HAND REHABILITATION DEVICE

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

The aim of this project was to make a hand rehabilitation device which could be used by physiotherapists for quick recovery of patients suffering from hand impairment after a stroke.

Approximately 400 people in a population of 100,000 have a stroke each year in United States and the numbers are even greater in Pakistan. After the stroke patients different body parts get affected and are unable to perform in daily life activities. Such a machine could make their therapy easy and make recovery faster, giving them a better control over their hand.

After the intense study, requirements were established and the necessary data about the forces required and the dimensions of hand was collected from research papers. Several design options were created and evaluated, and the most economical and effective design was selected to achieve the desire task. During the design finalization the availability of products in market was kept in mind. The required material was procured from the markets of Lahore, Rawalpindi and Karachi using online stores, majorly for electronic components.

PREFACE

Pakistan is a developing country with very limited resources and large population. Due to very limited resources available especially in the health sector, a large population is deprived of basic treatments. SMME NUST and our professors have invested resources, knowledge and time in us and it is our duty to pay back to our society. The motivation behind this project is to create a product which could directly help someone recover and remove their dependency on others.

This project is one of the many projects related to rehabilitation, done by our supervisor Dr. Nabeel Anwar. Our seniors did a similar project for rehabilitation of arm and the aim is to create equipment for rehabilitation of all the major body parts that get affected after strokes. Hand and finger rehabilitation is one which we chose to work on, considering the way life gets affected due to hand impairment.

ACKNOWLEDGMENTS

Firstly thanks to Allah Almighty for giving us the ability to learn and blessing us with knowledge and resources required for this project. Nothing could have been done without His help, guidance and blessing.

Secondly we would like to thank SMME NUST for their unconditional support, not only during this project but for the past four years of our degree. The Lab engineers, workers from MRC, teachers, people from administration and everyone co-operated and helped us during the execution of this project.

Our supervisor Dr. Nabeel Anwar was the biggest motivation during this journey. Thank you for trusting us with this project and giving us the opportunity to work with you and learn from you. We are also thankful to our mentor, Umair Hassan, for guiding us and always pushing us to come up with new ideas. Moreover, to Rao Muhammad Danial, our dear friend, for his help and support throughout the project.

Last but not the least our parents whose unconditional love and confidence in us made us believe in ourselves and gave us hope and positivity during the harder times.

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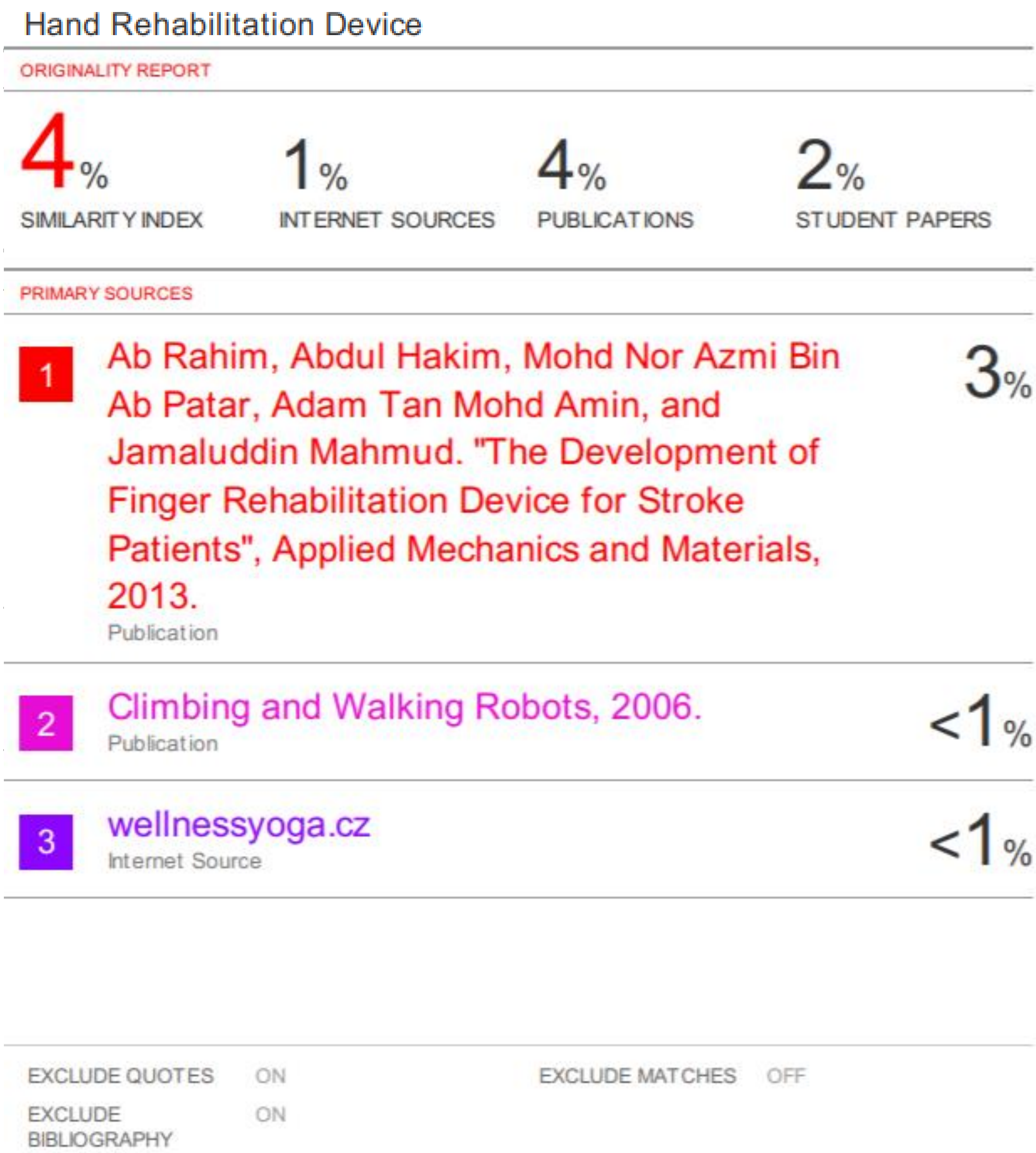
ORIGINALITY REPORT



