National Institute of Technology, Patna
Electronics and Communication Engineering

A Project Report on

Development of a 3D Printed Prosthetic Robotic Arm with Multiple Control Mechanisms

For the Fulfilment of Bachelor's Degree in Electronics and Communication Engineering

by

Govindu Devi Sriram (2004087)
Pilla Durga Phani Danayya (2004155)
Karra Vinay Kumar(2004117)

Under the guidance of

Associate Prof Dr.Anupam Kumar

Date – 11th November, 2023

LIST OF CONTENTS

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our guide and motivator Associate Prof Dr. Anupam Kumar, Electronics and Communication Engineering Department, National Institute of Technology, Patna for his valuable guidance, valuable inputs from time to time and co-operation for providing necessary facilities and resources during the entire period of project.

We wish convey our profound gratitude to all the facilities of Electronics and Communication Engineering Department who have enlightened us during our completion of project. The facilities and co-operation received from the technical staff of Electronics and Communication Engineering Department are thankfully acknowledged.

We express our thanks to all those who helped us in our endeavour and work. I would also like to thank those individuals who contributed to this project, and particularly, employees who provided insights and comments as part of this project.

Last, but not least, we would like to thank the various authors of various research articles and books whose reference have been incorporated in our project.

Govindu Devi Sriram (2004087)
Pilla Phani Durga Danayya (2004155)
Karra Vinay Kumar (2004117)

ABSTRACT (Objective of the project)

The initiative consists of three crucial phases designed to revolutionize the functionality and control mechanisms of prosthetic arms for individuals facing hand loss due to accidents, medical conditions, or congenital disabilities. The initial phase revolves around the development of a lightweight and responsive 3D-printed arm using Polylactic Acid (PLA) filament material. This is complemented by the integration of flex sensors, which serve as the nerve centre, detecting intricate hand movements and transmitting signals to drive servo motors. The servo motors, in turn, orchestrate natural hand and finger motions. The outcome of this foundational phase is a promising prototype that demonstrates functionality and dexterity akin to a natural hand.

Expanding the scope, the second phase introduces Electromyography (EMG) sensors to diversify control mechanisms. The integration of EMG sensors establishes a direct interface between muscle signals and the prosthetic arm's actions, allowing users to manipulate the arm intuitively through muscle movements. This phase significantly enhances accessibility, catering to users with different capabilities and preferences, thereby empowering a more personalized interaction.

Moreover, the third phase integrates Bluetooth technology, introducing remote control functionality via an Android application. This feature grants users unparalleled flexibility in operating their prosthetic limb wirelessly. The Android app enables seamless communication with the prosthetic arm, allowing for remote adjustments, personalized settings, and intuitive controls, thereby elevating convenience and adaptability in daily usage.

AI Integration and Future Prospects:

Furthermore, the project explores the integration of Artificial Intelligence (AI) into the robotic arm's functionalities. By incorporating AI algorithms, the arm gains the ability to learn and adapt, enhancing its performance across various fields. This AI-driven enhancement opens doors for advancements in fields like rehabilitation, where the arm can adapt to users' unique movements and aid in personalized rehabilitation programs. Additionally, AI integration could optimize the arm's functionality in industries requiring precise and repetitive tasks, such as manufacturing or assembly lines.

Anticipating future advancements, the project acknowledges the potential of advanced materials, particularly carbon fibre for 3D printing, promising unparalleled strength and durability. Embracing the continuous evolution within the 3D printing industry, this project serves as a cornerstone for developing robust, commercially viable prosthetic devices that cater to diverse user needs, ensuring longevity and reliability.

CHAPTER 1

INTRODUCTION

In India, the number of amputees exceeds 12 million, with an annual increase of 50,000 to 100,000 new amputations. Among these instances, 10% are attributed to hand-related amputations. The majority of amputations result from accidents and health conditions such as trauma, malignancy, vascular disease, congenital deformities, and infection. Amputation profoundly impacts individuals, leading some to alter their professions post-amputation. Additionally, it poses challenges in daily life, contributing to a decline in life satisfaction for those affected.

In aiding amputees in resuming their daily routines, various hand prosthesis devices have been developed since the era when body-powered prostheses were prevalent. Thanks to the ongoing progress in biotechnology and robotics, contemporary innovations have significantly influenced the design and control of prostheses. Modern hand prostheses, surpassing their predecessors, feature an array of sensors and actuators to enhance their functionality.

A functional prosthetic hand should enable amputees to engage in activities of daily living (ADLs). One essential function of the human hand is the capability to grasp objects of diverse and complex shapes. Numerous efforts have been made by different groups to replicate this aspect of the human hand, focusing on advancements in sensing, control, actuation, and structural design of hand prostheses. Despite these efforts, the challenge of creating a prosthesis that fully replicates the multifaceted functions of the human hand remains a concern.

Essentially, for efficient object manipulation, the prosthesis must address three key tasks. The first involves perceiving and attaining an appropriate gesture, adjusting the device's configuration to match the required shape for the intended motion outlined in Figure 1. These grasping gestures typically fall into categories such as power, precision, and lateral grasps. The second task is to apply a gripping force effectively, ensuring that the object is securely held without slipping or causing damage. Finally, the mechanical mechanisms must execute the grasping action, necessitating the prosthesis's structure to adapt to the shape of the grasped object.

Basically, human hand gestures can be divided based on their function into two groups of power and precision and based on their gesture's shape into two groups of round and flat gestures (Figure 1).

Various design considerations, encompassing aesthetics, cost, functionality, and more, must be taken into account when creating a prosthetic hand. This study seeks to compile the latest advancements in hand prosthesis design, specifically focusing on approaches to enhance the grasping function of artificial hands. Despite numerous research efforts aimed at improving the grasping function of hand prostheses, the existing information is scattered, lacking a consolidated source that organizes these diverse system designs.

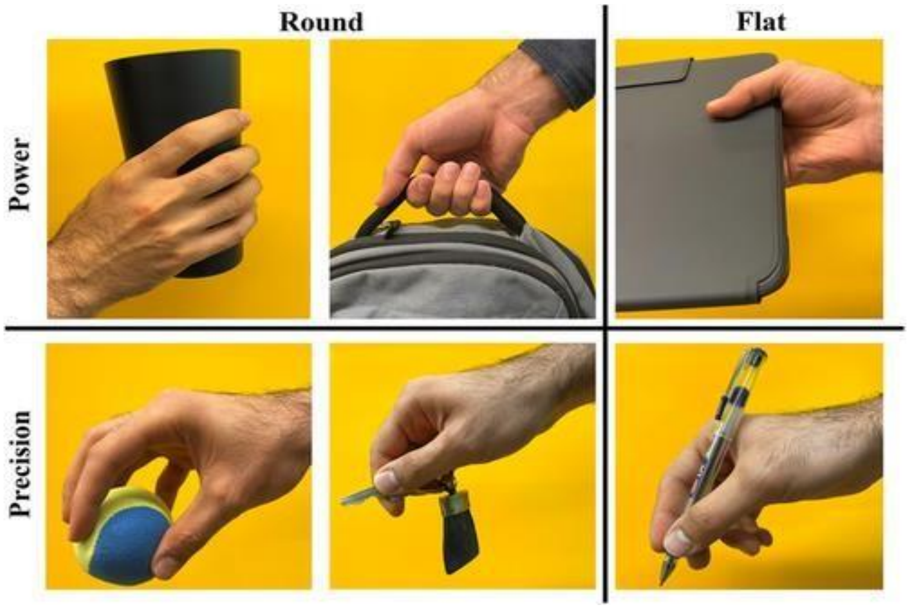


Figure1

Examples of human grasp gestures: the ability of the human hand to adjust its shape to the form of complex-shape objects.

This article undertakes a thorough examination of the innovative design approaches employed in various systems. It delves into the advantages and disadvantages of the developed systems, providing valuable insights to assist researchers in crafting prosthetic hands with enhanced grasping functions.

