DE-40 (DC&SE)

YEAR 2022

NUST COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING

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A PROJECT REPORT

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Submitted by

GC Muhammad Hamza Arshad

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DECLARATION

We hereby declare that no portion of the work referred to this Project Thesis has been submitted in support of an application for another degree or qualification of this of any other university or other institute of learning.

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ACKNOWLEDGMENT

First and foremost, thanks to Allah Almighty. Who gave us the ability and courage to understand the things, by the grace of whom every obstacle was dissolved in the fulfilment of this arduous task.

Apart of the efforts of the group, the success of any project depends largely on the encouragement and guidelines of many others. We wish to express our gratitude to our supervisor, **Dr. Mohsin Islam Tiwana, Dr. Umer Asgher** and **Dr. Usman Akram** who were abundantly helpful and offered invaluable assistance, support and guidance.

In addition nothing would have been possible without the help of our beloved parents. Their unrelenting support and patience was instrumental. They were always there for us in our time of need.

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ABSTRACT

After decades of advancement in rehabilitation technologies, it has become a necessity to modernize the rehabilitation practices. Keeping in view the dire need of restoration motor activities of a post-stroke patients and ease of access, new gadget is developed. The focal point of restoration is focused on the human hand, mostly for recapturing motor functions by the guide of mechanical technology. A far-reaching measurable investigation will be introduced in the field of rehabilitation, clinical advanced mechanics and advances utilized for automated exoskeletons dependent on existing distributed papers. A short audit on existing models is additionally introduced.

So, after completing the research about existing hand exoskeletons for rehabilitation purposes, We created a new model and fabricated its hardware. Then through cloud storage the database of patient was received and using the android app the patient was able to perform various exercises on his/her hand.

All the performed and to be performed exercises will be shown on android application “Rehab” and could be analyzed by the physiotherapist.

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Chapter 1: Introduction

1.1. Introduction:

Stroke can cause inadequacy in different Neurological regions and essentially, it causes inability in the motor system of human. An overall state in the vast majority of the stroke survivor is loss of motion of one side of the body. Motor rehabilitation research has shown that to accelerate the motion recovery of the upper limb function, movements subordinated by external means could be utilized to help the utilization of paralyzed limb. To fix the hand motor function after an individual goes through stroke has been the significant focal point of rehabilitation research as human hand is assumed as a crucial part in everyday life exercises. Besides, in the rehabilitation of the hand motor function the significant concern has been the way to accomplish the ideal rebuilding of handwork. The stroke patients who have gone through severe, moderate, or gentle motor disorders, a well-known therapy known as bilateral development has exhibited positive outcomes. In contrast with one-sided stroke patients, who get stroke on both sides are relatively hard to recover from paralysis.[1] Our main outcome of this project is to rehabilitate a patient having stroke on one side limb i.e. hand.

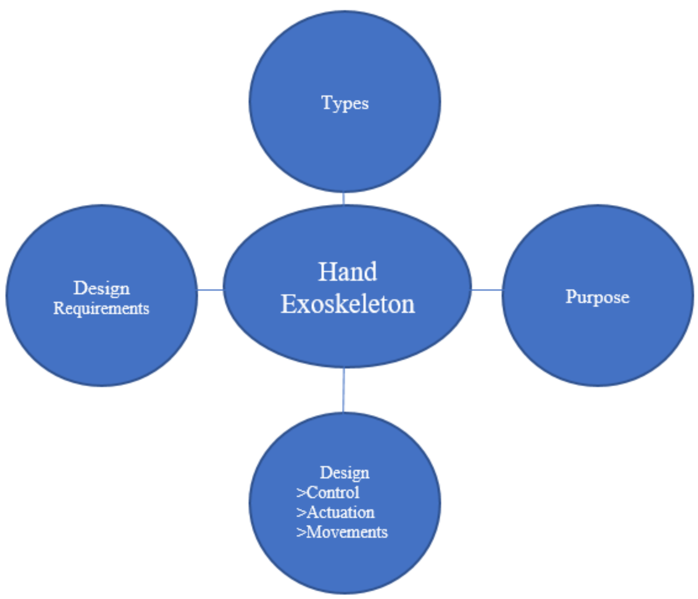


Figure 1: The basic outline of contents covered [1]

The significant point is to plan and foster a Post Stroke medicinal framework that can help the stroke patients to flex/contract every digit of the disabled hand independently of any manpower. By performing bilateral exercise, the hand motor capacity of the stroke patient can be improved.

1.2. Problem Statement:

After a person gets a stroke attack, he has to visit rehabilitation centers and physiotherapists to carry out different hand exercises to get its motor activities back. [1]The process is time consuming and the person has to be consistent about the appointments as one missing appointment can delay his/her recovery speed. On the scale of moderate to severe stroke patients, have to visit rehabilitation centers weekly or daily basis respectively. Some people have busy life routine and cannot visit the physiotherapists and some are quite aged to make to rehabilitation center easily.

Therefore, for the ease of people [2] there should be a portable device that could make them get rid of their repeated visits to rehabilitations centers to recover their motor activities. These exoskeletons are intended to rehabilitate patients with handicaps and help advisors to treat these patients. These gadgets are planned with the focal point of executing tedious activities and movements. This incorporates the flexion and expansion of the fingers to imitate the exercises of everyday living or to execute constant involved movements.

1.3. Motivation:

To recover from stroke the patients have to get appointments from physiotherapists. For their ease, we will make a portable, onetime expense device that could help the stroke patients to carry out their exercises wherever they want to. This will lower their expense of repeated visits to rehabilitation centers. So, our main aim is to develop a reliable portable device which will be available easily in the market for the rehabilitation of post-stroke patients.

1.4. Objectives:

- To design a mechanical model and fabricate a portable hand exoskeleton.
- To make a user-friendly android application.
- To provide a Google cloud storage to store database and profile of the user.
- To make it reliable.
- To make it easy to use.
- To 3D print it for lighter weight.

1.5. Scope:

The basic aim of the advancement of the technology[3] is to make everyday life of people easy. To make reliable, portable, easy-to-use gadgets to make their life easier. We have researched about the assistive arm and hands to help stroke patients carry out their daily routine and then they have to go for different therapy sessions to rehabilitation centers to get their motor activities recovered. Therefore, our aim was to develop a portable device that could help stroke patients to get their rehabilitation exercise at their home or anywhere, as it would be a portable device, which will be lightweight and user friendly. To control it we will build a user-friendly android application and provide a google cloud storage to store patient's database. Such devices can save time and energy of patients who have to visit rehabilitation centers regularly.

1.6. Structure

Following is the structure of the report ahead

Chapter 2 provides the literature review undertaken to make this project

Chapter 3 provides information about all the hardware and components used to fabricate the exoskeleton

Chapter 4 provides information about android application and database.

Chapter 5 provides results

Chapter 6 provides conclusions to our project

Chapter 7 provides future work to our project

Chapter 2: Literature Review

2.1. Hand exploration and its movements:

The human hand [2] is made up of the wrist, palm, and fingers and consists of 27 bones, 27 joints, 34 muscles, over 100 ligaments and tendons, and many blood vessels and nerves.

The hands enable us to perform many of our daily activities such as driving, writing and cooking. It is important to understand the normal anatomy of the hand in order to learn more about diseases and conditions that can affect our hands. [4]Our hand bones are held in place and supported by various soft tissues. These include articular cartilage, ligaments, muscles and tendons. Articular cartilage is a smooth material that acts as a shock absorber and cushions the ends of bones at each of the 27 joints, allowing smooth movement of the hand.

Muscles and ligaments function[5] to control the movement of the hand. Ligaments are tough rope-like tissue that connect bones to other bones, holding them in place and providing stability to the joints. Each finger joint has two collateral ligaments on either side, which prevents the abnormal sideways bending of the joints.

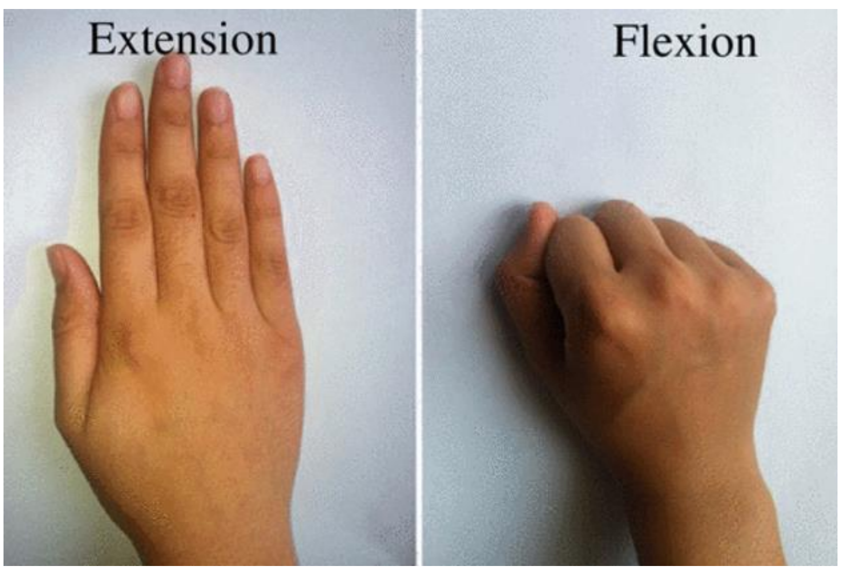


Figure 2: Flexion and Extension of hand[21]

Muscles are fibrous tissues that help produce movement. Muscles work by contracting. There are two types of muscles in the hand, intrinsic and extrinsic muscles. Intrinsic muscles are small muscles that originate in the wrist and hand. They are responsible for fine motor movement of the fingers during activities such as writing or playing the piano. Extrinsic muscles originate in the forearm or elbow and control the movement[6] of the wrist and hand. These muscles are responsible for gross hand movements. They position the wrist and hand while the fingers perform fine motor movements. Each finger has six muscles controlling its movement: three extrinsic and three intrinsic muscles. The index and little finger each have an extra extrinsic extensor. Tendons are soft tissues that connect muscles to bones. When muscles contract, tendons pull the bones causing the finger to move.

When a person have a stroke attack, it directly attacks on your nerves[7], resulting failure of control on your hand muscles. Thus, after the stroke the patient needs some external assistance to move his muscles and to regain his motor activities [2].

The hand has four fingers and a restricting thumb and offers 21 DOF.

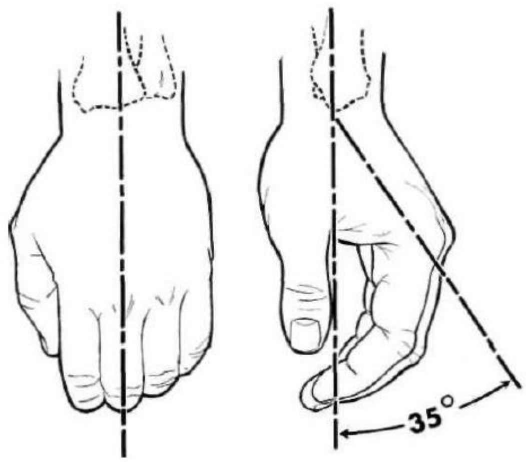


Figure 3: Movement of hand [2].

2.2. Existing Hand Exoskeletons:

In the writing, there is a huge number of ways to deal with tackling the issues of sending movement from the Actuator to the fingers of the patient. These methodologies are assessed and introduced in this part to have a more extensive comprehension of the limits accomplished by the current state. In expounding this examination, we will think about the main chips away at this part of Medicale Robotics, with specific accentuation on works with functional accomplishments of the creators.[8] The advantages and, verifiably, the hindrances of each approach will be stressed. Above all else, Robotic Hand Exoskeleton can be gathered into two particular gatherings, those with an unbending development, that have a design of the exoskeleton made of inflexible solids however expressed by the idea of the get together, and those having a flexible development made of deformable and versatile materials, found in the writing in the field of Soft Robotics and Soft Actuators.