Hand Rehabilitation Device

ORIGINALITY REPORT

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2	Climbing and Walking Robots, 2006. Publication	<1%
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ABBREVIATIONS

MRC	Manufacturing Resource Center
DOF	Degree of Freedom
MP	Middle Phalanx
PIP	Proximal InterPhalangeal
SMME	School of Mechanical and Manufacturing Engineering

CHAPTER 1

INTRODUCTION

Description of the Problem:

Following the stroke, the patients are left with a hemi paretic hand which leaves them immobile and motor dysfunction emerges. The rehabilitation exercises show considerable improvements in the condition of the patients. The paralysis occurs because of the memory loss of the motor neurons which enable a normal human being to move their hands. The hand has a critical role in performing daily activities and this is the very reason that it has attracted a lot of interest for the fast rehabilitation of hands. The human hand has the characteristics: 21 degrees of freedom (DOF) structure (wrist included) consisting of 29 muscles and loaded with neurons as well as mechanoreceptors on palmar side mostly. However, the main determinant of the hand's deftness is the complex and advance neural system that controls and senses hand movements. The drawback of this well advanced, cortical reliance of hand movement is loss of skill and the severe impairments that result to the loss of control in the hand. The dysfunction of hand is very common among the

Figure 1. Stroke affected hand

stroke patients: around 70% of stroke patients suffer from some kind of hand impairment. The use of robotics for rehabilitation in motor therapy has shown significant results.

The advantage of using robotics for therapy includes:

- Precision and repeatability in the exercises,
- Relief from physical burden on the physiotherapists
- Incorporation of control systems
- Collection of data for analysis and improvement of exercise

There is a growing interest in the robotics for rehabilitation. Recently, a lot of research has taken place for the use of such devices for the rehabilitation and a number of devices have been manufactured in this regard. The main objective of device include: to help patients re-establish the finger movement and the ability to grab the objects, to be able to conduct daily activities and to perform handling tasks like a normal person. The devices differ on the basis of degree of freedom (DOF), range of their motion and methodology being used.

Hand rehabilitation device focuses on robotic and computer assisted therapy device for fingers and hands. We aim to build a machine that provides a passive and assistive therapy that would allow the patients to restore their motor neurons' memory.

Objectives:

Our main objective is the construction of a device which can be used for the fast recovery of the stroke patients. Our focus is to build a cost effective machine aimed at precise results. Depending upon the damage, the recovery depends on various different techniques i.e. active or passive. The machine should have:

1. Passive Therapy: In this therapy, the machine provides a passive motion to the hand.
2. Assistive (resistive) Therapy: The part of the force is provided by the machine and the rest is exerted by the user itself. The machine also exerts resistive force and the patient has to exert greater forces. This is very much needed in the rehabilitation procedure.

The project is divided into the following stages to achieve the required aims:

1. Research Phase:

The research phase is very important phase in the project planning. The research phase consists of the need analysis and literature review for the project. The need analysis has been completed by doing a thorough research in the market and visiting the physiotherapists. The survey revealed that 80%+ physiotherapist would prefer the use of a device for the exercise. The next phase of the research phase is the literature review for the product development. The details of the literature review have been discussed in this report.

