identify these features.
6. To apply the output of the machine learning model to the actuators in Bionic Arm to actuate the gestures.
7. To design a low cost, high functionality (high Degrees of Freedom) Bionic Arm.
8. To design a lightweight Bionic Arm using 3D print technology.

2.LITERATURE SURVEY

2.1 Introduction

Prosthesis and orthotics are clinical disciplines that deal with artificial limbs(prostheses) for people with amputation and people with muscoskeletal weakness. Bionics is a field of engineering which is inspired from biology. Bionic Arm is by-product of prosthetics and Bionics whose aim is to provide an artificial arm for amputees. Thus, this artificial robotic prosthetic arm provides amputees with artificial hand which can help them to carry out daily activities as efficiently as they used to carry out when they had their biological hand intact to their body. The following literature survey consist of study of designing and building of Bionic Arm.

2.2 Prosthetic Arms

The hand is a powerful tool and its loss causes a severe psychological and physical drawback. Despite the significant impact of losing a hand, numbers of amputees requiring a prosthesis are too small to push manufacturers to innovate their products, so both the control interfaces and mechanisms have barely changed in the past 40 years. The most technologically advanced prostheses are myoelectric ones; one or two DoFs, motorized hands (or hooks) are activated by antagonist residual muscle contractions where the EMG signal is picked-up by surface electrodes in the prosthetic socket and processed to functionally open and close the palm (or pronate/supinate the wrist).

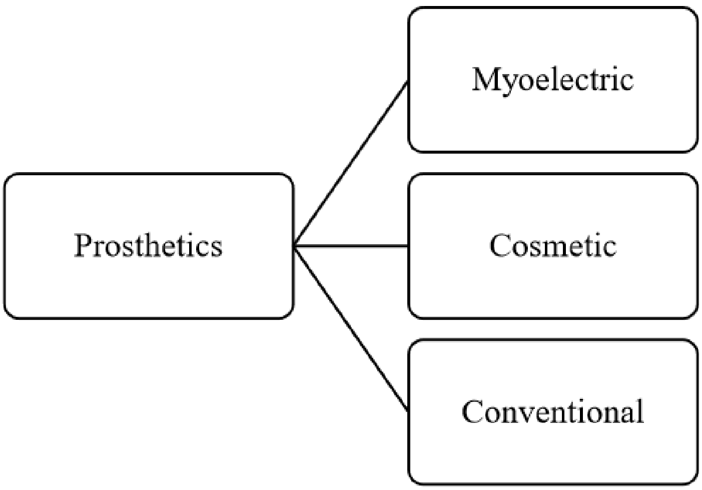


Figure 1: Types of prosthetics

Before learning to build highly functional, high DoF and light weight prosthetic arm study of human hand, its working, number of joints, tendon muscle relationship, etc. is needed.

2.3 Anatomy of Human Hand

The human hand consists of 4 fingers and a thumb and is the main organ for physical interaction with the environment surrounding the human body. A schematic of the bones in the human hand can be seen in Figure below.

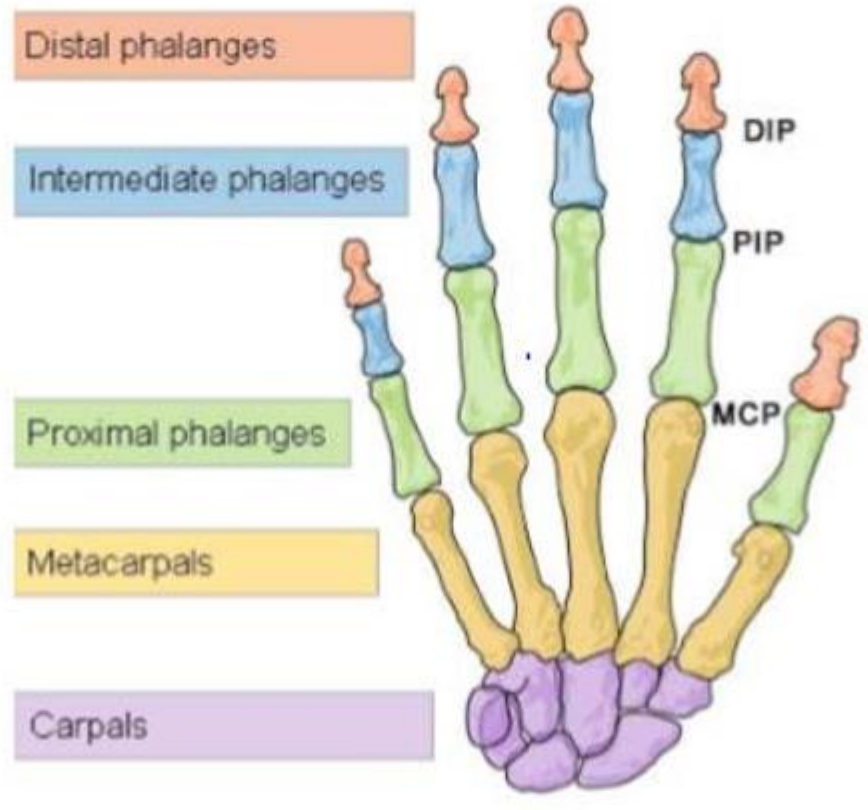


Figure 2: Anatomy of Human hand

Every finger has 3 joints, which are-

- DIP (Distal Interphalangeal Joint)
- PIP (Proximal Interphalangeal Joint)
- MCP (Metacarpal Phalangeal Joint)

Fingers are divided in different segments connected by joints called as Phalanx, following are different phalanxes -

2.3.1 Metacarpal Phalanx

The metacarpal phalanx (yellow) is connected to the first finger segment (proximal phalanx) with a joint called the metacarpophalangeal joint (MCP-joint). The MCP-joint is able to perform to types of movement, flexion/extension and abduction/adduction. Flexion in this case means bending the finger while extension means extending the finger. Abduction denotes the sideways motion of the finger away from the midline of the hand. The opposite movement, adduction, means moving the finger back against the midline of the hand.

2.3.2 Proximal Phalanx

The proximal phalanx (green) is connected to the metacarpal phalanx through the MCP-joint. On the other side of the finger segment it is connected to the second finger segment (intermediate phalanx) with a joint called the proximal interphalangeal joint (PIP joint). The PIP-joint only has one axis of motion and is therefore called a hinge joint. Flexion and extension of the PIP-joint means bending and stretching the first finger joint.

2.3.3 Intermediate and Distal Phalanx

The intermediate (blue) and distal (red) phalanges are the middle and outer segments of the finger, respectively. They are connected with the distal interphalangeal joint (DIP joint) which is a hinge joint like the PIP-joint.

2.4 Robotic approach to the human hand

There are several aspects of the human hand that makes it very hard to imitate in a robotic application. First of all, the human hand has a very complex kinematic model. The fingers alone possess 21 DoFs. In addition to the finger, movement of the palm includes 6 DoF, 27 for the whole hand. The movement of the palm itself is rarely seen in robotic hands; a solid palm is often used instead. In addition to the high degree of freedom, the finger is also very sensitive to external input. To imitate all the nerves on the surface of the finger is very complicated. Normally, a number of touch sensors are seen instead. Thus, mimicking human hand's functionality in prosthetic arm is a difficult task and a great amount of research is undertaken to create an anthropomorphic prosthetic arm.

To implement high functionality anthropomorphic prosthetic hand which will be controlled by myoelectric signals or EMG signals, efficient and light weight actuators are needed.

2.5 Grasps

For designing an artificial human hand there is need to study the human arm and its functionality. Human hand carries out different grasps to pick and handle different objects in our daily life. Thus, for designing purpose of Bionic Arm, study of different grasps was done.

The Cutkosky grasp taxonomy was referred. Mark Cutkosky wrote a paper in 1989 where he classified a set of manufacturing grasps in order to evaluate analytical models of grasping and manipulation with robotic hands. This taxonomy is widely used by robotic scientists and engineers who undertake designing of robotic arm. The following image is the hierarchical tree of grasps referred from Mark Cutkosky's paper-

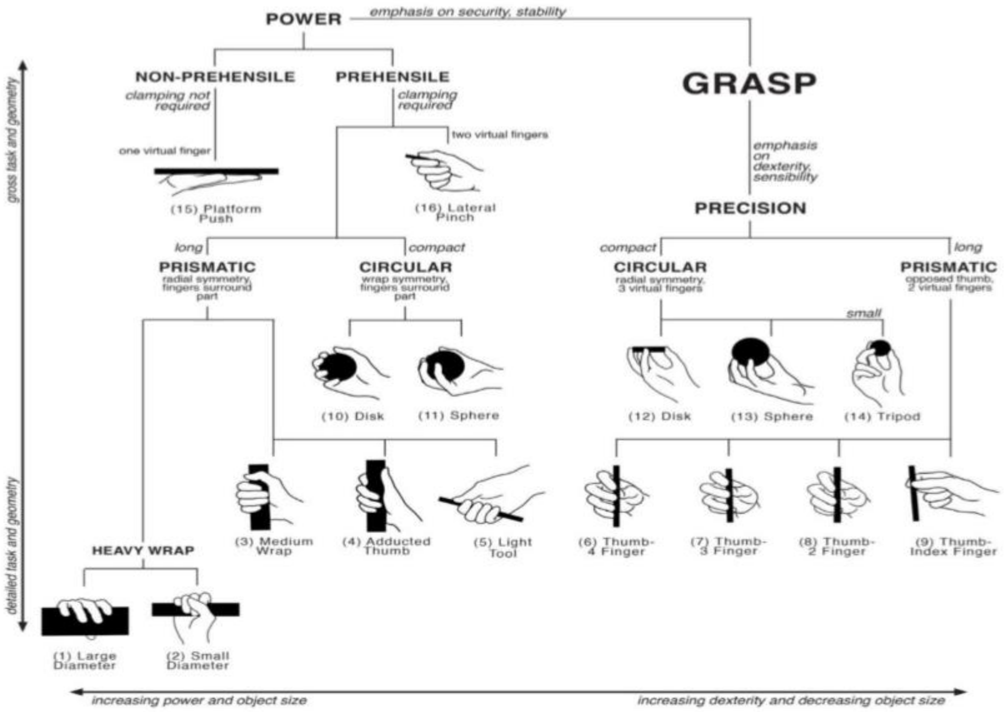


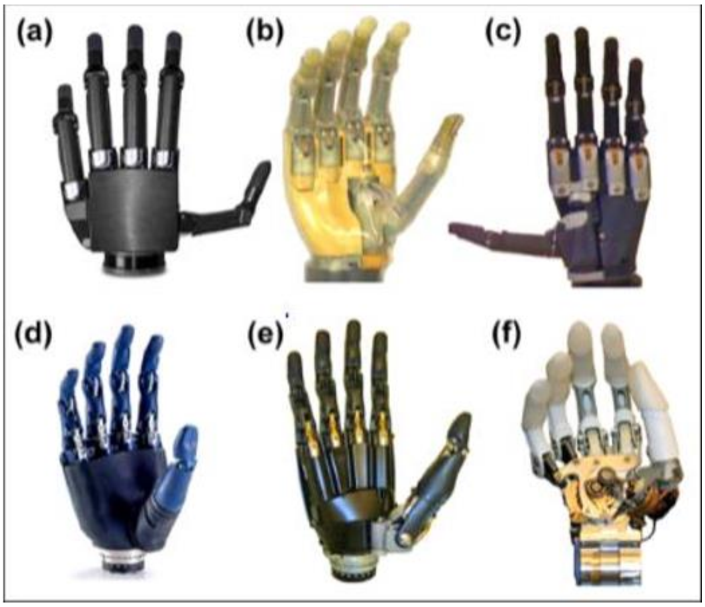
Figure 3: Hierarchy of grasps

Following is the list of important grasps studied and their use in everyday life-

- POWER GRASP- for picking heavy weights.
- PRECISION GRASP- for picking cherry from trees.
- LATERAL GRASP-for picking spoon laterally.
- INDEX Pointing for typing.
- Basic Gesture likes counting.

In Weir et al has made comparison analysis on different types of commercial Prosthesis and Bionic Arms designed by research institutes. Following Prosthetic arms were studied-

- Vincent hand by Vincent Systems.
- iLimb hand by Touch Bionics.
- BeBionic hand by RSL Steeper
- Michelangelo Hand.



2.6 Comparative Analysis

In general characteristics of commercial prosthetic hands is stated. Vincent Hand was designed for 6 DoF and DC motor worm gear was used for actuation. Adaptive Grip was the feature. BeBionic hand is the most successful commercial prosthetic arms which used DC Motor Worm Gear for actuation method. Bebionic used carbon fiber body which lead to reduction in weight. It only weights 465 gram. iLimb by touch bionic is also successful commercial prosthetic arms which consists of features like Wi-Fi control and adaptive grasps.

After studying these prosthetic arms, it is analyzed that all these companies used custom made expensive actuators which increases the total cost of entire device. Though they were light enough and had compliant actuation, they were very expensive which can't be afforded by middle-class and below middle-class people. Thus, work on cost effective Bionic Arm is an undergoing research.

Modular Prosthetic Limbs

Figure 2-18: Modular Prosthetic Arm

Modular Prosthetic Limbs are till now the most advanced prosthetic arm designed by researchers in John Hopkins University which was funded by DARPA. MPL is the most advanced prosthetic limb which achieved intuitive feedforward control through EMG sensor band and it also incorporated feature of natural sensory feedback to the user. MPL is the most expensive Bionic Arm which is successfully tested on an amputee. It incorporated more than 100 sensors on the Arm including force, contact and temperature sensor. No doubt it is the most advanced artificial limb

2.7 Actuators

Following are common different types of actuators that can be used in prosthetics-

- Hydraulics- Hydraulics, a widely used form of general actuation is hydraulic systems. A hydraulic system typically consists of a pump, a reservoir, a valve and an actuator. Hydraulics are bulky and include oils which will make difficult for amputee to use it as prosthetics.
- Pneumatics- In pneumatics, a pressurized gas is used to create actuation, typically by filling a cylinder with air. Pneumatic valves and cylinders are bulky so they cannot be used in prosthetic applications.
- Intelligent material used as actuator (Soft Robotics)- Intelligent material used as actuator are not seen in common life, these include Shape Memory Polymers (SMP) and Shape Memory Alloys (SMA). Some polymers change shape when

subjected to voltage and thus due to shape change actuation is incorporated. Shape memory alloys are also used similarly to actuate. Thus, such intelligent material can be used in prosthetics for creating actuation at joints. Such actuation method closely mimics the muscles of our finger and brings us close to the goal of anthropomorphism. Advantages of such actuators is low cost and simplicity. But such actuators incorporate joule heating effect for shape change and actuation, such actuation mechanisms are not safe for prosthesis application and it will require insulation. Moreover, high DoF and robustness in prosthetics cannot be obtained using these actuators. We referred to, these companies manufactured SMA and SMP. SMP technologies, Japan, manufactured SMP material which had moulding point around 55 centigrade but due to its exorbitant price it was hard to be affordable for the project. Thus, intelligent material used as an actuator had to be dropped for this application.

- Electric actuators provide sufficient torque, force, robustness and flexibility and are suitable for this application. Following are different electric actuators that can be incorporated in prosthetic arms-

1. DC Motors
2. BLDC Motors
3. Servo Motors
4. Stepper Motors
5. Linear actuators

2.8 Review on Tactile Sensor

In tactile sensing technology has been reviewed. Tactile sensor or Force sensor detects pressure or force applied on the surface of the sensor. It provides information related to the interaction forces between object and fingers of robotic arm. Tactile sensor taken in closed loop, helps in precise control of force applied on the object by the fingers of robotic arm. Biological human hand also has many senses like the human hand can detect hotness or coldness of the object, pressure applied on the finger and pain on the finger.

Tactile sensors are incorporated by engineers and researchers working on prosthetic arms and Bionic Arms, to have precise object handling and manipulation. Tactile sensors help to control force imparted on the object. For Bionic Arm, having control on force imparted on the object is important because an amputee interacts with different types of objects like hammer, flower, eggs etc.

If the Bionic Arm applies same amount of force for holding hammer on holding an egg, it will destroy the egg.

One axis and 3 axis tactile sensors are available in market. 3 axis tactile sensors are used for calculating normal and tangential forces simultaneously, which also helps in detecting slippage of object from the fingers. But the 3-axis tactile sensor are expensive, so mostly people prefer to use single axis tactile sensor Thus, use of tactile sensor in field of prosthetics is important.

Following are different types of tactile sensors –

I. Piezo resistive sensor.
II. Capacitive sensors.
III. Piezoelectric sensors.
IV. Quantum Tunnel Eff ect Sensors.
V. Optical Tactile sensors.

Amongst these sensors, following is the description of piezo resistive sensor and capacitive sensors-

I. Piezo resistive Sensor

Piezo resistive effect is a physical process during which electrical resistance changes when the material is mechanically deformed. There are several technologies based on piezoelectric sensors. Force Sensitive Resistor (FSR) is based on piezo resistive effect. In FSR when the sensor is deformed, the resistance changes. The FSR voltage divider configuration can be given as input to the analog to division converter of microcontroller for calculation of force applied on the sensor.

FSR have advantages like low cost, flexible and simple to manufacture but it has many disadvantages like it has less repeatability after multiple deformation. The sensitivity of sensor also reduces due to wear and tear of the sensor. Thus, FSR are not accurate solution for precise force measurement.

II. Capacitive Force Sensor

Capacitive sensors consist of two conductive plates separated by compressible dielectric material. When force is applied on the object the gap between the plates changes and capacitance is also changed. The change in capacitance is detected and inferences are made for how much force is applied.

Capacitive sensor technology has several advantages over resistive, including greater stability in terms of repeatability and durability, and can measure low levels of pressure with accuracy. Capacitive sensor gives linear output; it facilitates measurement of proportional force.

Thus, capacitive sensor is more accurate than FSR and good for long term prototyping in Bionic Arms.

2.9 Grasp Control

Bionic Arm helps amputees to live a normal life and become less dependent on others. For amputees to carry out their daily activities, it is important for the Bionic Arm to have firm grasping skills on different types of object as their principal feature. Thus, having good grasping skills and improved dexterity leads to achieving the purpose of an artificial human hand.

To achieve good grasp, it is important to devise grasping control algorithm or grasping control mechanism.