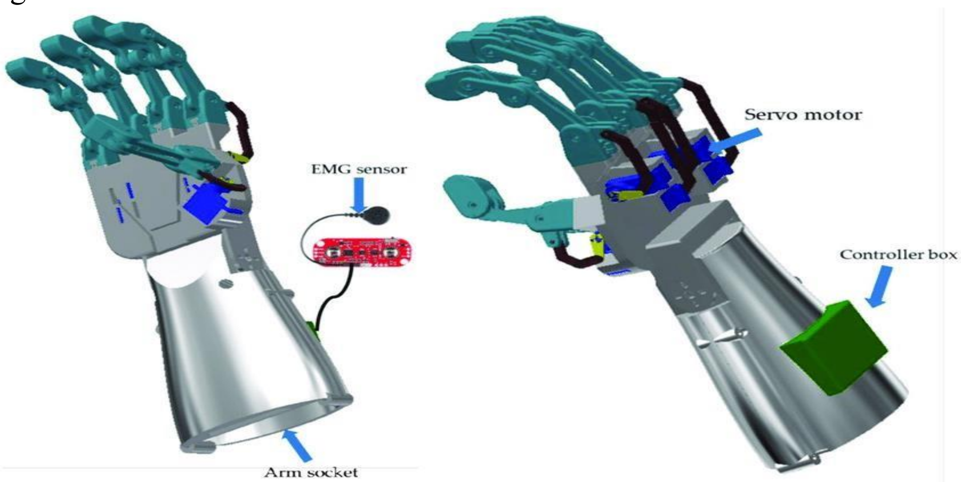


Figure 2
Prosthetic hand consists of a sensing system, actuation system, and structure and mechanisms.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Evolution of Prosthetic Technology

The evolution of prosthetic technology spans centuries, with significant advancements witnessed in recent years. Early prosthetic limbs were rudimentary, made primarily of wood and metal, providing limited functionality and comfort. Throughout history, innovators continually strived to improve these devices, leading to the introduction of more sophisticated materials and mechanisms.

Current State-of-the-Art in 3D Printed Prosthetic Arms:

Recent years have seen a surge in the utilization of 3D printing technology in prosthetic limb development. The ability to fabricate intricate designs layer-by-layer has revolutionized the field, offering tailored solutions at lower costs. 3D printed prosthetic arms exhibit lightweight yet durable structures, customized to fit individual anatomies, enhancing user comfort and functionality.

2.2 Sensor Systems

The comprehension of hand grasping mechanisms is paramount for the execution of manipulation tasks and significantly influences the efficacy of prostheses. Consequently, various research groups have directed their efforts toward designing innovative systems for capturing human hand motion, broadly classified into five categories: 1) glove-based data capturing; 2) marker-based data capturing; 3) electromyography (EMG)-based data capturing; 4) haptic-based data capturing; and 5) vision-based data capturing.[6, 7]. Notably, the EMG method stands out as the sole approach capable of extracting sensory information from the forearm, distinguishing it from other data capturing methods that rely on the hand itself. This uniqueness positions EMG signals as particularly valuable for amputees with hand losses, enabling the recognition of the amputee's grasping gestures.[8]

This article organizes sensing systems into three distinct groups. The first group encompasses sensors designed to perceive the intended hand motion from the user. The second group consists of motion sensors employed to assess the position and kinematics of each finger, facilitating control over the prosthesis' grasping motion. Lastly, the third group involves tactile sensors tasked with measuring biological sensations such as pressure, temperature, and pain.

2.2.1 Electromyography (EMG)

In recent times, human biological signal processing methods have been employed for perceiving the desired hand motion in amputees. These methods encompass a range of techniques, including electromyography (EMG), electroencephalography (EEG), electrocorticography (ECoG), intracortical neural signals, magnetoencephalography (MEG), and blood oxygen levels. Notably, EMG methods have emerged as the predominant choice among these techniques, primarily owing to their reliability, affordability, and ease of use.

Electromyography (EMG) is a method for measuring electrical muscle activity in response to nerve stimulation, and it involves two main approaches: intramuscular EMG and surface EMG (sEMG). Intramuscular EMG involves implanting EMG electrodes directly inside the human body to target specific muscles. While this method offers high accuracy in EMG measurements, it requires clinical procedures and may pose potential post-surgery complications.

On the other hand, sEMG is a widely used technique, particularly in EMG armbands, for measuring the electrical activities of muscles in prosthetic hands. This method is non-invasive and user-friendly. sEMG dry electrodes, for instance, can capture EMG signals on the forearm skin. Portable EMG sensors utilize these signals to detect and represent hand movements. Despite its convenience, sEMG is less accurate than intramuscular EMG, and it may be susceptible to electrical signal interactions between adjacent muscles, potentially leading to errors in measuring the activity of specific muscles.

Following the acquisition of electromyography (EMG) signals, it becomes essential to filter the raw data to address its inherent noise and enhance interpretability. Given that EMG signals are analog, employing a bandpass filter proves to be a suitable strategy for noise removal. This type of filter effectively eliminates high and low frequencies from the raw signals. Subsequently, the filtered signal undergoes amplification to compensate for the typically weak amplitude of raw EMG signals

In the context of hand prostheses, the measurement of the electrical contraction response from flexor or extensor muscles is a common practice to initiate grasping. Traditionally, the amplitude of EMG signals has been measured, and a threshold is established to trigger grasping. While effective for basic grasping functions, this method falls short when it comes to providing nuanced multigrasping gestures necessary for complex manipulation tasks. As such, there is a need for more sophisticated approaches to enable advanced and diverse functionalities in prosthetic hand control systems.In recent times, there has been a notable development in electromyogram pattern recognition (EMG-PR) methods, aiming to leverage not only the amplitude but also the pattern of the EMG signal. Various pattern recognition algorithms, often based on machine learning (ML) and virtual reality (VR) techniques, have emerged to analyze EMG signals and adapt to desired grasp patterns.

While processing EMG signals establishes a robust link between the muscle activities of an amputee and the prosthesis, these methods face challenges. The computational processes involved in EMG pattern recognition can be slow. Additionally, transforming EMG signals into a practical control signal remains a complex task. This challenge arises from the inherent physiological differences among amputees, including variations in muscle forces and electrode placement. Each amputee's unique physiology necessitates individualized approaches to ensure accurate and efficient control of prosthetic devices. Addressing these challenges is crucial for advancing the field of prosthetic control and enhancing the user experience for individuals with limb loss.

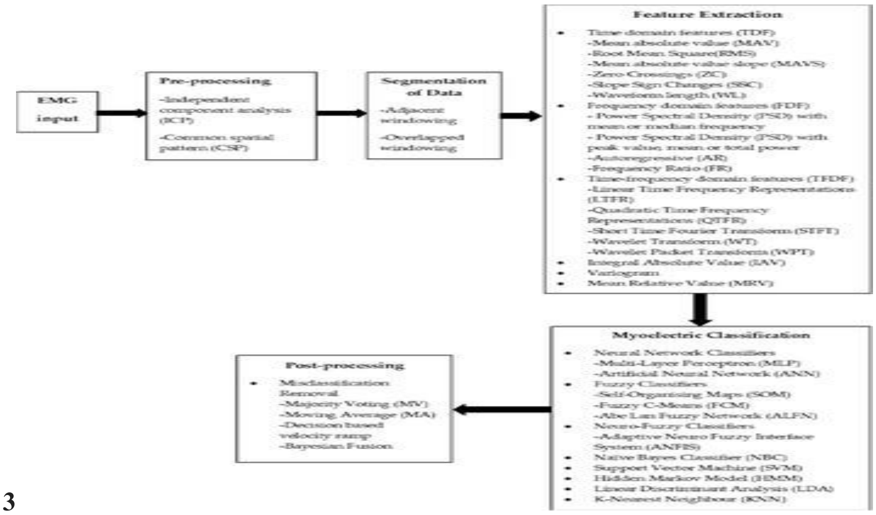


Figure 3

EMG pattern recognition (EMG-PR): five steps of processing EMG input to distinguish desired grasping patterns. Reproduced under terms of the CC-BY license.[39] 2019, MDPI.

2.2.2 Motion Sensing

Motion sensors play a crucial role in enhancing the grasping motion of prostheses by providing feedback for closed-loop control, contributing to more precise and controlled movements. As advancements in sensory and control technologies continue, there is a growing demand for achieving more accurate grasping and manipulation gestures, leading to the development of multimodal sensory systems for prosthetic fingers.