2. Design:

The design phase consists of the methodology to be adopted for the product development. The forces and lengths are extracted through various literatures available. This has also been discussed in this report.

3. Fabrication:

The fabrication of the product would be based on the design finalized. The fabrication is estimated to be completed in one and a half month. The fabrication would consist of device synthesis as well as developing a control system for the product.

4. Testing:

The device would then be tested on the patients and would be enhanced for better results. The testing would take 15 days and would help us analyze the result.

Project Management:

The timeline is shown below and project is being controlled using this timeline and Trello is used for communication.

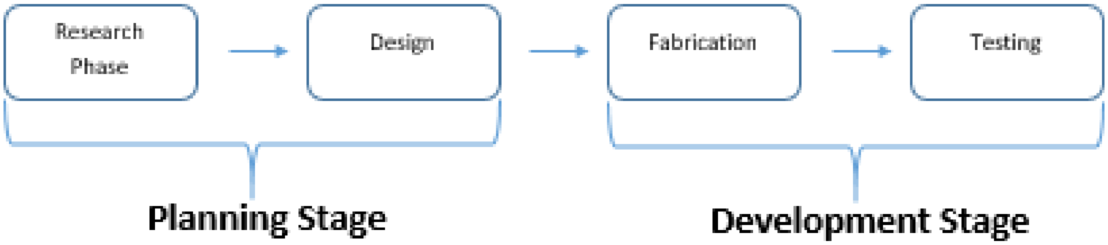
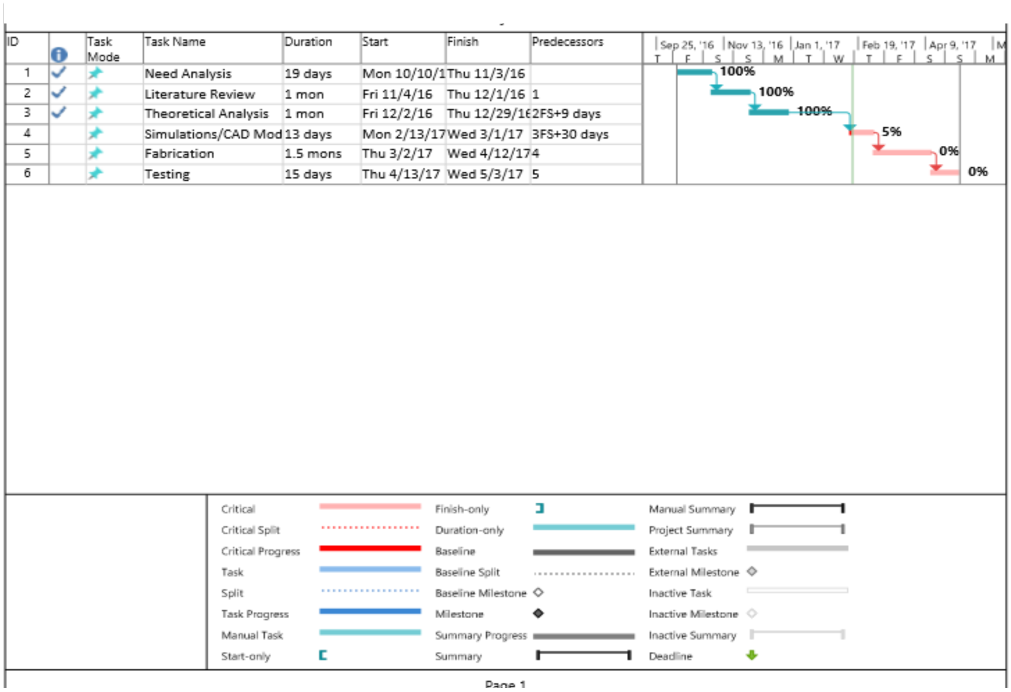
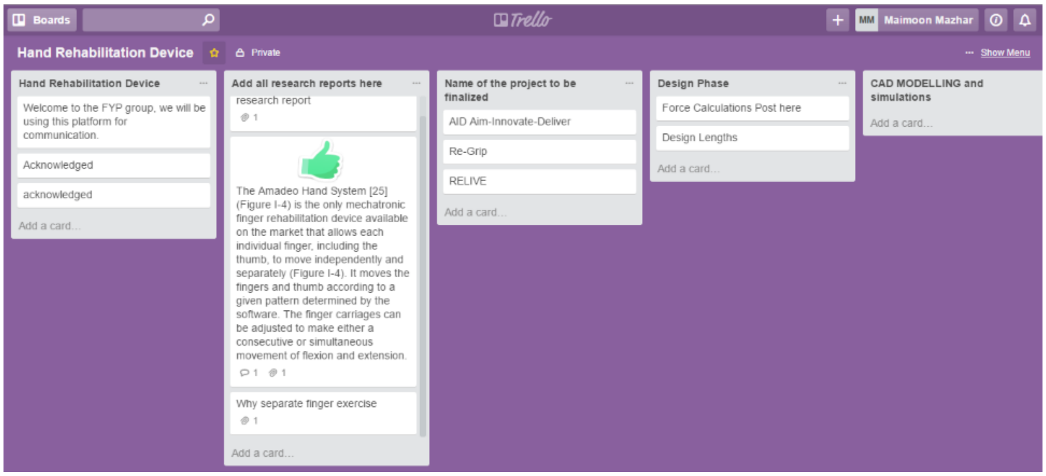