To achieve a stable grasp following prerequisites should be followed:

To hold the object properly, minimum grip force should be applied. The minimum grip depends on the weight and surface friction of the object trying to be lifted.

Grip force is naturally adjusted by human hands when it feels that object is slipping from the hands. When an object slips, it generates vibrations which can be measured and quantified. This is susceptible to noise, but is still viable with adequate filtering.

To hold heavy object maximum force should be applied. The maximum grip force depends on the mechanics of the hand and the maximum force that can be applied by the actuators/motors. Depending upon how much force can be applied by the Bionic Arm, there must be a standard grip strength which cover range of scenarios. Haptic feedback could play a role here. Firstly, by providing feedback in terms of pressure and secondly by amplifying the vibrations caused by slipping. This approach allows to have natural feedback to the amputees. Having these prerequisites followed leads to good base for achieving stable grasp of the Bionic Arm on any object.

2.10 Wrist Design

The human wrist contributes greatly to hand mobility and manipulation capabilities in healthy individuals, but both the commercial and research domains have often overlooked prosthetic wrists in favour of terminal device development.

The healthy human wrist is capable of three degrees of freedom (DOF). These DOFs are pronation/supination, flexion/extension, and radial/ulnar deviation (Figure). Radial/ulnar deviation is sometimes called abduction/adduction (respectively), and pronation/supination may be called wrist rotation. pronation/supination does not occur at the carpal bones of the wrist, but actually occurs within the forearm, as the radius crosses over the ulna in a twisting motion when moving from supinated to pronated positions. It should also be noted that motion originating in the carpal bones (flexion/extension and radial/ulnar deviation) is coupled, meaning that motion in one DOF limits motion in the other (e.g. the amount of radial deviation is reduced when fully extended than from the neutral position).

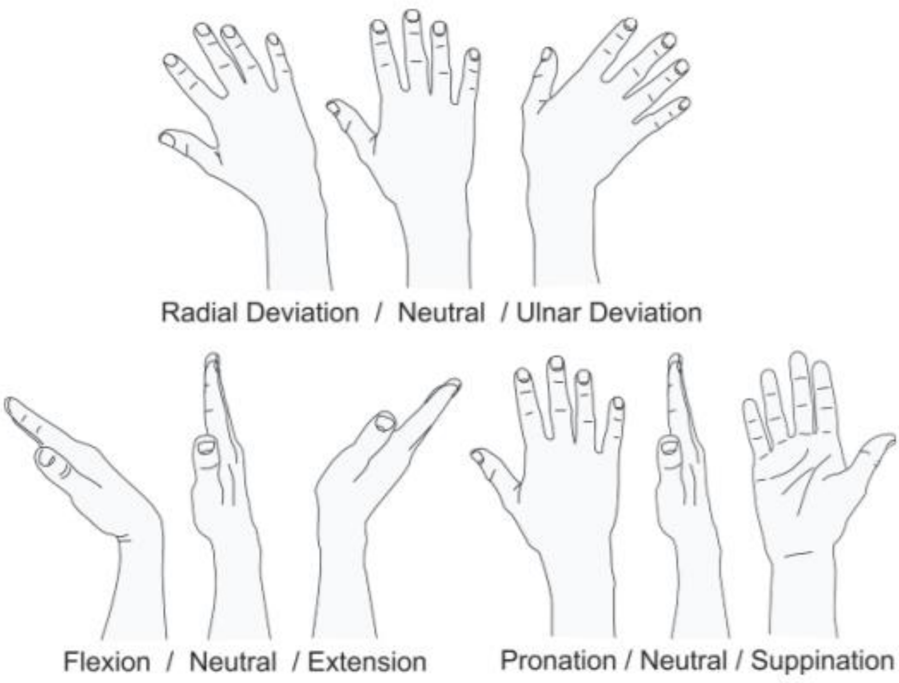


Fig 6 - Three degrees of freedom (DOF) of the healthy human wrist

For an unaffected human wrist, the maximal ranges of each DOF fall within the bounds of 76°/85°, 75°/75°, and 20°/45° for pronation/supination, flexion/extension, and radial/ulnar deviation, respectively. Various groups have studied the range of motion (ROM) of the various DOF of the human wrist while performing Activities of Daily Living (ADLs).

These investigations have generated a variety of ROM that fall within the bounds of 65°/77°, 50°/70°, 18°/40° for pronation/supination, flexion/extension, and radial/ulnar deviation, respectively. Wrist pronation torque ranges from 6-10 Nm and flexion torque ranges from 8-14 Nm.

2.10.1 Articulation Method

The function of a prosthetic wrist is to enable reorientation of a TD relative to the forearm. Articulation is achieved via Passive, Body Powered, or Active methods. In a passive wrist the user manually adjusts wrist and terminal device (TD) position, either through their contralateral arm, body and/or environmental features. For example, a terminal device may be clamped between the hip and table edge to enable re-orientation. Body powered devices utilize motion and accompanying forces in other parts of user's body to achieve motion of a prosthetic device. The user typically wears a shoulder harness with an attached Bowden cable to transmit force from the shoulder to the prosthesis. Most commonly this is used to achieve opening/closing of a terminal device, such as a Hosmer Hook, but body powered mechanisms have also been applied to other prosthetic components. In active devices, an actuator, such as an electric motor, is used to generate force and motion in the prosthesis. Such devices are typically part of myoelectric systems. Note that a prosthetic device may have an actuator in it, but will not be considered an active mechanism in this paper if the actuator does not exert control over at least 1 DOF of the wrist.

2.10.2 Joint Types

There are 4 types of joints, which may be used as standalone elements or form a serial chain. The 4 types of joints a chain is revolute (R), prismatic (P), universal (U), and spherical (S) joints. These 4 joints are schematically shown in Fig Combinations of joint are used to create mechanisms.

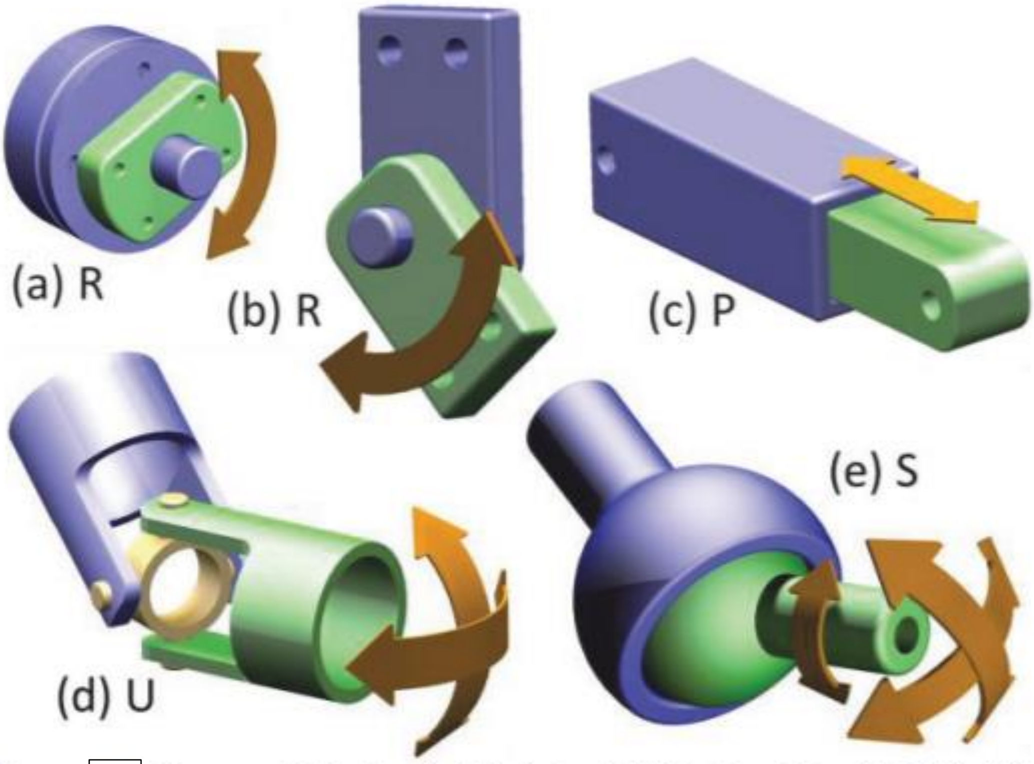


Figure 7 Types of Mechanical joints: (a),(b) Revolute (1DOF, R) either arranged as a rotator (a) or flexor (b). (c) Prismatic (1DOF, P) capable or linear motion. (d) Universal (2DOF - U) and (e) Spherical 8

2.10.3 Mechanism Type

A mechanism may be a serial, parallel, or hybrid depending on the relationship of its linkage(s). A serial mechanism is a sequential connection of joints and links. For example, a 2R mechanism (also known as an RR mechanism) is a 2DOF system composed of two revolute joints located sequentially after one another. A parallel mechanism consists of 2 or more serial chains which span from a common base to a common distal platform, which in this case is generally the TD. A hybrid mechanism, finally, is a combination of serial and parallel mechanisms. This could be, for example, a parallel mechanism in series with a serial mechanism, so that the base of one mechanism may not be fixed in space or the distal part of one mechanism may not terminate in the end effector. An example of a hybrid mechanisms occurs in the PKM Tricept T805 industrial robot, where a 3DOF parallel mechanism terminates in a 3DOF serial wrist.

Possible combinations for actuation of wrist are listed below-

1. SINGLE-DOF WRISTS

A. Serial 1-DOF

1) Passive Serial 1-DOF:

2) Body-Powered Serial 1-DOF

3) Active Serial 1-DOF:

B. Parallel 1-DOF

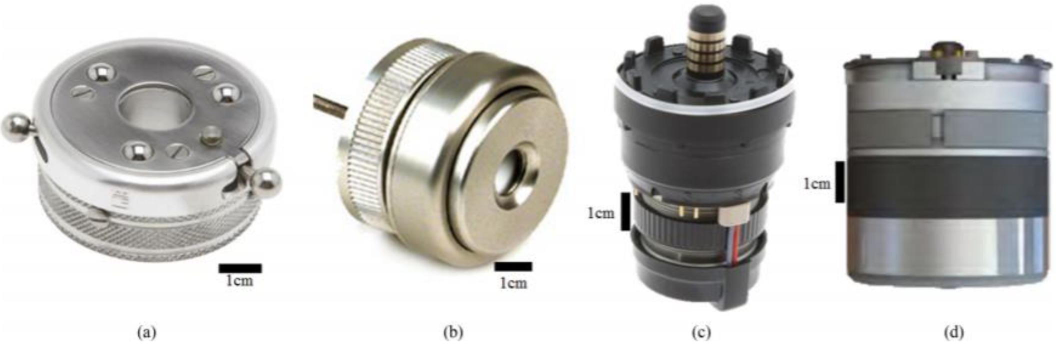


Fig. 4. Single-DOF prosthetic wrists. (a) OB Ratchet Type Rotation (R) [15]. (b) HD Rotation Wrist (R) [11]. (c) OB Electric Wrist Rotator [15]. (d) TB Supro Wrist. Size scales indicated by black bars are shown.

2. 2-DOF WRISTS

Unlike single-DOF wrists, 2-DOF devices not only include prosthetic wrists, (including those proposed in academic environments), but wrists used in robotic applications, such as solar panel and camera orientation, as well.

A. Serial 2-DOF

There are only two combinations of serial wrist mechanisms resulting in 2-DOF rotational motion, namely, revolute-revolute (RR) chains or universal (U) joints. Both are employed regularly to achieve 2-DOF rotational motion.

1) Passive Serial 2-DOF

2) Body-Powered Serial 2-DOF

3) Active Serial 2-DOF

B. Parallel 2-DOF

1) Active Parallel 2-DOF

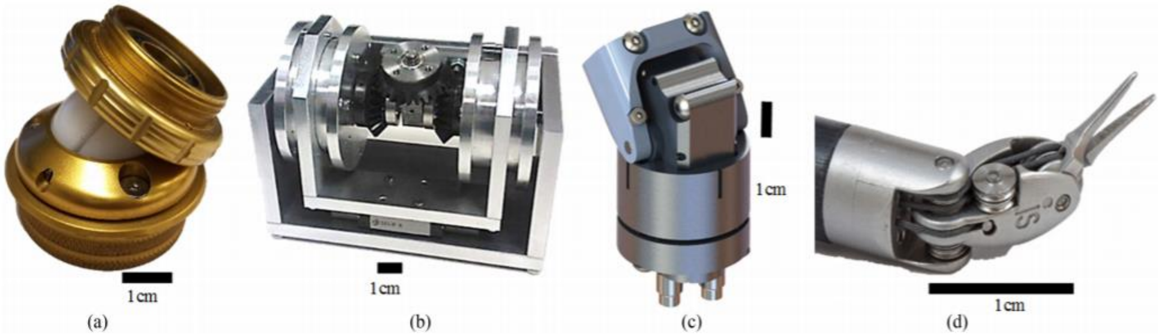


Fig. 5. Serial 2-DOF prosthetic and robotic wrists. (a) OB Myolino (U) [15]. (b) Montagnani switchable stiffness wrist (RR) [44]. (c) Verleg Hydraulic Wrist Prosthesis (RR) [61]. (d) Intuitive Surgical EndoWrist with forceps (RR) [70]. Size scales indicated by black bars are shown.

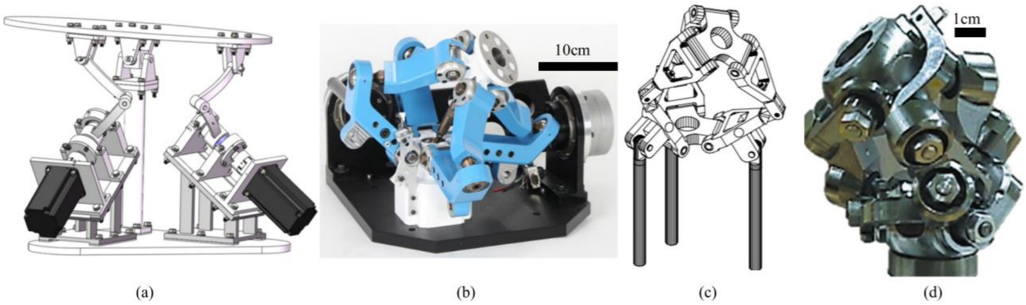


Fig. 6. Parallel 2-DOF robotic wrists. (a) Duan parallel mechanism (U, 2RRR) [77]. (b) Rosheim Omni-Wrist VI (SS, 4RSR) [82]. (c) Canfield Carpal Robot Wrist (3RSR) [83]. (d) Sone High Angle Active Link (3RRRR) [81]. Size scales indicated by black bars are shown when known.

C. Hybrid 2-DOF

By the definition of hybrid mechanisms, hybrid 2-DOF wrists consist solely of a single DOF rotator in series with a 1-DOF parallel mechanism. Only active hybrid mechanisms were found, thus passive and body-powered sections shall be omitted.

1) Active Hybrid 2-DOF:

3. 3-DOF WRISTS

Wrist designs capable of 3-DOF rotational motion can arbitrarily orient their end-effectors (up to a workspace limit). While the human wrist is naturally capable of 3-DOF motion, some of the subsequently described wrists outperform the human wrist in some aspects, such as range of motion or torque output, but generally not size or compactness.

A. Serial 3-DOF Serial

1) Passive Serial 3-DOF:

2) Active Serial 3-DOF:

B. Parallel 3-DOF

Parallel 3-DOF motions are capable of exhibiting fully spherical motion, though some mechanisms are cable of coupled translation with 3-DOF rotation. Moreover, these mechanisms are all active devices, so passive and body-powered subsections shall be omitted.

1) Active Parallel 3-DOF:

2) Hybrid 3-DOF

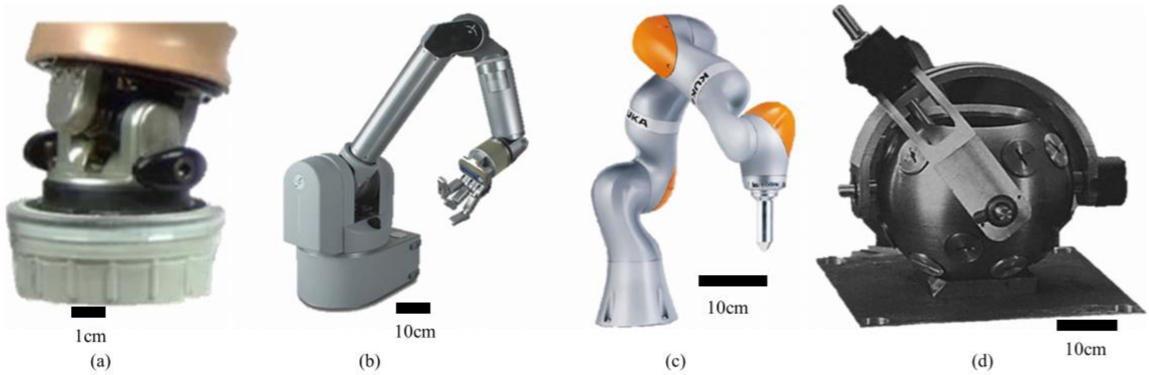


Fig. 7. Serial 3-DOF wrists. (a) MC MultiFlex (RU) [89]. (b) Barrett WAM Arm (RRR) [98]. (c) Kuka LBR iiwa (RRR) [106]. (d) Chirikjian Spherical Stepper Motor (S) [112]. Size scales are indicated by black bars.

2.10.4 Common issues with Wrist

Prostheses Major issues that limit the application of wrist prostheses are the additional weight and limb length resulting from the integration of a wrist unit into an existing socket (worn over the residual limb) and terminal device arrangement. Although additional weight of a prosthetic can lead to fatigue and discomfort, excessive length can create a discrepancy between limbs that impacts co-ordination and aesthetics. Upper limb prosthetics are already subject to abandonment due to these reasons, even without the inclusion of a wrist. Though forearm socket length may be reduced to accommodate the additional length of a wrist, this is only applicable to amputees with relatively short residual limbs (proximal amputation). It is essential to make the distinction between a wrist disarticulation amputee vs. a transracial (forearm) and other type of upper limb amputee when preparing a prosthesis. In the former case, a long residual limb prevents the prosthesis from occupying any forearm volume, whereas in the latter cases, a portion of the forearm socket is available to house components of the prosthesis (such as the battery in myoelectric devices).