Figure 3 shows previously made hand exoskeletons [3]:

a) Handexos
b) Hexosys
c) Wege A and Hommel G
d) Exo-Glove – Hyunki In Et Al
e) Exoglove - Hong Kai. Yap
f) Space Suit Glove – Shields

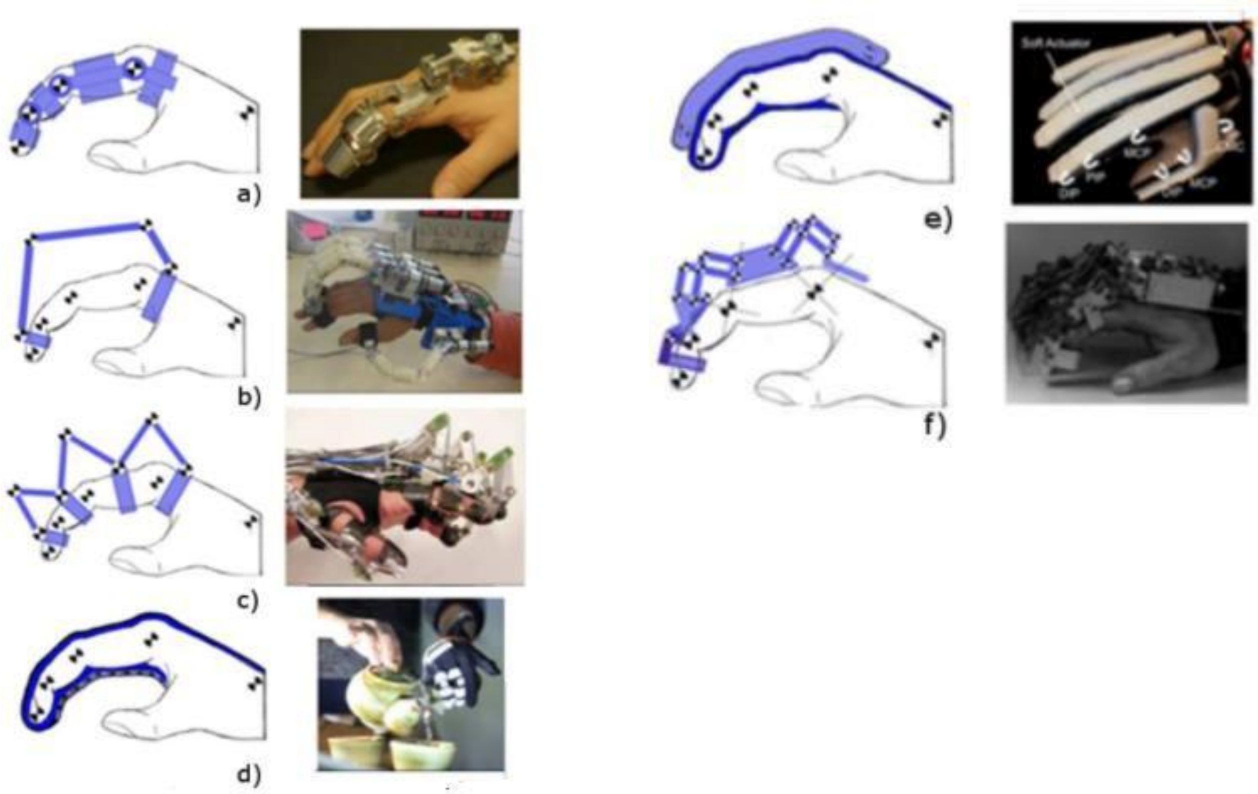


Figure 4: Existing hand exoskeletons [3]

2.3. Actuation:

Actuation can be done by several means [4] i.e., Pneumatic actuation, hydraulic actuation, DC motors. Since pneumatic and hydraulic have complex assembly, DC motor actuations meet our requirement best.

There are mainly two types of actuations;

- Active actuation (need external power)
- Passive actuation (that work without external source of power i.e., springs)

An actuator is such a component that we mostly use to get some work done, control some movement or mechanical system. There is a need of an input signal and the power source to drive the actuator to get its job done. Their main applications are in valves, gates, machines, open close and automatic control system etc. Actuator can open or close any gate or system when input signal is given to it in the presence of power supply to actuator. Actuator deliver power to valve for open closing or to get work done wherever it is used. They are high energy components used. [9]There are available in various types and in many shapes and there power is also vary from model to model. There are many types of actuators with are used in industries

- Rotary Actuator
- Hydraulic Actuator
- Pneumatic Actuator
- Electric Actuator
- Mechanical Actuator
- Thermal Actuator
- Magnetic Actuator
- Supercoiled polymer Actuator

We have used linear actuators for actuation, which are powered by external 12V battery or charger.
Linear actuator is used to get the motion in straight direction, while other traditional motors gives circular motion. Linear actuators have wide range of use in every field such as industry, medical industry machinery, in printers and in computer processing unit as well. It is also used in valves and damper etc. Linear motion is created by many ways such as in some cases we get linear motion from actuator by rotating motor, pneumatic and from hydraulic cylinders.

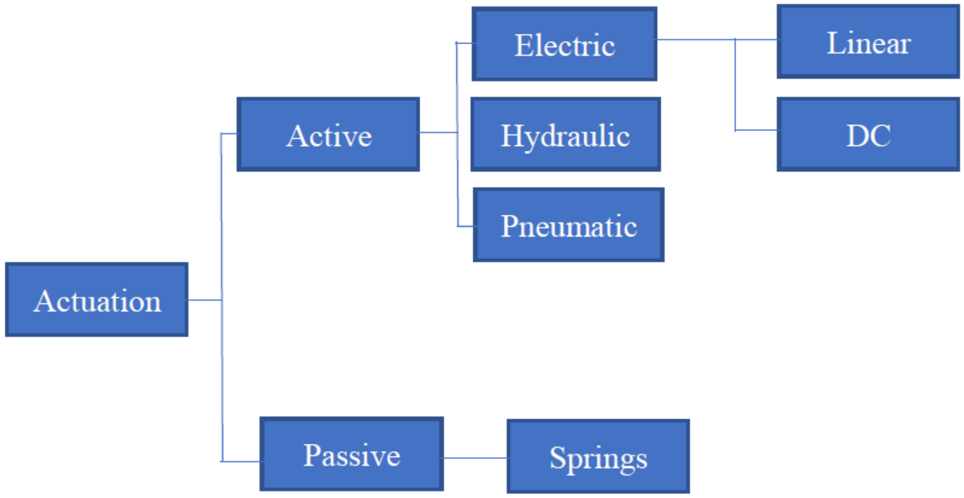


Figure 5: Actuation methods [4]

2.4. Pattern of movements:

According to all available research papers, we can divide the human movements into two main categories keeping in mind the hand rehabilitation by using exoskeleton model. First movement level tells us the details about the range of the motion, muscular strengths, and capacity while the second level of movement discuss the functional tasks performance especially those who are required for ADL. While in the International Classification of Functioning, Disability and Health (ICF) framework, human complete body functionality is defined into three levels.

1. Activity level (body structures and function),
2. Functional level (task execution),
3. Precipitation level (involvement in life situations)

In initial trials results the exoskeleton analysis shows that it does the improvement in the functional level. It may be caused by the poor understanding of these two, which are functional level and activity level.

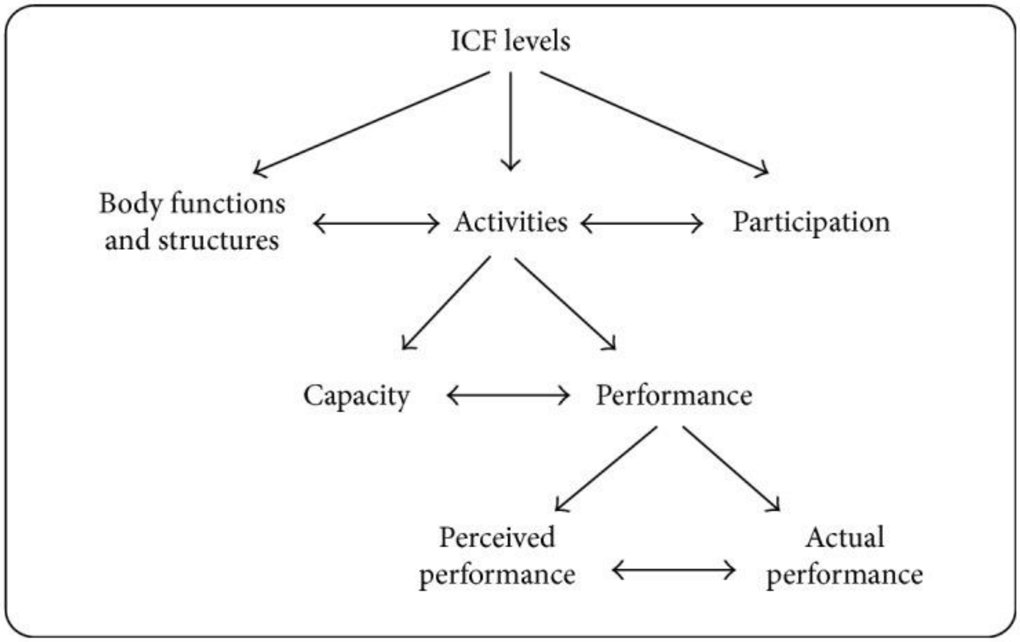


Figure 6: Movement Patterns

2.4.1 Functional level Movement:

Currently available designs in the market mainly focus on the functional level rehabilitation, which include the increase in joint motion range, improvement in muscles strength and noticeable decrease in spasticity. Repetitive movement on the functional level plays an important role in rehabilitation. Such motions include grasping object and palm extension and such kind of training.

2.4.2 Activity Level Movement:

Activity level movement training includes the task specific training. These tasks include our daily life tasks, which are commonly known as ADL. For this purpose, no rigid movement is required. Such exercises can be done with available devices, which includes the soft robotic glove. These activities are the involvement of patients directly in daily life activities.

2.5. Power Transmission:

- **Rigid mechanical system**

  To transmit the power for any kind of exoskeleton device there are following methods [5]:
- Cable
- Complaint
- Rigid Mechanical Structure

We are transmitting our power from actuators to fingers by using rigid mechanical structure: There are three ways to transmit power in rigid mechanical structure:

- Mechanical links
- Gears
- Direct Drive

We have used the mechanical links[12] for our power transmission from actuators to fingers. As we have showed, there are single part of links mount on proximal, medial and district phalanges of finger. When the actuator makes forward movement then actuator arm one end that is attach with the end of actuator move forward. There is a pivot point on the center of actuator arm, due to that pivot point the other end of actuator arm move backward, which in result pull the finger upward. When actuator make backward movement the end of actuator arm which is attached with the actuator move backward and due to pivot in center of actuator arm the other end move forward. Due to this movement, the hand starts to close, and fingers make punch movement. This method is repeated and again which aids in exercise of hand muscles for recovery of patients.

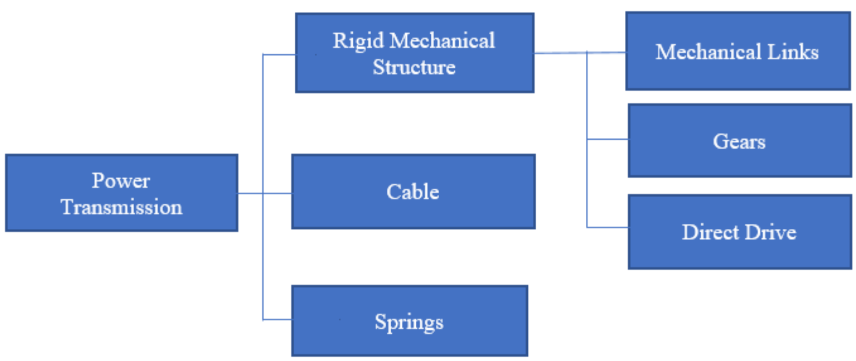


Figure 7: Power Transmission Method [5]

Chapter 3: Hardware

3.1. Components:

3.1.1. Raspberry Pi pico:

Raspberry Pi Pico [6] is a latest microcontroller board by raspberry. Due to its low cost and high performance, it is preferred over pi 3 and pi zero versions for executing small codes. The chip contain [7] Dual-core Arm Cortex M0+ processor, with the clock running at 132 MHz.