Resistance-based flexor sensors are commonly utilized to measure the rotational angle of fingers, particularly in glove-based motion capturing systems. For instance, Canizares et al.[43] designed a glove-based hand prosthesis that employed flex sensors to measure desired finger flexion from the user's glove, as illustrated in Figure 4. The rotational data obtained from these sensors were then applied to control the movement of the prosthetic fingers. In this specific case, the prosthetic hand was manufactured using fused deposition modeling (FDM) 3D printing, and DC motors were integrated into the forearm of the prosthesis.

However, it's important to note that while flex sensors are affordable and accurate, they are limited to use in glove-based motion capturing systems and are not suitable for amputees with hand losses. This limitation stems from their reliance on hand-based motion capturing.

In parallel, vision and haptic sensory systems, although not directly employed for detecting amputees' grasping gestures, can serve a monitoring role. These systems provide sensory feedback information to the motion controller unit, contributing to the overall control of the prosthesis. Recent developments in control technologies have explored the integration of vision and haptic sensory information to enhance the precision and functionality of prosthetic motion control. Inertial measurement unit's (IMU) information also can be integrated with EMG data to resolve the sensitivity of EMG signals to the physical and physiological variations. (Figure 4).

2.2.3 Tactile Sensing

Tactile sensors play a pivotal role in measuring the physical interaction between a device and its environment. When integrated into hand prostheses, they offer the potential to significantly enhance grasping function and improve the overall user experience. Over the past few decades, various tactile sensors have been developed to replicate biological sensing for users, with a focus on improving key characteristics such as linearity, accuracy, repeatability, stability, and dynamic response.

As anthropomorphic hands advance in design, the use of flexible structures in fabricating prosthetic hands has become more prevalent. This presents a challenge in maintaining the performance of tactile sensors when incorporated into flexible structures. To address this, researchers have explored the integration of rigid body sensors with effective arrangements into soft robot hands. This approach aims to balance the flexibility of the hand with the need for precise tactile feedback.

Additionally, there has been significant progress in the creation of entirely soft electronics to match the flexibility of soft prosthetic hands. This innovation holds promise for seamlessly integrating tactile sensors into the soft and flexible structures of prosthetic hands, overcoming challenges associated with rigid components in dynamic environments.The continuous improvement and integration of tactile sensors within flexible and soft prosthetic hands mark significant strides in the development of prosthetic devices that closely mimic the dexterity and sensitivity of natural hands.

2.3 Actuation Systems

The actuator component of a hand prosthesis serves as the device's power source, playing a pivotal role in influencing both grasping force and reaction time. Typically, hand prostheses utilize two primary types of power sources: externally powered and body-powered systems.

In body-powered actuation systems, the amputee manually exerts the grasping force. However, these prosthetic hands are limited to a few grasping patterns due to the restricted power inputs from the user. To overcome these limitations, there has been a recent advancement in externally powered prosthetic hands. These innovations aim to address the challenges associated with body-powered systems and have led to the development of innovative actuation systems, ultimately enhancing the overall grasping function of hand prostheses.

2.3.1 Electric Motors

Electric motors are used as a conventional actuator system of the prosthesis due to their low cost, availability, and being well developed (in a wide range of torque, speed, and power). DC motors are divided into two groups: brushed and brushless DC motors. Brushless DC motors (BLDC) have been broadly used in different applications due to their high speed, torque, and efficiency. Stepper motors are one type of BLDCs that can provide precise motion control and are used in prosthesis applications to provide accurate grasping gestures. Also, ultrasonic motors have been used as an actuator due to their large output power relative to their small size. Although electric motors have been commonly used as actuators in hand prostheses, in order to provide abundant torque for grasping, a gear train with a high reduction ratio should be used, which increases the size of motors and causes problems in fitting these motors inside the prostheses. Microgear DC motors are common actuators fit inside the prosthetic hands without enlarging the device and increasing the device's cost. These electric motors are mostly installed in the prosthesis's arm, palm, or fingers (**Figure** 6).

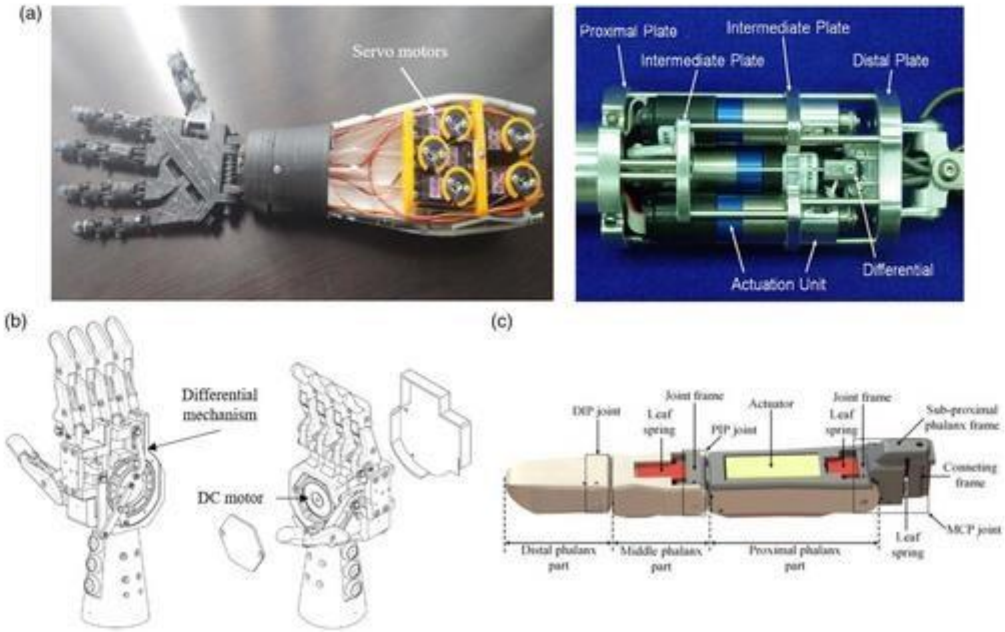


Figure 6

Moreover, prosthetic hands have been designed with varying numbers of actuators. Some commercial and non-commercial prosthetic hands employ distinct actuators for individual finger control. While this approach enhances flexibility in prosthetic hand motion control, the challenge arises as each motor must be smaller when accommodating a greater number of DC motors, resulting in a reduction of generated grasping force. In response to this concern, underactuated and differential mechanisms have been developed.

CHAPTER 3

CHALLENGES AND ISSUES

The emergence of 3D printing has transformed the landscape of prosthetics, providing enhanced customization, affordability, and accessibility for those requiring these devices. Although 3D printers can create a diverse array of prosthetic devices, challenges arise when dealing with intricately designed prosthetics, as their complexity introduces difficulties in utilizing additive manufacturing technologies.

3.1 Multi-Axis Articulated Prosthetics:

One of the primary challenges in 3D printing complex prosthetics lies in creating multi-axis articulated designs. These prosthetics mimic the natural range of motion of human limbs, enabling enhanced functionality for users. Designing and printing components with intricate interlocking mechanisms, such as joints and hinges, require advanced modeling techniques and precise calibration to ensure accurate fit and smooth movement.

3.2 Prosthetics with Integrated Electronics:

Contemporary prosthetics frequently integrate electronic elements like sensors, motors, or microcontrollers to deliver advanced functionality and user engagement. The inclusion of electronics adds a layer of complexity to the 3D printing procedure, presenting challenges such as the seamless integration of electronic components into the prosthetic structure, ensuring precise wiring, and preserving structural integrity while accommodating these electrical elements.

3.3 Prosthetics with Soft Materials:

Certain prosthetics, especially those tailored for the upper limbs or aiming to enhance grip and dexterity, incorporate soft materials like silicone or elastomers. Printing these materials using standard desktop 3D printers presents challenges, primarily due to the scarcity of cost-effective printers equipped to manage flexible filaments. Additionally, ensuring consistent print quality and achieving precise control over the material's durometer (hardness) pose further obstacles in the printing process.

3.4 Complex Surface Textures and Patterns:

Prosthetics, especially those for aesthetic purposes, may require intricate surface textures, patterns, or personalized designs. Replicating such intricate details through 3D printing can be demanding. Achieving high-resolution surface finishes often requires specialized printers or post-processing techniques, such as sanding, polishing, or painting, to achieve the desired aesthetics and functional outcomes.