2.11 DEVELOPMENT BOARDS

Development board is basically a printed circuit board with circuitry and hardware on-board to facilitate experimentation with certain microcontrollers. These boards can save you from a lot of repetitive tasks.

1. Arduino Development Board: ...
2. Raspberry Pi Development Board: ...
3. The BeagleBone Black Development Board: ...
4. The Intel Galileo Development Board: ...
5. The pcDuino Development Board:
6. The Uruk Development Board: ...
7. The Goldilocks Development Board: ...
8. The ExtraCore Development Board:
9. DIY Printed Circuit (PCB) Boards:

Arduino Development Board:

Arduino is the popular open-source electronics prototyping stage focused around simple to-utilize equipment and software. It's proposed for specialists, designers, and anybody intrigued by making intelligent articles or situations and is intended to be as adaptable as would be prudent to fit your venture's necessities. The Arduino Development Board is a good example of top development boards for DIY projects. Arduino is a company that deals with open source computer hard ware and software. The company designs and does manufacturing of kits creating digital devices and many interactive objects which have the capability of sensing and making good control of the whole physical world. Since it is an example of a microcontroller, it works swiftly and steadily. It is manufactured primarily by Smart Projects in Italy and many other countries and vendors.

ARDUINO MEGA 2560 REV3

The MEGA 2560 is designed for more complex projects. With 54 digital I/O pins, 16 analogue inputs and a larger space for your sketch it is the recommended board for 3D printers and robotics projects. This gives your projects plenty of room and opportunities.

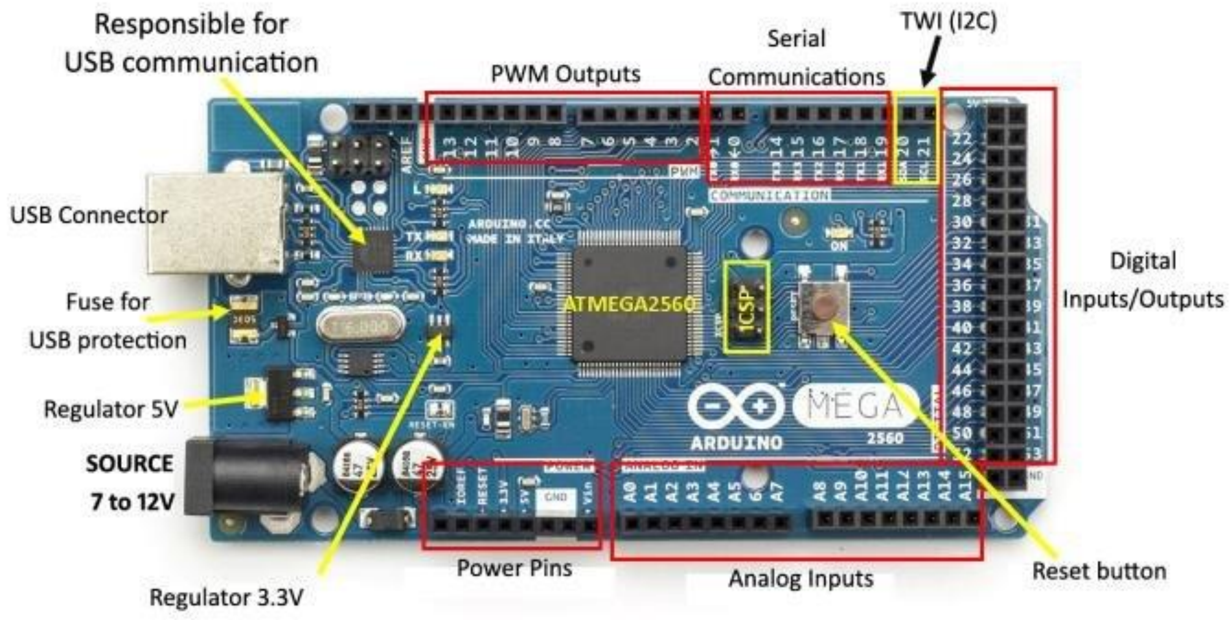


Fig 8. Controlling of servo actuation

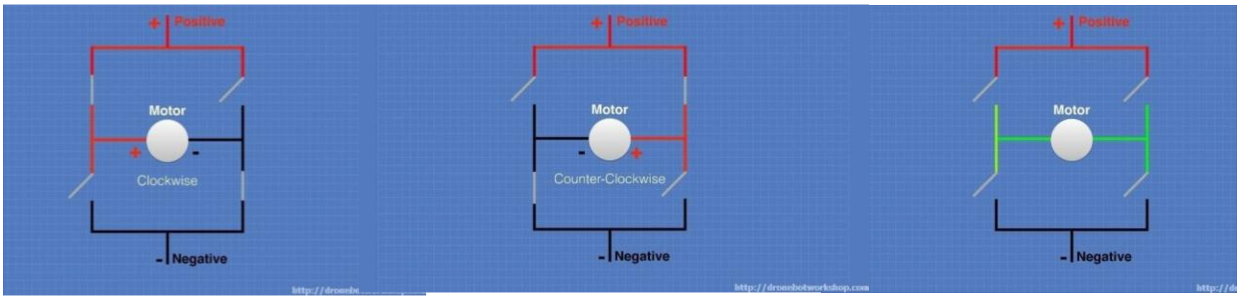
H-Bridge

An "H-Bridge" is simply an arrangement of switching the polarity of the voltage applied to a DC motor, thus controlling its direction of rotation. To visualize how this all works I'll use some switches, although in real life an H-Bridge is usually built using transistors. Using transistors also allows you to control the motor speed with PWM, as described above.

In the first diagram we can see four switches which are all in the open or "off" position. In the center of the circuit is a DC motor. If you look at the circuit as it is drawn here you can distinctly see a letter "H", with the motor attached in the center or "bridge" section – thus the term "H-Bridge".

If we close (i.e. turn on) two of the switches you can see how the voltage is applied to the motor, causing it to turn clockwise.

Now we'll open those switches and close the other two. As you can see this causes the polarity of the voltage applied to the motor to be reversed, resulting in our motor spinning counterclockwise.



This is pretty simple but effective. In fact if all you need to do is design a circuit to drive the motor

FIG 9 – H BRIDGE

full-speed in either direction you could actually build this as shown here, using a 4PDT (4 Pole Double-Throw) center-off switch. But of course, we want to control the motor using an Arduino, so an electronic circuit where the switches are replaced by transistors is what we need.

1) L298N Module Pinouts

You'll find a few different styles of L298N boards but they all operate in the same fashion. The board contains an L298N mounted on a heatsink, a 5 volt voltage regulator to "optionally) provide power for logic circuits, supporting diodes and capacitors and connectors as follows:

- Logic inputs for each H-Bridge circuit
- Power supply inputs for the motor power supply
- An optional 5 Volt power input for the logic circuits.

- Outputs for each DC motor

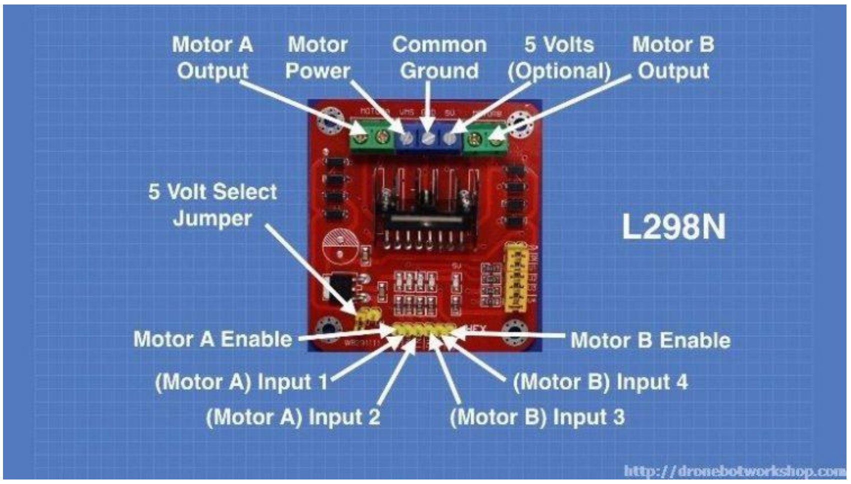


FIG 10 - L298N Module Pinouts

You'll notice that the board also has a number of jumpers. Most of the time you will leave them in place, with the exception of one. They are as follows:

- **CSA** – This is the "current sensing" function for Motor A. If the jumper is in this function is ignored. Most of the time you'll leave this jumper in place.
- **CSB** – The "current sensing" function for Motor B. Again, you'll usually just leave this in place to disable this function.
- **U1** – Input 1 pull-up resistor. You will usually leave this in place, which enables a 10k pull-up resistor for the input.
- **U2** – Input 2 pull-up resistor.
- **U3** – Input 3 pull-up resistor.
- **U4** – Input 4 pull-up resistor.
- **5v-EN** – This is the only jumper that you need to really pay attention to. When this jumper is in place it enables the boards internal 78M05 5 Volt regulator, supplying logic power from the motor power supply. When this jumper is enabled you will NOT supply 5 volts to the 5 Volt input terminal. When the jumper is removed you will need to supply 5 Volts to the 5 Volt input terminal.

If you do use the internal voltage regulator you'll have to supply the motor power supply with at least 7.5 volts.

Speaking of the motor power supply it needs to be a bit higher voltage than the actual motor requirements. This is due to the internal voltage drop in the transistors that form the H-Bridge circuit. The combined voltage drop is 1.4 volts, so if you are using 6 Volt motors you'll need to give the board 7.4 volts, if you have 12 volt motors then your motor supply voltage will need to be 13.4 volts.

The board has four input terminals plus two enable terminals. You will use these terminals to control both direction and speed or each motor. They are as follows:

- **IN1** – Input 1 for Motor A
- **IN2** – Input 2 for Motor A
- **IN3** – Input 3 for Motor B
- **IN4** – Input 4 for Motor B
- **EN1** – Enable line for Motor A
- **EN2** – Enable Line for Motor B

In order to simplify things a bit I'll just discuss the inputs and enable for Motor A, Motor B functions identically.

The two Input lines control the direction that the motor rotates. I will call one direction "forward" and the other one "reverse", if it makes more sense to you just substitute "clockwise" and "counterclockwise".

You control motor direction by applying either a Logic 1 (5 Volts) or Logic 0 (Ground) to the inputs. This chart illustrates how this is done.

INPUT 1	INPUT 2	DIRECTION
Ground (0)	Ground (0)	Motor Off
5 Volts (1)	Ground (0)	Forward
Ground (0)	5 Volts (1)	Reverse
5 Volts (1)	5 Volts (1)	Not Used

As you can see only two combinations are actually used to control the direction of the motors rotation.

The Enable line can be used to turn the motor on, to turn it off and to control its speed. When the Enable line is at 5 Volts (1) the motor will be on. Grounding the Enable line (0) will turn the motor off.

To control the speed of the motor you apply a Pulse Width Modulation (PWM) signal to the Enable line. The shorter the pulse width, the slower the motor will spin.

1) MD10C

➢ Introduction:

Enhanced 10Amp DC Motor Driver (MD10C) is an enhanced version of the MD10B which is designed to drive high current brushed DC motor up to 13A continuously (for Rev2.0). It offers several enhancements over the MD10B such as support for both locked anti-phase and sign-magnitude PWM signal as well as using full solid state components which result in faster response time and eliminate the wear and tear of the mechanical relay.

Arduino main boards such as Arduino Uno are quite popular these days due to its easy-to-use programming environment. Therefore, by interfacing Arduino main board with MD10C, we gain easier control of DC motors. In addition, further adding an Arduino LCD Keypad Shield can help us to control the DC motor that connected to MD10C with the 6 momentary push buttons (built-in push buttons on LCD keypad shield including 1 Reset button) and also display some useful message or information.

➢ How does MD10C work?

One of the features of MD10C is it supports both sign-magnitude and locked anti-phase PWM signal, means you can control motor in 2 different ways!

- Sign-magnitude mode

You require 2 separate signals to control the motor, one is for direction (counterclockwise or clockwise) and another is for the speed. To control motor direction, DIR pin is connected to HIGH or LOW for different direction, whereas PWM pin is fed with PWM signal to control the motor speed.

- Locked anti-phase mode

In this mode, only 1 signal is required to control both speed and direction of motor. PWM pin of MD10C is always connected to HIGH (5V), while DIR pin is fed with d to PWM signal.
The direction of motor depends on whether the duty cycle of PWM signal is less than or more than 50%. The motor will run in one direction if the duty cycle is less than 50% and another direction if more than 50%. The motor stops if duty cycle is 50% (approximately). The speed

depends on the percentage of duty cycle.

<u>Sign-magnitude VS Locked anti-phase</u>

Main advantage of using locked anti-phase mode compare to sign-magnitude mode in motor controlling is it reduces number of I/O pins used since it uses only 1 signal for controlling both the speed and direction of motor. However, if locked anti-phase is used, in the beginning motor will run at maximum speed (as you can see in the video) when there is no PWM signal. Users will have to provide PWM signal at 50% duty cycle to DIR pin or set PWM pin (MD10C) to LOW state in the beginning. In terms of programming, the algorithm will be more complex because in locked anti-phase mode, motor speed changes with increment or decrement of PWM value depends on the direction which the motor is at. Motor becomes slower with increment of duty cycle if duty cycle of PWM signal

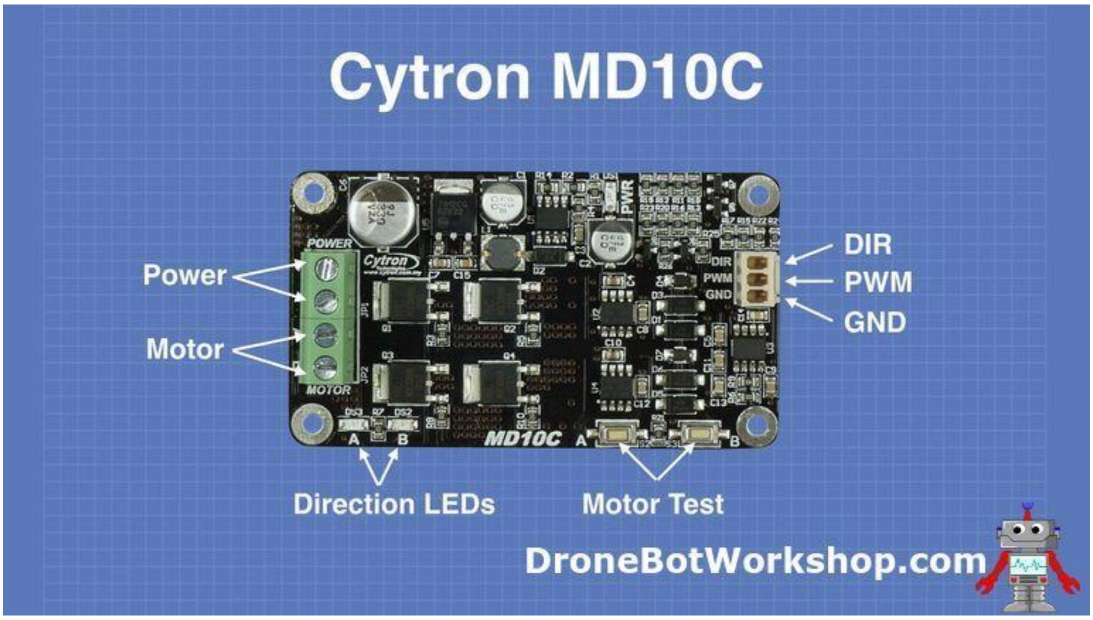


FIG 11 – CYTRON MD10C

is less than 50% or otherwise if duty cycle is more than 50%.

2) Md10a

- **Introduction**

MDD10A stands for Motor Driver Dual Channel 10(Amps). This DRIVER is the dual channel version of MD10C which is designed to drive 2 brushed DC motors at high current s up to 10A each, continuously. Just like MD10C, MDD10A also supports locked-antiphase and sign-magnitude PWM control. It uses all solid-state components resulting in faster response times and eliminates the wear and tear of mechanical relays.

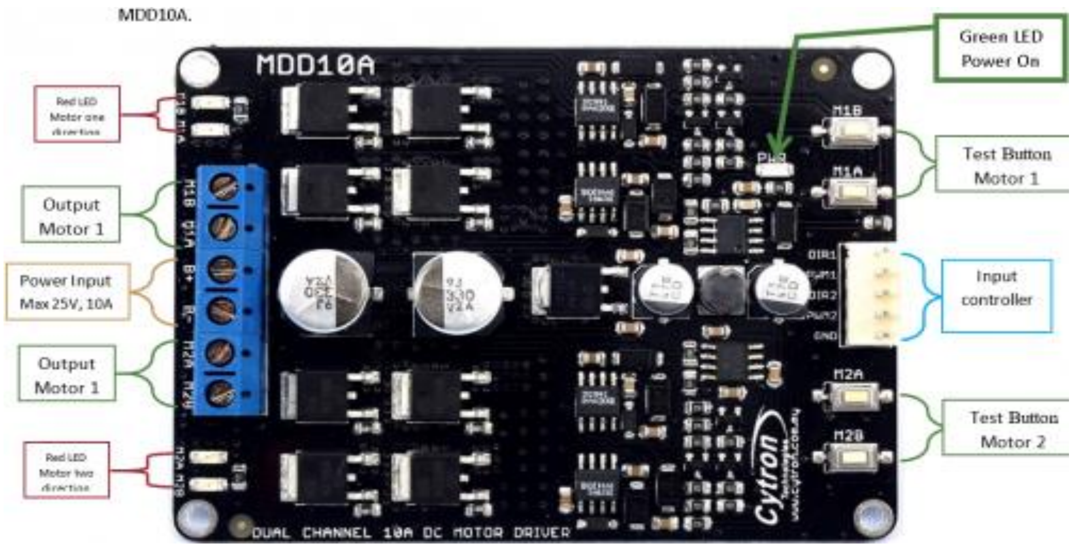


FIG 12 - MD10A

BIONIC ARM DATA ACQUISITION AND CLASSIFICATION

Many different approaches are presently used to control the Bionic Arm. Some of the widely used approaches are-

1. EEG signal analysis approach. 2. EMG signal analysis approach.

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain[3]In EEG signal approach, the brainwaves are sensed from different regions of brain. The Signal frequency range is around 1 to 500 Hz and amplitude is around 50 micro volts[4]. These signals are weak in amplitude and have a lot of noise. Plus, it is hard to distinguish between the signal for left and right hand movements. In EMG signal approach, the brainwaves are sensed near the arm. This signal is produced due to the neural and muscular activity. So the signal is comparatively strong and easy to extract. Since the signal is sensed near the arm there is no problem of right and left hand movement differentiation. In addition to that, processing EEG is complex and consumes more power.

