Designing a Control for an Anthropomorphic Hand

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DEDICATION

To our guiding stars, our unwavering pillars of support, and the embodiment of unconditional love: our beloved parents.

This thesis is not merely a culmination of our engineering journey; it is a heartfelt tribute to your immeasurable impact on our lives. From the moment we took our first steps, you instilled in us the values of perseverance, curiosity, and a relentless pursuit of knowledge. You believed in our dreams and encouraged us to reach for the stars, even when the path seemed arduous.

You have been our mentors, our cheerleaders, and our confidants, providing unwavering support through every triumph and setback. Your boundless patience, words of wisdom, and endless sacrifices have shaped us into the individuals we are today. You have given us wings to soar and the confidence to take on the world.

In the late nights and early mornings, while we toiled away at our projects, you were there, providing nourishment for both our bodies and souls. You created a haven of warmth and love, a sanctuary where we could find solace and rejuvenation amidst the challenges we faced. Your unwavering belief in our abilities never wavered, even when doubts clouded our minds.

It is with immense gratitude and pride that we dedicate this thesis to you, our beloved parents. Your unwavering love and support have been the cornerstone of our achievements, and this work stands as a testament to the values you have instilled within us. We are eternally grateful for your sacrifices, your guidance, and the love that has propelled us forward.

May this dedication serve as a small token of our appreciation, a mere reflection of the infinite debt of gratitude we owe you. As we embark on new horizons, we carry with us the lessons you have taught us, the values you have nurtured, and the strength you have bestowed upon us.

With deepest love and heartfelt thanks,

M. Junaid Khan Jadoon
M. Hammad Ahmad
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ABSTRACT

Designing a Control for Anthropomorphic Hand

A big fraction of the population suffer from some form of amputation and automated prosthetics are very expensive. The mechanical prosthetics that are currently being used in the rehabilitation industry are bulky and fatigue for the amputees to use which is the core reason they are not used in long runs. Belt harness prosthetics are typically attached to the body using a belt system, which places a significant load on the waist and hip area. The weight of the prosthetic limbs, along with any additional components, can lead to muscle fatigue and strain over time, especially if the user needs to wear the prosthetics for extended periods. Our main objective is to provide assistance to already available mechanical setup and to automate it. The project involves facilitating 2-DOF movements, griping and wrist rotation and DC motor selection to meet our torque and force requirements along with interfacing the DC motors with the controller and joystick module and integration with the electromechanical setup. The project also includes the transient and state power consumption analysis. Basic objective is to provide a cost effective solution for lower limb amputation as we a using the already available mechanical structure that is currently being used in the rehabilitation industry of Pakistan. Closed loop control is implemented for precise position and speed control of the objects. Servo driven systems are very stable. Servo motors in prosthetic hands are typically equipped with position control feedback mechanisms. This feedback allows for accurate control of the motor's position, ensuring that the fingers maintain the desired position and stability during various tasks and movements. Wrist rotation would be done using a gear assembly that amplifies the mechanical torque of the motor for the effective and smooth wrist rotation.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

PTSD	Post-traumatic stress disorder
DOF	Degree of Freedom
Inc	Incorporated

Chapter 1

Introduction

1.1 Project Background:

Amputation is the loss or surgical removal of any body parts such as arm or limb due to trauma, accident or any other illness. It affects life critically as the amputee is not able to do the daily routine tasks that requires manual adroitness especially if he loses his dominant hand, which is normal for the healthy person. It creates a lack of sensation and feelings. The memories of the incident cause severe psychological conditions such as post-traumatic stress disorder (PTSD). Amputation not only effects the person itself but the people close to them such as family and friend. A study was conducted to quantify and interpret patterns in global distribution and prevalence of traumatic limb amputation by cause, region, and age within the context of prosthetic rehabilitation, prosthetist need, and prosthetist education.The resuts shows that in 2017, 57.7 million people were living with limb amputation due to traumatic causes worldwide. Leading traumatic causes of limb amputation were falls (36.2%), road injuries (15.7%), other transportation injuries (11.2%), and mechanical forces (10.4%). The highest number of prevalent traumatic amputations was in East Asia and South Asia followed by Western Europe, North Africa, and the Middle East, high-income North America and Eastern Europe. Based on these prevalence estimates, approximately 75,850 prosthetists are needed globally to treat people with traumatic amputations [1]. Some amputees has mentioned the loss of upper limb as feeling of deprivation after the death of loved ones. To accumulate the loss of upper limb prosthetic hands are adopted by amputees which are used to replace some of the appearance and function of human hand. Some prosthetic hand have limited or no movement, but other can grip objects and even move in a natural way. There are mainly three ways prosthetic hand are used which include passive prosthetic hand, It does not open or close, often they are used for cosmetic purpose but it also acts as support for some activities such as catching and stabilizing an object etc. Body powered prosthetic hand are open and close using a harness that is suspended over the shoulder. Movement of shoulder opens or closes the hand to hold the items, they look like a hand or hook. Myoelectric prosthetic hands are controlled electrically using sensors that detect your muscles moving to open or close the prosthetic hand. Similarly, these can be a hook or a hand. Typically, these can also incorporate multiple hand movements to improve the function of the prosthetic hand. There are two types of arms available in the market for amputees fully actuated and under actuated, when an arm is manipulating the object with degree of freedoms it becomes under-actuated, if force closure is achieved, and maintained, then we can think of this system as fully-actuated. Anthropomorphic hands are already been developed to help the lower limb amputees. Companies that are involved in prosthesis such as Morbius robotics [2] and Open Bionics [3] etc. However, all of these companies are based outside Pakistan. It is difficult for the local companies to purchase the prosthetic hands from them. That is why this project is proposed to target local manufacturing of the anthropomorphic hands.