Figure 8: Raspberry pi Pico [6]

Features[14] :

Table 1: Properties of rasp berry pi pico

Form factor	21 mm × 51 mm
CPU	Dual-core Arm Cortex-M0+ @ 133MHz
Memory	264KB on-chip SRAM; 2MB on-board QSPI Flash
Interfacing	26 GPIO pins, including 3 analogue inputs
Peripherals	2 × UART 2 × SPI controllers 2 × I2C controllers 16 × PWM channels

	1 × USB 1.1 controller and PHY, with host and Device support 8 × PIO state machines
Input power	1.8–5.5V DC
Operating temperature	-20°C to +85°C

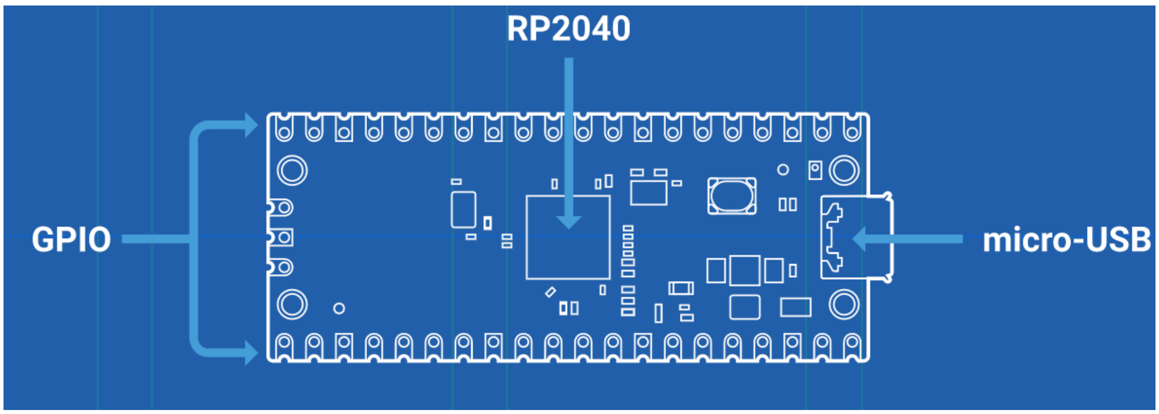


Figure 9: Raspberry pi Pico (blueprint) [7]

3.1.2. Linear Actuators:

Linear actuator is used to get the motion in straight direction[15], while other traditional motors gives circular motion. Linear actuators have wide range of use in every field such as industry, medical industry machinery, in printers and in computer processing unit as well. It is also used in valves and damper etc. Linear motion is created by many ways such as in some cases we get linear motion from actuator by rotating motor, pneumatic and from hydraulic cylinders.

We have used total three linear actuators in our project from which two are having same stroke length and one is having less stroke then other two and this one in mound on thumb.

Figure 10: Liner Actuator

Specifications

Table 2: Linear actuator properties

Power	60N
Stroke Length	30 mm (2 actuators) 17mm (1 actuator)
Working Voltage	12 volts

3.1.3. L293d Motor Driver IC:

The L293d motor driver IC consists of two inbuilt H-bridges. Magical chip working with 5 volts of enabling voltage and 9V-36V of current can be supplies to the actuator.

Figure 12: L293d motor driver IC

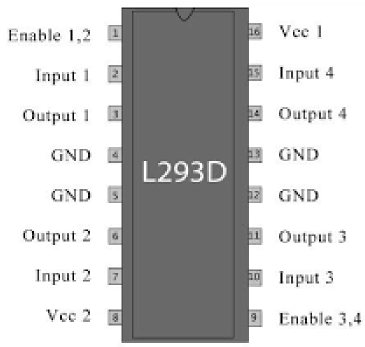


Figure 11: L293d pinout

Reversing Polarity

Since the linear actuators need to reverse its terminals when it once fully extended, means to get it backward we have to reverse the polarity. This could be done by H-bridge, for this purpose, we have used L293d motor driver IC due to its compact size.

Switching

The second reason to use L293d is that linear actuators works at 12 Volts, so we had to give it external 12V source and signal from the raspberry pi so we used external 12V charger and switch it through L293d IC using 3.3 Volts of switching signal from raspberry pi Pico.

3.1.4. HC-06 Bluetooth Module:

The HC-06 is a class 2 slave Bluetooth device for wireless communication. With up to 10 meters of range, it provides the wireless communication between our android application and the exoskeleton glove.

Figure 13: HC-06 Bluetooth module

Specifications

- Default Baud Rate: 9600
- Built in antenna
- Coverage up to 30 feet
- Bluetooth version: V2.0+EDR

- Operating voltage: 3.3V

3.1.5. Velcro:

Mounting CAD Model on hand

There in some hollow space in distal medial and proximal phalanges for each finger part. We have used the Velcro to mound phalanges parts on each phalange of each finger.

Figure 14: Velcro

Reason to use Velcro

As this device is used for hand exercise of post stroke patients so we design our CAD Model in such a way that we can mound it on hand using Velcro because it is easy to mud using Velcro and it has strong grip to hold.

3.2. Design Requirements:

The requirement of our hand exoskeleton was to provide maximum angular displacement of the DIP, MCP and PIP joints of the fingers, nearly comparable to the angular displacements in the active motion of the hand.

Stroke patients' survivors go through continue passive motion training during paralysis period. They also must keep their attention of motion rehabilitation by using some exoskeleton designed for short period. For rehabilitation during their paralysis time the must use such a designed exoskeleton which have minimal ADL interference and can exert flexion and extension within the defined range of rehabilitation or we can say that slightly lower motion range then the natural motion range.
To achieve the minimal required ADL interference device is supposed to be attached on the upper side of

the hand. The length of the device linkages should not exceed then the hand length. Smaller designed constrained should not by greater then 20mm which are to be attached on the fingers. Low weight hand exoskeleton in of the most important and key design for larger population of stroke patients. So, we must minimize the weight of the device as much as we can so that it can becomes patient friendly. It range should be between 0.5kg to 3kg maximum.

Hand has many multiple and complex joints mentioned below:

Thumb: interphalangeal (IP), a metacarpophalangeal (MP), and a carpometacarpal (CM).

Four fingers: three joints which are metacarpophalangeal (MCP), a proximal interphalangeal (PIP), and a distal interphalangeal (DIP).

Human finger has 3 active degrees of freedom[19] so we should design our structure in such a way that finger linkage has 3 degrees of freedom. In some rehabilitation processes it is necessary to move all three joints which are metacarpophalangeal (MCP), a proximal interphalangeal (PIP), and a distal interphalangeal (DIP). In some rehabilitation it is not necessary to move all three joints, IT depends upon the suggestion of the therapist. holding the tripod (MPJ and the IPJ of thumb joint bends around 51° and 27°; MCP, PIP, and DIP joint of the index finger bends about 46°, 48°, and 12° and for the middle finger to bend around 46°, 54°, and 12°. so that why we consider our achieved angles are suitable for ADL assistance and for the rehabilitation of the hand muscles of finger. Speed of the mechanical structure while doing the exercises is suggested about 20 seconds for complete flexion and extension cycle. One of the most important things is to avoid the hypertension of all these joints. The exerted force should be such that we can grasp some light things such as tripod and the structure should be well designed that it can do the repetitive motion. the minimum pinch force required to do the tasks is about 20 newton.

Design should be such that we can customize it according to type of rehabilitation and for different stages of exercises for different patients.

For the purpose we have developed a model which will provide linear motion from the actuator and will exert perpendicular force to the phalanges of each finger.

3.2.1. Model of hand used:

The figure below shows the angular displacements of MCP, PIP and DIP. Furthermore, we have calculated the forward and backward kinematics of a finger to find the values of given joints.

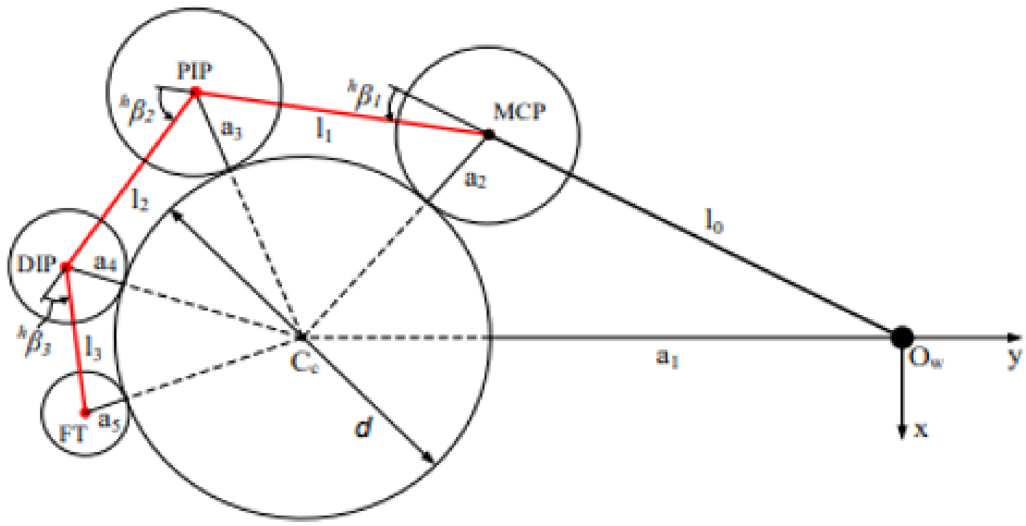


Figure 15: Model of Hand Used[18]

3.2.2. Forward and Backward Kinematics of fingers (less thumb):

Consider the three link planar manipulator shown in figure as below, which has similar linkage as human finger (less thumb). The DH-Parameters of the fingers can be calculated similarly as shown in the table below. The three joints here (starting from the fixed base) shows MCP, PIP and DIP and the links L1, L2 and L3 shows Proximal, Medial and Distal phalanx respectively.

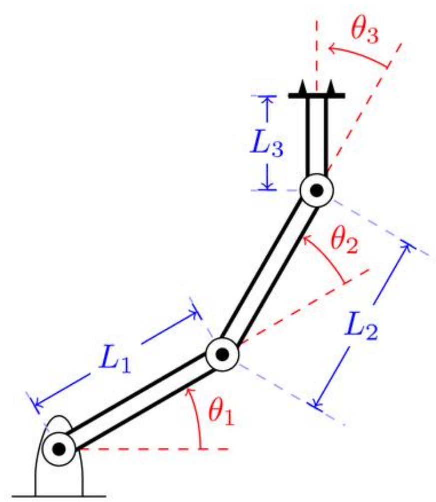


Figure 16: Three link planar manipulator showing representing human finger.

Table 3: The DH-parameter table of above mechanism

Link	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3

Where,

$\alpha i{-}1$: is the angle from $Zi{-}1$ to Zi in the direction of Xi
$ai{-}1$: is the distance from $Zi{-}1$ to Xi in the direction of Xi
di : is the distance of $Zi{-}1$ to Xi in the direction of $Zi{-}1$
θi : is angle from of $Xi{-}1$ to Xi to in the direction of $Zi{-}1$

Solving the above table gives the forward kinematics:

$$ {}^0_3T = \begin{bmatrix} C_{123} & -S_{123} & 0 & C_1L_1 + L_2C_{12} \\ S_{123} & C_{123} & 0 & S_1L_1 + L_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Similarly, for the position and orientation of fingertip, we can perform inverse kinematics as follows:

$$ {}^0_3T = \begin{bmatrix} C_\varphi & -S_\varphi & 0 & x \\ S_\varphi & -C_\varphi & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

After solving, we get four non-linear equations as expressed:

$$ C_\varphi = C_{123} $$

$$ S_\varphi = S_{123} $$

$$ x = C_1L_1 + L_2C_{12} $$

$$ y = S_1L_1 + L_2S_{12} $$

Now, we can solve above four equations to get the respective values of ($\theta 1$,2 and $\theta 3$)

$$ \theta_1 = \mathrm{A\,tan2}(x,y) - \mathrm{A\,Tan2}(k_1,k_2) \quad (3) $$

Where,

$$ K_1 = L_1 + L_2C_2 \quad (3) $$

$$K_1 = L_2 S_2 \quad (4)$$

And,

$$\theta_2 = A\tan2\,(S_2, C_2) \quad (5)$$

Where,

$$C_2 = \frac{x^2+y^2-L_1^2-L_2^2}{2L_1L_2} \quad (6)$$

The value of C_2 or the equation 6 remains in between -1 and 1, else the Tan function will reach infinity which mean our Distal part of the finger is at infinity which is abnormal case.