The EMG signal is a biomedical signal that measures electrical currents generated in muscles during its contraction representing neuromuscular activities[5]. The amplitude of the signal is in the range of 0-10 mV[5]. Signal frequency range is above 12 Hz. It is proposed to use EMG signal approach since is easy to implement and gives better signal quality. With good analysis tools and algorithms, the EMG signals can be mapped with the control signals for the servo motors in Bionic Arm with a high degree of accuracy.

There are two ways to extract the EMG signal.

1) Intramuscular EMG (invasive electrode)

2) Surface EMG (non-invasive electrode)

Commercially many different Bionic Arm options are available with a varying degree of freedom in the motions. It is intended to design a Bionic Arm that mirrors as many motions of the actual human hand as possible. For this, study of various actuators and robotic mechanisms will be undertaken to design the Bionic Arm.

Sensors

The requirements for a sensor to successfully acquire EMG signal are as follows

- It should contain a 10-500Hz Band Pass filter to remove the high frequency noise from the signal.
- It should contain a 50 Hz Notch filter for noise reduction.
- The signal strength of EMG signals is very low. It is in the range of 0-10 mV. Thus, the sensor should have an amplifier to amplify the signal strength.
- A high-resolution ADC is needed to convert the EMG signal from analog to digital value.

Along with sensors, right electrodes also need to be chosen to obtain accurate readings. There are various types of electrodes available. Since we are going for sEMG signal extraction, the non-invasive electrodes will be used. The signal extracted with dry electrodes tends to be noisy and weak in strength. Conductive gel electrodes provide better signal extraction as compared to dry electrodes but they need to be replaced regularly since the conductive gel is not long lasting.

3.BIONIC ARM DESIGN

3.1 Palm Design

Introduction

The aim of the project is to build a high DoF Bionic Arm which will be light in weight. Achieving high dexterity is a herculean task, so a step by step approach was undertaken. For incorporating dexterity in artificial robotic hand, the fingers of the hand should have more than one DoF. So initially the work initiated with designing and implementation of 1 DoF finger. The design of Bionic Arm is divided into 3 phases, following is the detail description of the phases-

3.1.1 Design Phase 1

The design process of Bionic Arm initiated with single DoF finger actuated by string mechanism. The string was actuated by high torque servo motors. The string mechanism consisted of a nylon string which was passed through the finger in such a way that when the string is pulled by adequate force, the finger flexes. Thus, providing a flexion and extension motion of finger.

Single DoF finger actuated by servo motor.

NRS 995 servo motor used for experimenting

Specifications of servomotor -

- Dimension-40.7mm x 20.5mm x39.5mm
- Torque-15.5kg/cm at 4.8V, 17kg/cm at 6V
- Dual bearing with metal gear
- Motor weight-60gms
- Operating speed-0.15sec/60 degree
- Operating voltage-4.8V to 6V
- Temperature range-0-55C
- 0.6 ms for 0-degree Rotation
- 2.2 ms for 180-degree Rotation

After pulling the strings, actuation is observed at PIP, DIP and MCP joints. Though the actuation is not an independent one, the movement at DIP and PIP are passive DoF.

Advantages

- Simple Mechanism due to use of servo motor and strings,
- Servo motor is easy to control.
- The total weight of the hand can be close to 500 grams.
- Simple Kinematics of the finger.

Disadvantages

- The mechanism is mainly based on the quality of strings; highly tensile strings are required which can endure millions of cycles of pulling forces. So, a high tensile string is required. But as amputees heavily use the artificial hand, the

servo string mechanism will fail in long terms as string will fail to provide that tensile strength due to wear and tear.
- As it is only 1 DoF per finger, it has less dexterity.
- String-servo motor mechanism can only give flexion and extension motion and lack of feedback in servo motors leads to inefficient actuation.

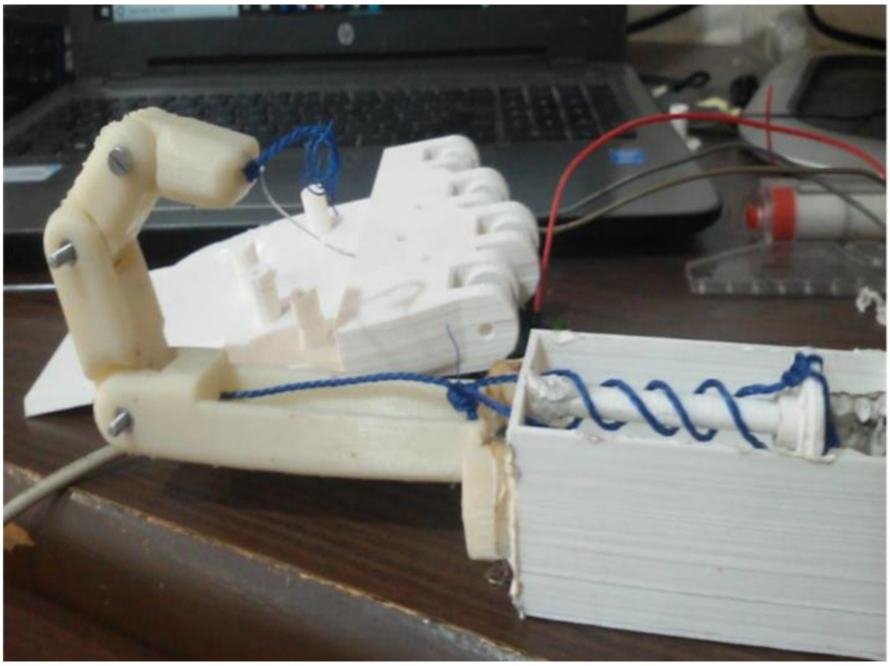
Thus, it was concluded that servo string mechanism cannot be used to design fingers with more than one active DoF.

3.1.2 Design Phase 2

After experimenting with servo string mechanism, design phase 2 was initiated. In phase 2 of design, after considering the advantages and disadvantages of previous mechanism it was decided to continue with the same finger model. This time rather than using a servo motor, Johnson DC motor was used.
The purpose of using a DC motor was to incorporate precise control over flexion and extension motion of the finger. Here for actuation of finger, rather than using single string, a twisted string was used. The DC motor was coupled to two strings and the rotatory motion of DC motor twisted the strings leading it to linear actuation which flexed the finger.
Specifications of Johnson DC Motor-

- Base Motor RPM-18000
- Operating Voltage-6-18 V
- Rated Voltage-12 V
- Rated Torque-7.5 kg-cm
- Stall Torque-30 kg-cm
- Gearbox Dimensions-25×37 (LxW) mm

Twisted String Actuation using DC motor



Finger mounted on holder, holding Johnson DC motor

Advantages

4 Johnson DC motor provided enough torque which was converted to force imparted on the tip of the finger.
5 Precise angular control of the finger.
6 Adequate grasping was achieved.

Disadvantages

7 Johnson DC motor provided enough torque but at the cost of its high weight due to heavy metal gears. 60 RPM motor weighted 164 grams. So, weight of single finger mechanism was about 180 grams. This will lead to overall weight of arm up to 1kg.
8 High weight was not acceptable as it is not suitable for amputee to use such a heavy artificial arm.
9 Arm has used Maxon motors with planetary gears. Maxon motor are costly and are not feasible for low cost Bionic Arm design.
10 Less dexterous.

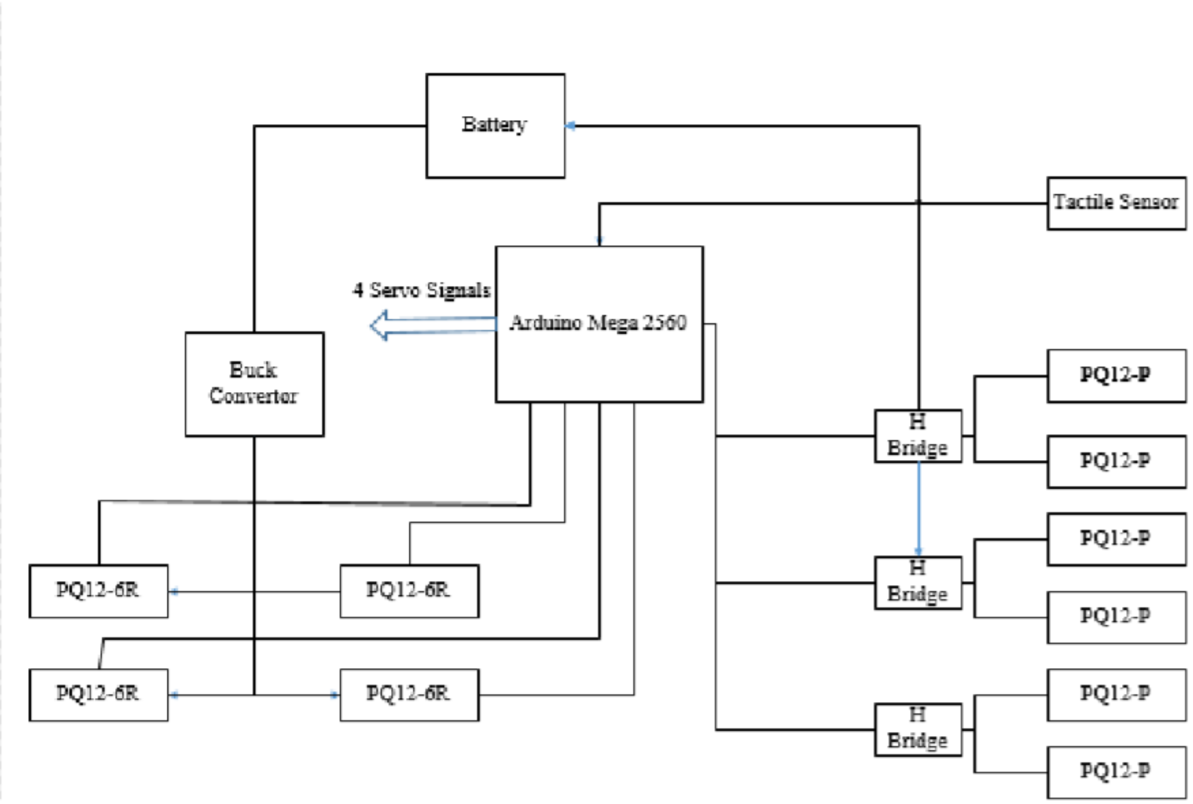
Thus, this mechanism was not feasible solution for the problem statement.

3.1.3 Design Phase 3

Need for Design Phase 3

11 After experimenting on two mechanisms, a better mechanism for fingers was required which will provide more DoF and dexterity.
12 While maintaining the dexterity, goal of light weight prosthetic was also to be achieved.
13 Though DC motor and Servo motors are famously used for actuation in robotic arms and prosthetic arms, a different type of light weight and high force imparting actuator was needed to address the problem statement.
14 Thus, it paved the roads for the design phase 3.

Block Diagram of Proposed System



Working of the Bionic Arm- As finalization of incorporating of linear actuator in the Bionic Arm was done, detail working of Bionic Arm is as follows-

Working of PQ12 Linear Actuator Linear Actuator consist of following parts-

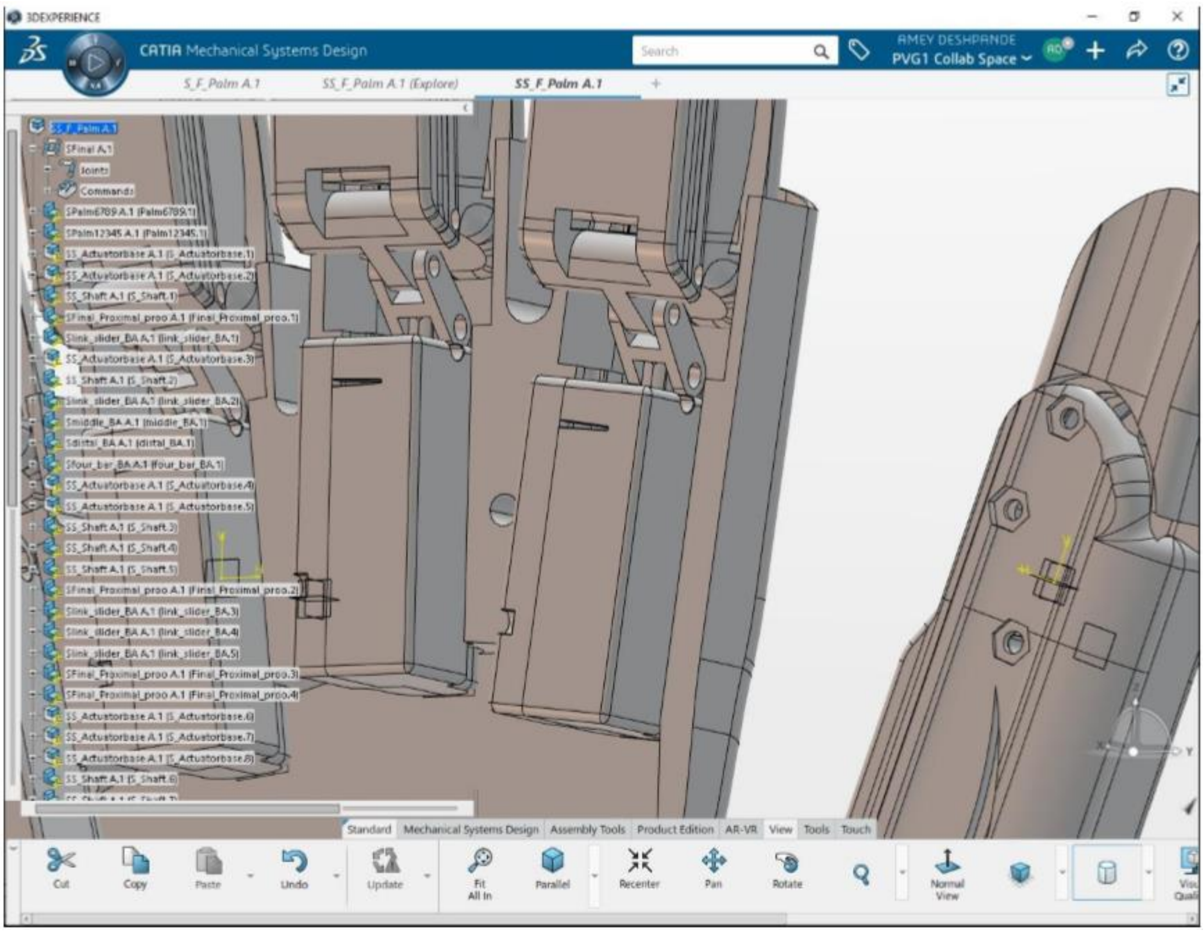
- DC Motor
- Gears
- Lead Screw

In linear actuator linear motion is obtained from conversion of rotational motion of DC motor. The DC motor is connected to set of gears which improves the torque, while the set of gears are also connected to lead screw. The lead screw moves in linear direction. So, as the motor rotates, lead screw moves in linear direction.

Mechanism Design and incorporation of Linear Actuators in the mechanism-

Linear Actuator works on the principle of slider crank mechanism. These slider crank mechanisms provide linear movement. This linear movement has to be converted into rotatory motion. So, to have angular motion at joints of finger, a revolute joint is introduced by a small link at the MCP and PIP joints of the finger. The finger mechanism was designed in 3DExpereince platform, which provided many tools like Part Design, Assembly Design, Mechanical System Design.

Thus, using 3DExperience entire Bionic Arm was designed



Linear actuator connected to a revolute joint link for actuation at MCP joint

Here to improve the DoF, PQ12 actuator is placed in proximal phalange of a finger to actuate PIP joint and another PQ12 actuator is placed in the palm to actuate MCP joint. Thus, each finger is actuated by two Linear actuators and each finger thus has two active DoFs.

The Figure 6-7describes the mechanism of MCP revolute joint. A small link was designed which converted linear actuation into rotatory actuation. The link was connected to the shaft of the linear actuator by a screw. When linear actuator extends up to 16 mm, the finger was rotated about that link for 90 degrees. Thus, there was rotation for 0-90 degrees at MCP joint, which also mimicked the human finger rotation at MCP joint.

Actuator in Proximal Phalange for actuation at PIP joint

The above Figure 6-8describes actuation at proximal joint. Here a separate DoF is introduced at PIP joint. An independent DoF at proximal joint helps for stable pinch and lateral grasp. This also improves the dexterity of the Bionic Arm. A linear actuator is placed in proximal phalange of the finger. The design was such that when the actuator extends, the upper part of the proximal joint was supposed to rotate for 90 degrees.

One more feature added to this joint was that it was connected to the DIP joint of the finger by a link. The famous four bar mechanism was implemented between PIP and DIP joint. The implementation of four bar mechanism lead to the relative movement of DIP joint with respect to PIP joint Due to this motion, an intuitive finger motion was implemented which had an anthropomorphic design.

Thumb assembly and actuation on servo motor

The thumb is an important part of human hand. Without thumb, it would be impossible to achieve any kind of grasp. So, the goal was to improve the dexterity of the thumb. In human hand thumb has 5 DoFs but implementing 5 DoFs in thumb was not an easy task. So only main and important DoF/movement of thumb had to be selected. After studying the role of thumb in object grasping ,3 DoFs were selected. Following were the 3 DoF selected-

- Flexion extension motion(1-DoF) of thumb was implemented by mounting thumb on a servo motor which rotated from 0 to 90 degrees.

- One linear actuator was placed in thumb phalange to actuate DIP joint of thumb (1 DoF). The actuation at this joint was important for pinch grasp

- Another linear actuator was placed in another thumb phalange for actuation at MCP joint (1 DoF). The actuation at this joint was important for lateral grasp

Thus, 3 DoF for thumb was implemented.

Bionic Arm assembly (11 DoF.)