1.2 Problem Statement:

In Pakistan every year thousands of people suffer from upper limb amputation due to accident and other illness. The amputees suffer severely because of the physical and psychological stress that came with the loss. They aren't able to perform daily routine work. The additional effort required by amputees to perform many of the routine activities of daily life can result in increased levels of tiredness and fatigue. For example, this might be from the increased exertion required by a lower-limb amputee to walk with a prosthetic limb, or simply from the fact that many ordinary activities can take longer to complete than previously. In some cases, the side effects of a person's pain medication might make them feel more tired or cause them to sleep for longer. In addition, the psychological effects of the injury and accident may disturb a person's sleep and exacerbate their fatigue [4]. As majority of the population of our country is poor and aren't able to afford the expensive prosthetic hands. Secondly our country doesn't have companies which are making fully actuated hands. Moreover, ordering prosthesis equipment from the foreign country is too expensive and requires a lot of time. In order to reduce these problems, the best solution is to provide the locally manufactured prosthetic hands. Although there are a lot of prosthetic hands that have been commercialized, the market not reaches Pakistan. The local companies cannot afford to have this system since they need to consider the purchase cost, shipping and maintenance fee. We have taken the opportunity to create this affordable system in order to help the poor patient and the companies to solve the problem of prosthesis.

1.3 Objective:

The objective of this project is to develop simple and light weight two DOF controller design for already available mechanical setup of an anthropomorphic hand. Here are two main objectives in this project:

- To design and develop a controller for two servo motor, one of which would control gripping and other of which would control wrist rotation.
- To control the whole motion ny interfacing a joystick with Arduino UNO.

1.4 Scope:

The development of Designing Control Mechanism for Anthropomorphic Hand covers the aspect such as Controller, mechanical structure and electrical circuitry where the scope of this project can be summarized as below:

4.11 To design an efficient electromechanical setup.

4.12 Interfacing and integration of electrical components with mechanical components.

Chapter 2

Literature Review

2.1 Introduction:

This chapter we have two major sections, first the currently available prosthesis available for the lower limb amputees. Secondly research started on development of prosthetic hand.

2.2 Currently Available Prosthetic hands:

Many types of prosthetic hands are available commercially having unique features and quality like be-Bionics, RSL Steeper, Michelangelo Hand, Ottobock Inc. and Handiii, from exiii Inc. The detail discussion of these prosthetic hands are given below.

2.2.1 Be-Bionics, RSL Steeper:

Be-Bionic hand is a RSL Steeper smart hand with unique ergonomic features which has given the hand unrivalled, versatility, functionality and performance. Each finger is powered by individual motor for natural coordinated grip and hand movement, controlled by powerful microprocessors which monitors the position of each finger, giving precise, reliable control over hand movements. The motors are positioned to optimize weight distribution making the hand feel lighter and more comfortable. It has fourteen selectable grip patterns and hand positions resulting wide everyday activities. It has auto grip function to avoid slipping of gripped item, foldaway fingers for natural looking movement. The hand cost between $25,000 and $35,000. Refer Figure 2.1 [4] [5].

Figure 2.1; Bebionic Hand (Image curtsey RSL Steeper).

2.2.2 Michelangelo Hand, Ottobock Inc:

The new Michelangelo Hand from Otto Bock features a thumb that electronically moves into position, enabling it to function more like a human hand. The Michelangelo Hand has multiple grip functions that allow users to master everyday tasks like opening a tube of toothpaste, gripping a key, holding a credit card, and using a clothes iron. The thumb can also open up to create a natural palm shape for holding a plate or bowl, and the flexible-positional wrist joint offers a more natural shape and movement. Advanced software and EMG signal processing increases the responsiveness and predictability of the Michelangelo Hand. Refer Figure 2.2 [6] [5].

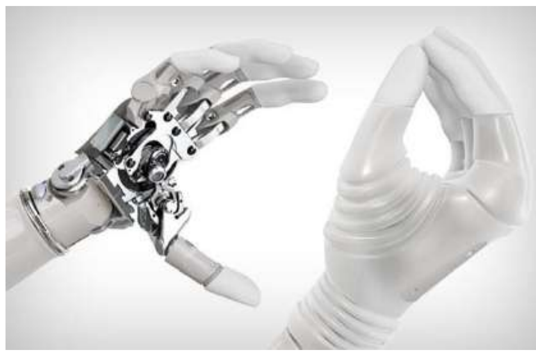


Figure 2.2; Michelangelo Hand from Ottobock

2.2.3 Handiii, from exiii Inc. Japan:

A Japanese Company established by Genta Kondo Using smartphone to process muscle signals. Wirelessly collects signals from skin surface. Detects the hand motion intended by the user. Reduction in motors; One motor per 3DOF fingers, Mechanism adaptive to various sizes and shapes.3D printer production for Reduce production cost & Easy to repair and customized design. (Refer Figure.2.3) [7] [5].

Figure 2.3: Handiii from exiii.

2.3 Research Project Related to Prosthetic Hand:

Here we discuss a research project which related to automatic storage and retrieval system in term of methodologies and implementations. The project that we discuss is designed by teams of engineers Victoria, Canada, at the University of Victoria.

2.3.1 Victoria Hand:

The Victoria Hand is a complete body-powered prosthesis consisting of a hand, a wrist, a limb-socket, and a harness. It has high functionality, natural-appearance, and is custom-made to fit each amputee. The hand is capable of adaptive grasp, which allows the fingers and thumb to conform around the shape of various objects creating a secure grip. As well, the fingers and thumb are rubber-tipped to help grasp smaller objects. The prosthesis has an adjustable ball-and-socket wrist, to orient the hand to various postures. The wrist is easy and intuitive to use and give the amputee ability to perform many different tasks. Refer Figure 2.4 [8] [5].

Figure 2.4; Victoria Hand

2.4 Chapter Summary:

In this chapter we have discussed prosthetic hands which are already available in the market for amputees such as Be-Bionics, RSL Steeper, Michelangelo Hand, Ottobock Inc and Handiii from exiii Inc, japan. We have also discussed the research project related to prosthetic hand called Victoria Hand designed by team of Engineers from University of Victoria, Canada.