And,

$$S2 = \pm\sqrt{1 - C2}$$

$$\theta 3 = A\tan 2(S\varphi, C\varphi) == \varphi - (\theta_1 + \theta_2) \quad (7)$$

The equation (3), (5) and (7) give the values of rotation of DIP, MCP and PIP joints should be less than the values in following table [2]:

Table 4: Maximum Active angular displacements provided by fingers [2]

	Joints		
Position	MCP (degrees)	PIP(degrees)	DIP(degrees)
Resting	45	30-45	10-20
Flexion	90	110	90

3.3. Kinematic of Hand:

The basic kinematics of a hand are shown below in a figure [16], showing all the joint and phalanges and the direction of the flexion/ extension for the fingers and thumb.

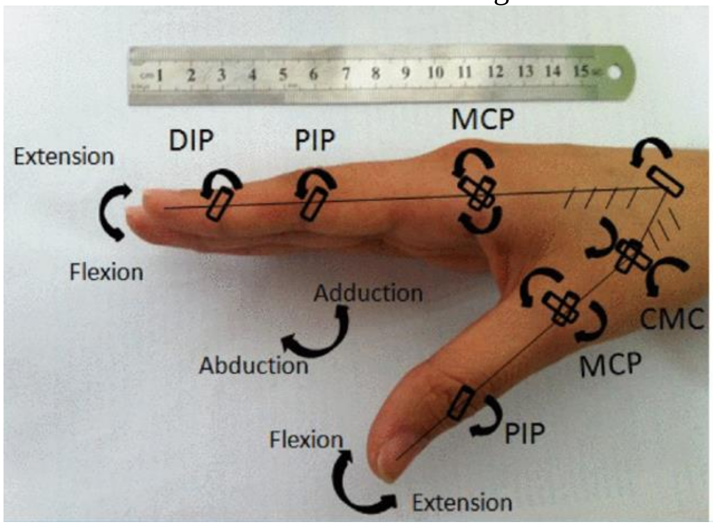


Figure 17: Kinematic of a hand [16]

3.3.1. Basic Measurements of a normal hand:

The dimensions for our CAD model are taken from the Pheasant 2003, which shows the size of a hand for average male. The values from the 5^{th}, 50^{th} and 95^{th} percentile are shown in the table [3] below;

Table 5: Average hand lengths of male (taken from Pheasant 2003) [3]

Percentile	L(mm)	W(mm)
5^{th}	173	78
50^{th}	189	87
95^{th}	205	95

The measurements for our linkages are taken on following basis shown in figure [17].

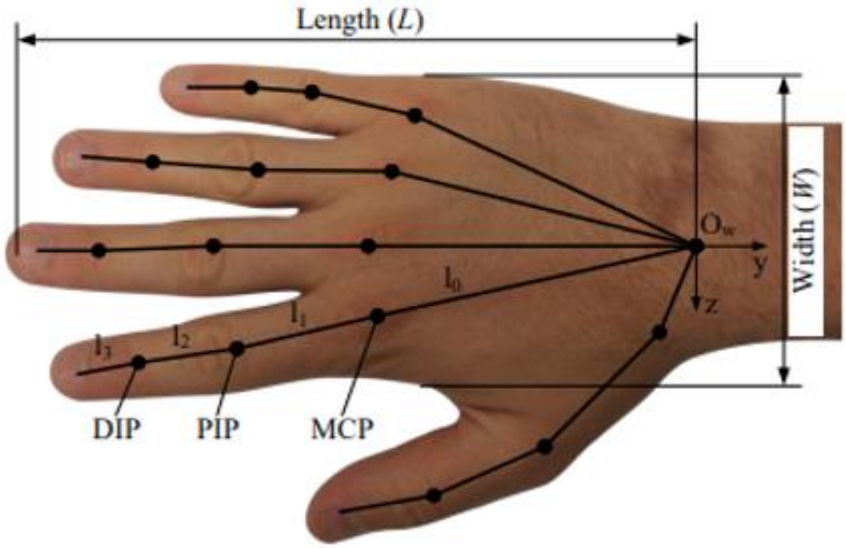


Figure 18: Lengths for linkages [17]

3.4. Hand Exoskeleton CAD Model:

- ARM 1 [14]
- ARM 2 [15]
- ARM 3 [16]
- ARM 4 [17]
- ARM 5 [18]
- Actuator Arm [19]
- Distal Phalanges [20]
- Medial Phalanges [21]
- Proximal Phalanges [22]
- Hand Plate [23]
- Complete Hand [24]

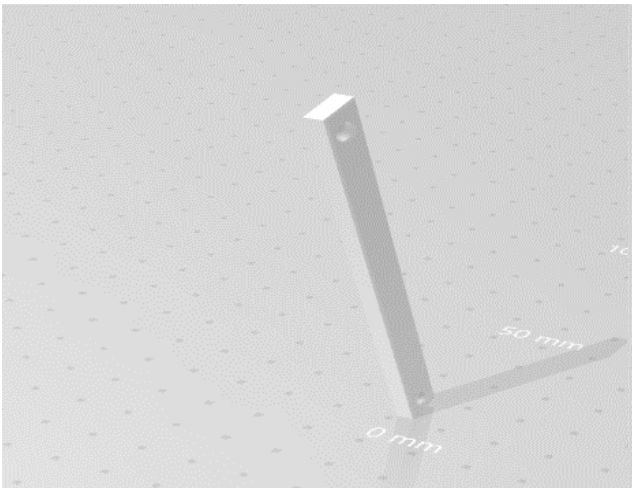


Figure 19: ARM 1 [14]

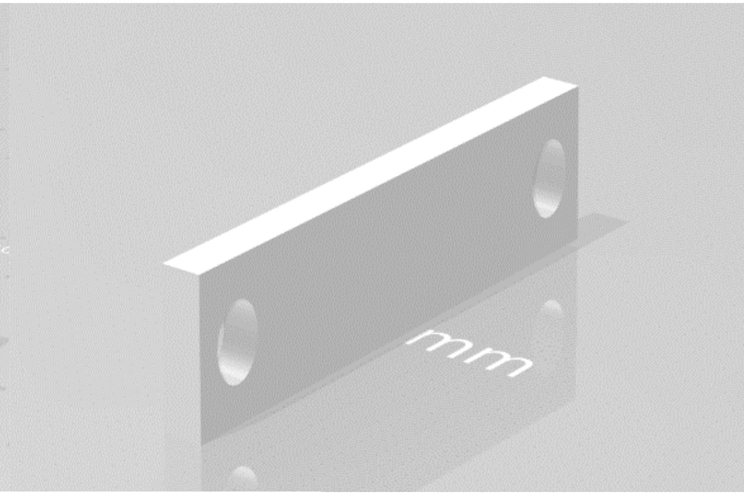


Figure 20: ARM 2 [15]

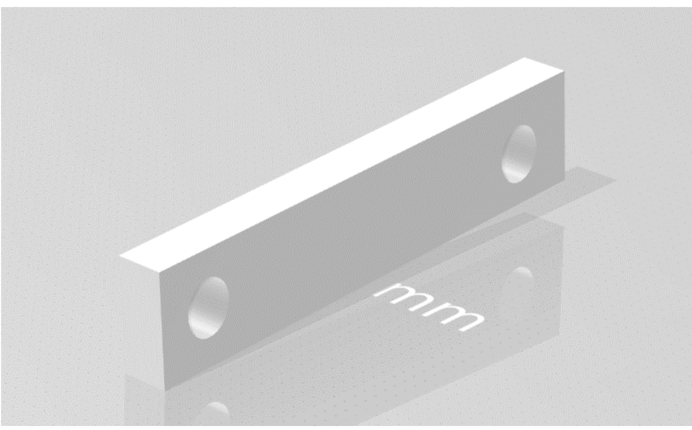


Figure 23: ARM 3 [16]

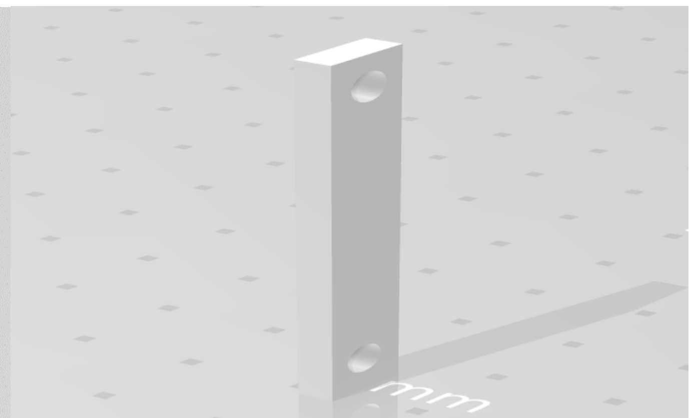


Figure 21: ARM 4 [17]

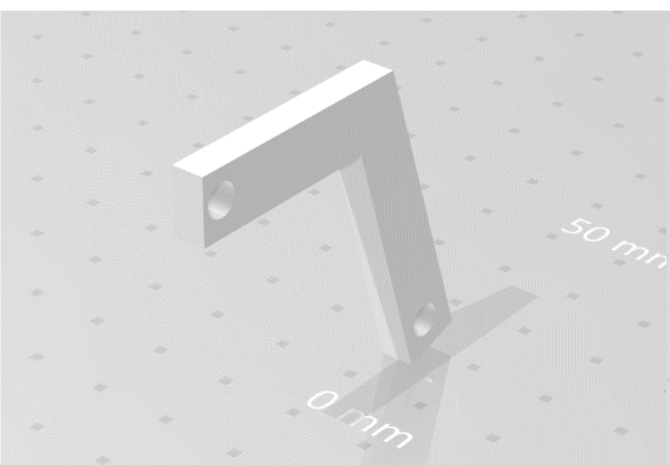


Figure 24: ARM 5 [18]

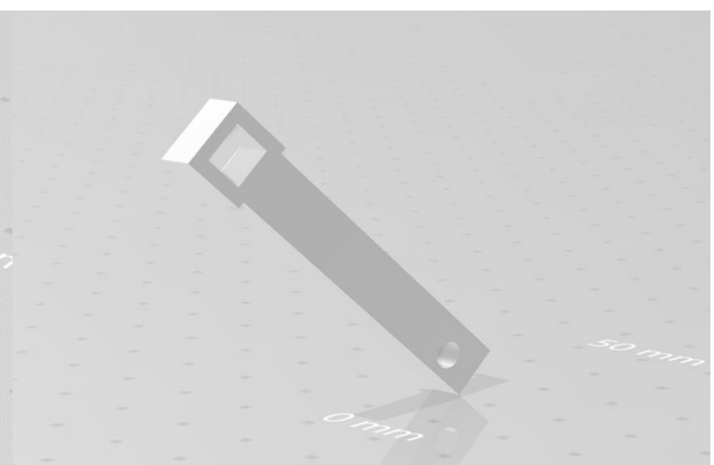


Figure 22: Actuator ARM [19]