Total DoFs in the Bionic Arm-

- Each finger has two DoFs, so total DoF including all fingers is 8 Thumb takes an important part of our hand and all the stable grasps are achieved due to thumb. A decision was taken to increase the DoF of thumb. So, thumb had 3 DoF.
- The thumb of Bionic Arm has actuation at IP joint and MP joint as well as flexion and extension movement of finger was implemented using servo motor fixed in palm.
- Thus, total DoFs in the Bionic Arm is 11.

3.2 Design of Wrist

Introduction

The human wrist contributes greatly to the mobility of the arm/hand system, empowering dexterity and manipulation capabilities. Wrists can improve manipulation capabilities, as they can orient the end-effector of a system without imparting significant translational motion.

The healthy human wrist serves as an effective baseline toward which prosthetic wrists are designed, and a point of reference for which any orientation device may be considered. It is capable of motion in 3-DOFs, namely pronation/supination, flexion/extension, and radial/ulnar deviation. Each DOF is a paired set of motions, referring to positive and negative motion within each DOF.

3.2.1 Mechanism selection

After studying different types of articulation methods, joint types of healthy human wrist and mechanism types, it was decided to design and manufacture the wrist having 3 Dof.

Universal joint-

A universal joint is a positive, mechanical connection between rotating shafts, which are usually not parallel, but intersecting. They are used to transmit motion, power, or both.

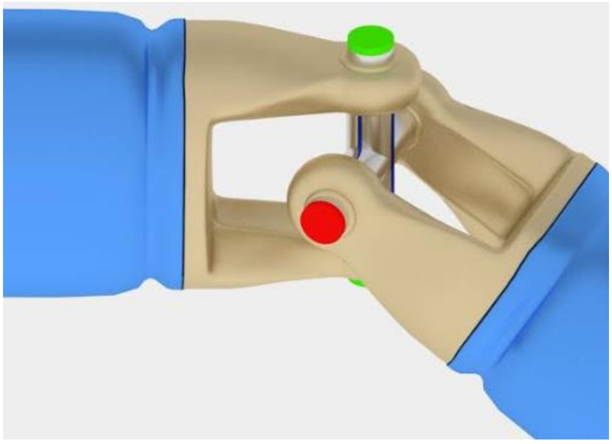


FIG 13 – UNIVERSAL JOINT

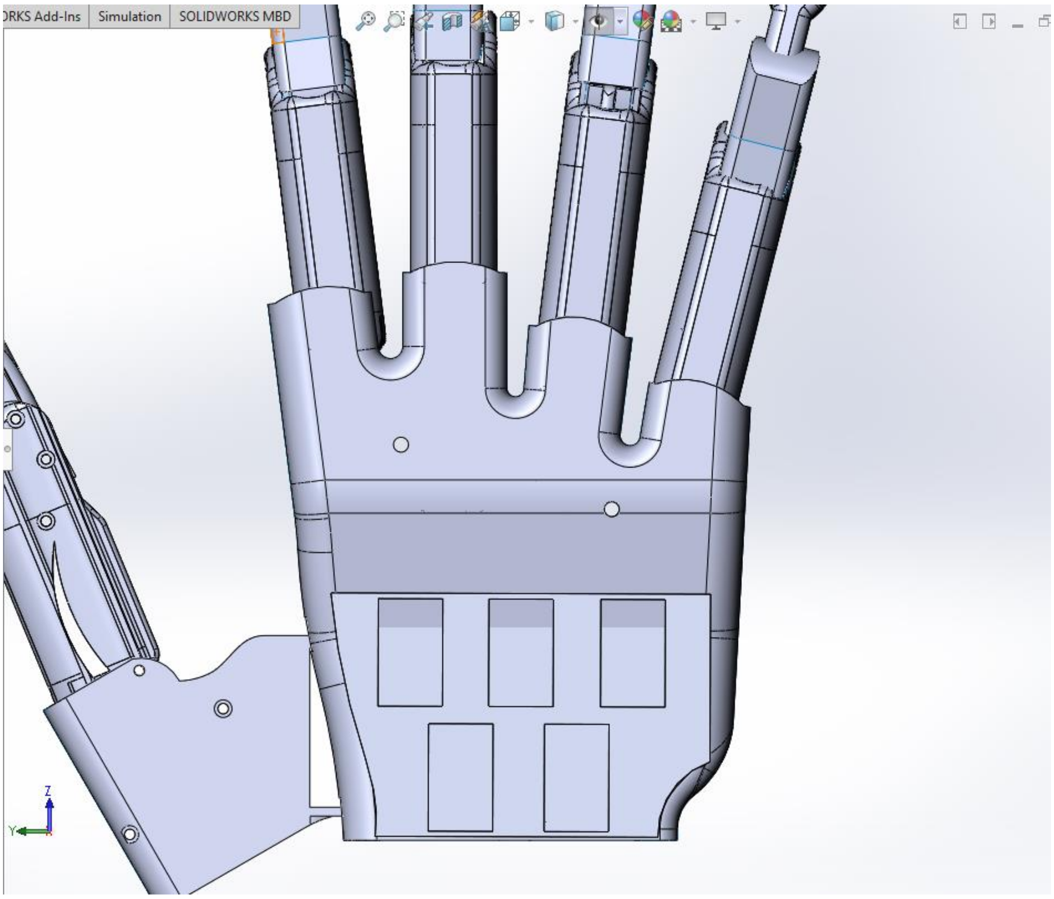
The universal joint was appropriate for the purpose because of following reasons-

- Torque transmission efficiency is high.
- The joint permits angular displacements.
- Low side thrust on bearings.
- Large angular displacements are possible.
- High torsional stiffness.
- Simple design.

3.2.2 Design Stage 1.

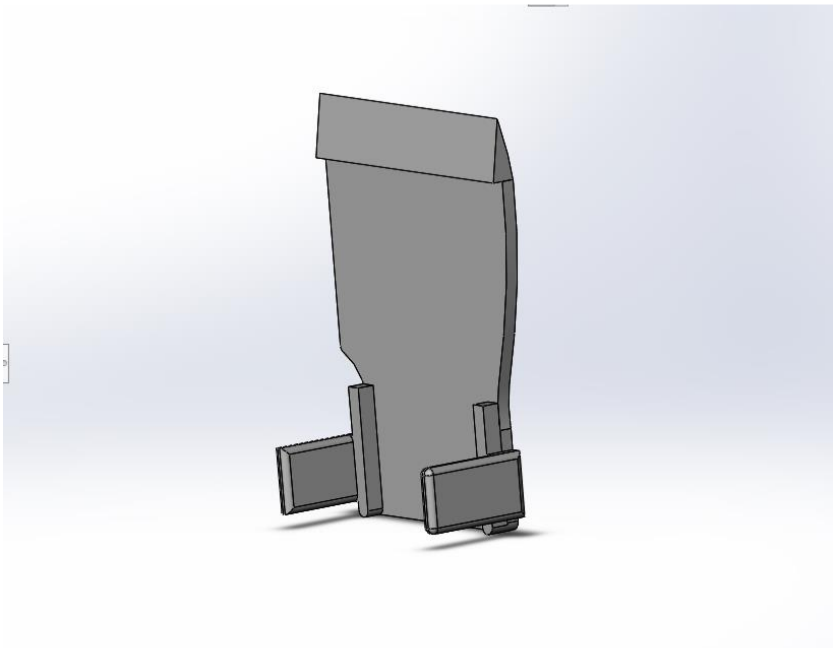
- **Slots for motor drivers**

To make the connection of actuating wires and motor drivers easier and understandable and also for providing correct position to motor driver boards so that no incorrect positioning of boards will happen the slots are provided. This makes connection of wires from outer side of the palm and hence in case of any damage, repairing becomes easier.



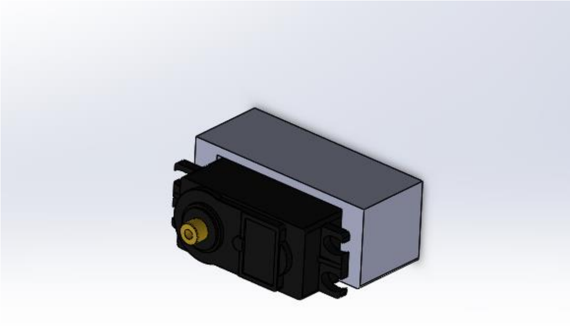
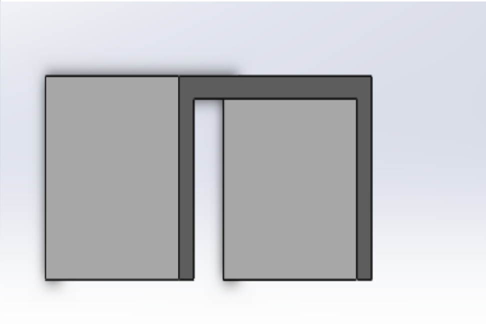
4 Palm cover

This is used to give better aesthetic appearance to the palm and also to give support to the palm during its rotation.



5 Link 1 and Link 2

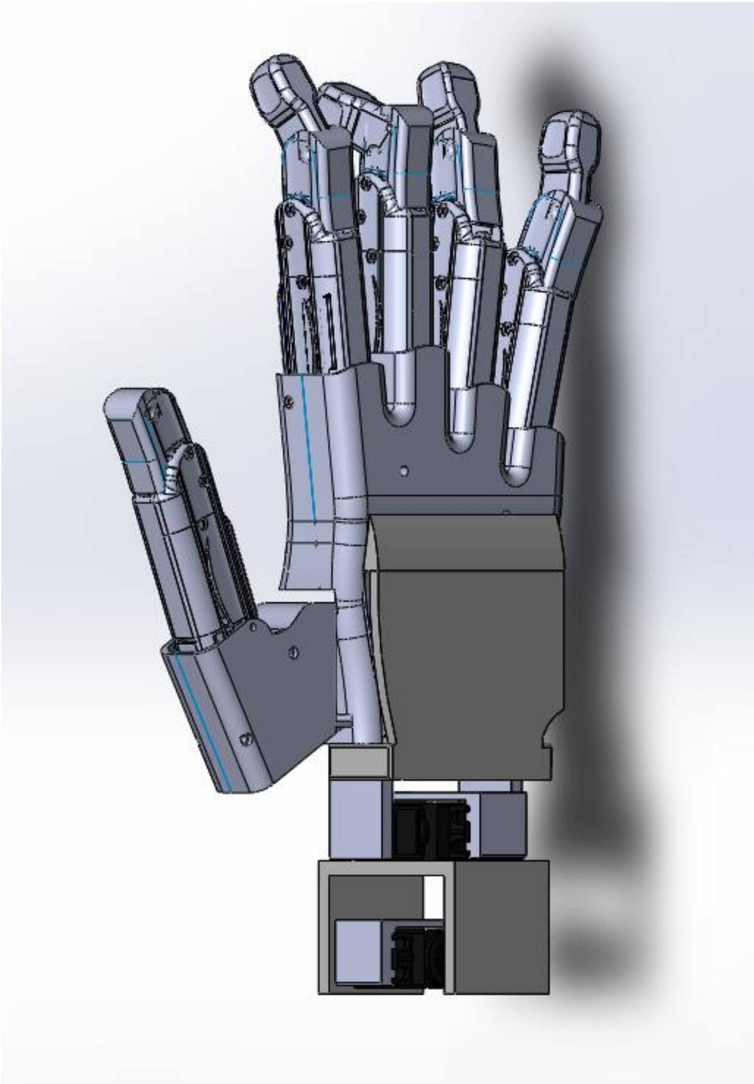
Drawings below show the selected motor (MG 995) and links used to connect motor and to give proposed wrist motion to the palm. The link 1 is used to give front-back motion to the palm and link 2 is used to give side by side motion to the palm. A casing is made to cover the motor to give it stiffness while mounting.

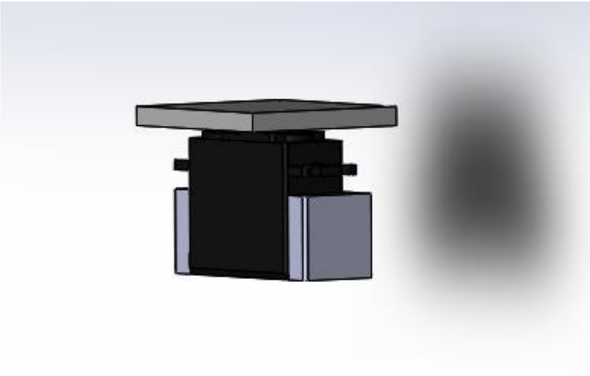
6 Assembly of palm cover link 1 and link 2

CAD model below shows the assembly of palm, cover, links and the mounting plate.

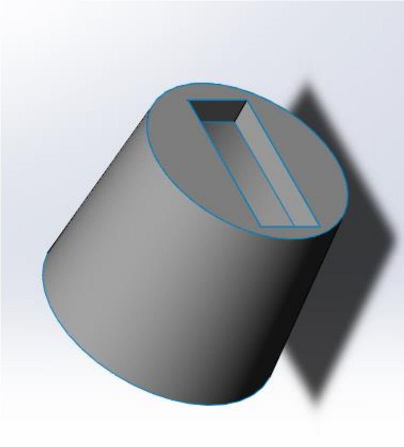
This assembly is used for giving 2 Dof to the palm.



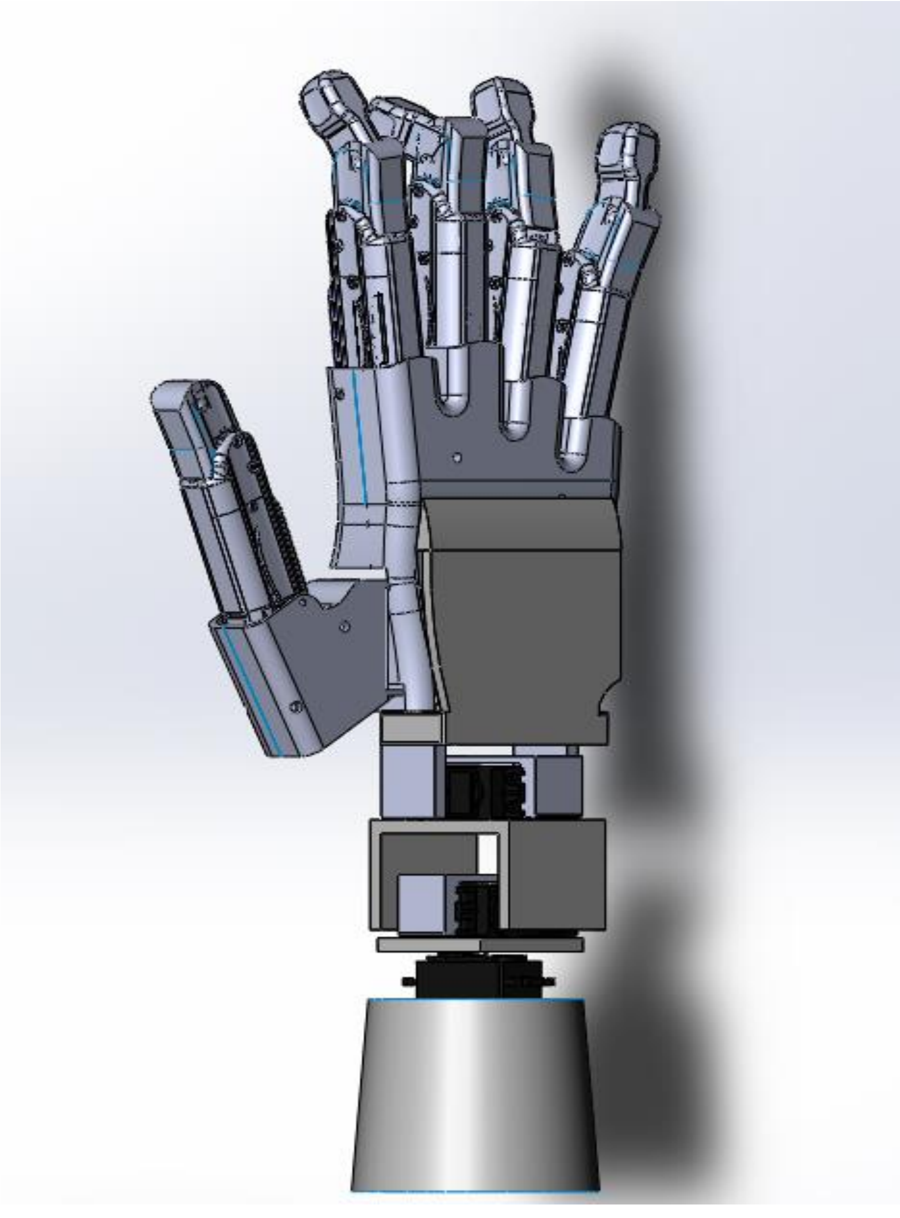
7 Link 3



8 Wrist



9 Final assembly



Need for design stage 2 –

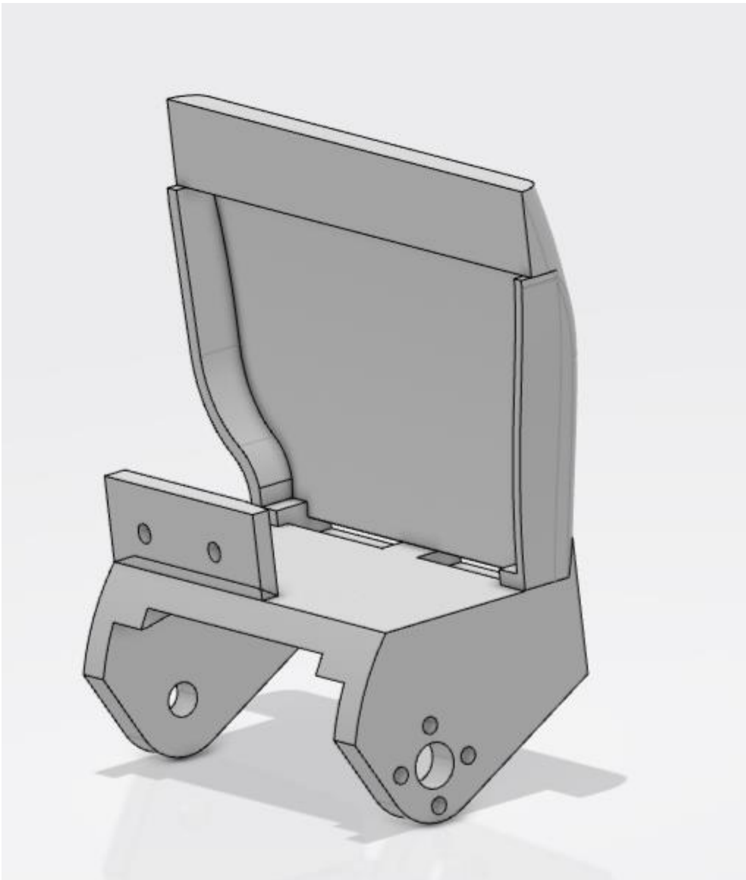
1. Previous design is aesthetically poor as it consists of many gaps between the links.
2. Some unnecessary links can be eliminated.
3. Some mechanism can be added at the bottom to reduce friction at bottom part.