Chapter 3

Methodology

3.1 Introduction:

This chapter discusses the methodologies that have been taken to develop the Control Mechanism for Anthropomorphic Hand.

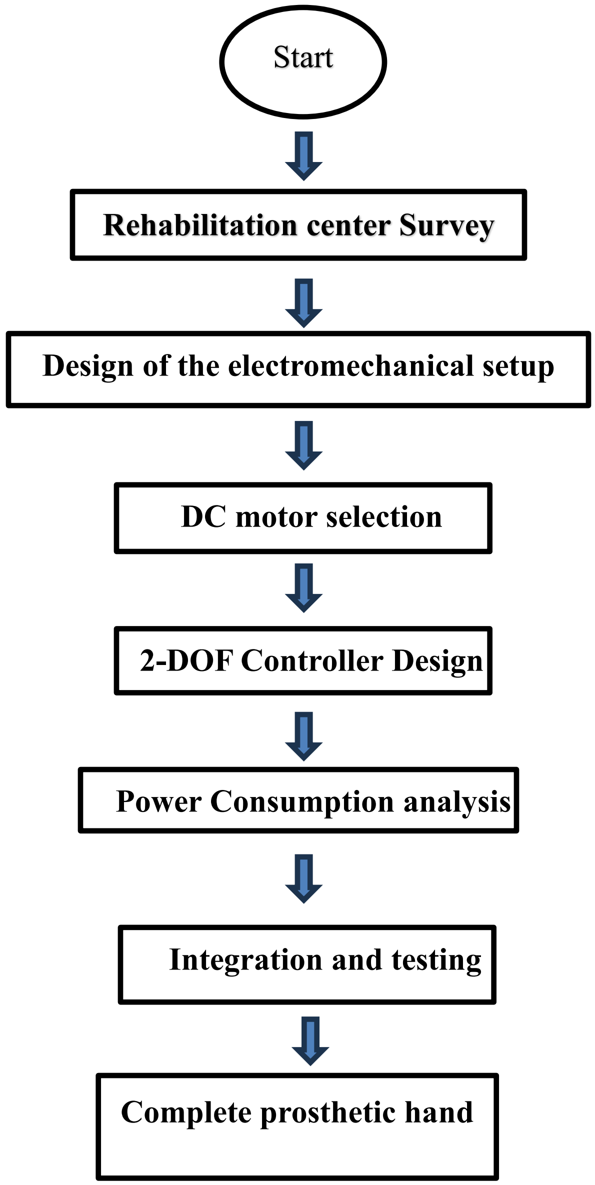


Fig. 3.1 (Project Flowchart)

The overall flow of the project in given in figure 3.1. The project involves the designing and construction of Anthropomorphic Hand. The flow of the project includes the research of available prosthesis of upper limb amputees in the market, as well as collecting information from the relevant project regarding the prosthetic hand, conducting a market survey all around the Pakistan. We designed the Software for the Arduino UNO for the already available mechanical design. Then we constructed the Electrical design. Then we have done the system testing.

3.2Market Survey:

In order to find out the need of prosthesis automation, we have done the research and find out that there is dire need of cost affective prosthesis in Pakistan, As lot of rehabilitation center in our country rely on mechanical prosthesis which is basically based on belt and harness system. We have also visited the PIRC (Pak-Irish Rehab Center) for that purpose, where we found a prosthetic hand based on mechanical system. We give them the idea of the idea of automation of prosthesis which they accepted and appreciate as they have also shows the concerns about the patients of lower limb amputees and the difficulty they face while performing daily tasks. After that we discussed the project with our supervisor to design the control mechanism for the Anthropomorphic hand.

3.3 Controller Design:

We have done the coding of the controller for the opening and closing of the grip as well as for the wrist rotation. We have interfaced the joystick with the controller, the knob of the controller in vertical axis open and close the grip while in horizontal axis it rotates the wrist**.**

3.4 Gear Design:

We have designed the gears for the wrist rotation for which we have used the software. The gears are attached to the servo motor connected to the joystick through the controller for effective rotation of the wrist.

3.5 Electrical Design:

Our Electrical design consists of two servo motors attached to the gripper and the wrist for the effective movement and rotation of the grip and the wrist. They are interfaced with the controller through the joystick to control the movement. The controller is used to send the signal from the joystick to the servo motors.

3.6 Software Design:

Our project mainly concerned with the design and integration of an electromechanical setup that facilitates 2-DOF movements as addressed many times. However, a power consumption analysis along with transient and steady state analysis was carried out in MATLAB to check the effectiveness and efficiency of the servo driven system.

3.7 Testing and Tuning:

Finally we have tested and tuned the Anthropomorphic hand to achieve the objectives mentioned in chap No 1. In the tuning phase we have pick certain weights for the effective gripping of the actuator.

3.8 Cost Analysis:

S.No	Components	Diagram	Specifications	Price	Reference
1.	Dual Axis XY Analog Joystick Module KY 023 2 Axis PS2 Joystick control Lever Breakout Sensor		This module uses the 5V power supply, and value, when reading through analog input, would be about 2.5V, a value will increase with joystick movement and will go up till maximum 5V.	RS 170/-	https://electrobes.com/product/joystick-module-2-axis-dual-axis
2.	servo motor (DS3225)		Weight 67 gm Stall Torque: 21Kg/cm (5.0 V) 25Kg/cm (6.8V) Operating Voltage 4.8 V-6.8 V	RS 2850/-	https://ewall.com.pk/product_view/DS3225-25kg-6V-Waterproof-Full-Metal-Gear-Digital-Servo-for-RC-Car-Boat-Robot/3193