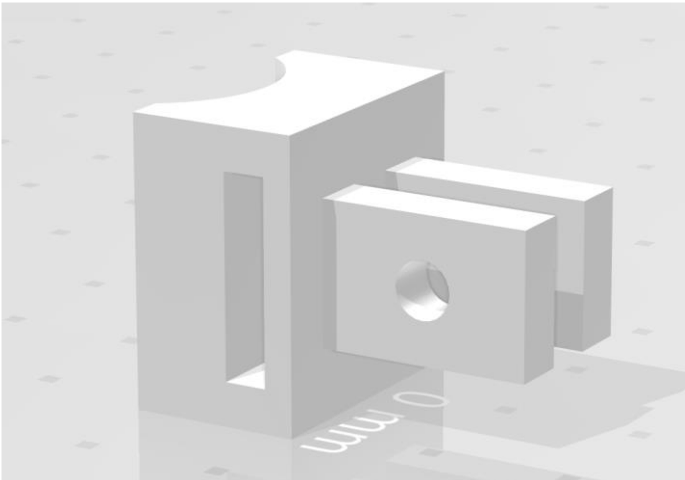


Figure 28: Distal Phalanges [20]

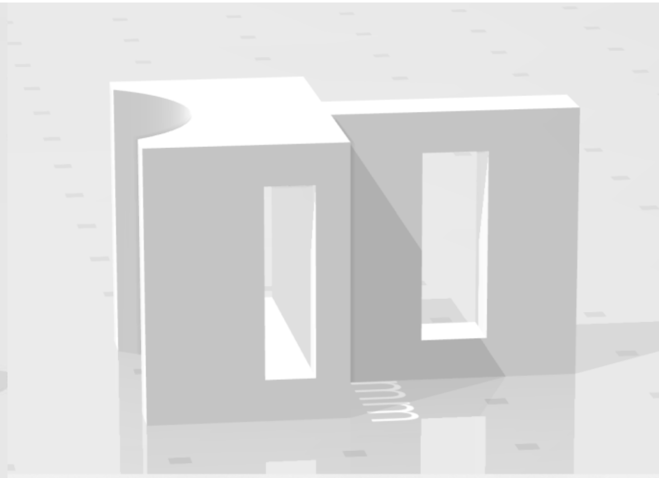


Figure 27:: Medial Phalanges [21]

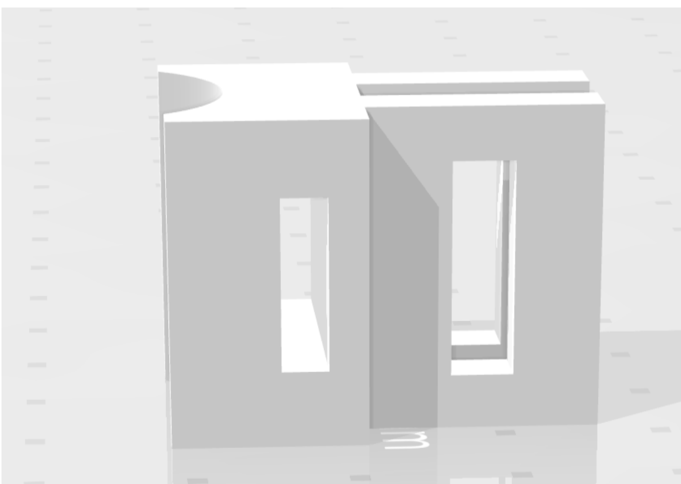


Figure 26: Proximal Phalange [22]

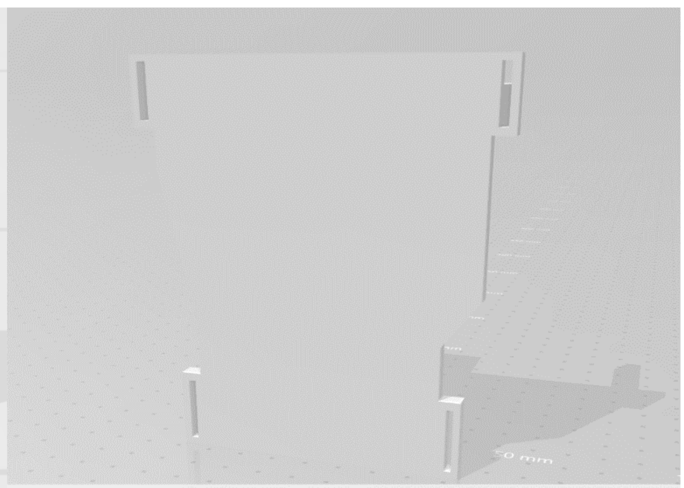


Figure 25: Hand Plate [23]

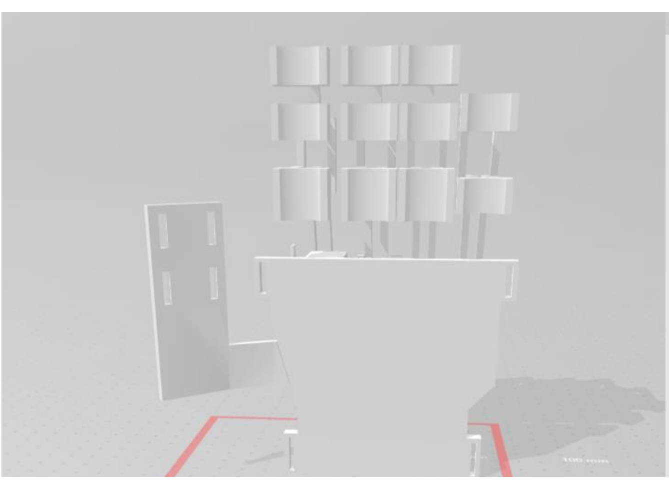


Figure 30: Complete Assembled Hand [24]

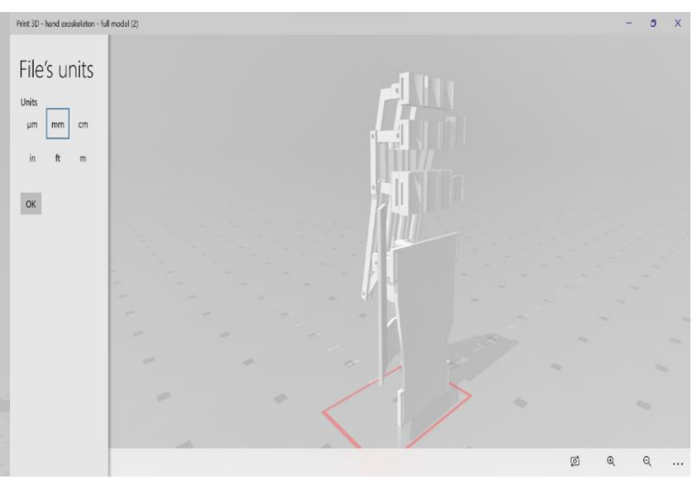


Figure 29: Complete Assembled Hand (2nd view) [25]

3.4.1. 3D Printer:

3D Printer is a new technology in the market which is used to manufacture any kind of parts with different materials. It is addictive because it does not require metal or plastic pieces to make desired parts, it simply uses the thread like plastic and fuses its layers to make desired required part. It is fast technology which do not require much time, it is not so much costly and it can also create many critical and complex geometries then other traditional technologies which are used to manufacture the parts. It create light weight geometries and for making prototype parts.

Materials used in 3D Printing

- Plastic
- Powders
- Resins
- Carbon Fiber

From all these different materials we have used the plastic material which we found the best suitable material for out project because it is hard can bear the force and stress which we need, and it is light weighted.

Plastic Types for 3D Printing

- Polyastic acid (PLA)
- Acrylonitrile butadiene styrene (ABS)
- Polyvinyl Alcohol Plastic (PVA)
- Polycarbonate (PC)

We have chosen the Polyastic acid (PLA) from all these plastics because of following reasons:

We have chosen the Polyastic acid from the list of materials used is 3d Printing. It is an Eco friendly material although there were many other ecofriendly as well. This material is made from the natural products like sugar cane and starch etc. It is also a biodegradable material. This material can be found is both hard and soft forms. This material is widely used now days and maybe it can dominate the 3D printing industry in coming years. Hard form of PLA is used to manufacture many products and therefore this is widely used. The properties of PLA are given in the table below which are used for its analysis.

Table 6: PLA Properties

Property	**Value**
Technical name	Polylactic Acid (PLA)
Chemical formula	$(C3H4O2)n$
Melt temperature	PLLA: 157 - 170 °C (315 - 338 °F)
Typical Injection Molding Temperature	PLLA: 178 - 240 °C (353 - 464 °F)
Heat Deflection Temperature (HDT)	49 - 52 °C (121 - 126 °F) at 0.46 MPa (66 PSI)
Flexural strength	PLLA: 48 - 110 MPa (6,950 - 16,000 PSI)
Tensile strength	PLLA: 61 - 66 MPa (8840 - 9500 PSI)
Shrink rate	PLLA: 0.37 - 0.41% (0.0037 - 0.0041 in/in)
Specific gravity	PLLA: 1.24

3.4.2. Assembled Hardware

- We design the CAD model keeping in view the movement of hand.
- We get the 3D print of our CAD Model.
- Assembled the CAD Model.
- Get the remaining components such as raspberry pi Pico small electrical components and Actuators.
- Design and making of electrical components.
- Connection of electrical part with 3D printed assembled CAD Model.
- In parallel to all these, design and making of mobile application.
- Integration of mobile app with hardware using Bluetooth module.

The figure, [31] [32] below shows the 3D printed CAD model and its assembly with linear actuators.

Figure 31: Assembled Hardware

Figure 32: Assembled Hardware II [32]

3.4.3. Hand Exercises for Stroke Patients

Stroke is such a worse thing that it can happen to any individual at any time and can change the life of anyone within just seconds. In some cases, it can be such a worse that it causes the permanent damage of the individual but in cases it can be recovered automatically or with the help of using medicines. However, in most of its cases after its attack the patients' needs to different type of exercises for different muscles which are attacked and effected by the stroke. There are different kind of exercises for recovery of muscles from the stroke. Some physiotherapist doctor suggests all these exercises. The effected body may have complete movement, but it has decreased muscles strength such as grasping and releasing the objects can become difficult.

For these exercises [26] in presence of physiotherapist, patients must visit the rehab center with constant cycle time. However, by using our device patient can have all these exercises at any place and this device is portable as well. It can be carried with anyone. The exercises in which this device aid is discussed with the doctor which is specialist in rehabilitation of patients from post stroke. The same exercises are saved in our device using the code and setting of the actuator's movements.

There are lot of exercises, but patient must do the only recommended by the doctor. Few of them are most used and recommended by the doctor.

EXERCISE 1:

Hold the ball between your fingers and squeeze them together to insert force of the ball [31]. Hold the force then relax the hand after that repeat the exercise

EXERCISE 2:

Hold the ball in hand tightly and continue squeezing the ball [30] and repeat the exercise.

Figure 34: Exercise 1 [30]

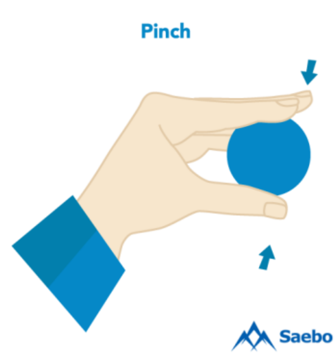


Figure 33: Exercise 2 [31]

.

EXERCISE 3:

Put putty between thumb and sides of your finger and insert some force on this [33]. Repeat 10 time and 2 sets of this exercise.

EXERCISE 4:

Place putty on the palm and push if with your thumb toward the base of hand [32]. 10 times repetition with two sets of this exercise.

Figure 36: Exercise 3 [32]

Figure 35: Exercise 4 [33]

EXERCISE 5:

Take a putty and place it on your palm. Squeeze your fingers 10 times [34]. Two sets of this exercise.

EXERCISE 6:

Place putty on palm bend your fingers try to bend only two joints of the finger and exert force on it [35]. Repeat 10 times this exercise with two sets.

Figure 38: Figure 5 [34]

Figure 37: Exercise 6 [35]

Chapter 4: Software Design

Using Flutter, we have made an android application. Application is a software that allows the user to perform certain specific tasks and if it has made specifically for android version of smart phones, then it is known as android application. The Design of our Mobile Application is based upon modern post that contains many clean and curved lines that exist in gradient or vector colors. It also includes the outlined buttons, the text input rows and the bold and highlighted text. The salient features of our mobile application is as following:

4.1. Android Application GUI:

- Signup allows the user to create account for a new user by entering their details like Name, Phone Number, E-mail, Password, Age, Doctor & Hospital. All these data sets will be saved in the firebase. Login allows the user to go to their accounts by entering their email and password of their existing accounts, which will be authenticate using the firebase.