3.5 Large-Scale Prosthetics:

Certain prosthetic devices, such as those for lower limb amputations or customized orthoses, may necessitate printing on a larger scale. Traditional desktop 3D printers may have limitations in terms of build volume, making it difficult to print larger prosthetics in a single piece. Overcoming this challenge often involves breaking down the design into smaller printable components, which then require precise alignment and assembly to ensure structural integrity and optimal fit.

Conclusion:

While 3D printing has opened up new possibilities in prosthetics manufacturing, the production of complex prosthetics presents unique challenges. Overcoming these challenges requires advancements in technology, materials, and design techniques. As researchers and engineers continue to innovate in the field of additive manufacturing, we can expect to see further advancements that will address these complexities and improve the accessibility and functionality of prosthetic devices for individuals in need.

CHAPTER 4

METHODOLOGY
(Approach to the Problem)

The methodology adopted for the development of the 3D printed prosthetic robotic arm with integrated flex sensors, EMG sensors, and Bluetooth control via an Android app involves a structured approach across three pivotal phases

4.1 Phase One: Control of 3D Printed Prosthetic Arm with the Flex sensors

The initial phase focuses on integrating flex sensors into the prosthetic arm to enable intuitive control mechanisms. The methodology employed includes:

4.1.1 Flex Sensor Selection and Integration:

Extensive research to select appropriate flex sensors considering sensitivity, durability, and compatibility with the prosthetic arm's materials.

Precise placement of flex sensors on the arm to capture natural hand movements.

Integration with microcontrollers or control boards to interpret and process sensor data.

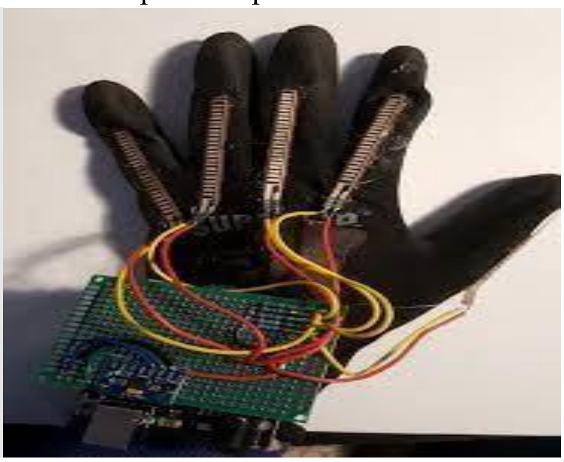


Fig 1: Arduino compactible Flex Sensor **Fig 2:** Integration of Flexsensor with Arduino

4.1.2 Hardware and Software Development:

Development of the hardware interface to connect flex sensors to the prosthetic arm.

The Flex sensors is connected to the Arduino board as shown in the schematic below

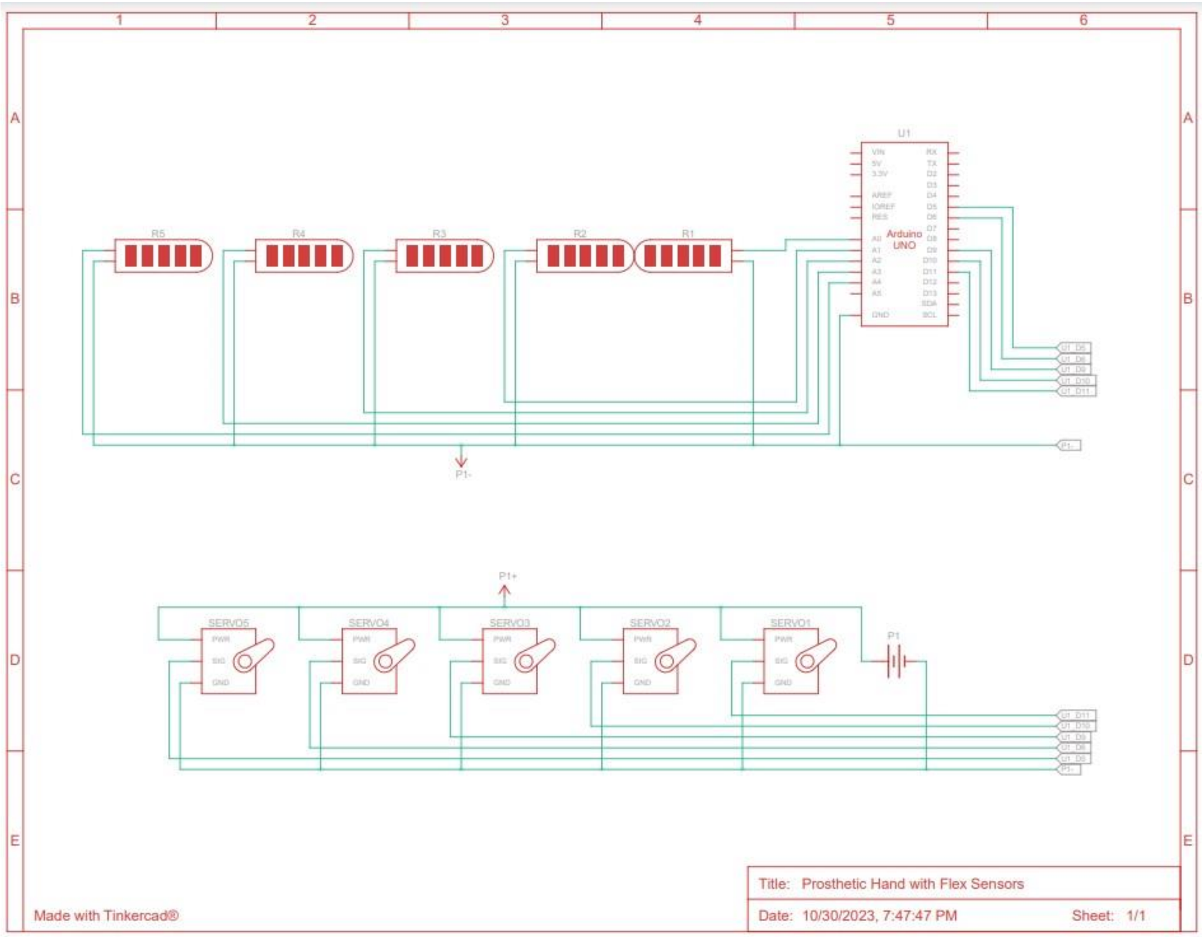


Fig 3: Schematic of Prosthetic Hand with Flex Sensors

Design and implementation of software algorithms for signal processing and interpretation.

The Arduino Code for the control of the 3D Prosthetic Arm with Flex Sensors

```
#include <stdint.h>
#include <Servo.h>
#define FLEX_MIN    384
#define FLEX_MAX    783
#define SERVO_MIN   180
#define SERVO_MAX   50
#define LENGTH(arr)   sizeof(arr)/sizeof(arr[0])
 uint8_t glove[5] = {A0, A1, A2, A3, A4}; // Glove input pins.
uint8_t robot[5] = {11, 10,  9,  6,  5}; // Servo output pins (PWM).

// Create 5 servo objects to represent our fingers.
Servo finger[5];
 uint8_t pin;  // Which pin we are currently using.
int16_t pos;  // The new position to write to the servo.
```

```
void setup() {   Serial.begin(9600);   for
(pin = 0; pin < LENGTH(glove); pin++) {
pinMode(glove[pin], INPUT_PULLUP);
  }      for (pin = 0; pin < LENGTH(robot);
pin++) {     finger[pin].attach(robot[pin]);
  }
}  void loop() {   for (pin = 0; pin <
LENGTH(glove); pin++) {         pos =
analogRead(glove[pin]);
     // Scale this value according to what a servo can do.
pos = map(pos, FLEX_MIN, FLEX_MAX, SERVO_MIN, SERVO_MAX);
    // Print out how much each finger is moving.
    Serial.print(pos); Serial.print("  ");
    // Write the new position of the current finger to the servo.
finger[pin].write(pos);
  }
  Serial.println("");
delay(1);
}
```

Calibration procedures to ensure accurate translation of flex sensor inputs into arm movements.

4.1.3 Testing and Validation:

Rigorous testing protocols to assess the accuracy, responsiveness, and reliability of the flex sensor-controlled arm.

Real-time simulations and controlled experiments to validate the functionality and effectiveness of the flex sensor integration.