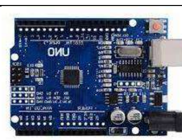
3.	Servo motor MG946R		Weight 55gm Stall Torque 10.5kg/cm (4.8v); 13kg/cm 96v) Operating voltage 4.6-6.6v	RS 1000/-	https://digilog.pk/products/mg946r-mg946-r-180-degree-metal-gear-servo-motor-in-pakistan-lahore-karachi-islamabad
4.	Buck Converter LM2956		Input Voltage 4.75 to 35 V Output Voltage 1.25 to 26V Output Current Rated current is 2A, Maximum 3A	RS 350/-	https://hallroadlahore.pk/lm2596-dc-dc-buck-converter-in-pakistan-1198.html
5.	Battery		11.1V 2800mah Weight 194g/6.8z	RS 2900/-	https://hallroadlahore.pk/1-pcs-lion-power-lipo-battery-11.1-v-2800-mah-35c-max-50c-t-file-for-rc-car-airplane-align-trex-450-helicopterpakistan.html
6.	Arduino		Microcontroller ATmega328P – 8 bit Operating Voltage: 5V	RS 2300/-	https://digilog.pk/products/arduino-uno-r3-in-

Table 3.1 Cost of different Electrical Equipments along with specifications and link of Purchase

3.9 Chapter Summary:

The project involves researching available prostheses, conducting a market survey, designing the controller and gears, constructing the electrical setup, designing the software, and testing and tuning the Anthropomorphic Hand to meet the project's objectives.

Chapter 4

Electro-Mechanical Design

4.1 Introduction:

This chapter covers the Electro-Mechanical design of the Anthropomorphic hand. First we discuss the mechanical design, then we discuss the components used in the electro- mechanical design and finally we discuss the electro-mechanical structure of anthropomorphic hand.

4.2 Mechanical Design:

4.2.1 Mechanical Hand:

The figure 4.1 shows the mechanical hand that is already designed setup. The hand is made of solid iron. The mechanical system consists of jaws for gripping attached to a wire through pulley. The dimensions of the mechanical setup is given below.

Fig 4.1 (Mechanical hand)

4.2.2 Gears:

We have designed the gears using solid works software for the wrist rotation of the anthropomorphic hand. After confirming the design we send it to the 3D printing shop name 3D Print Pakistan. The gears are assembled in a way so that they work smoothly and efficiently. The whole gear assembly consists of a ring gear have diameter 9cm, a big gear having diameter of 3cm and small gear having diameter of 2cm. The gears are connected to the wrist servo motor through nut and bolt. The ring gear have 40 tooths, big gear have 15 tooths while small one have 10 tooths. The designed and the real pictures of the gears are shown in figure 4.2 and 4.3 respectively.

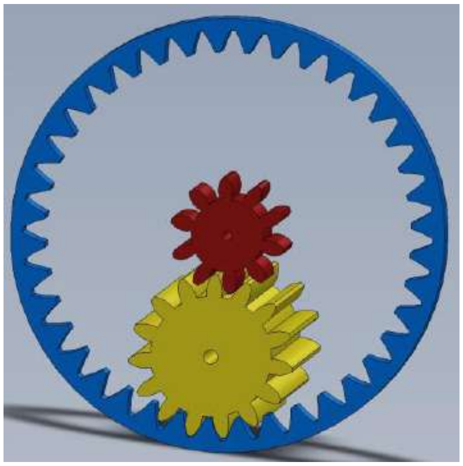


Fig 4.2 Solidworks design of gears

4.3 Electrical Design:

We have two servo motors, a controller and a joystick for 2-DOF movement of the hand. We have used servo motors over linear actuators as it excels in applications that require simple linear motions and high force output. Secondly the actuators are way to expensive than servo motors as we have to import it from another country which would increase the cost of the project. As Servo motors offer a wide range of motion options, including rotational, oscillatory, and continuous motion. They can provide precise position control, speed control, and even torque control. As servo motors typically have higher speed and acceleration capabilities compared to linear actuators. They can achieve rapid changes in direction and respond quickly to control signals, making them suitable for dynamic applications where fast and precise movements are required. Precise and fast movement was also required by the project that's why we go for the servo motors. Because of the compactness of its design we choose servo over linear actuators because the design on which we are working have limited space, as it helps us in in its installation to the mechanical setup easily.

4.4 Working Principle of Servo Motor:

Servo Motor consists of a DC Motor, a Gear system, a position sensor, and a control circuit. The DC motors get powered from a battery and run at high speed and low torque. The Gear and shaft assembly connected to the DC motors lower this speed into sufficient speed and higher torque. The position sensor senses the position of the shaft from its definite position and feeds the information to the control circuit. The control circuit accordingly decodes the signals from the position sensor and compares the actual position of the motors with the desired position and accordingly controls the direction of rotation of the DC motor to get the required position. Servo Motor generally requires a DC supply of 4.8V to 6 V [9].

4.4.1 Motor for Gripping:

For effective gripping, we used servo motor (DS3225) whose specification is given below. The motor is selected on the basis of torque, it is fitted in such a way that It don't interrupt with wrist rotation motor.

Weight:	67 g
Stall Torque:	21Kg/cm (5.0 V) 25Kg/cm (6.8V)
Operating Voltage	4.8 V-6.8 V

Fig 4.3 (DC Servo DS3225)

4.4.2 Motor for Wrist Rotation:

For wrist rotation we have used servo motor MG946R, It is also selected on the basis of torque and is fitted in such a way so that it don't interrupt the motion of motor used for grasping. This motor rotates the hand through 180^0 imitating the natural wrist rotation of the human hand. The motor is shown in the figure below along with their specification

Weight	55g
Stall Torque	10.5kg/cm (4.8v); 13kg/cm 96v)
Operating Voltage	4.6-6.6v

Fig 4.4 Servo Motor (MG956R)

4.4.3 DC-DC (Buck) Converter LM2956:

The operation of the buck converter is based on the principle of storing energy in an inductor. The voltage drop across an inductor is proportional to the change in the electric current flowing through the device. A switching transistor is used in between input and output for continuous switches on and off at high frequency. To maintain a continuous output, the circuit uses the energy stored in the inductor [10]. As we want to step down the voltage for Arduino UNO which requires 5V to operates. For this purpose we had used buck converter LM2956 in figure 4.4 whose specification data is given below.