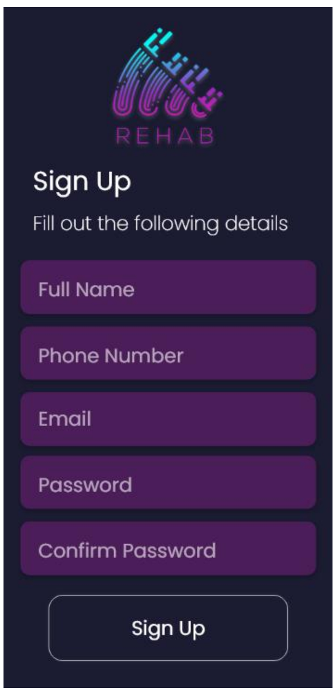


Figure 41: Signup screen

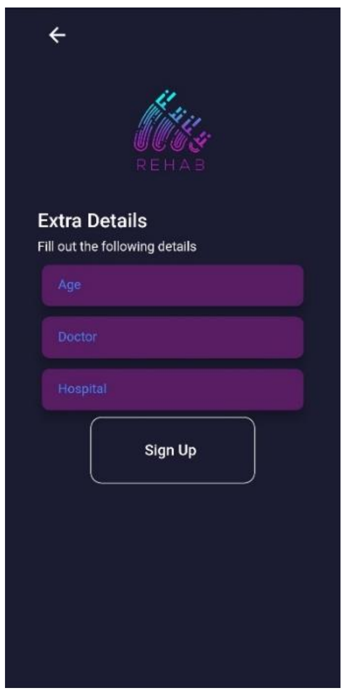


Figure 39: Enter details

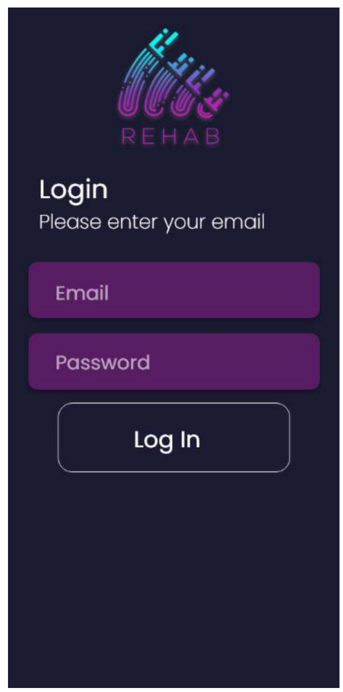


Figure 40: Login screen

- After you will get connected to the Bluetooth device, a screen will show the message of Successfully Connected and will ask to start the activity. By clicking the Button of Start, it will direct you to the Activity screen. In the activity screen, mobile application will offer the patient to have six exercises. Each exercise will have two repetitions on a single click. The exercises that we will perform will be saved in the firebase with the date & time just to monitor the sessions afterwards that how many exercises have done so far & how many remaining for the current day or how much the previous sessions are going.

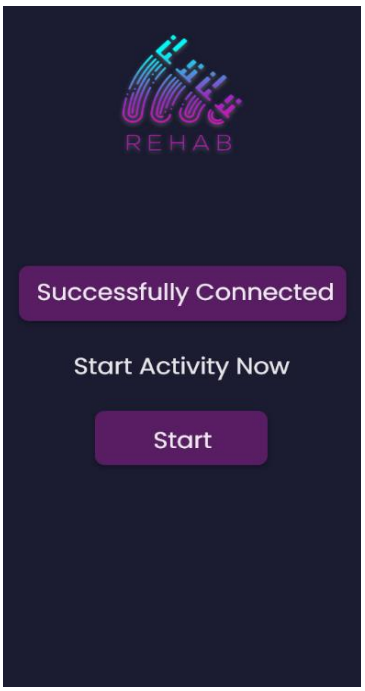


Figure 44: Connection established

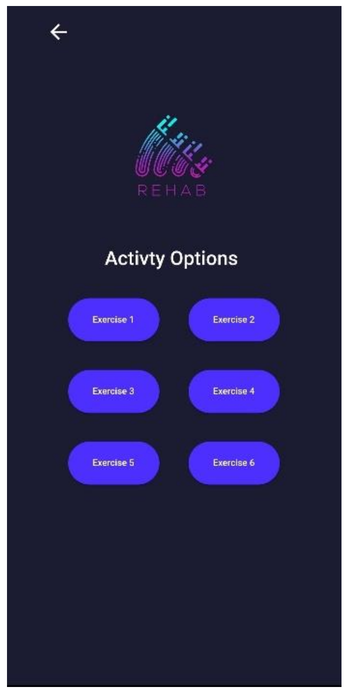


Figure 42: Activity screen

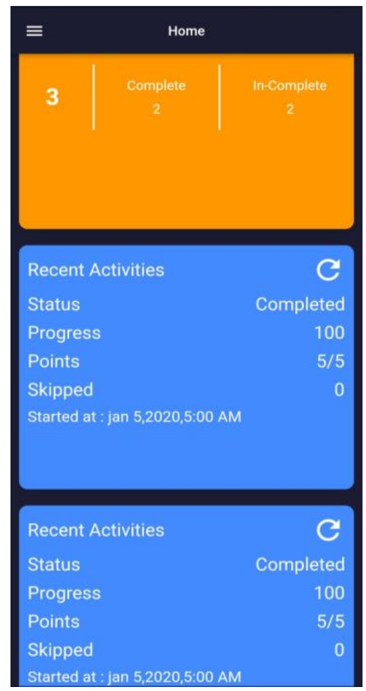


Figure 43: Activity history screen

4.2. Firebase:

A database is a collection of information that is organized in such a manner that it can easily be accessed, managed or updated. The database stores the data of the mobile application-using internet to online database.

Firebase is a cloud-based NoSQL database, which have flexible schemas for building modern applications. This is an application development software enables developers of Android, IOS and web applications to backend their data.

It also provides tools for tracking analytics, fixing application crashes and product experiment. Firebase is a real-time database that let you store and synch data between your users in real-time at global scale. In our database we are storing the User's account information and exercise history of last two days that which exercise he have done in the previous sessions and which one is remaining. So that they can complete their exercises accordingly.

We use Firebase for the authentication which provides many methods and utilities for enabling you to integrate secure authentication into your new and existing user profile.

Figure 45: Firebase authentication

The firebase along with the google console in this particular app is used to send and receive from the flutter app and authenticate the sent packages with the help of the data on the firebase cloud. We use Firebase for the authentication. It provides various methods and utilities, which are used to integrate authentication into new and existing Flutter applications. Firebase as well as the Google Console in this particular app are used to send and receive from Flutter apps and validate sent packets using Firebase cloud data. The firebase console here can be divided into two parts, one is for authentication, just like sign up with any email and the other is for login which validates the email and password entered by the user. The second part is about using a user database to store user-provided data as well as to save the application's own data, in this case the activity log of the exercises performed in Last 2 days and also user data which was entered by the user upon registration.

As we can see here in figure [46] [47], one of the user entered his data while signup was saved here, the owner can see all the details that user added while creating his account and the exercises that he have performed.

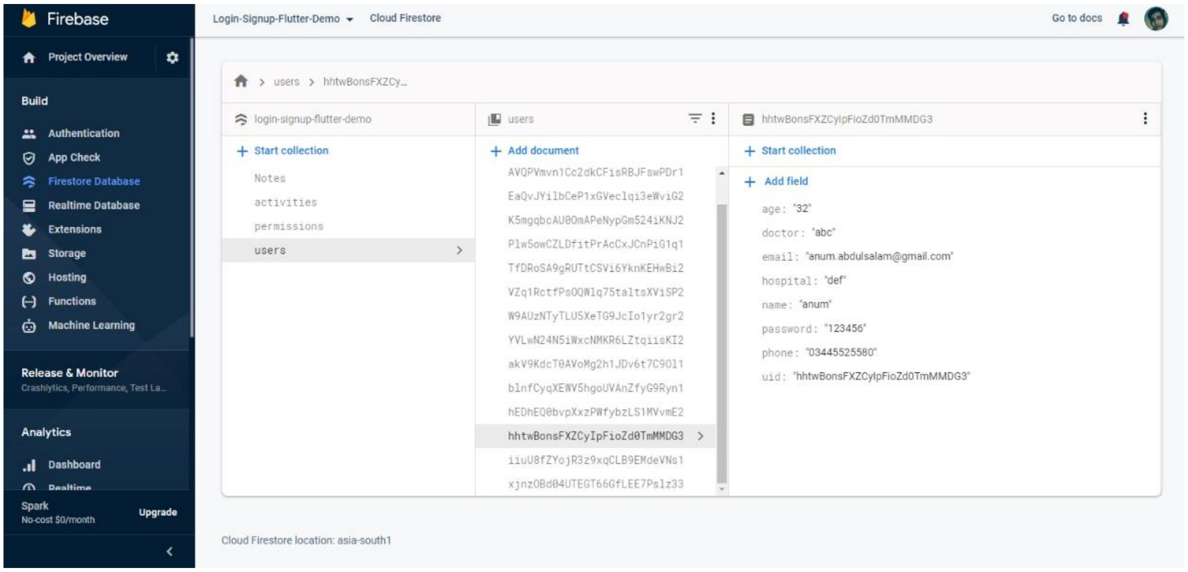


Figure 46: Real-time database storage [46]

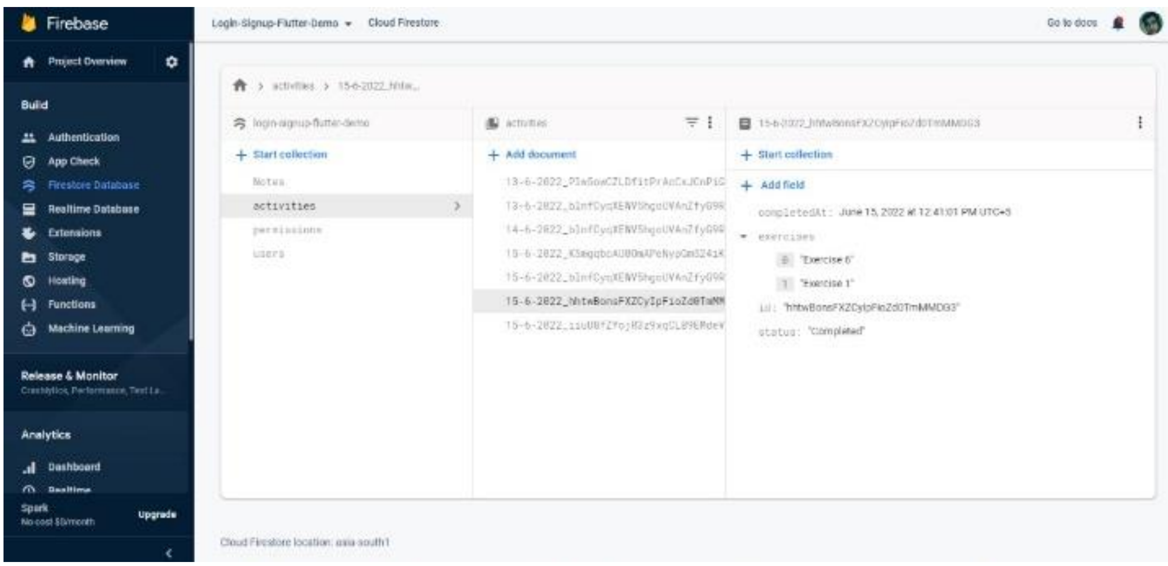


Figure 47: Real time activities performed info [47]

4.3. System Level Diagram:

The system level diagram shows that our exoskeleton will take commands from our microprocessor Raspberry pi Pico which will receive string data from the Bluetooth module which will be connected to our android application. Our smartphone must be connected to the internet as we have used firebase for the authentication.