Analysis of testing results to refine sensor placement and system calibration for optimal performance.

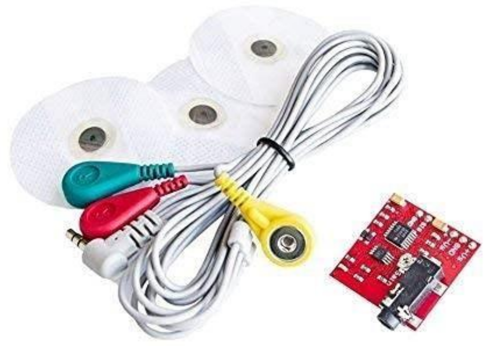
4.2 Phase Two: EMG Sensor Control

The subsequent phase involves the integration of EMG sensors to enhance control precision based on muscle signals. The methodology encompasses:

4.2.1 EMG Sensor Installation and Configuration:

Selection and installation of EMG sensors to capture residual muscle signals from the user's limb.

Interface development for integrating EMG sensors with the prosthetic arm's control system.



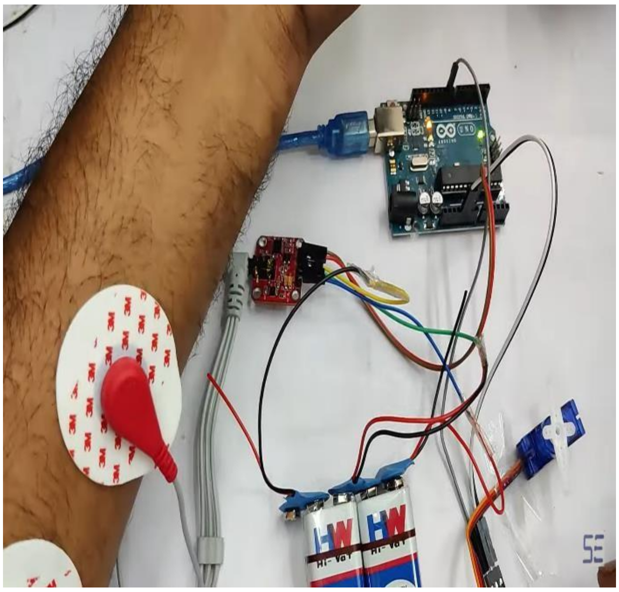


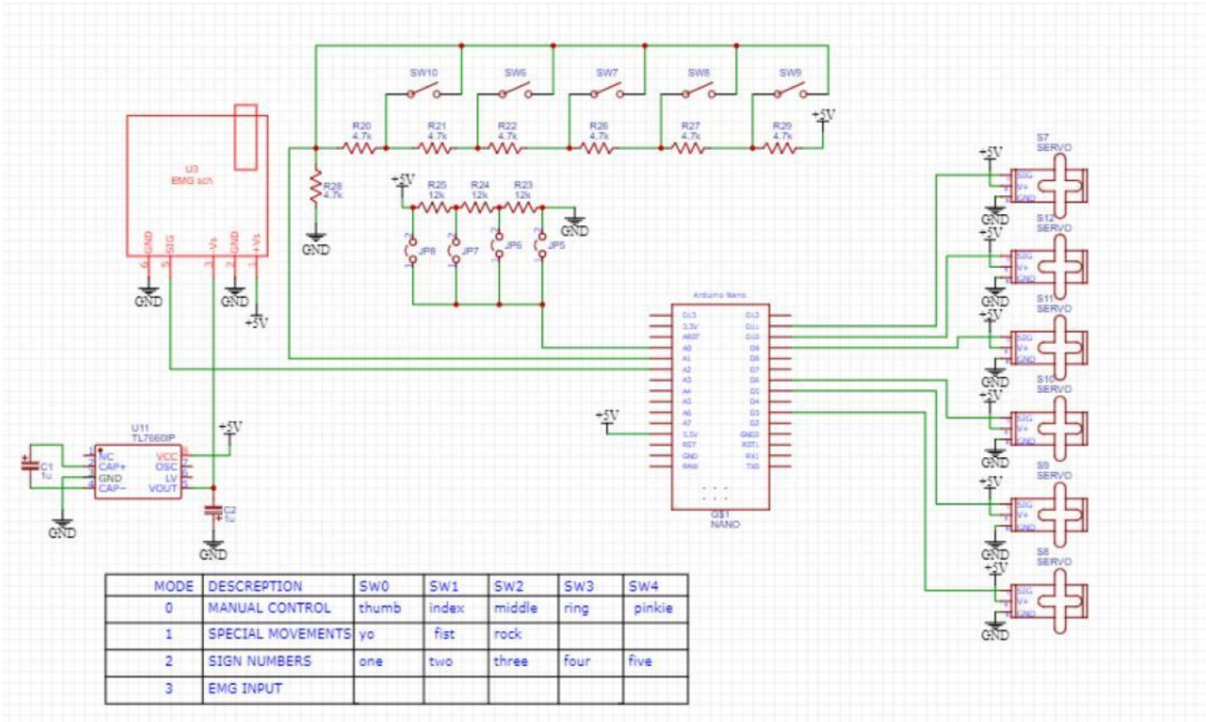
Fig 4: Arduino compactible EMG sensor **Fig 5:** Integration of EMG sensor with Arduino

4.2.2 Signal Interpretation and Arm Movement:

Algorithm development to interpret EMG signals and map them to specific arm movements.

Technical validation to ensure accurate interpretation and translation of muscle signals into corresponding actions of the prosthetic arm.

The EMG sensors is connected to the Arduino board as shown in the schematic below



MODE	DESCREPTION	SW0	SW1	SW2	SW3	SW4
0	MANUAL CONTROL	thumb	index	middle	ring	pinkie
1	SPECIAL MOVEMENTS	yo	fist	rock		
2	SIGN NUMBERS	one	two	three	four	five
3	EMG INPUT					

Fig 6: Schematic of Prosthetic Hand with EMG Sensors

The Arduino Code for the control of the 3D Prosthetic Arm with EMG Sensors

4.2.3 Experimentation and Analysis:

Conduct of controlled experiments involving users or simulated muscle signals to analyze the efficacy and precision of EMG sensor-based control.

Detailed analysis of captured data to refine signal processing algorithms and optimize arm movement based on EMG inputs.

4.3 Phase Three: Speech Recognition Bluetooth Control via Android App

The final phase revolves around the development of an Android app for wireless Bluetooth control of the prosthetic arm. The methodology includes:

4.3.1 App Development and Integration:

Design and development of an Android application enabling wireless control of the arm through Bluetooth connectivity.

Integration of the app's interface with the prosthetic arm's control system.

Schematic of Bluetooth control 3D prosthetic arm is

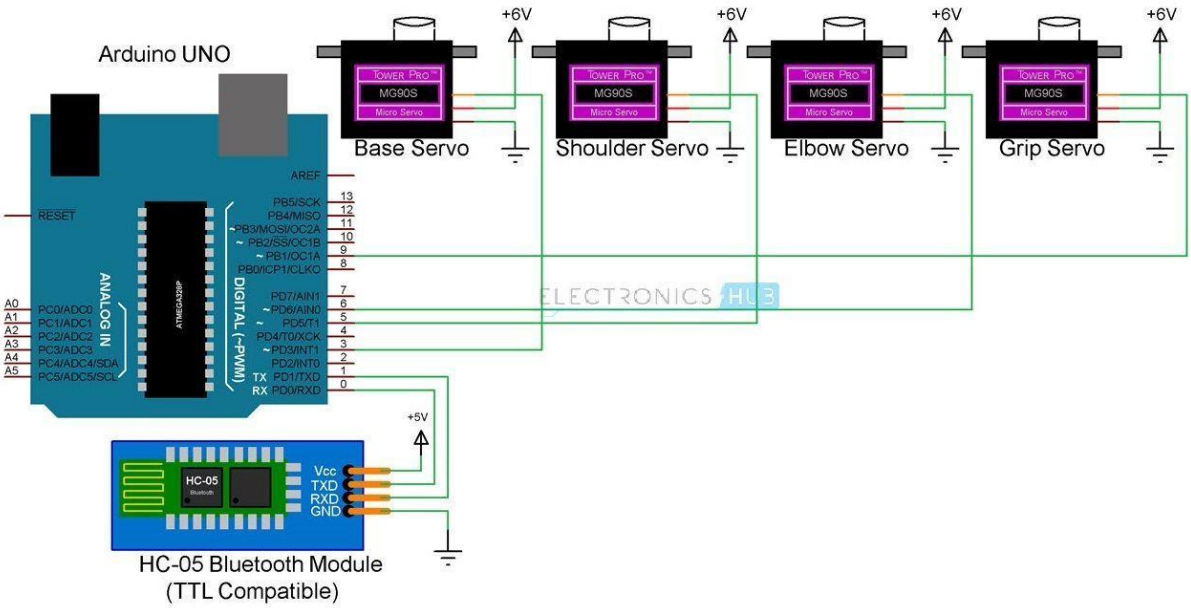


Fig 7: Schematic of Bluetooth control 3D prosthetic arm

4.3.2 User Interface Design and Usability Testing:

Iterative design processes focusing on creating an intuitive and user-friendly interface.