Input voltage:	4.75-35V
Output voltage:	1.25-26V(Adjustable)
Output current:	Rated current is 2A, maximum 3A

Fig 4.5 Buck Converter (LM2956)

4.4.4 Joystick:

For the 2 DOF moment of the hand we are using a joystick module. We are controlling both the motors through that joystick. For wrist rotation we move the “hat” of the joystick in X axis and for the gripping we move it in the Y axis directions. This joystick Module is very similar to the ‘analog’ joysticks on PS2 (PlayStation 2) controllers. Directional movements are simply two potentiometers – one for each axis. Pots are ~10k each. This joystick also has a select button that is actuated when the joystick is press down. With the help of this Joystick Module, you can measure position coordinates on the X and Y axis by moving the “hat”. It also contains a switch that is press-able by pushing the “hat”. It also contains a switch that is press-able by pushing the “hat” down. Similar to the XBOX controller. The X and Y axes are two 10k potentiometers which control 2D movement by generating analog signals. When the module is in working mode, it will output two analog values, representing two directions. This module uses the 5V power supply, and value, when reading through analog input, would be about 2.5V, a value will increase with joystick movement and will go up till maximum 5V; the value will decrease when the joystick is moved in other direction till 0V. Specifications and Features of Joystick Module: Dimensions: 40 x 27 x 15 (L x W x H) mm Weight: 10gm (without Hat). 2.54mm pin interface leads Operating Voltage: 5V [11]. The module is shown in figure 4.7 below.

Fig 4.6 Joystick Module

4.4.5 Battery:

To power the motor and the Arduino UNO we have used the Lion Power Lipo RC Battery, we had experimented with different batteries but the power rating other batteries had was not sufficient enough to run the motor for a long time that’s why we had choose this battery. The Specification of the battery are given below. The battery is also shown in the figure below.

Product Type: Lithium Polymer Battery Rechargeable
Battery Parameter: Lion Power 11.1V 2800Mah 35C
Battery Capacity: 2800MAh
Continuous Discharge
Rate: 35CMAX50C
Battery Size: 11.5*3.7*2.2cm/4.5*1.4*0.9in
Battery Weight: 194g/6.8oz.

Figure 4.7 Lion Power Lipo RC Battery

4.4.6 Arduino:

We have used Arduino as microcontroller for the optimal control of the servo motors. We have encoded the Arduino with the codes, it take signal from the joystick sensor and then it sends the signals to both the motors to move in specific direction. The motors then rotate the wrists of the hand as well as grip anything according to the command provided by the Arduino. Arduino is an open-source physical computing platform based on a simple i/o board and a development environment that implements the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on your computer (e.g. Flash, Processing, MaxMSP). The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, 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 AC-to-DC adapter or battery to get started [12]. Specification of the Arduino are provided in the table. The Arduino UNO is shown in the figure 4.9 below.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Table 4.1 Specifications of Arduino UNO

Fig 4.8 Arduino UNO

4.5 DC motor selection:

DC motors were selected based on our torque requirements. We conducted multiple experiments in order to determine the force required to open and close the jaws. This force helped us determine the required torque for that purpose.

Load Requirements: Determine the torque and speed requirements of your application. This will help you select a motor with the appropriate power and performance characteristics.

Voltage and Current Ratings: Consider the power supply available for your application and select a motor that operates within that voltage range. Also, check the current rating to ensure it is compatible with your power source and control circuitry.

Motor Size and Weight: Depending on the available space and weight restrictions, choose a motor that fits within your application's constraints.

Efficiency: Look for motors with high efficiency to minimize power consumption and reduce operating costs. Some motors may offer additional features such as integrated encoders for position feedback, built-in gearboxes for torque multiplication, or special coatings for protection against moisture or corrosive substances. We can evaluate if any of these features are necessary for our application.

Speed Control: If you require variable speed control, choose a motor that allows for speed regulation through methods like pulse width modulation (PWM) or voltage control.

The mathematical model for the DC motor selection based on force and torque requirements is given below in the table along with the motor specification.

DC Motor For Gripping	**Dsservo DS3225**
Weight	67g
Stall torque	21Kg/cm (5.0V) 25Kg/cm (6.8V)
Operating voltage	4.8 V- 6.8 V
DC Motor For Wrist Rotation	MG946R
Weight	55g
Stall torque	10.5Kg/cm (4.8V) 13Kg/cm (6.0V)
Operating voltage	4.8 V- 6.6 V
DC-DC Buck converter LM2956	3.2-46V/1.25-35V
Joystick Control Lever	5V (low weight)
Lion Power Lipo RC Battery	2800 mAh (190g)

Selected motor's torque at $5V = 21\ kg/cm$

Our required force= $6\ kg$f

As, Torque= $F \times r$

So, if we take the distance from point of rotation as 2cm,

$$F = \frac{21\ kg/cm}{2cm}$$

$$F = 10.5\ Kg$$

At 5.5V, the motors draw a current of 0.56 amp so,

$$I = 0.56\,A$$

$$V = 5\sim5.5V$$

$$P = VI$$

$$P = 3.08W$$

So, the power consumption of the gripper motor is 1.925W

For spur gears,

Gear impedance reflection ratio is given by:

$$\frac{N1}{N2} = \frac{\theta 2}{\theta 1} = \frac{\text{r1}}{\text{r2}}$$

$$\frac{N1}{N2} = \frac{10}{15} = 0.6666$$

Arduino:

```
#include <Servo.h>

//Servo objects created to control the servos

Servo myServo1;

Servo myServo2;


int servo1 = 3; //Digital PWM pin used by the servo 1

int servo2 = 5; //Digital PWM pin used by the servo 2

int joyX = 0;   //Analog pin to which the joystick (X) is connected

int joyY = 1;   //Analog pin to which the joystick (Y) is connected


void setup(){

  myServo1.attach(servo1);

  myServo2.attach(servo2);
```

```
}

void loop(){

  int valX = analogRead(joyX); //Read the joystick X value (value between 0 and 1023)
  int valY = analogRead(joyY); //Read the joystick Y value (value between 0 and 1023)

  valX = map(valX, 0, 1023, 0, 180); //Scale the joystick X value to use it with the servo
  valY = map(valY, 0, 1023, 0, 180); //Scale the joystick y value to use it with the servo

  //Sets the servo position according to the scaled values.
  myServo1.write(valY);
  delay(5);
  myServo2.write(valX);

  delay(5);
}
```

4.6 Chapter Summary:

In this chapter, the electromechanical design with DC motor selection along with the gears that facilitate wrist rotation was discussed also the mathematical model for the DC motor torque and force on the basis of which the actuators were selected.