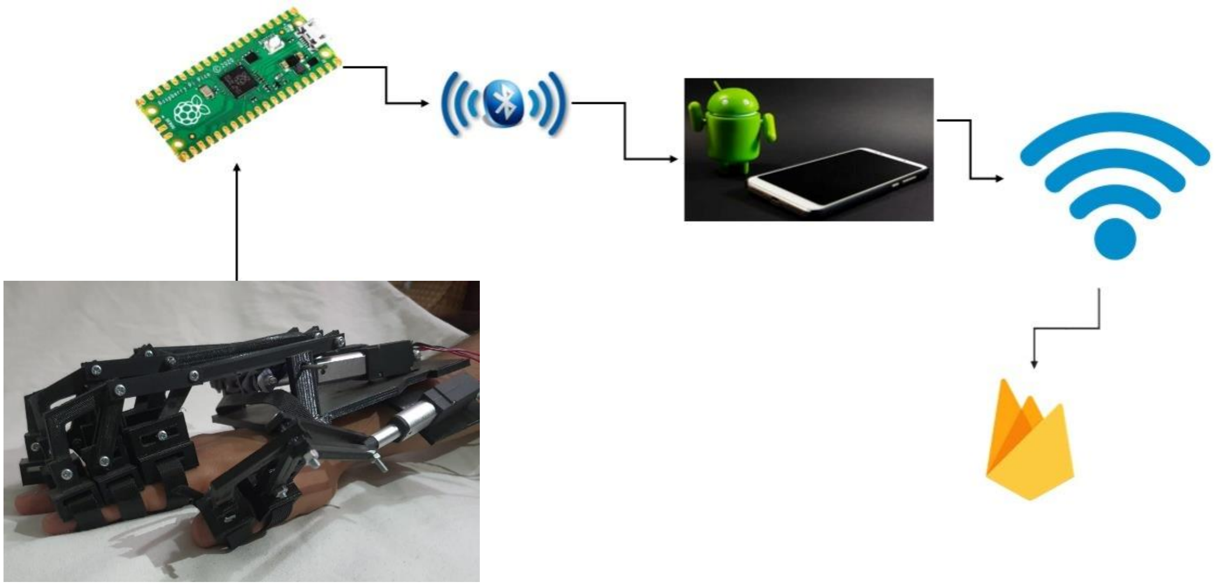


Figure 48: System Level Diagram

4.4. Software Used:

4.4.1. Thonny IDE:

Thonny is a python integrated development environment designed for beginners. It upholds various approaches to check the certainty of you code, point by point representation of the call stack and a mode for making sense of the ideas of references and load. Some of it features are it completes the code automatically, it checks the code, highlights all the errors and interface is very simple and easy to use.

4.4.2. Adobe XD:

We have used adobe XD to design the UX of the Mobile Application. Adobe XD is the vector based user experience design tool for web and mobile app, which is a type of graphical user interface where elements are drawn using vectors instead of a null information.

The Design implemented here is based on one taken from the Adobe XD template made in the first phase of our FYP work because of its simple and intuitive UI, powerful features, and low barrier to entry. The Design was based upon modern post 2000s UX design that contains many clean and curved lines that exist in gradient

Figure 49: Adobe XD logo

or vector colors overall with minimalistic design aesthetics. This choice was made on purpose to maximize the user interacting by using a soothing and pleasing architectural design.

4.4.3. Flutter:

Flutter is Google's open-source UI development software. Android, IOS, Linux, Windows, Mac, etc. use it to build cross-tier applications while maintaining a consistent user experience. Flutter is ready to use your existing code, customizable widgets, libraries, tools and documentation. It is a free and open source, so developers around the world mainly use it. Flutter is a front-end development framework that allows developers to create their own type of beautiful front-end for any screen.

The version of Flutter we used here is Flutter 2.0. It controls every pixel to create customized and adaptive design that looks fascinating on any screen. Takes control of your codebase plugins, testing, dev tools, multi-platform, native performance, fast development, null safe code, hot reload and in this version they also added a flutter view to an android application which allows user during the flutter activity to see what he actually made.

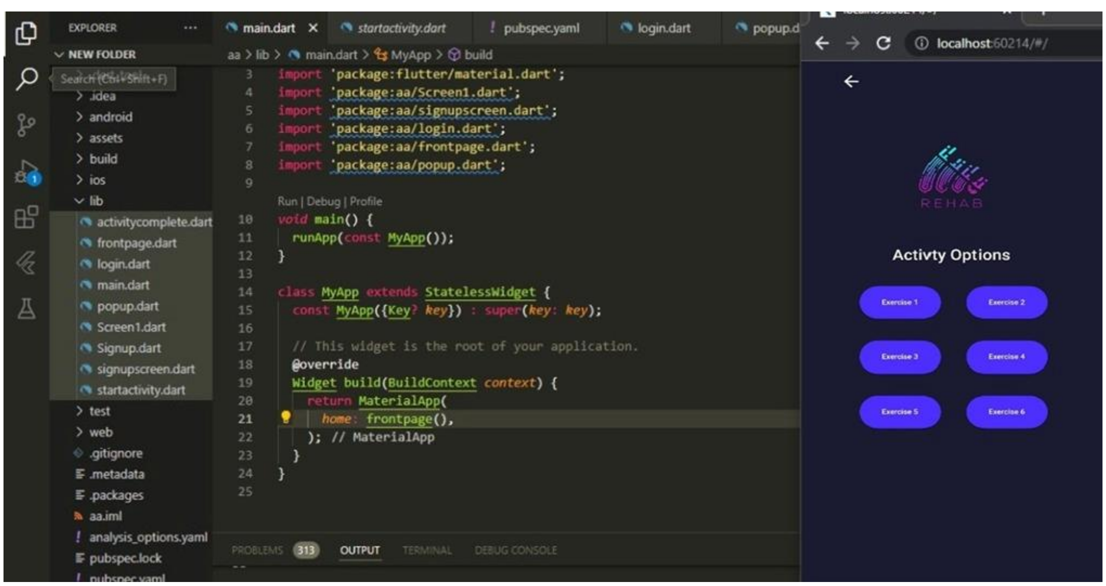


Figure 50: Application backend

Flutter uses Dart programming language, which is an open source and is purely object oriented, class based and a C style syntax language, which has incredible functional as well as receptive programming.

Dart is not bloated in any way. In fact, it is moderately straightforward, modern and exceptionally effective language to work with. Dart is similar to C# and java in syntax therefore it is easy to learn, stable and can create high performance applications. With dart, you can write code using a flexible type system with rich static analysis and powerful configurable tooling. I used Visual Studio code by Microsoft for the Dart plugin. This is a code editor redefined and optimized for debugging and building modern web and cloud applications. It provides developers with the instruments they need for fast code debugging cycles, leaving complex workflows to a more comprehensive IDE. It Supports variety of programming languages. We have imported different necessary packages & libraries in visual studio code to make it more useable for making android application.

Chapter 5: Results

5.1. Motion Control Test:

This test is completely experimental base and is done in order to know about the range of motion of hand exoskeleton by actuators. Following two tests of motion are done in complete motion control test:

- **Active Actuation:**
  This motion is done by the user without the aid of any other force. It is done by the actual muscles with their own power.
- **Passive Actuation:**

This motion is done by the user without the aid of any other force. It is done by the actual muscles with their own power.

We have compared the range of hand movement in with active actuation and passive actuation. A healthy human hand (age 24 years) was used for this experiment. During the active movement the hand was stretched and relaxed without any external force and the angle of movement of each phalanx was measured. The angle and motion were measured 1st when fingers and palm were straight. After that hand was closed in a normal way not pressing extra. This was done to obtain the maximum angle rotation on each joint. All these angles were counted in active actuation.

After all this movement and measurement, a passive session was done in which hand move with the external aid which was provided by the exoskeleton. In the passive actuation movement session, first the hand of the object was in complete relaxed position. The actuation with exoskeleton structure was done in which hand perform the closing motion and then opening motion. During the motion the finger movement was measured with the help of geometrical instruments and drawn on the paper as well to get the values. The angles on each joint were calculated and they were known here as passive actuation angles.

5.1.1. Motion Control Test Results:

In the test result session, the motion angle of active actuation and passive actuation was compared for each joint of our hand. Our purposed mechanical exoskeleton design makes the bending of joint angles to the small extent as compared to active auction joint angles. Exoskeleton motion was mechanically guided its force, speed and time was already known. Our mechanically guided motion angles were smaller than actual active actuation angles but they were greater than those angles which our joint did while holding the tripod (MPJ and the IPJ of thumb joint bends around 51° and 27°; MCP, PIP, and DIP joint of the index finger bends about 46°, 48°, and 12°; so that why we consider the our achieved angles are suitable for ADL assistance and for the rehabilitation of the hand muscles of fingers.

Here we are attaching the table and graph of motion compared while active and passive actuation angles.

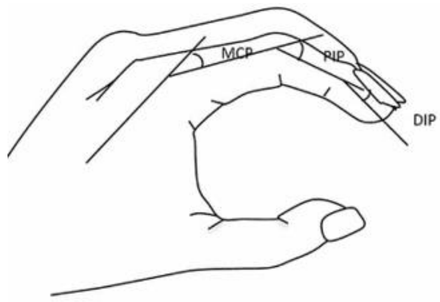
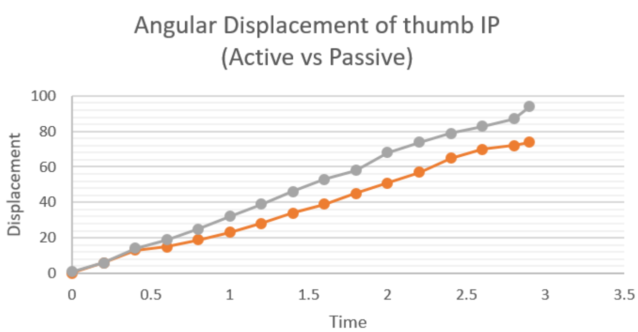


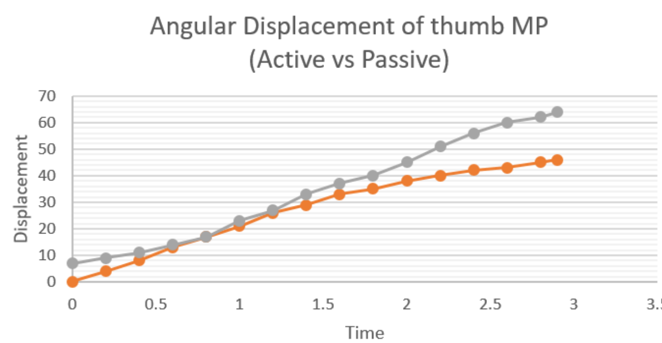
Figure 51: Different angles specified

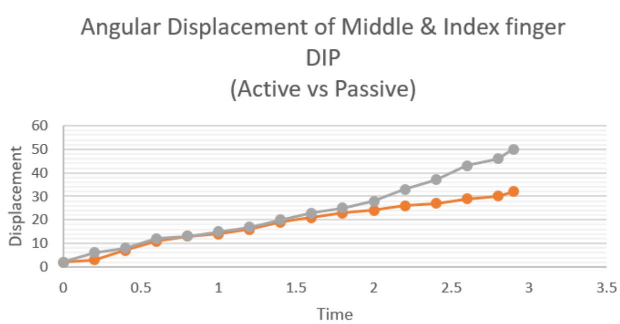
5.1.1.1. Comparison of Active and Passive Actuation of Phalanges:

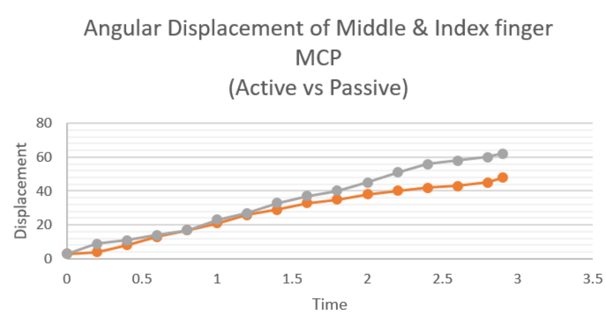
We have calculated the active and passive angular displacement of Distal, Proximal and Medial phalange of each finger and then compared them graphically with respect to time. For the passive actuation, the time was constant 2.9 seconds. The grey series shows the active actuation of a normal hand and the red series show the passive actuation of the stroke patient aided by hand exoskeleton.