Figure 2. Stages of the project



ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1	✓		Need Analysis	19 days	Mon 10/10/1	Thu 11/3/16	
2	✓		Literature Review	1 mon	Fri 11/4/16	Thu 12/1/16	1
3	✓		Theoretical Analysis	1 mon	Fri 12/2/16	Thu 12/29/16	2FS+9 days
4			Simulations/CAD Mod	13 days	Mon 2/13/17	Wed 3/1/17	3FS+30 days
5			Fabrication	1.5 mons	Thu 3/2/17	Wed 4/12/17	4
6			Testing	15 days	Thu 4/13/17	Wed 5/3/17	5

Figure 3. Gantt Chart



Hand Rehabilitation Device

Hand Rehabilitation Device

Welcome to the FYP group, we will be using this platform for communication.

Acknowledged

acknowledged

Add all research reports here

research report

The Amadeo Hand System [25] (Figure I-4) is the only mechatronic finger rehabilitation device available on the market that allows each individual finger, including the thumb, to move independently and separately (Figure I-4). It moves the fingers and thumb according to a given pattern determined by the software. The finger carriages can be adjusted to make either a consecutive or simultaneous movement of flexion and extension.

Why separate finger exercise

Name of the project to be finalized

AID Aim-Innovate-Deliver

Re-Grip

RELIVE

Design Phase

Force Calculations Post here

Design Lengths

CAD MODELLING and simulations

Figure 4. Trello layout

CHAPTER 2

LITERATURE REVIEW

Anatomy and Physiology of Human Hand:

We need to understand the anatomy of hand before going to manufacture this device. A hand has a total of 22 Degree of freedom (DOF) and consist of 5 fingers namely the thumb, index finger, middle finger, ring finger and little finger. Gripping consists of 3 stages the first one is opening the hand, spread around the object which needs to be held, and gripping the object between fingers, palms and hands. The fingers comprises of small carpal bones, each finger has three bones and thumb has two, and they all have a common connection with palm which consists of 4 larger bones known as metacarpals. These bones are known as phalanges. The bone of the fingers that attaches to the base is known as proximal phalanges and the bones at the end of each finger are known as distant phalanges. More mobile metacarpals are attached to thumb. The index and middle finger have fixed metacarpals but those for the ring finger and little finger can have small motion.

Hand Anthropometry:

In order to design the device we need the dimensions of hand such as the length of each individual finger when contracted and when extended, the distance between fingers and the total length of the hand from the tip of middle finger to the base of the hand. The dimensions of hands vary and especially there is a great difference in a male and female

Figure 5. Hand Anatomy

hand; keeping this in mind we have decided to take the average value so that our device could fit an average hand. Some other changes would have to be done depending on the size of hand.

Design Dimensions:

We take maximum dimensions in our design so that it could be utilized for hands of all sizes

The dimension for hands of male and female are as follows:

Table 1. Female Hand Dimensions

Dimension	cm (inch)
Hand Length	18.7(7.3)
Hand Breadth	8.6(3.4)
Hand Circumference	19.3(7.6)

Table 2. Male Hand Dimension

Dimension	cm (inch)
Hand Length	20.6(8.1)
Hand Breadth	9.6(3.8)
Hand Circumference	23.4(9.2)

Table 3. Design Dimensions

Dimension	cm (inch)
Hand Length	20.6(8.1)
Hand Breadth	9.6(3.8)
Hand Circumference	23.4(9.2)

Mass and Moment Inertia:

The mass and moment of inertia is also used in designing our device. The forces will be calculated using the mass and moment of inertia of hand. These forces will determine the current required in the motors to move the slider which will finally move the finger.