3.3.3 Design Stage 2-

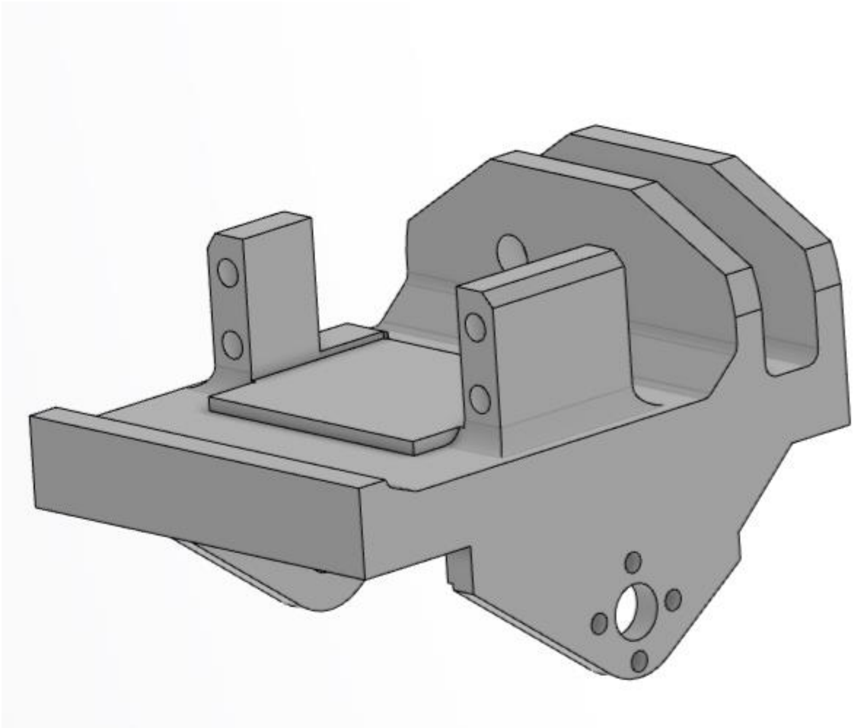
In design stage 2, the basic mechanism of wrist was kept same but some unnecessary links were removed and links were given round shape from inner side to give perfect hinge type motion. From new links it was easier to locate exact position of motors. Also, bearing is added at the lowest portion to reduce friction and support rolling action.

Following snapshots explains the design. Wrist was also designed using 3D-Experience software.

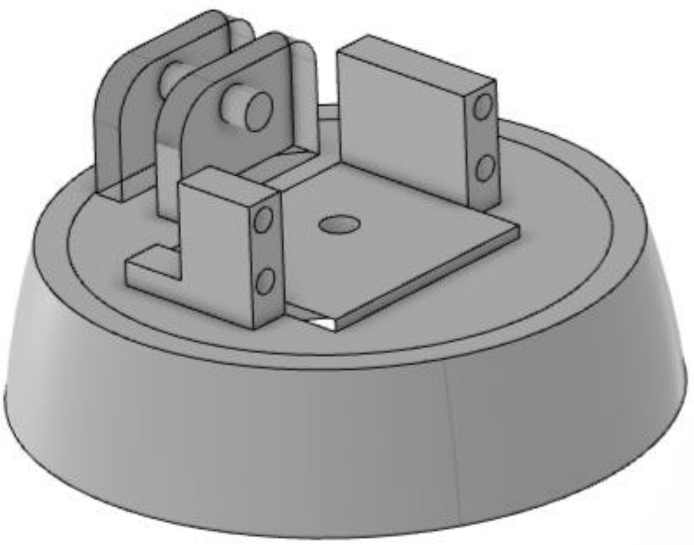
10 Back cover



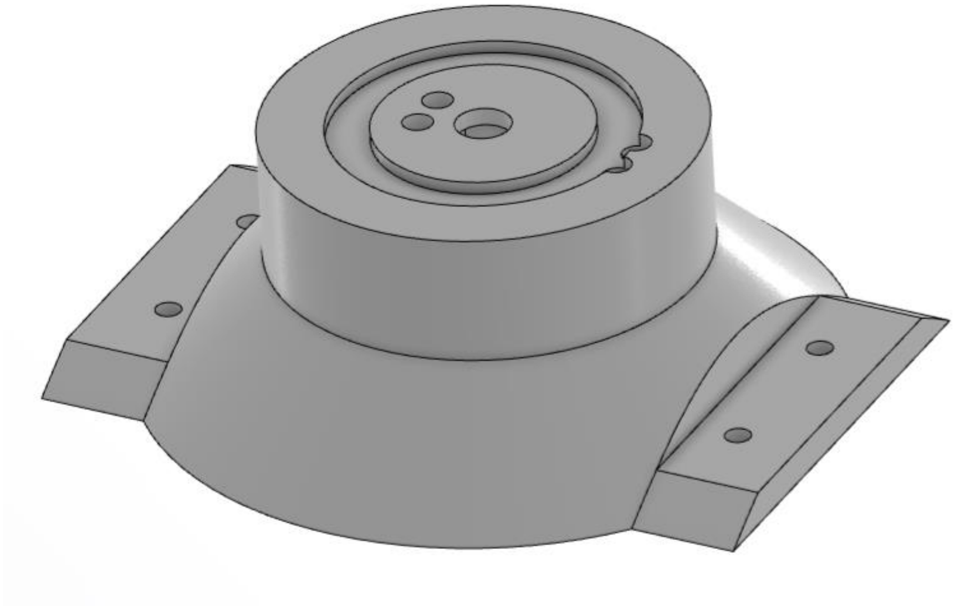
11 Link 1



12 Link 2



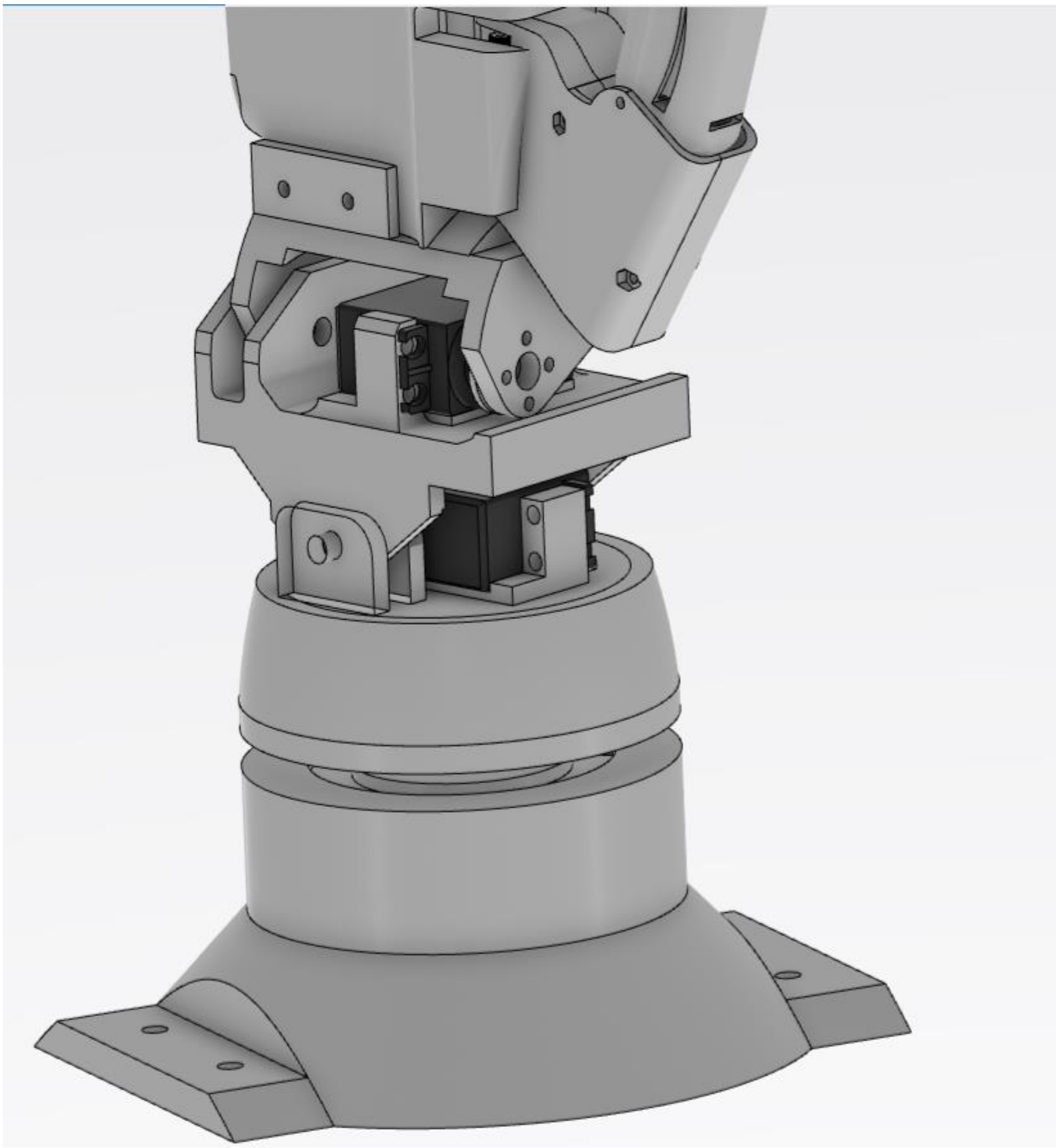
13 Link 3



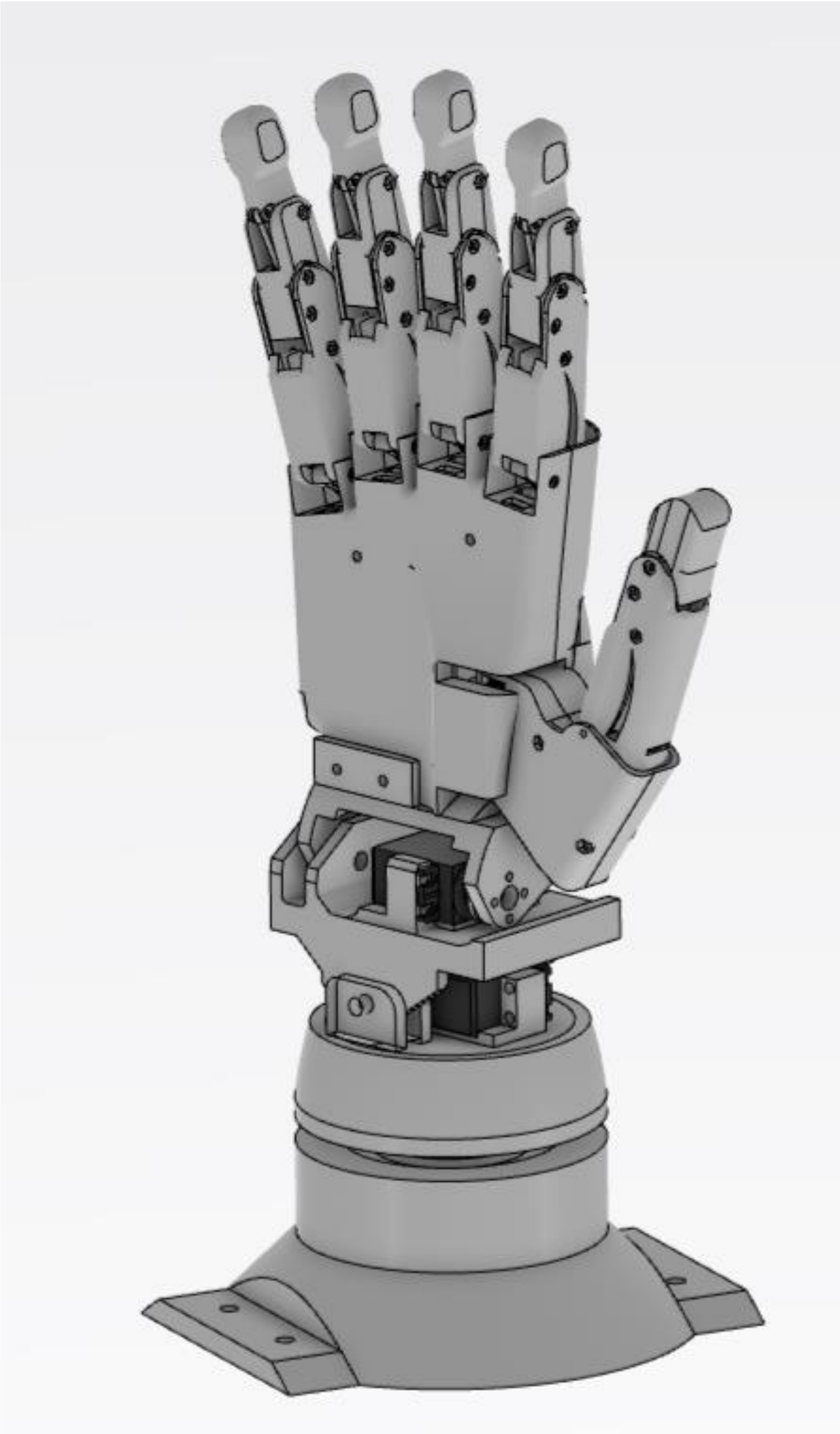
Circular slot is made on the top to accommodate bearing to support rotary motion.

Flanges provide mounting of arm and supports the arm.

14 Assembly of wrist



Assembly of arm



4.CALCULATIONS

4.1 Selection of motor

4.1.1 Selection Procedure

The data required for selection of motor is as followed-

- Dimensions and mass (or density) of load
- Dimensions and mass (or density) of each part
- Friction coefficient of the sliding surface of each moving part

The required specifications for the equipment are:

- Operating speed and operating time
- Positioning distance and positioning time
- Resolution
- Stopping accuracy
- Position holding
- Power supply and voltage
- Operating environment
- Specific features and requirements such as; Open-Loop, Closed-Loop, Programmable, Feedback, IP rating, Agent approvals, etc.

4.1.2 Motor Sizing Calculations

There are three factors to calculate when sizing a motor; Moment of Inertia, Torque, and Speed.

Moment of Inertia

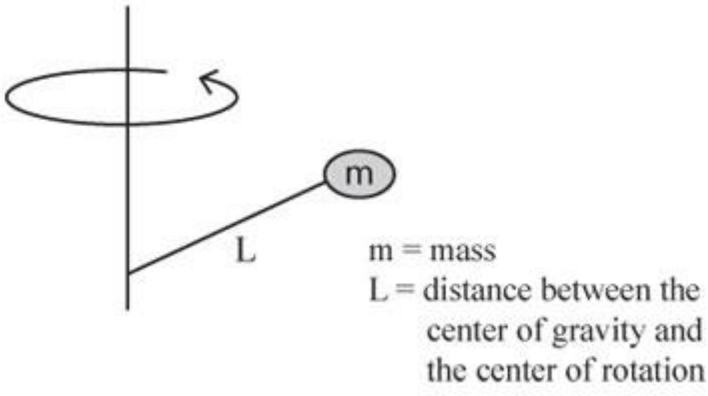
Moment of inertia is the measure of an object's resistance to changes in its rotation rate.

When an object is just sitting without any motion, the moment of inertia is 0.

When you try to make it move that mean you want to change the speed of the object from 0 to any, there will be moment of inertia effect.

Moment of Inertia Calculation for a Rotating Object

$$J = mL^2$$



4.1.3 Torque:

Torque is the tendency of a force to rotate an object about an axis. Torque is made up of two components; a load (constant) component and an acceleration component.

The load torque component is usually due to friction and/or gravity and is always acting on the motor. This component can usually be determined by calculation or by putting a torque wrench on the system and reading the torque value. When it is not able to measure, then we use some equations to calculate the approximate value.

The acceleration torque however, is only acting on the motor when it is accelerating or decelerating. Once the motor is running at a constant speed, this component goes away. Measuring the acceleration component is difficult not to mention dangerous. If you want the load to be up to speed within 50 milliseconds, it's likely that a torque wrench will fly off. Therefore, we calculate the acceleration component. This component is a function of the inertia of the system and the acceleration rate. So, once we determine these values, we can figure out the acceleration torque.

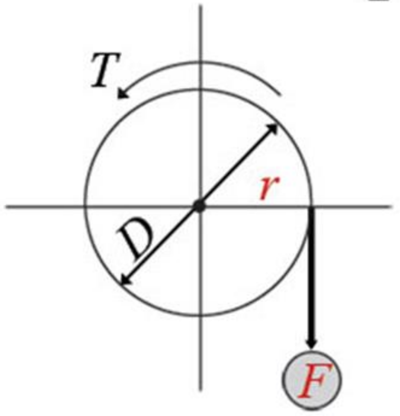
4.1.4 Load Torque (*T*)

Load torque is very simple.

As you see this equation torque is the product of the force and the distance between the force and the center of rotation. For example, if you want to hold the force acting on the end of pulley, $T = F \times r$. So calculating load torque is determine the force in the system and the logical distance between the motor shaft and the where the force is acting.

When the mechanics become complicated, we need to convert the F and r to fit the mechanics.

$$T = F \times r = F \times \frac{D}{2}$$



r = distance between the center of rotation
F = force point

With each application, the drive system requirements greatly vary.