Chapter 5

Results and Discussions

5.1 Introduction:

The electromechanical setup design and integration of a prosthetic hand involves careful selection of components and meticulous planning to ensure efficient functionality. In this section, we will explore the initial design and integration process of the electromechanical setup, focusing on the selection of DC motors, structure replication, and the use of CAD software for design refinement. Additionally, we will discuss the circuit diagram and wiring connections for interfacing the motors with a controller, specifically using an Arduino and joystick module for control operations.

5.2 Electro-mechanical design stages:

The electromechanical setup design and integration was carried out in multiple phases each having it's own unique importance. We selected DC motors based on our torque requirements for effective opening and closing of the jaws. The structure is made in such a way that it replicates the behavior of the three main functional fingers being the thumb, index and ring finger. The motors were fitted according to the electromechanical setup design that was initially made in AutoCAD and refined in solid works with gear assembly simulations for wrist rotation.

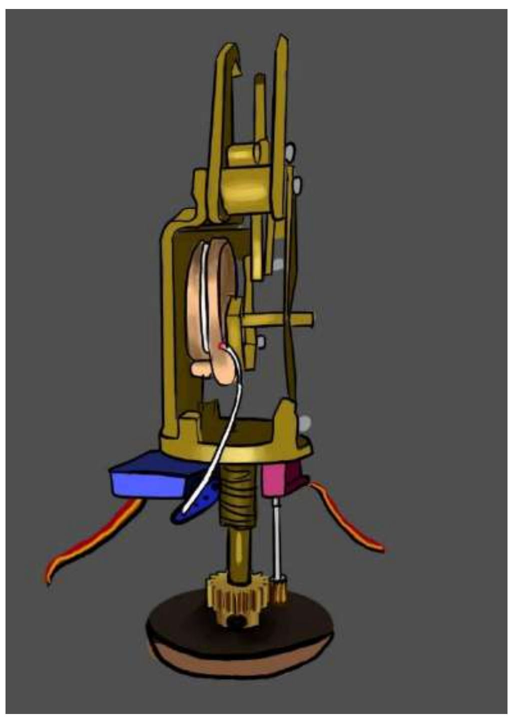


Fig 5.1 Initial Design of the Electromechanical Setup

The motors were fixed in the same positions as shown in the figure, as discussed motors are interfaced with the controller and controlled using a joystick module. The simplest circuit diagram is shown in the figure. There is controlling wire (orange), neutral or ground wire (black) and PWM (orange or white).

DC servo motors typically have three wires: positive (+), negative (-), and a control signal wire. The positive and negative wires are for the power supply and provide the necessary voltage and current to operate the motor. The control signal wire is used to send the control signal from the controller or driver to the motor, specifying the desired position or speed. Here is a common wire color convention for DC servo motors:

- Red wire: Positive power supply (+)
- Black wire: Negative power supply (-)
- White or yellow wire: Control signal

It's important to note that wire colors may vary depending on the manufacturer or specific model of the servo motor. Always refer to the motor's datasheet or documentation for accurate information on wire connections and color coding.

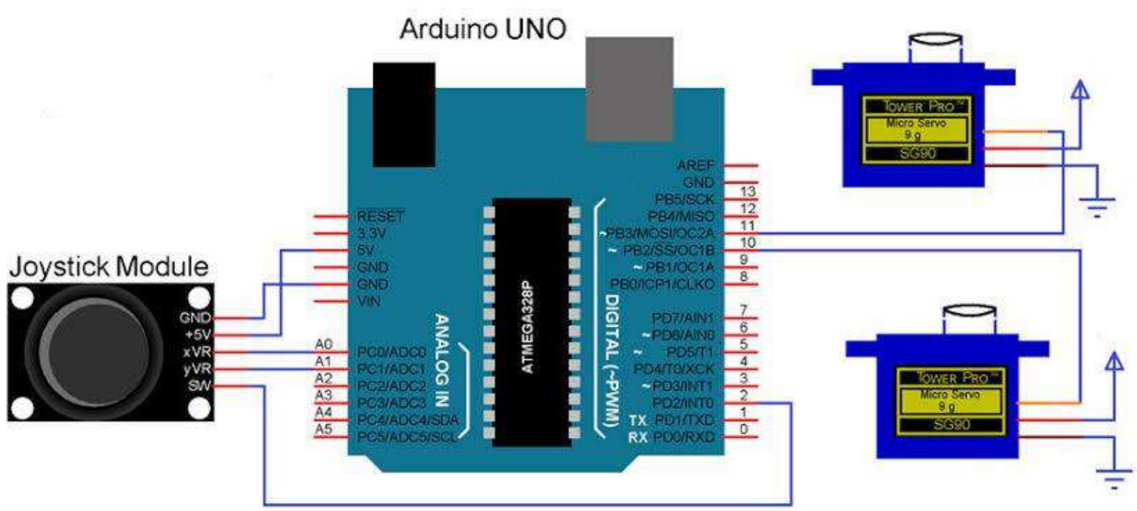


Fig 5.2 Simple Circuit Diagram of Motors Interfaced With Controller

Arduino's pin 5 and 3 are used for generating PWM signals which are sent to DC motors for control operations. A0 and A1 pin is connected to joystick module's X and Y pin. The positive terminals (power wire) of both the servo motors are connected to the V_{out} of the buck converter. Moreover, the positive terminal (5V slot) of the Arduino is connected to the V_{out} of the Arduino.