The forces mentioned above are the nominal forces that the motor will provide to the device to open the end. The sensor would sense the force applied by the patient's finger and compare the input value to the base value (above values). If the input value is less than the base value the difference of the two values will be provided by the device hence the system will work as a closed loop and the value of force will be varied, consequently the device will provide assistive, resistive and passive rehabilitation.

Table 4. Moment of Inertia for each finger

Quantity	gm/gm-cm^2*10^3
Mass	610
Moment of inertia	X 16.8 Y 13.7 Z 5.5

In order to design the equipment, we need to find the force that each finger requires to flex and contract. The normal healthy hand requires following force:

Table 5. Forces on a Hand

Force	Newton
Thumb	40
Index Finger	45
Middle Finger	45
Ring Finger	40
Little Finger	30

CHAPTER 3

METHODOLOGY

1st Design:

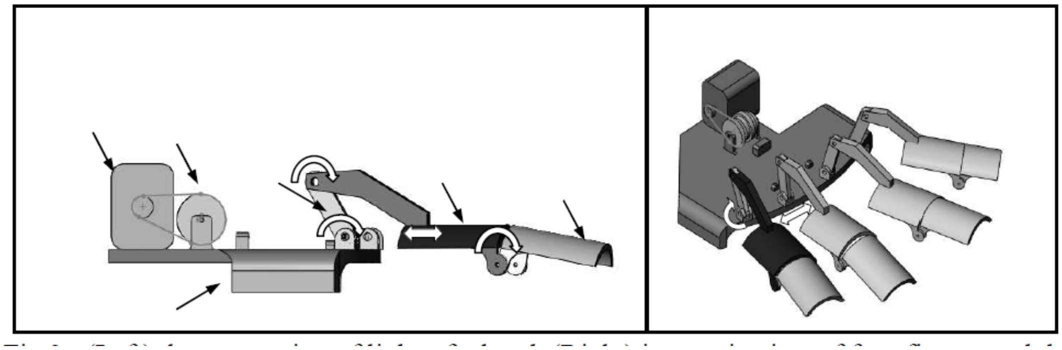


Figure 6. (left) the connection of links of hand (right) isometric view of four finger model

The main objective of this device is to provide passive range of motion to the five fingers of the stroke patient. These movements will be very simple and will drive the patient’s fingers to full extension and then to full flexion position. These movements are to make sure that the joints of the fingers are kept moving from time to time as this is one of the most simple rehab exercises. This activity is to prevent stiffness in the long run. These flexing and extending movements are the most common movements for a normal hand

This is a **Cable Actuated Finger Exoskeleton** and this will work according to the concept of tendon in a hand by using cable retraction to produce flexion and extension in fingers.

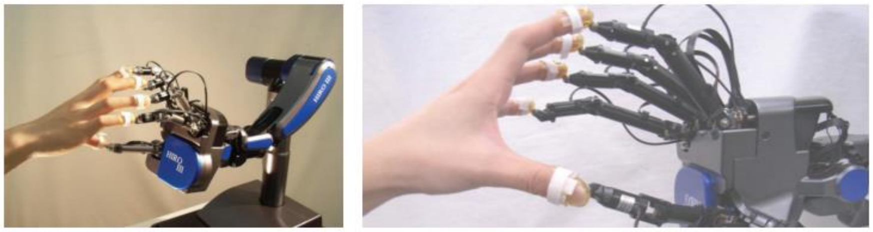
This design consists of 5 modules, one for each finger. Each of these modules contains two shell-like links (PP and DP link) and one extension link (MP link). One shell-like link (PP link) is for proximal phalange and another one (DP link) for medial-distal phalange. DP link will be connected to one end of PP link, and the other end of the PP link will be connected securely to the main base with the intermediary part of the MP link. The connection point of the links is located at the joints of each finger. The joint for DP link is located at the finger's side while the joint for the MP and PP links are located above the metacarpal joint. All these links are coupled with a pulley-like design as the cable will use those pulleys as its channel.

To address the issue of different size of hand, there are two features included in the design. One is the difference in the length of patient's proximal phalange can be tuned on the PP-link, and the different location of patient's finger can be altered on the MP-link and the base connection.

The motors are connected to a main pulley. The main pulley contains 5 different sizes of pulleys, a single driven pulley for each finger and another driving pulley which connects all the fingers at the same time. The pulleys are sized according to the ratio required for each finger to be pulled back together by the driving cable. Clockwise rotation of the pulley will result an extension of the finger and vice versa.