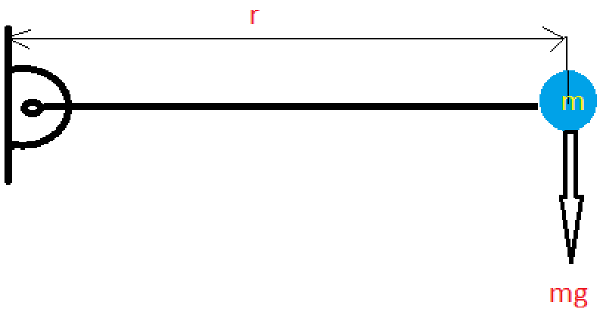
DC Servomotors

Advantages	Disadvantages
Smooth operation, low-velocity ripple	Brushes limit ability to continuously start and stop
High torque	Brushes require maintenance

4.1.5 Stall torque calculations

Stall torque is the torque produced by a mechanical device whose output rotational speed is zero. It may also mean the torque load that causes the output rotational speed of a device to become zero, i.e., to cause stalling. Electric motors, steam engines and hydrodynamic transmissions are all capable of developing torque when stalled.

considering the system in horizontal position (maximum stall torque)



m = mass centre of mass of the system

r = distane of centre of mass

Stall torque = force * displacement

Observed data,

Total mass of the system (m) = 656 gm

Distance of centre of mass (r) = 7.376 cm

Now,

Stall torque = mg * r

= 0.656* 9.81 * 0.07376 N. m

= 0.4736 N. m

= 0.656 * 7.376 kg.cm = 4.8386 kg.cm

Given,

Operating voltage = 5 v

ω = (60 degrees/0.2 sec) = 5.235 rad/sec,

torque = 10 kg.cm

power rating (@ 4.8v) = torque * ω

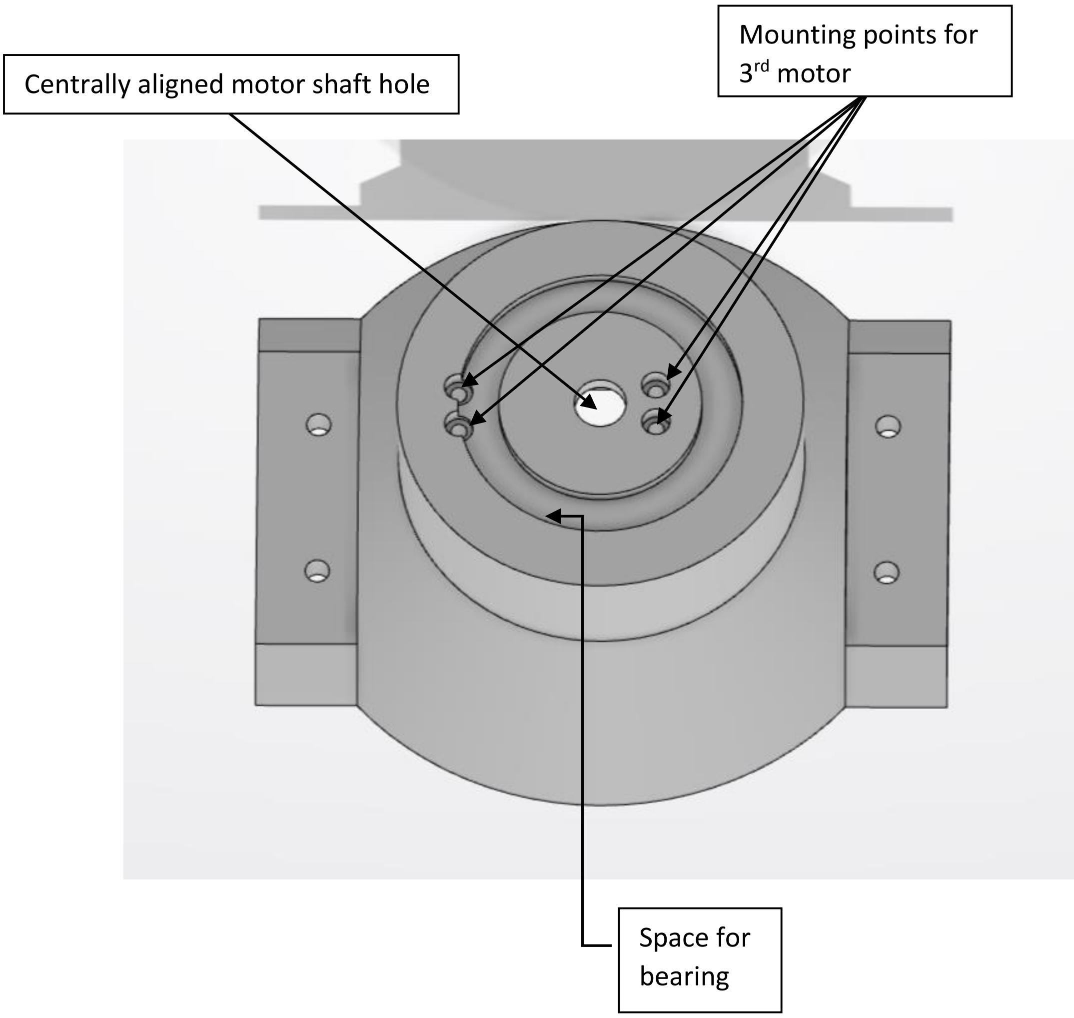
= 0.10 * 9.81 *5.235

= 5.135 watts

1. Model: MG995
2. Weight: 55 gm
3. Operating voltage: 4.8V~ 7.2V
4. Servo Plug: JR
5. Stall torque @4.8V : 10 kg-cm
6. Stall torque @6.6V : 12 kg-cm

TowerPro MG995 Metal Gear Servo Motor
(180° Rotation)-Standard Quality

4.2 BEARING SELECTION



Because of the position of motor, the only constraint for selection of bearing was dimensions of the bearing. The bearing should be placed such that it is centrally aligned with the upper arm.

For the current movement of arm, we selected Thrust ball bearing having following specifications.

4.2.1 Specifications of 51110 Thrust Ball Bearing 50x70x14mm –

SKF Single direction thrust ball bearings consist of a shaft washer, a housing washer and a ball and cage thrust assembly. The bearings are separable so that mounting is simple as the washers and the ball and cage assembly can be mounted separately. Single direction thrust ball bearings, as their name suggests, can accommodate axial loads in one direction and thus locate a shaft axially in one direction. They must not be subjected to any radial load.

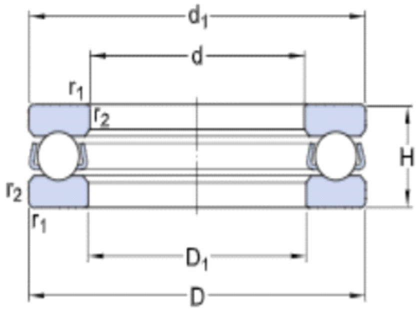
CALCULATION DATA

Basic dynamic load rating	C	27 kN
Basic static load rating	C_0	75 kN
Fatigue load limit	P_u	2.8 kN
Reference speed		4300 r/min
Limiting speed		6300 r/min
Minimum load factor	A	0.029

MASS

Mass bearing (including seat washer where applicable)	0.16 kg

Technical Specification



DIMENSIONS

d	50 mm
D	70 mm
H	14 mm
d_1	≈ 70 mm
D_1	≈ 52 mm
$r_{1,2}$	min. 0.6 mm

5.MANUFACTURING PROCESS AND MATERIAL SELECTION

5.1 Manufacturing Process

5.1.1 Introduction:

It is wise to think about the best tools and processes to finish your design when you want to develop a product prototype. The three primary ways to make prototypes are subtractive manufacturing (CNC machine parts), injection molding (designed to pre-produce prototypes), or additive manufacturing (3D printing).

3D printing, refers to the process of producing 3-dimensional solid objects from a computer file. Printing happens in an additive process where a solid object is developed through the successive layering of material. There are a wide range of materials to choose from including plastic and metal. The procedure starts with the creation of a 3D digital file such as Computer Aided Design. The 3D digital file is then sent to a 3D printer for printing using a simple print command.

5.1.2 Benefits of using 3D Printing-

- Better Quality

3D printing allows the step-by-step assembly of the object, which guarantees enhanced designs and eventually better-quality objects.

- Tangible Design and Product Testing

There's no way seeing a product on the screen or virtually can compare to the actual feel of a prototype. 3D printing offers that benefit. It is possible to experience the touch and feel of the product prototype to physically test it and find flaws in the design. If a problem is found, you can modify the CAD file and print out a new version by the next day.

- Cost-effectiveness
- Creative Designs and Customization Freedom

3D printing allows for endless personalization, which makes it much simpler to accommodate personal touches

- Unlimited Shapes and Geometry

Old methods of manufacturing rely on moulds and cutting technologies to generate the desired shapes. Designing geometrically complex shapes can be hard and expensive with this technology. 3D printing takes on this challenge with ease and there's not much the technology can't do with the proper support material.

- Less Waste Production

3D printing only uses material that is needed to create a prototype part – no more, no less. As a result, additive manufacturing creates very little waste, and saves a company a lot of money.

- Risk Reduction

3D printing technology enables product designers to verify product prototypes before starting out on substantial manufacturing investments that can sometimes be disastrous.

In addition to above all advantages, we were Provided by a 3D printer in our college by Dassault systems. So, using 3D printer was more preferable. Products are built quickly and cheaply with the 3D printing technology.

Because of all above reasons we used 3D printing technology for manufacturing prototype of bionic arm.

5.2 Material Selection –

After selecting manufacturing process, it is crucial to select right material for the purpose. There are various materials such as ABS, PLA, HIPS, PETG, PVA, Polycarbonate etc. available in the market.

The main selection criteria was machine available with us in the college which is FDM (Fused deposition modelling) machine. PLA and ABS are the 2 most common FDM desktop printing materials. Both are thermoplastics, meaning they enter a soft and mouldable state when heated and then return to a solid when cooled. Via the FDM process, both are melted and then extruded through a nozzle to build up the layers that create a final part.

5.2.1 Comparison between ABS and PLA

Properties	ABS	PLA
Tensile Strength	27 MPa	37 MPa
Elongation	3.5 - 50%	6%
Flexural Modulus	2.1 - 7.6 GPa	4 GPa
Density	1.0 - 1.4 g/cm^3	1.3 g/cm^3
Glass Transition Temperature	105 ℃	60 ℃

- Part accuracy

ABS and PLA can be used to create dimensionally accurate parts, printing details down to 0.8 mm and minimum features down to 1.2 mm. Due to its lower printing temperature, PLA, when properly cooled, is less likely to warp (making it easier to print with) and can print sharper corners and features compared to ABS.

- Strength

With similar tensile strengths, ABS and PLA are both adequate for many prototyping applications. 3D printed ABS can be employed for end use applications whereas PLA remains popular for rapid prototyping when form is more critical than function.

- Surface finish and post processing

ABS typically print in a matte finish while PLA is semi-transparent, often resulting in a glossier finish. PLA is ideal for 3D prints where aesthetics are important. Due to its lower printing temperature is easier to print with and therefore better suited for parts with fine details,

In additional, PLA is Strong material, has Low cost and is easy for post-production PLA was selected as a working material

PLA (Polylactic Acid) is a biodegradable (under the correct conditions) thermoplastic derived from renewable resources such as corn starch or sugarcane. It is one of the most popular bioplastics, used for many applications ranging from plastic cups to medical implants.

6.ACTUATION OF WRIST

6.1 Why Arduino?

Thanks to its simple and accessible user experience, Arduino has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles, or to get started with programming and robotics. Designers and architects build interactive prototypes, musicians and artists use it for installations and to experiment with new musical instruments. Makers, of course, use it to build many of the projects exhibited at the Maker Faire, for example. Arduino is a key tool to learn new things. Anyone - children, hobbyists, artists, programmers - can start tinkering just following the step by step instructions of a kit, or sharing ideas online with other members of the Arduino community.

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

- **Inexpensive** - Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than $50
- **Cross-platform** - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.
- **Simple, clear programming environment** - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.
- **Open source and extensible software** - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to.

- **Open source and extensible hardware** - The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

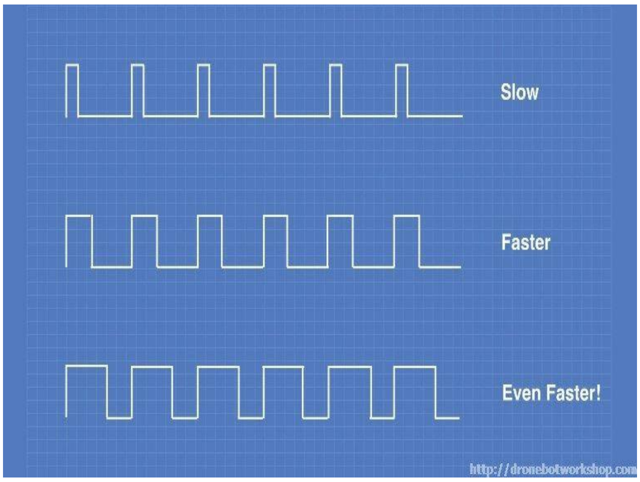
6.1.1 Why Arduino MEGA 2560 ?

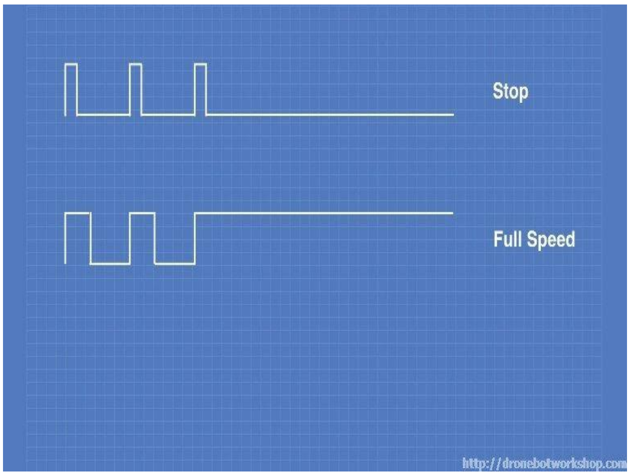
The MEGA 2560 is designed for more complex projects. With 54 digital I/O pins, 16 analog inputs and a larger space for your sketch it is the recommended board for 3D printers and robotics projects. This gives your projects plenty of room and opportunities.

The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila.

6.1.2 Pulse Width Modulation (PWM)

A far better method of controlling DC motors is to use pulse width modulation or PWM. If you've read up on controlling LED's with your microcontroller you probably have already run into PWM as it's also a good method of controlling the brightness of an LED.





With PWM the motor is sent a series of pulses. Each pulse is of the full voltage that the motor can handle so a 6-volt motor will be sent 6-volt pulses while a 12-volt motor will be sent 12-volt pulses. The width of the pulses are varied to control the motor speed, pulses with a narrow width will cause the motor to spin quite slowly. Increasing the pulse width will increase the speed of the motor, as illustrated below.

In order to stop the motor completely you just stop pulsing it, essentially sending it zero volts. To run it at full speed you send it the full voltage, again without pulsing it. You can build a simple PWM generator using a 555 timer and discrete components but it's a lot easier to use an Arduino. The Arduino has a function called "analogWrite" which is used to drive any of its PWM-capable outputs (the Arduino Uno has 6 digital outputs that are also capable of PWM).

6.2 Miniature Linear Motion actuation

PQ12 Actuonix Motion Devices unique line of Miniature Linear Actuators enables a new generation of motion-enabled product designs, with capabilities that have never before been combined in a device of this size. These tiny linear actuators are a superior alternative to designing your own push/pull mechanisms. Their low cost and easy availability make them attractive to hobbyists and OEM designers alike. The PQ12 actuators are complete, self-contained linear motion devices with position feedback for sophisticated position control capabilities, or end of stroke limit switches for simple two position automation.

PQ12 Controller Options

Option P – Potentiometer Position Feedback WIRING: (see next page for pin numbering)

1 – Feedback Potentiometer negative reference rail

2 – Actuator Motor Power

3 – Actuator Motor Power

4 – Feedback Potentiometer positive reference rail

5 – Feedback Potentiometer wiper

The –P actuators have no built-in controller, but do provide analogue position feedback. While voltage is applied to the motor power pins (2 & 3) the actuator extends. Reverse the polarity and the actuator retracts. Position of the actuator stroke can be monitored using the internal linear potentiometer. Provide any stable low and high reference voltage on pins 1 & 4, then read the position signal on pin 5. The voltage on pin 5 will vary linearly between the two reference voltages in proportion to the position of the actuator stroke. Connect to a LAC board for easy interface with any of the following control signals: Analog 0-5V or 4- 20mA, or Digital 0-5V PWM, 1-2ms Standard RC, or USB.

Option P **Option R**

Option R – RC Linear Servo WIRING:

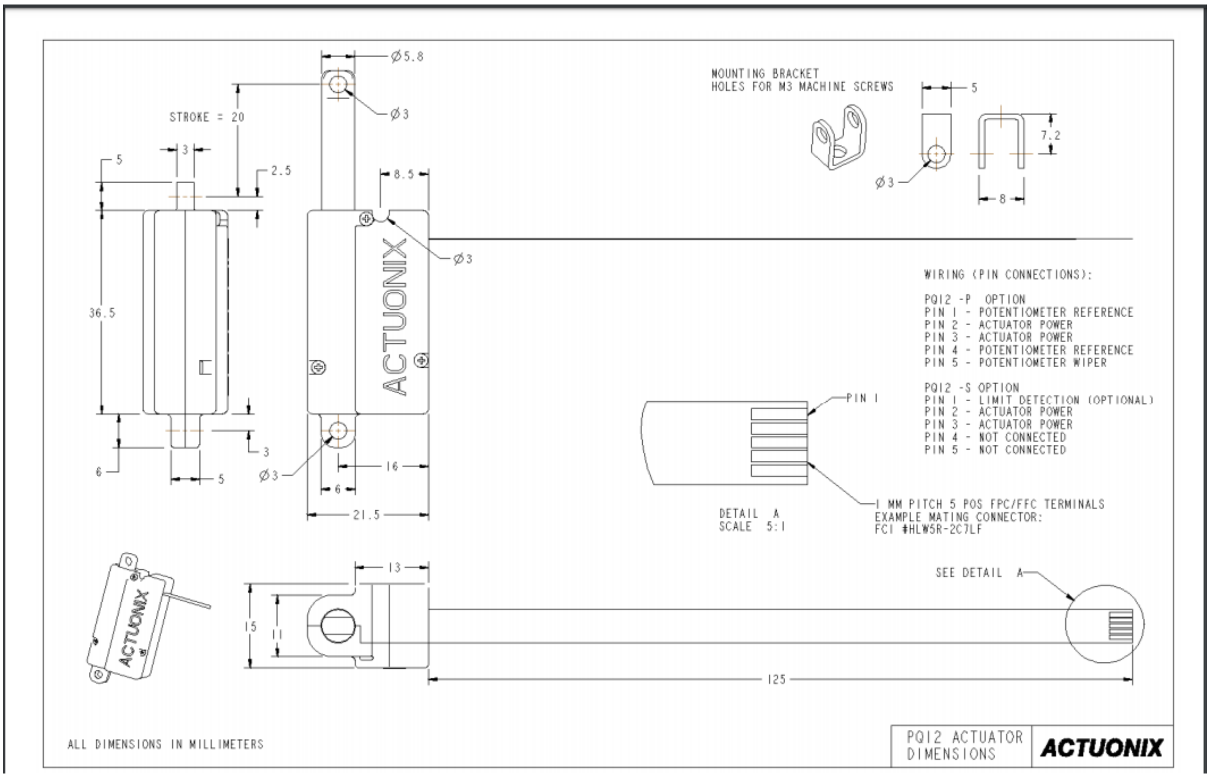
1 - RC input signal (RC-servo compatible)

2 - Power (+6 VDC)

3 - Ground

The –R actuators or 'linear servos' are a direct replacement for regular radio-controlled hobby servos. The desired actuator position is input to the actuator on lead 1 as a positive 5 Volt pulse width signal. A 2.0 MS pulse commands the controller to fully retract the actuator, and a 1.0 ms pulse signals it to fully extend. If the motion of the actuator, or of other servos in your system, seems erratic, place a 1–4Ω resistor in series with the actuator's red V+ lead wire. The PQ12–R Linear Servos are designed to work with typical RC receivers and battery packs. Consequently, they also are compatible with Arduino control boards, VEX Microcontrollers and many other similar boards designed for robotics.