The negative terminals of the motors (ground wire) is mutually grounded with the negative terminal of the Arduino's 5V slot.

The initial design is shown in figure 5.1. The only difference is the gear assembly was extended to give the electromechanical setup support. the electrical design includes the servo motors interfaced with Arduino and controlled using the joystick module for 2-DOF movements. All the electrical components including the controller are combined into a shield to ensure the safety and sustainability of the setup as well as the patient using the prosthetic. The figure shows the shield with all the electrical elements integrated on it. These include the connections of motors, switch for turning it on or off for economic power consumption and buck converter to get the voltage to our required values.

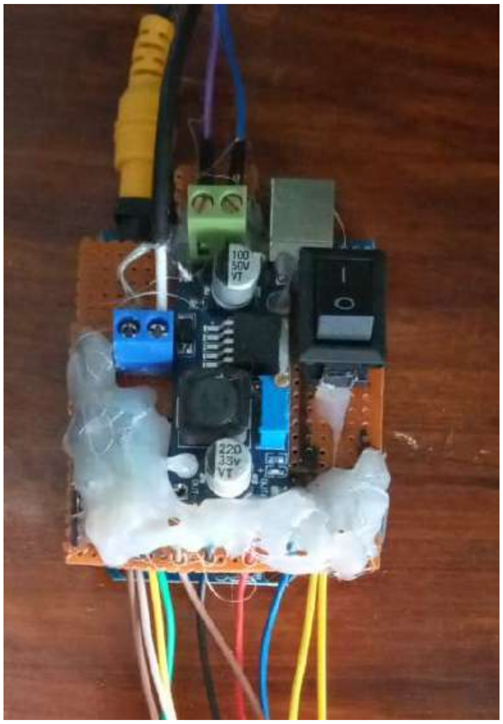


Fig 5.3 Developed Shield of the Controller with all the Connections and Electrical Components Integrated on it

5.3 Power Consumption Analysis:

Power consumption analysis is the most important part of the project as the setup is if no use without it. As we discussed earlier that lipo battery is used to power the prosthetic hand as it meets our current requirements. The motors in stall condition draw excessive current before going to steady state. A power consumption analysis in both transient and steady state is carried out for both motors in MATLAB whose results are shown below. These results show the relationship of the current drawn by the motors with respect to time. The analysis was done for motors individually as well as both 2-DOF movements simultaneously to study the combined current behavior of both actuators operating at the same time.