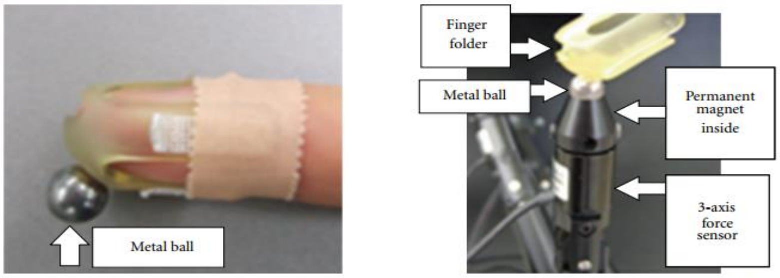
The haptic (interaction involving touch) finger design has 3 DC motors in the frames and three active joints (Figures (e) and (f)). The first joint is for abduction-adduction of the **Middle phalanx** (MP) joint of the haptic finger, and the second and third are for flexion extension of the MP and **Proximal interphalangeal** (PIP) joint, respectively.

2nd Design:



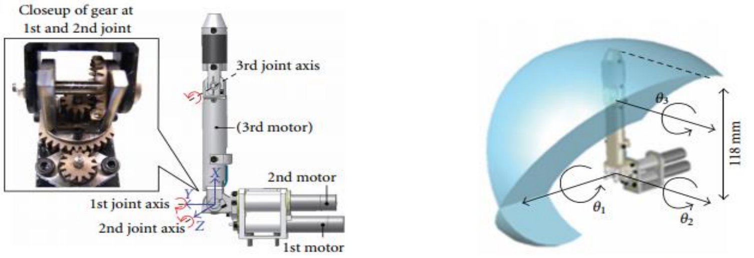
(a) The haptic interface: HIRO III overview with arm

(b) Connect to hand part of HIRO III



(c) Installation of finger folder at fingertip

(d) Passive spherical joint at the top of haptic finger



(e) Finger mechanism

(f) Work space and joint axis of a haptic finger

Figure 7. Haptic finger design

Furthermore, the haptic finger design has a 3-axis force sensor at the tip (Figure (d)), and each motor has an encoder.

This design has five haptic fingers and can simultaneously provide 3-directional forces on multiple fingertips. Similarly, the haptic finger has a permanent magnet at the tip (Figure (d)).

The machinist sets up the finger folders (Figure (c)) at the fingertips, and this folder has a metal ball. The folder and the metal ball together form a passive spherical joint (Figure (d)) that can change the posture of a user's finger against the haptic finger.

3rd Design:

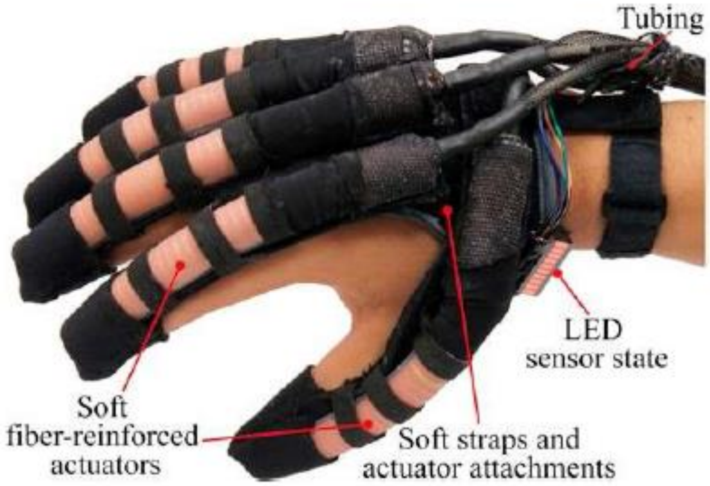


Figure 8. Soft hand robotic glove

This design uses a wearable glove which helps in rehabilitation and assists the patient in daily life activities such as holding objects. It consists of soft hydraulic actuators made from elastomeric materials with fiber reinforcements to control the fingers fitted on the dorsal side of hand. The sensors fitted in the glove measure the pressure in the actuators and correspondingly control the flexion or extension of hand. The actuators need to follow the motion of a normal finger and generate forces of the range that finger generates. The actuators have a tubular structure and the fluid pressurization controls the motion of soft actuator to achieve the desired movement.

4th Design:

Figure 9. Mechatronic Hand Rehabilitation Device

This Design is a mechatronic rehabilitation device and is not very common in the field of robotic rehabilitation. It is used for the betterment of functional disorders of the hand, mainly fingers.

The above mentioned system enables working of both each finger at a time or all of them together, including the thumb which usually gets neglected in the orthodox form of rehabilitation. The design is such that it imitates hand movement and natural grip action of a healthy human being. The movement and strength of the motion can be attuned according to the specific requirements of the patient. The arm of the patient is supported and the fingers are placed on the device. Due to this, the patient is prepared for the automatic movement procession.