Usability testing involving potential users to assess ease of operation, functionality, and overall user experience.

```
#include <stdint.h>
#include <Servo.h>
#define LITTLEPIN  11 //Digital pin used by Little servo
#define RINGPIN    10 //Digital pin used by Ring servo
#define MIDDLEPIN  9//Digital pin used by Middle servo
#define INDEXPIN   6 //Digital pin used by Index servo
#define THUMBPIN   5 //Digital pin used by Thumb servo
Servo servoLittleFinger;
Servo servoRingFinger;
Servo servoMiddleFinger;
Servo servoIndexFinger;
Servo servoThumbFinger;
String voice;

void setup() {
  Serial.begin(9600);
  servoLittleFinger.attach(LITTLEPIN);
   servoRingFinger.attach(RINGPIN);
   servoMiddleFinger.attach(MIDDLEPIN);
   servoIndexFinger.attach(INDEXPIN);
   servoThumbFinger.attach(THUMBPIN);


}

void loop() {
        while(Serial.available()){
          delay(10);
        char c = Serial.read();
        if(c == '#'){break;}
        voice +=c;
        }
      if(voice.length()>0){
        Serial.print(voice);
          if(voice == "show little finger"){
              servoLittleFinger.write(170);
              delay(1000);
              servoLittleFinger.write(50);
          }else if(voice == "show ring finger"){
              servoRingFinger.write(170);
              delay(1000);
              servoRingFinger.write(50);
          }else if(voice =="show middle finger"){
              servoMiddleFinger.write(170);
              delay(1000);
              servoMiddleFinger.write(50);
          }else if(voice == "show index finger"){
              servoIndexFinger.write(170);
              delay(1000);
```

```
        servoIndexFinger.write(50);
    }else if(voice == "show Thumb"){
        servoThumbFinger.write(170);
        delay(1000);
        servoThumbFinger.write(50);
    }else if(voice == "Move all fingers"){
             servoLittleFinger.write(170);
              servoRingFinger.write(170);
              servoMiddleFinger.write(170);
              servoIndexFinger.write(170);
              servoThumbFinger.write(170);
              delay(1000);
              servoLittleFinger.write(0);
              servoRingFinger.write(0);
              servoMiddleFinger.write(0);
              servoIndexFinger.write(0);
              servoThumbFinger.write(0);
    }else if(voice == "Open all fingers"){
      servoLittleFinger.write(170);
              servoRingFinger.write(170);
              servoMiddleFinger.write(170);
              servoIndexFinger.write(170);
              servoThumbFinger.write(170);
              delay(1000);

    }else if(voice == "Close all fingers"){
      servoLittleFinger.write(50);
              servoRingFinger.write(50);
              servoMiddleFinger.write(50);
              servoIndexFinger.write(50);
              servoThumbFinger.write(50);
              delay(1000);

    }else if(voice == "oneplus 0" || voice == "0+1"){
      servoLittleFinger.write(50);
              servoRingFinger.write(50);
              servoMiddleFinger.write(50);
              servoIndexFinger.write(170);
              servoThumbFinger.write(50);
              delay(1000);

    } else if(voice == "0+2" || voice == "2+0" || voice == "1+1"){
      servoLittleFinger.write(50);
              servoRingFinger.write(50);
              servoMiddleFinger.write(170);
              servoIndexFinger.write(170);
              servoThumbFinger.write(50);
              delay(1000);
```

```
        } else if(voice == "0+3" || voice =="3+0" || voice == "1+2" || voice
== "2+1" ){
          servoLittleFinger.write(170);
                  servoRingFinger.write(170);
                  servoMiddleFinger.write(170);
                  servoIndexFinger.write(50);
                  servoThumbFinger.write(50);
                  delay(1000);

        }else if(voice == "0+4" || voice =="4+0" || voice == "1+3" || voice
== "3+1" || voice == "2+2" ){
          servoLittleFinger.write(170);
                  servoRingFinger.write(170);
                  servoMiddleFinger.write(170);
                  servoIndexFinger.write(170);
                  servoThumbFinger.write(50);
                  delay(1000);

        }else if(voice == "0+5" || voice =="5+0" || voice == "1+4" || voice
== "4+1" || voice == "3+2" || voice=="2+3" ){
          servoLittleFinger.write(170);
                  servoRingFinger.write(170);
                  servoMiddleFinger.write(170);
                  servoIndexFinger.write(170);
                  servoThumbFinger.write(170);
                  delay(1000);

        }else if(voice =="super"){
           servoLittleFinger.write(170);
                  servoRingFinger.write(170);
                  servoMiddleFinger.write(170);
                  servoIndexFinger.write(50);
                  servoThumbFinger.write(50);
                  delay(1000);
        }else if(voice == "Thums up"){
          servoLittleFinger.write(50);
                  servoRingFinger.write(50);
                  servoMiddleFinger.write(50);
                  servoIndexFinger.write(50);
                  servoThumbFinger.write(170);
                  delay(1000);
        }
        voice = "";
    }

}
```

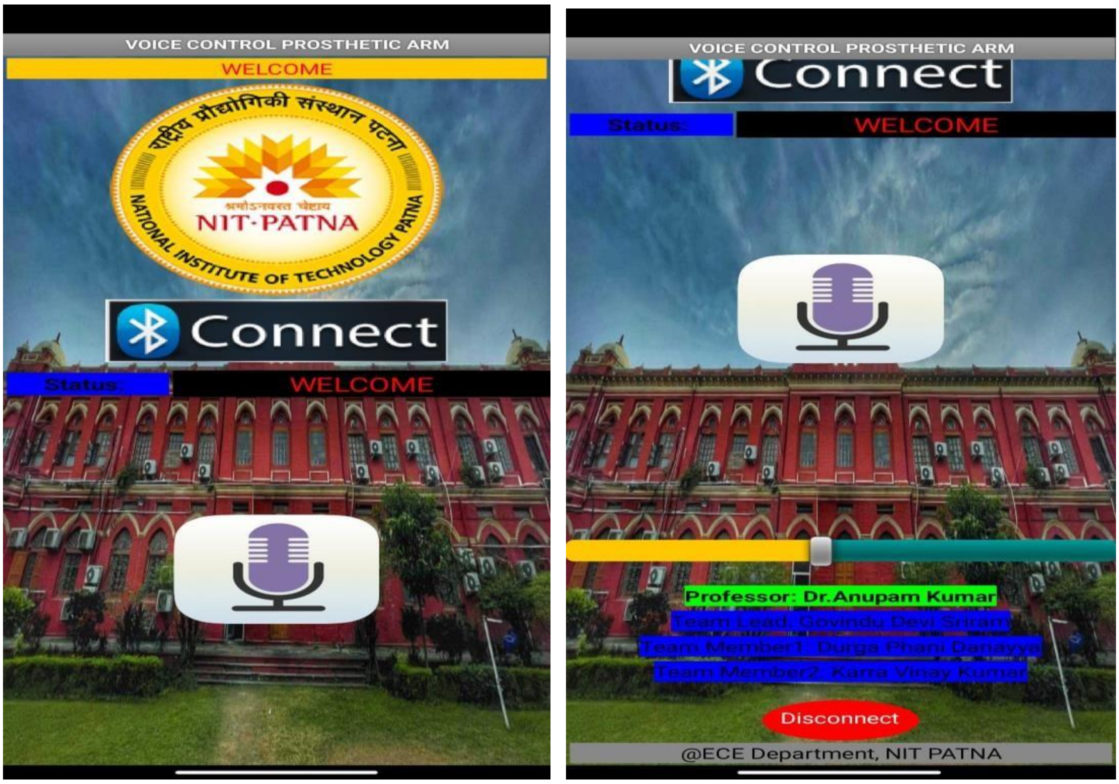


Fig 7: App Interface of Voice Control Prosthetic Arm

CHAPTER 5

DESIGN AND DEVELOPMENT OF 3D PROSTHETIC ARM

3D Designs and Mechanisms

5.1 3D-Printed Prosthetic Designs

3D printing technology has been a promising method for researchers to fabricate customizable, lightweight, cheap, and rapid prosthetic hands. This technology can be used to fabricate both rigid and soft structures.