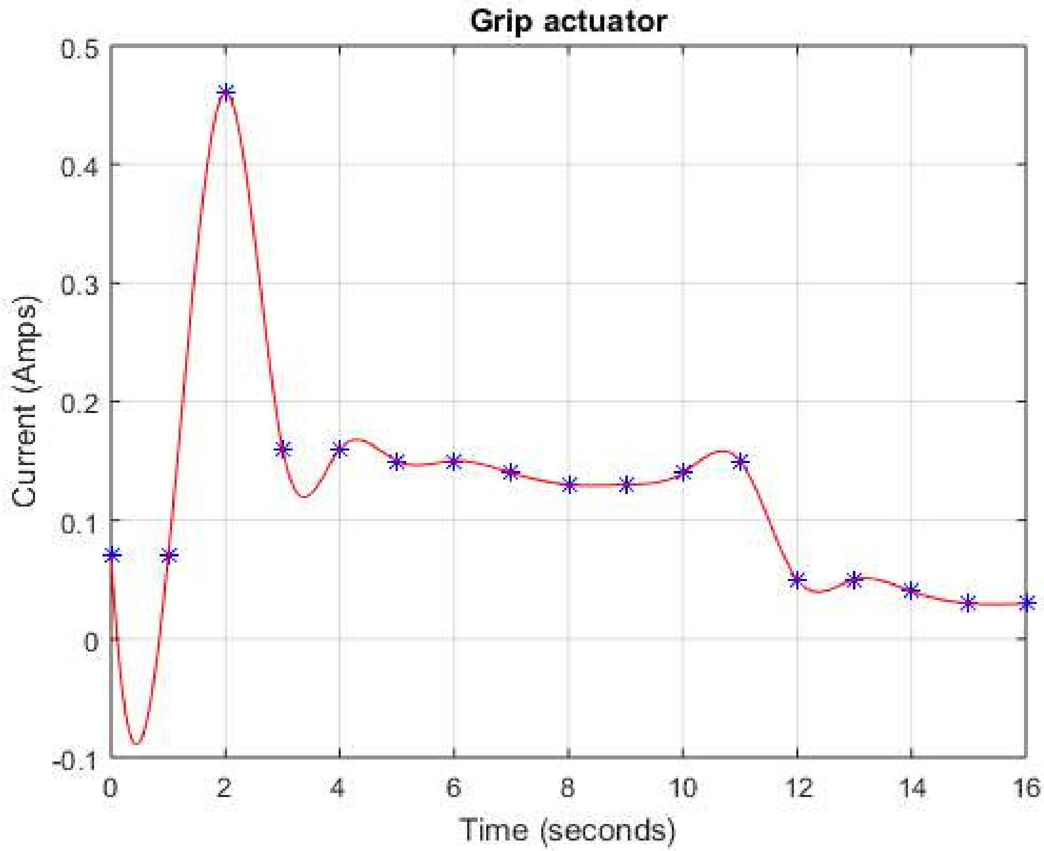


Fig 5.4 Current drawn by Grip Actuator with respect to time

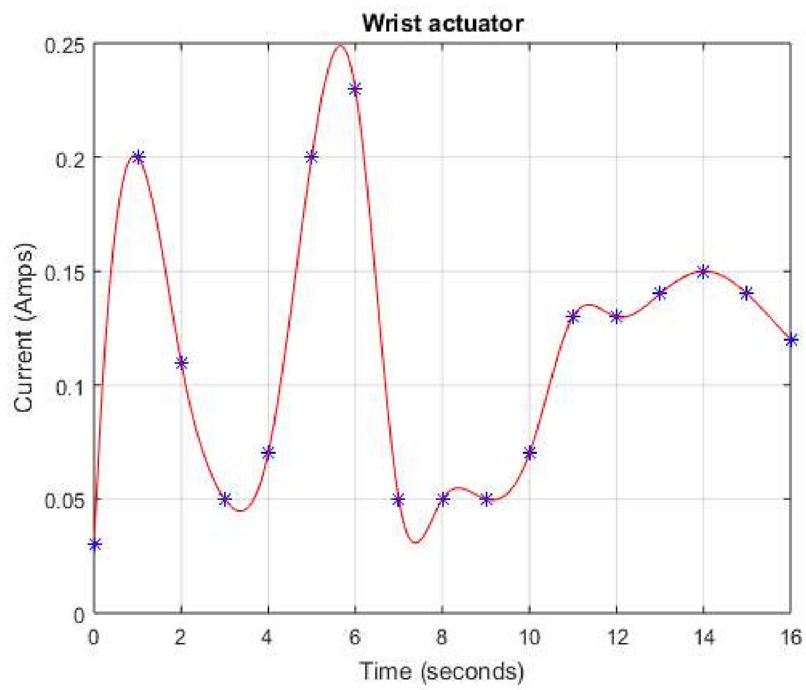


Fig 5.5 Current Drawn by Wrist Actuator with respect to time

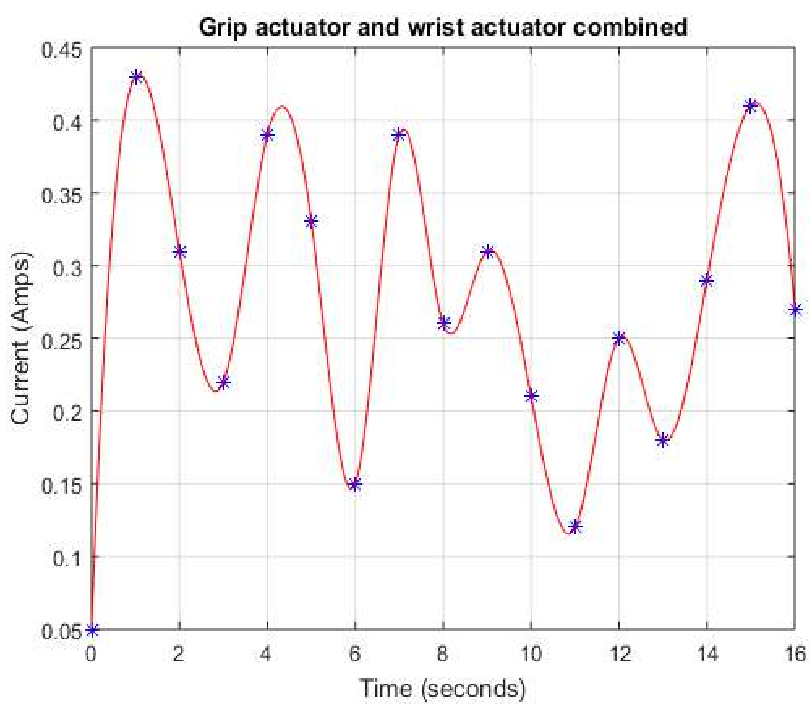


Fig 5.6 Current drawn by both actuators on simultaneous opening and closing of the jaws along with rotation

Fig 5.6 Electromechanical prosthetic hand DOF-1 gripping

Fig 5.7 Electromechanical prosthetic hand DOF-2 Wrist rotation with gripping

5.4 Chapter Summary:

In this section the results with electromechanical design integration with controller and power consumption analysis using current as a function of time was discussed for motors in various conditions such as opening and closing of the jaws and wrist rotation. The results show the current behavior during transient and steady state for both actuators individually as well as simultaneously operating together. The control is facilitated by the joystick that lets the user control the gripping and wrist rotation.

Chapter 6

Conclusion

In conclusion, the development of a simple and lightweight two-degree-of-freedom (2-DOF) controller design for an anthropomorphic hand has been successfully achieved. The project aimed to address the challenges faced by upper limb amputees in Pakistan by providing locally manufactured and affordable prosthetic hands.

The project began with a comprehensive literature review, which explored the currently available prosthetic hands in the market and research projects related to prosthetic hand development. This review provided insights into the existing technologies and guided the project in designing an effective solution.

The methodology section outlined the project's flow, which involved market surveys, controller design, gear design, electrical design, software design, testing, and tuning. The market survey highlighted the need for cost-effective prosthetic solutions in Pakistan, particularly for the lower-income population. The controller design involved coding and interfacing a joystick with an Arduino UNO, enabling control over the gripping and wrist rotation movements of the hand.

The electro-mechanical design phase focused on the mechanical structure and electrical circuitry. The mechanical design utilized a solid iron hand structure with jaws for gripping, while the gears were designed and 3D printed for wrist rotation. The electrical design incorporated servo motors, a DC-DC buck converter, a joystick module, and an Arduino UNO as the microcontroller. These components were integrated and connected to create the electromechanical setup.

The results and discussions section presented the achieved results and power consumption analysis. The results showed the current behavior of the grip and wrist motors during different movements, and the power consumption analysis provided insights into the energy requirements of the setup.

Overall, this project successfully developed a simple and lightweight 2-DOF controller design for an anthropomorphic hand, addressing the need for affordable prosthetic solutions in Pakistan. The locally manufactured prosthetic hands have the potential to improve the quality of life for upper limb amputees and facilitate their daily activities. Further research and development can be conducted to enhance the functionality and accessibility of prosthetic hands in the future.

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