Actuator dimensioning and wiring diagram



6.3 Description of MG995:

Getting an original TowerPro Servo Motor is not an economical option at all!!! And is also a very difficult task to recognize and buy an original TowerPro servo, because there are many suppliers spread over different online shops who are selling fake servo motors under this Brand name. Robu.in believes in satisfied customers, so whatever the product is we first import them then test them for their supplier defined and standard capabilities. Only after doing all the possible quality checks we make the product available to our customers.

We have imported this copy of original TowerPro MG995 High-Speed Servo from our trusted supplier. Though the motor is the copy of the original High-Speed TowerPro MG995 servo, it is compatible with all the applications that use the genuine TowerPro MG995 Metal Gear Servo Motor because of its same size, comparable quality, and optimized performance. It has metal gears which makes it robust and reliable motors. These TowerPro MG995 Metal Gear Servo Motors are the high-speed servo motors with the mighty torque of 10 kg/cm.

The optimized performance and reliability of this servo have made it the favorite choice of many RC hobbyists. The TowerPro MG995 High-Speed Digital Servo Motor rotates 90° in each direction making it 180° servo motor. It is a Digital Servo Motor which receives and processes PWM signal faster and better. It equips sophisticated internal circuitry that provides good torque, holding power, and faster updates in response to external forces. They are packed within a tight sturdy plastic case which makes them water and dust resistant which is a very useful feature in RC planes, Boats, and RC Monster Trucks etc. It equips 3-wire JR servo plug which is compatible with Futaba connectors too.

Wire Description

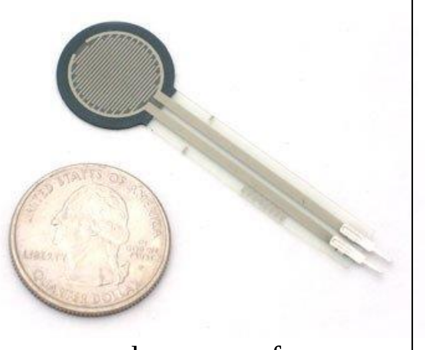
RED – Positive

Brown – Negative

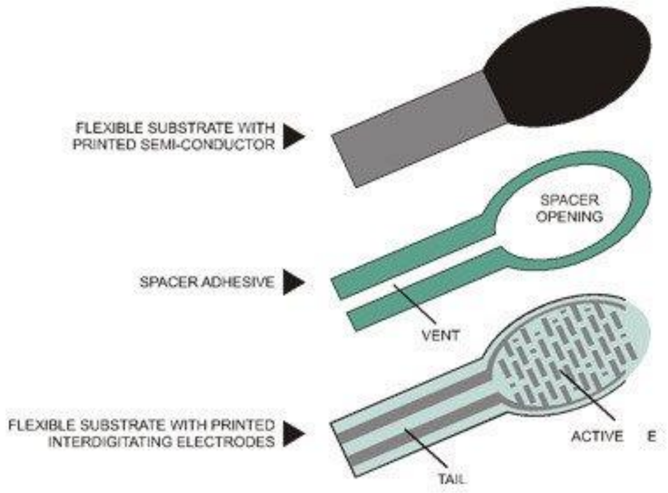
Orange – Signal

Overview of FSR

FSRs are sensors that allow you to detect physical pressure, squeezing and weight. They are simple to use and low cost. This is a photo of an FSR, specifically the Interlink 402 model. The 1/2" diameter round part is the sensitive bit.



The FSR is made of 2 layers separated by a spacer. The more one presses, the more of those Active Element dots touch the semiconductor and that makes the resistance go down.



FSRs are basically a resistor that changes its resistive value (in ohms Ω) depending on how much it is pressed. These sensors are fairly low cost, and easy to use but they're rarely accurate. They also vary some from sensor to sensor perhaps 10%. So basically, when you use FSRs you should only expect to get *ranges* of response. While FSRs can detect weight, they're a bad choice for detecting exactly how many pounds of weight are on them.

7.EXPERIMENTAL VALIDATION

7.1 Actuator 3 pin and 5 pin.

➢ Simple program

actuator_3pin | Arduino 1.8.5

File Edit Sketch Tools Help

actuator_3pin

```
#include <Servo.h>
Servo actuator;
 int stroke;

void setup() {
  actuator.attach(7);
  actuator.write(stroke);
}

void loop()
{

 // scan from 0 to 180 degrees
  for(stroke = 0;stroke < 200; stroke++)
  {
    actuator.write(stroke);
    delay(15);
  }
  // now scan back from 180 to 0 degrees
  for(stroke = 200; stroke >0 ; stroke--)
  {
    actuator.write(stroke);
    delay(15);
  }
}
```

➢ Actuation:

7.2 Servo mg995 micro servo and metal gear servo

- **Simple program**

servo | Arduino 1.8.5

File Edit Sketch Tools Help

servo

```
#include <Servo.h>
Servo servo;
 int angle;

void setup() {
  servo.attach(7);
  servo.write(angle);
}

void loop()
{

 // scan from 0 to 180 degrees
  for(angle = -100; angle < 110; angle++)
  {
    servo.write(angle);
    delay(15);
  }
  // now scan back from 180 to 0 degrees
 for(angle = 110; angle > -140; angle--)
  {
    servo.write(angle);
    delay(15);
  }


}
```

- **Actuation**

7.3 force sensor

- **Simple program**

fsr | Arduino 1.8.5

File Edit Sketch Tools Help

fsr

```
int analog=2;  // pwm [pin
int fsr_reading;   //75 to 250


void setup() {
  Serial.begin(9600);




}

void loop() {

    fsr_reading= analogRead(analog);
    Serial.print("fsranlog reading =");
    Serial.println(fsr_reading);
  delay(1000);

}
```

- **Serial monitor**

COM3

```
fsranlog reading =105
fsranlog reading =104
fsranlog reading =106
fsranlog reading =105
fsranlog reading =104
fsranlog reading =104
fsranlog reading =104
fsranlog reading =104
fsranlog reading =105
fsranlog reading =106
fsranlog reading =106
fsranlog reading =106
fsranlog reading =106
fsranlog reading =106
fsranlog reading =106
```

Autoscroll Show timestamp

7.4 Arduino Codes

Below is the code for Wrist Actuation –

total actuation = 3 (mg995 servo actuation) + 1 (sg90 micro_servo actuation) +
4 (pq12 p linear actuators) + 5 (pq12 r linear actuators)
= 13 actuations

total pins required = 13 (actuators) * 3 (pins)
= 39 pins

ground power pin will be attached to breadboard ie total 28 pins
signal pin of each actuator will be connected to arduino mega ie total 14 pins

arduino mega has total 54 pins of which 14 pins can be used as pwm pins and 16 analog input pins

as arduino mega has 16 analog input pins , sensors can be connected to these input pins and value can be given as input
to actuators ...sensors like pressure sensor or another

basic code:

```
#include <Servo.h>

  Servo index1;        // linear actuator p series
  Servo index2;        // linear actuator r series

  Servo middle1;       // linear actuator p series
  Servo middle2;       // linear actuator r series


  Servo ring1; // linear actuator p series
  Servo ring2;         // linear actuator r series

  Servo little1;       // linear actuator p series
  Servo little2;       // linear actuator r series

  Servo thumb1;        // linear actuator r series
  Servo thumb2;        //micro servo actuator


  servo wrist1;//servo mg995
  servo wrist2;//servo mg995
```

```
  servo wrist3;//servo mg995

  int potpin = 0; // analog pin used to connect the potentiometer
  int val; // variable to read the value from the analog pin

void setup() {

  index1.attach(2);
  index2.attach(3);

  middle1.attach(4);
  middle2.attach(5);

  ring1.attach(6);
  ring2.attach(7);

  little1.attach(8);
  little2.attach(9);
```

Code used for actuation of arm for various movements of arm is shown below-

```
#include <Servo.h>

  Servo index1;  // linear actuator p series
  Servo index2;  // linear actuator r series

  Servo middle1;           // linear actuator p series
  Servo middle2;           // linear actuator r series


  Servo ring1;    // linear actuator p series
  Servo ring2;             // linear actuator r series

  Servo little1;   // linear actuator p series
  Servo little2;   // linear actuator r series

  Servo thumb1;            // linear actuator r series
  Servo thumb2;            //micro servo actuator


  servo wrist1;   //servo mg995
  servo wrist2;   //servo mg995
  servo wrist3;   //servo mg995

  int potpin = 0; // analog pin used to connect the potentiometer
  int val; // variable to read the value from the analog pin
```

```
void setup() {

  index1.attach(2);
  index2.attach(3);

  middle1.attach(4);
  middle2.attach(5);

  ring1.attach(6);
  ring2.attach(7);

  little1.attach(8);
  little2.attach(9);

  thumb1.attach(10);
  thumb2.attach(11);

  wrist1.attach(44); // attaches the servo on pin 9 to the servo object
  wrist2.attach(45);
  wrist3.attach(46);
}

void loop() {
                                                        // wist actuations
                                                        // wrist 3
  for(pos=0;pos<=90;pos++){
  wrist3.write(pos);
  delay(15);
  }
  delay(1000);
```

```
for(pos=90;pos>=-90;pos--){
wrist3.write(pos);
delay(15);
}
delay(1000);

for(pos=-90;pos<=0;pos++){
wrist3.write(pos);
delay(15);
}
delay(1000);

                                        // wrist 2
for(pos=0;pos<=90;pos++){
wrist2.write(pos);
delay(15);
}
delay(1000);

for(pos=90;pos>=-90;pos--){
wrist2.write(pos);
delay(15);
}
delay(1000);

for(pos=-90;pos<=0;pos++){
wrist2.write(pos);
delay(15);
}
```

```
delay(1000);

                                        // wrist 1
for(pos=0;pos<=90;pos++){
wrist1.write(pos);
delay(15);
}
delay(1000);

for(pos=90;pos>=-90;pos--){
wrist1.write(pos);
delay(15);
}
delay(1000);

for(pos=-90;pos<=0;pos++){
wrist1.write(pos);
delay(15);
}
delay(1000);



                                   // finger actuations single single  ( FIST )


    // thumb micro servo
for(pos=0;pos<=90;pos++){
thumb2.write(pos);
delay(15);
}
delay(1000);
```

```
thumb1.write(100);

index2.write(90);
delay(15);
index1.write(100);
delay(15);

middle2.write(90);
delay(15);
middle1.write(100);
delay(15);

ring2.write(90);
delay(15);
ring1.write(100);
delay(15);

little2.write(90);
delay(15);
little1.write(100);
delay(15);

            // finger actuation single single   ( RELAX POSITION )

little2.write(0);
delay(15);
little1.write(0);
delay(15);

ring2.write(0);
delay(15);
```

```
    ring1.write(0);
    delay(15);

    middle2.write(0);
    delay(15);
    middle1.write(0);
    delay(15);

    index2.write(0);
    delay(15);
    index1.write(0);
    delay(15);

            // thumb micro servo
    for(pos=90;pos>=0;pos--){
    thumb2.write(pos);
    delay(15);
    }
    delay(1000);
    thumb1.write(0);

}
```

(Actual Images to be attached)

(Actual Images to be attached)

8. BILL OF MATERIALS

Table below shows the bill of material for single unit-

Sr. No.	Name	Quantity	Total Cost including GST
1.	MyoWare Muscle Sensor	4	17980=00
2.	Raspberry Pi B+	1	2990=00
3.	PQ12-R Micro Linear Servos6V	4	43,896=00
4.	PQ12-P Linear Actuators with feedback(Gear ratio-30-1)12V	1	10,974=00
5.	PQ12-P Linear Actuators with feedback(Gear ratio-63-1)12V	6	65,844=00
6.	PQ12 Cable Adapter with "P" Extension cable	11	4,212=60
7.	16-Channel 12-bit PWM/Servo Driver w/ I2C interface	1	350=00
8.	Mini Servo 2.5 kg	2	524=00
9.	5A DC-DC Step Down Buck Module	2	300=00
10.	Miscellaneous Laser Cutting 100 X 175 X THK 2MM MS	1	379=00
11.	Orange 5200mAh 3S 40C LiPo Battery	1	4389=00
12.	SkyRC IMAX Balanced Charger	1	3290=00
13.	MSP430 Launch Pad	2	2828=00
14.	WOL3D Filament PLA	2	2180=00
15.	Arduino Mega	1	885=00
16.	Medico EMG Electrodes Pack of 500	1	2500=00
17.	Miscellaneous -Sandisk SD card 16Gb	1	500=00
18.	MG 90Servo	3	920=40
19.	Miscellaneous-Male to Male Wire	10	47=20
20.	Miscellaneous-Jumper Wires + Single stranded wire(30m)	250	879=00
21.	Miscellaneous-Screws and nuts	80	287=00
22.	Miscellaneous-Screws and nuts	70	266=00

23.	Miscellaneous-Multi Strand wire(20m), 3pin connector and PCB	30	448=00
24.	Miscellaneous-XC60Connector and Flux	4+1	207=00
25.	Miscellaneous-Male to Male Jumpers	50	118=00
26.	BP Belt	1	50=00
27.	Arduino Due	1	1652=00
28.	WOL3D Filament PLA	1	1090=00
29..	TowerPro MG995	3	885=00
30.	51110 ball thrust bearing	1	229=00
31.	Miscellaneous-Screws and nuts	20	110=00
		Total-	171,210=00

9. FUTURE SCOPE

As discussed earlier the DoF is one of the important parameter when it comes to designing a Bionic Arm. The project holds a lot of social as well as technological scope in future. This project has a huge scope So, the scope of different aspects of the project has been described separately in the following parts.

9.1 Future scope for the EMG sensor design

In the present situation there aren't good quality EMG sensors present in the market. The ones that are there have very less reliability. Also, technical documentation of the sensors available in the market is not exhaustive. Also, sensors present outside India are very costly and thus not viable for use for a low-cost Bionic Arm. The sensors used in this project were unreliable, noisy and the technical details were not properly mentioned in the datasheet.

Thus, design and development of EMG sensors in house will be of great use for the next batch of students. It will be cheap and reliable too. This in-house EMG sensor can also lead to the design of other Bio signal acquisition system.

9.2 Future scope for the EMG signal analysis and classification

Various noise reduction techniques can be used to refine the EMG signals. Combination of hardware and digital filters can be used for the same.

We have explored the time domain features but the frequency domain features and advance time domain features are remaining. These features can be explored to get better prediction accuracy.

Neural networks and deep learning can be used to increase the prediction accuracy. More number of gestures can also be classified using these non-linear classifiers.

Finally, the total time required for the processing and classification of EMG signal can also be worked on to make it more responsive and real time.

9.3 Future scope for the Bionic Arm

The idea of using these EMG signals as a control signal and using it as a helping aid to the amputees is a big thing in it itself to achieve. Yet the future scope for this particular phase of the project would be increasing the DOFs. Currently, the project has achieved 11 DOFs, which includes movements of the fingers and the human palm as a whole.

Other than increasing DoFs in the arm, various algorithms and transformation techniques can be applied which may give better results than the current techniques.

Development in the Bionic Arms and the challenge related to that mainly lies in the structure of the arm. It is really difficult to imitate an exact human arm with number of miniature motors. Different structures have been proposed and currently the ball and socket technology is used. A lot of research is being carried out regarding refining the technology of the design of the Bionic Arm. Advanced 3D printing techniques and coating techniques have to be developed.

The Bionic Arms available today provide a mental control over the arm but there is no sensory feedback. Sometimes the corresponding muscle may not get actuated accurately and hence there can be a sensory feedback in order to get proper results. Another advancement that can be added in the arm for the amputees is the feeling of the material it touches. While gripping or holding an object, a Bionic Arm may hold it too tightly or to loosely. For example, the arm must have a feedback that may be able to differentiate between whether it is holding a glass or a pillow. Depending on the material the arm will apply the appropriate amount of pressure in gripping it.

Soft Robotics is a new field which has huge prospects. Usage of soft material like SMA and SMP for prosthetic arm will be a great prospect as the Bionic Arm will look more like a original human hand rather than an artificial robotic hand.

Camera can be mounted on the Bionic Arm and computer vision can be implemented. Control of Bionic Arm on basis of object detection through image processing can help to develop complex grasps of complex shaped objects.

9.4 Future scope for prosthetics

The present myoelectric technology is appropriate for arms. The bionic legs face a lot of technological problems. The movement of knees, feet and ankles in normal walking are more autonomous and they bear entire load of the body, so mechanism and actuators imparting high torque are required. Thus, detail research on leg prosthesis is needed and has a good future prospects for leg amputees.

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