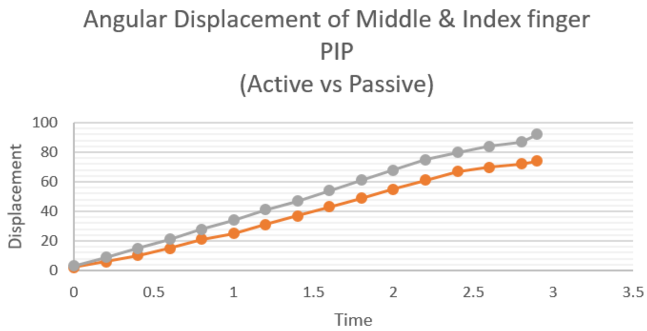
The active actuation in every case provides more angular displacement than the passive action since it is the natural movement of a hand. While passive is done with the help of exoskeleton.

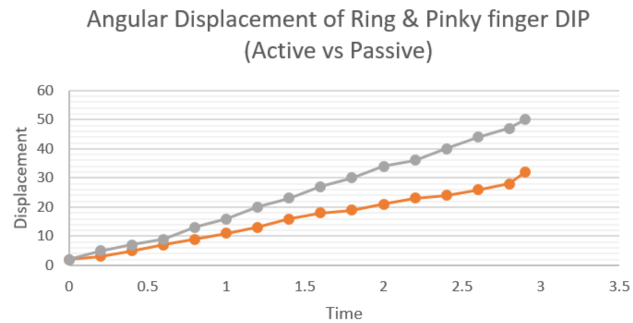


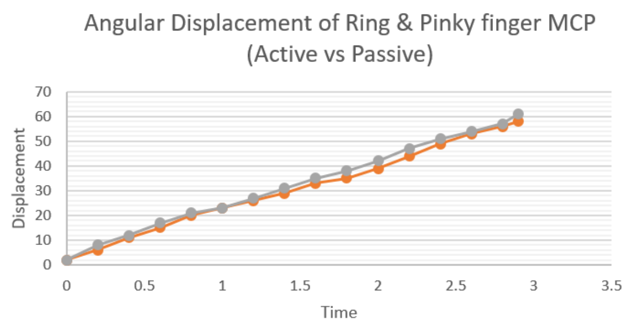


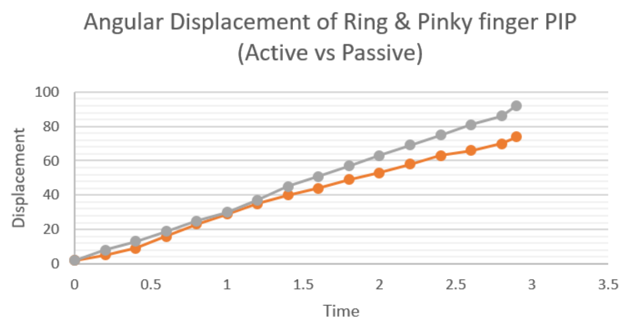












Following table [5] shows the passive angular displacement on each phalange provided by our exoskeleton:

Table 7: Provided angles by our exoskeleton. [5]

	finger	MCP (degrees)	PIP(Degrees)	DIP(Degrees)
Passive	Thumb	46	82	-
Passive	Index Middle	48	75	33
Passive	Ring Pinky	45	67	28

Chapter 6: Conclusions

6.1. Safety:

As in the robotic hand exoskeleton humans are directly involved in it to get the rehabilitation after stroke attack by using the robotic hand exoskeleton. Therefore, safety becomes our top priority here. Any type of mechanical problem or mechanical design failure can become a cause of serious harm or maybe injury in some cases for humans. It is because the robotic skeleton system and the hand were in close relation are strongly attached with each other. Therefore, there should be enough motion considerations on all aspects of the motion characteristics of hand finger, which are done by robotic hand exoskeleton system. Center of rotation of the mechanical structure and the center of axis of the human finger's joints should coincide accurately with each other. Therefor suitable mechanical stopper can be used to limit the motion of linkage. As a result, we can say that hand motion anatomy and the protentional emergency must be intercepted in every kind of rehabilitation exoskeleton design by the designers.

6.2. Availability:

The exoskeleton recovery is little, long and costly for patients as they are not much common thing for rehabilitation. Many of the researchers thought that the main limitation in for practical using the hand exoskeleton for rehabilitation is the availability. Availability of this design is depending upon complexity of the device and the expenses which are spend on building the device.

Such type of complex rehabilitation devices manufacturing requires the supervision specially from the specialist therapists. The common available device now a days only offer the single degree of freedom and if we want to add the two more degree of freedom them it will expense more on manufacturing and as a result availability will become less. There are also big structures available for rehabilitation, but they expense more and, they prove the much more burden on hospitals and also require extra space and room for stroke patients. Nowadays the growth in number of stroke patients' condition of current rehabilitation center clearly says rehabilitation at home with the help of hand exoskeleton will becomes more common. The transformation of this application which is mostly present in labs to the home needs to be improve on urgent basis.

6.3. Comfort:

The developed hand exoskeleton must comfortable. As the patient will be wearing it to perform the exercises so it should not cause any harm and pain to the patient. For this the force exerted by our actuators is controlled 60N which provide different rage of angular displacement s to the three joints of the finger as described below in the table by providing 30mm of stroke by the linear actuator.

6.4. Affordability:

The hand exoskeleton should be affordable to the stroke patient. Its cost should not increase the cost to visit the rehabilitation centers. The exoskeleton developed by us will be more affordable if made on a large scale since it does not contain much expensive components.

Chapter 7: Future Work

7.1. Connecting Different Rehabilitation Centers:

we can rehabilitate different patients with some specific exercises, which are commonly used in rehabilitation centers worldwide such as ball grip, finger pinch, thumb press, finger hook and full grip. It can be operated using mobile application, so that some data of the previous sessions as well as current session can be monitored. By our app a centralized control system can me made so that all rehabilitation centers can be attached with each other.

7.2. Exercises Update from any Rehabilitation Center:

The future of the rehabilitation devices is not to far as people will be having full access to the low-cost rehabilitation devices. They can do their exercises conveniently at their homes or in their free time as advised. After specific mentioned time they can get the updated exercises from any rehabilitation center when they are inter linked with centralized system.

7.3. Cost Friendly:

This will lower the cost of their traveling and charges of rehabilitation centers, their time to take appointments and travel for it on the given time. This is single time investment device and patients can buy his own device and after successful recovery any other patient can use the same device after conclusion with the doctor and getting the suggestion of exercises.

7.4. Rehabilitation devices for more limbs:

we can do one thing that we can link our app with different rehabilitation centers or hospitals where doctors can suggest which rehabilitation device they have to buy or how much sessions they have to take in one day or after how much time they have to continue the session. Many other rehabilitation devices for other body parts can be made similar and app design can be extend in future where multiple rehabilitation devices can be controlled with single app. This can for those patients who have to do the therapy of multiple body parts such as hand, ankle arm etc.

7.5. Human Mind Control Hand Exoskeleton:

Brain linked EEG sensor can be used to control hand exercises. EEG sensor will work here as a switch which will get the signal from the brain after processing them, they can be used to control actuators movements which could help in rehabilitation. This device will be much patient friendly and there will be no need of use of any type of jell. In such device a specially designed electric circuit will be used which will interfere with brain get signals from brain and remove the noise. After removing the noise, it will process the signal and then covert it to the digital power. EEG sensor in this case will me integrated of hand.

These electrodes will be used which are EEG Signal Channel REF (reference point) and a GND (Common ground). The EEG band powers the values for Alpha, Beta, Delta, Gamma, and Theta. This device is used to monitor the connection between skin and the electrodes and if user feel any kind of interruption, then a message will be top up which will say to correct the electrode.

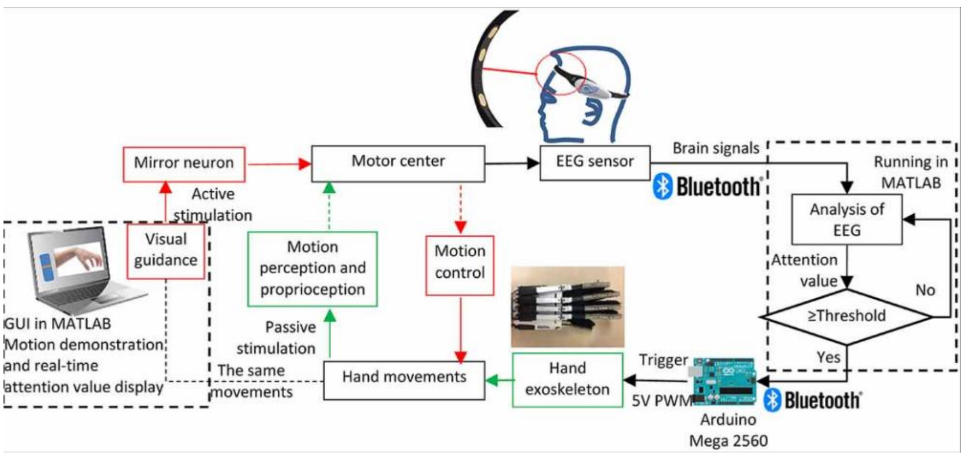


Figure 52: EEG controlled exoskeleton

7.6. Attention-Based Control of Hand Exoskeleton:

This can also be built in future with much accurate sensors. In this system the motion of the hand will be controlled by the attention of the user. In a sample test run it was noticed that the focus was more when a motion video was played in which someone was doing grasping motion in which the object was grasping something with his hands. After that a visual test was also done in which user was only told about grasping motion. According to the test results it was found that the focus was much on which video was played. So, by making much more attention threshold point can be reached early. When the patient was subject to such with all sensors in working condition attached the exoskeleton exercises can be done by making more attention and reaching the threshold value. It also depends upon the ongoing thoughts in spice man mind. Its main limitation was that it is difficult for human mind to concenter on the same thought for the long time.

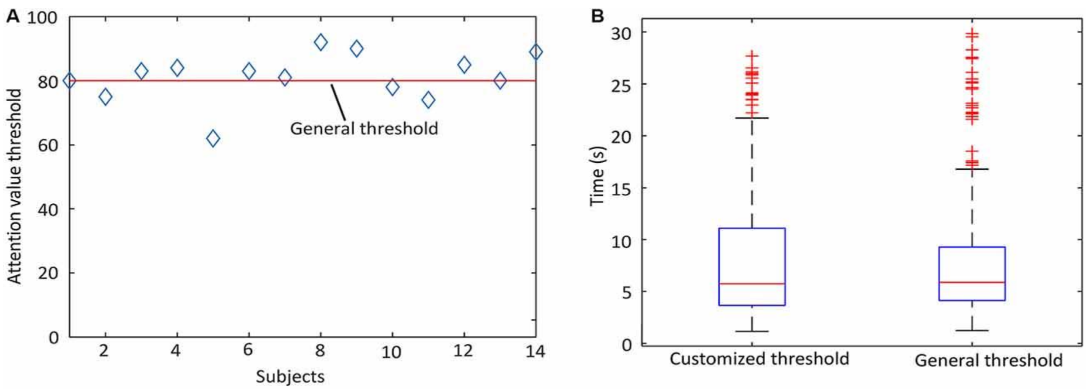


Figure 53: Attention based exoskeleton

7.7. Flexible Design:

In our project, we can also design it in such a way that some other exercises can be performed by making our hardware design more flexible. It can be improved to much extent making it more patient friendly. Its design could be made adjustable to different hand sizes. It is already portable can be carried any where and at any place therapy sessions can be done.

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