Grasping an object with a complex shape requires the prosthetic hand's design to be mechanically compliant. The human hand structure is made of rigid parts (skeletal part) and soft parts (soft tissues) to make a perfectly compliant structure for grasping objects. Articular cartilage mechanism in finger's joints provides smooth and flexible relative motion between bones. Inspiring by the human hand, researchers developed elastic joints for rigid prostheses.

Recently, soft robotics emerged to provide compliant, lightweight, and simple structures for prostheses. Designing monolithic soft structures using 3D printing technologies is a favourable way of reducing the weight and complexity of manufacturing a prosthetic hand. This prosthetic hand could provide three grasp gestures as well as individual finger motion while having lightweight and low cost to fabricate. Also, 3D printing technology has been widely used to fabricate embedded sensor structures. Another use of 3D printing technologies is manufacturing the casting mold to produce prosthetic hands.

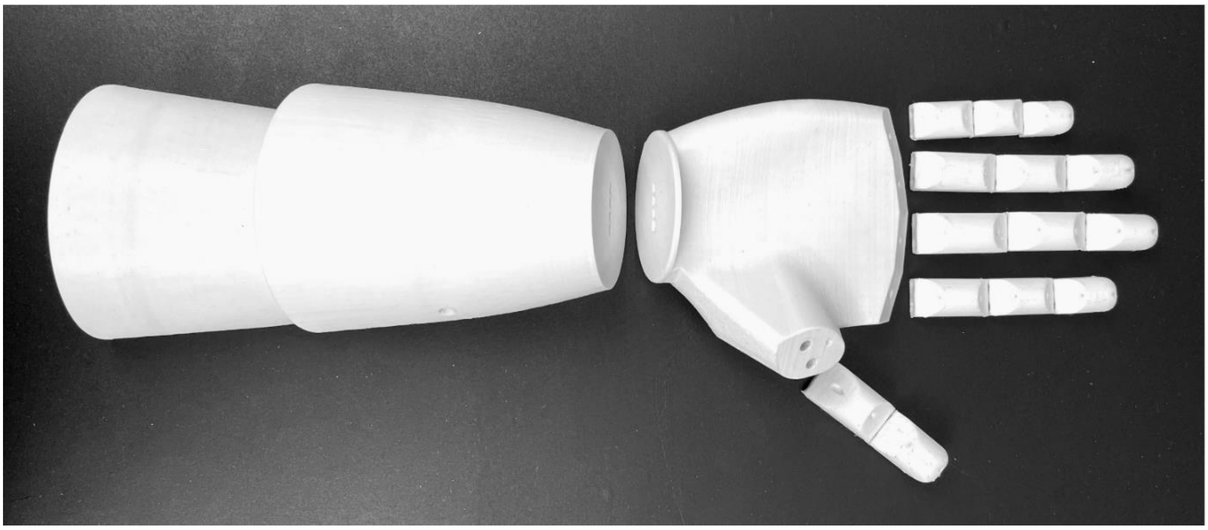


Fig1: 3D Printed Prosthetic Arm

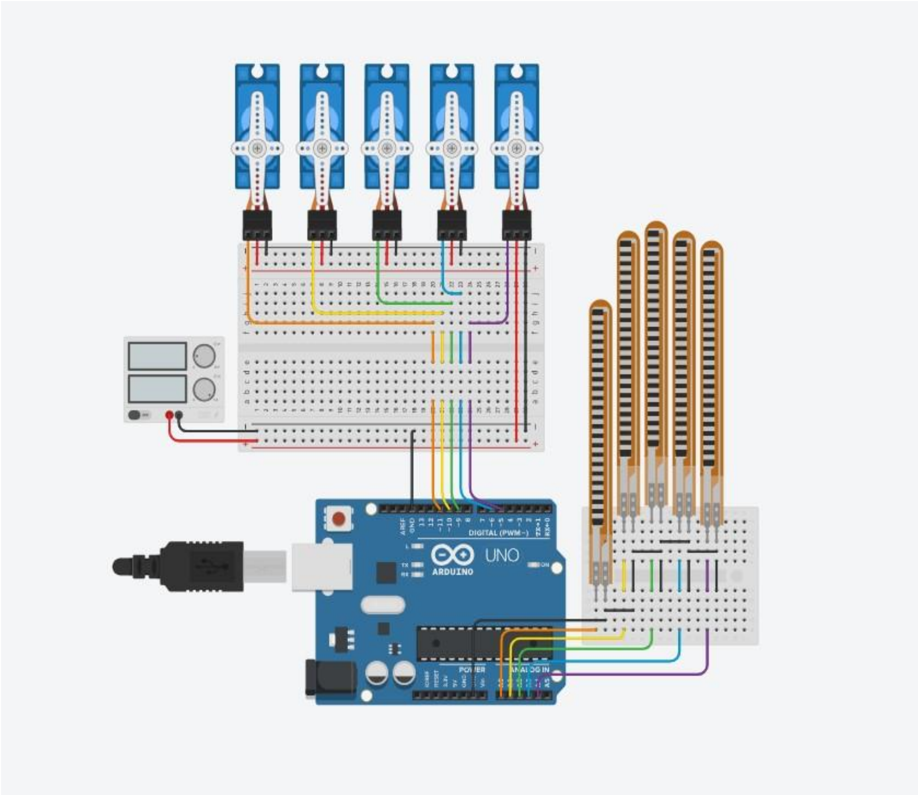


Fig: TinkerCad Simulation of the Prosthetic Arm with the help of the Flex Sensors **The link for the TinkerCad Simulation is**:

https://www.tinkercad.com/things/fXDGBYgGYj8-prosthetic-hand-with-flex-sensors

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Phase One: Flex Sensor Control 6.1.1
Results:

Successful integration of flex sensors onto the prosthetic arm allowing for intuitive control based on hand gestures.

Hardware and software development enabled precise interpretation of flex sensor signals for corresponding arm movements.

Testing revealed a high degree of accuracy in replicating hand gestures through the flex sensor-controlled arm.

6.1.2Discussion:

The integration of flex sensors proved effective in capturing natural hand movements, enabling a responsive control mechanism.

The developed hardware and software facilitated real-time interpretation and translation of flex sensor inputs, ensuring accurate and reliable arm movements. Testing results indicated promising feasibility and usability, laying a solid foundation for subsequent control mechanisms.

6.2 Phase Two: EMG Sensor Control 6.2.1 Results:

Successful installation and integration of EMG sensors, capturing muscle signals for arm movement interpretation.

Developed algorithms effectively interpreted EMG signals, enabling precise control of the prosthetic arm.

Controlled experiments demonstrated accurate arm movements based on user muscle signals.

6.2.2 Discussion:

Integration of EMG sensors allowed for a more refined and nuanced control mechanism, responding to muscle signals with increased precision.

The effectiveness of signal interpretation algorithms showcased the potential for intuitive and natural movements based on muscle inputs.

Controlled experiments validated the reliability and accuracy of the EMG sensorbased control system, paving the way for enhanced prosthetic functionality.

6.3 Phase Three: Bluetooth Control via Android App

6.3.1 Results:

Successful development and integration of an Android app enabling Bluetooth control of the prosthetic arm.

User interface design considerations resulted in an intuitive and user-friendly app interface.

Usability testing revealed positive feedback on the app's functionality and ease of use.

6.3.2 Discussion:

The developed Android app facilitated wireless control, providing users with a convenient and accessible means to control the arm.

User interface design played a crucial role in ensuring the app's usability, enhancing the overall user experience.

Usability testing feedback highlighted the effectiveness of the app in enabling seamless control and its potential for real-world application.

6.4 Overall Discussion:

The integration of multiple control mechanisms, including flex sensors, EMG sensors, and Bluetooth control via an Android app, has significantly enhanced the functionality and usability of the 3D printed prosthetic robotic arm. The successful integration of these mechanisms provides users with various intuitive control options, catering to different user preferences and capabilities. The results demonstrate the feasibility and potential of employing advanced control mechanisms in prosthetic technology, offering users improved mobility and control over their prosthetic limbs.

CHAPTER 7

CONCLUSION

The development of a 3D printed robotic arm integrated with multiple control mechanisms, including flex sensors, EMG sensors, and Bluetooth control via an Android app, represents a significant leap forward in prosthetic technology. Through meticulous design, integration, and testing, this project has demonstrated promising advancements and potential applications in the field of prosthetics.

The successful integration of flex sensors onto the prosthetic arm allowed for intuitive and natural control mechanisms based on hand gestures. The precise interpretation of flex sensor signals facilitated responsive arm movements, providing users with an efficient means of controlling the arm.

Furthermore, the incorporation of EMG sensors enhanced the arm's control precision by interpreting muscle signals for nuanced movements. The developed algorithms effectively translated muscle inputs into accurate arm actions, showcasing the potential for intuitive control based on the user's muscle movements.

The implementation of Bluetooth control via an Android app revolutionized the user experience by providing wireless and accessible control options. The intuitive user interface design of the app offered users a seamless means of controlling the prosthetic arm, enhancing usability and accessibility.

Overall, the culmination of these control mechanisms has resulted in a versatile and user-friendly prosthetic arm. This project's success lays the groundwork for future advancements in prosthetic technology, offering individuals with limb impairments enhanced mobility, control, and quality of life.

Moving forward, continuous research and development in this field hold immense promise for further refinements and innovations in prosthetic limbs. By addressing limitations, optimizing control mechanisms, and focusing on user-centric design, future iterations of prosthetic arms can offer even greater functionality and integration with the user's natural movements.

In conclusion, the culmination of the integration of flex sensors, EMG sensors, and Bluetooth control in a 3D printed prosthetic robotic arm marks a significant milestone in enhancing the functionality, usability, and accessibility of prosthetic technology, ultimately contributing to the improved well-being and quality of life for individuals with limb impairments.

CHAPTER 8

REFERENCES

[1] I. Standard, 8373: 1994.

[2] E. Punna, R. K. Nenavath, and B. Maloth, "Labview Controlled Robotic ARM." [3] A. Elfasakhany, E. Yanez, K. Baylon, and R. Salgado, "Design and development of a competitive low-cost robot arm with four degrees of freedom," Modern Mechanical Engineering, vol. 1, p.47, 2011.

[4] C. F. Olson, "Probabilistic self-localization for mobile robots," Robotics and Automation, IEEE Transactions on, vol. 16, pp. 55-66, 2000.

[5] I. P. MODEL, "Industry Based Automatic Robotic Arm."

[2] C. Bartneck and J. Forlizzi, "A design-centred framework for social human-robot interaction," in Proceedings of the 13th IEEE International Workshop on Robot and Human Interactive Communication, 2004, pp. 31-33.

[3] G. Katal, S. Gupta, and S. Kakkar, "DESIGN AND OPERATION OF SYNCHRONIZED ROBOTIC ARM."

[4] J. L. Jones, "Robots at the tipping point: the road to iRobot Roomba," Robotics & Automation Magazine, IEEE, vol. 13, pp.76-78, 2006.

[5] A. C. McDonald, "Robot technology: theory, design and applications," Sir Sanford Fleming Coll., Ontario1986.

[6] S. Yu, X. Yu, B. Shirinzadeh, and Z. Man, "Continuous finite-time control for robotic manipulators with terminal sliding mode," Automatica, vol. 41, pp. 1957-1964, 2005. [7] M. Hägele, K. Nilsson, and J. N. Pires, "Industrial robotics," in Springer handbook of robotics, ed: Springer, 2008, pp. 963-986.

[8] R.-J. Wang, J.-W. Zhang, J.-M. Xu, and H.-Y. Liu, "The multiplefunction intelligent robotic arms," in Fuzzy Systems, 2009. FUZZIEEE 2009. IEEE International Conference on, 2009, pp. 1995-2000.

[9] L. B. Duc, M. Syaifuddin, T. T. Toai, N. H. Tan, M. N. Saad, and L. C. Wai, "Designing 8 degrees of freedom humanoid robotic arm," in Intelligent and Advanced Systems, 2007. ICIAS 2007. International Conference on, 2007, pp. 1069-1074.

[10] C. Carignan, G. Gefke, and B. Roberts, "Intro to Space Mission Design: Space Robotics," in Seminar of Space Robotics, University of Maryland, Baltimore, 2002.

[11] R. Bonitz, J. Slostad, B. Bon, D. Braun, R. Brill, C. Buck, et al., "Mars volatiles and climate surveyor robotic arm," Journal of Geophysical Research: Planets (1991– 2012), vol. 106, pp. 17623-17634, 2001.

[12] R. Bonitz, L. Shiraishi, M. Robinson, J. Carsten, R. Volpe, A. Trebi-Ollennu, et al., "The Phoenix Mars lander robotic arm," in Aerospace conference, 2009 IEEE, 2009, pp. 1-12.

[13] R. Boyce and J. Mull, "Complying with the Occupational Safety and Health Administration: Guidelines for the dental office," Dental Clinics of North America, vol. 52, pp. 653-668, 2008.

[14] B. Siciliano, L. Sciavicco, L. Villani, and G. Oriolo, Robotics: modelling, planning and control: Springer Science & Business Media, 2009.
[15] M. A. Rahman, A. H. Khan, T. Ahmed, and M. M. Sajjad, "Design, Analysis and Implementation of a Robotic Arm-The Animator."
[16] P. Singh, A. Kumar, and M. Vashisth, "Design of a Robotic Arm with Gripper & End Effector for Spot Welding," Universal Journal of Mechanical Engineering, vol. 1, pp. 92-97, 2013.
[17] M. W. Spong, Vidyasagar, Robot Dynamics and Control, 1989. [18] A. J. Critchlow, Introduction to robotics: Macmillan New York, 1985.
[19] M. A. K. Yusoff, R. E. Samin, and B. S. K. Ibrahim, "Wireless mobile robotic arm," Procedia Engineering, vol. 41, pp. 1072-1078, 2012.
[20] G. Mikell and N. Roger, "Robótica Industrial. Tecnología, Programación y Aplicaciones. Ed," ed: Mc Graw Hill.
[21] C. A. Schuler and W. L. McNamee, Industrial electronics and robotics: McGraw- Hill, Inc., 1986.
[22] S. R. Nair, "Design of a Robotic Arm for picking and placing an object controlled using LabVIEW," International Journal of Scientific and Research Publications, vol. 2, pp. 1-4, 2012. [23] F. J. Diaz-Colorado and R. F. Martinez-Gonzalez, "Design and Implementation of a Low-Cost Embedded System to Turn Android Device into a Robotic Arm Controller," Technology, vol. 2, pp. 7-12, 2015.
[24] J. Olawale, A. Oludele, A. Ayodele, and N. M. Alejandro, "Development of a Microcontroller Based Robotic Arm," in Proceedings of the 2007 Computer Science and IT Education Conference, 2007.
[25] G. A, N. R, K. S, and G. R, "Design and Control of 3DOF Articulated Robotic Arm using LabVIEW and NI-myRIO," International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 3, 2015.
[26] M. C. C. Mouli, M. P. Jyothi, K. N. Raju, and C. Nagaraja, "Design and Implementation of Robot Arm Control Using LabVIEW and ARM Controller," IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN, pp. 2278- 1676, 2013.
[27] R. Pahuja and N. Kumar, "Android Mobile Phone Controlled Bluetooth Robot Using 8051 Microcontroller," Electronics & Communication Engineering, Department, BRCM College of Engineering & Technology, Bahal, India, International Journal of Scientific Engineering and Research (IJSER) www. ijser. in ISSN (Online), pp. 2347- 3878, 2014.