The design uses 5 electric motors and a gearing mechanism to control the motion of the fingers. The programming of the device is done using Arduino and the speed of the motion is controlled by varying the amount of current going in the motors. The amount of force applied on each finger is directly related to the amount of current in the motor.

The patient is set to make passive or active movements depending on his/her needs. In the meantime, all these are recorded by the device through sensors. As in other robotic systems, it is used successfully in treatment of paralysis caused after brain and spinal cord injuries or caused by nerve injuries of the hand or strokes.

CHAPTER 4

RESULTS AND DISCUSSIONS

Design Finalization:

We have decided to choose **“Design # 4”** because it will be the most effective device for the purpose of hand rehabilitation.

This device is ideal for the use in all the stages and phases of neurological rehabilitation including **passive, active, and assisted therapy**. The design is fully integrated and will give feedback in real time. The range of motion is highly flexible and it will be very easy to use for different patients. Real time measurement of the forces can also be integrated in the device.

In order to go for the mechatronics approach for hand rehabilitation we designed the whole system which could help us to produce linear motions in the fingers. A special part was designed on a rack-pinion approach which would be run by a motor and would convert rotation of motor into linear motion. Bars would be fitted at the one end of the rack which would project out of the outer case of the equipment and the fingers would be attached to it through finger holders and the required motion would be produced.

Linear Mechanism Design

The Linear Mechanism as described in the previous section follows the basic principle of Rack and Pinion. The development of the model is based on the fact that it would be 3d printed and the material-strength ratio has been achieved through various SolidWorks testing. The material used for the production of Linear Mechanism is polylactide (PLA) which has a strength of 57.8 MPa (Tensile Strength) and 55.3 MPa (Flexure Strength).

The final design of the linear Mechanism is shown below:

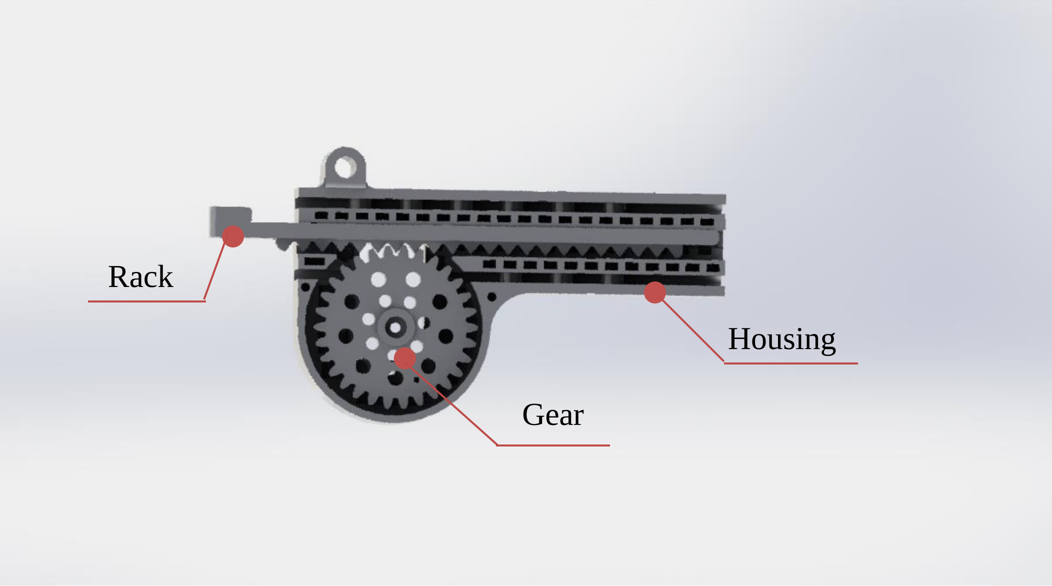


Figure 10. Linear Mechanism Design

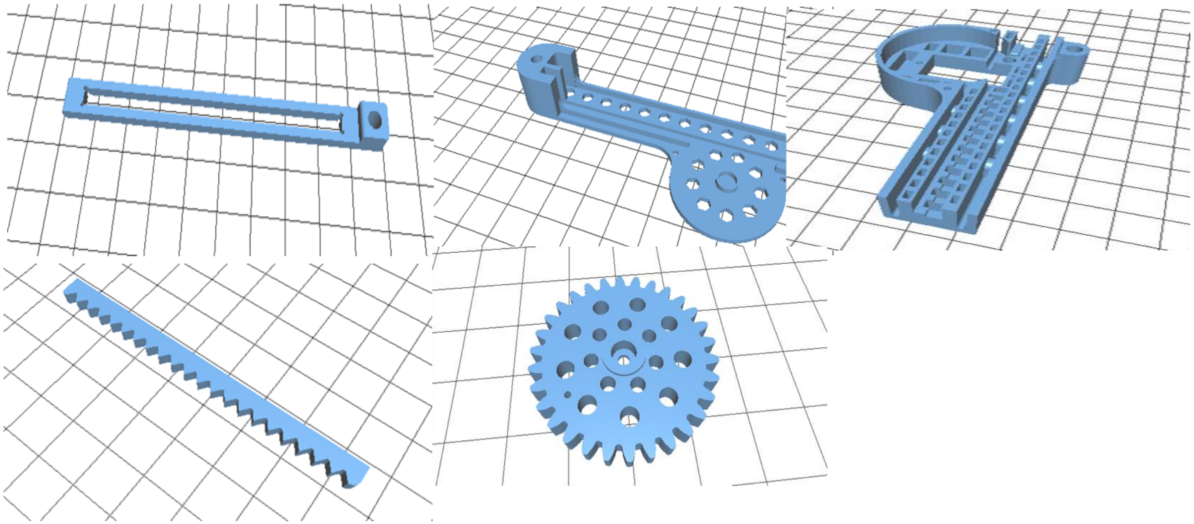


Figure 11. Parts of the Linear Mechanism Design

The dimensions of the above mechanism are given below

Table 6. Dimensions of the parts

Detail	Dimension (cm)
Stroke Length	3.5
Radius of the pinion (Gear)	1.5
Pitch of the Rack	0.35
Length of the Rack	8

Motor and Control Design:

The linear actuator that has been developed and printed through a 3d printer is then attached to the motor. The servo motor is mounted onto the gear which is shown in the Figure 10. The feedback system has been developed to control the individual motor and to vary the speed of the motor as well. The feedback system uses a potentiometer to obtain the position of the motor. The entire control is developed using the MATLAB and

Arduino software. The control loop can be explained by the figure below.

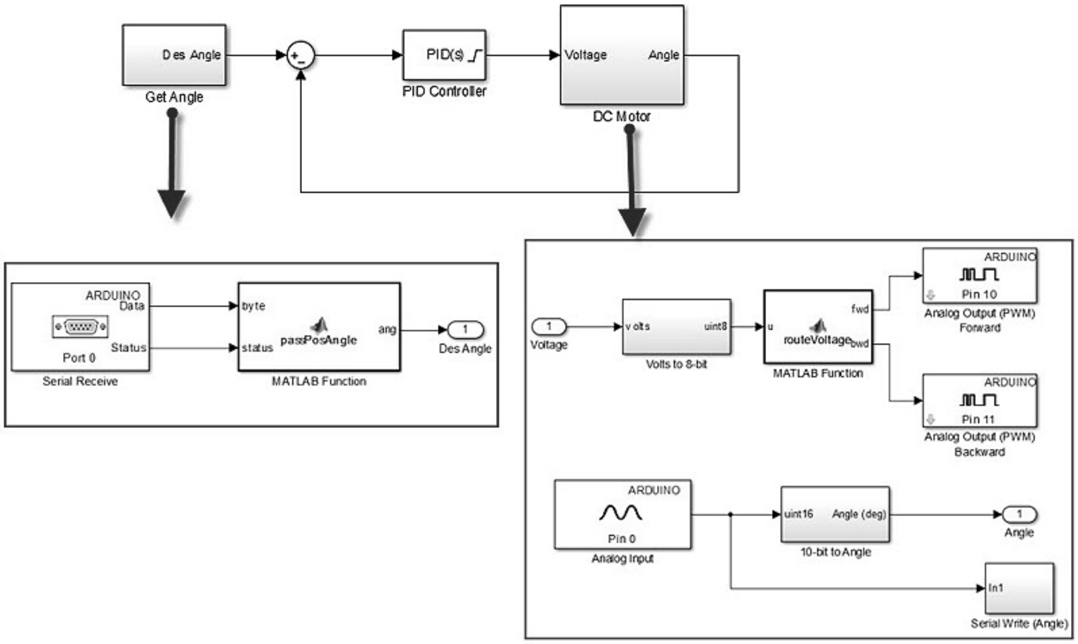


Figure 12. Control System used in the project

The control system has been established based on the above control loop. The program acquires the position from the potentiometer of the motor, checks if it is on the required position and then the PID sends a signal to the motor. It should also be considered that the Servo Motor receives the signal in the form of angles and this is the basis of the control loop design.

Speed Control of the Motor:

There are 4 servo motors being used in the project and each can be controlled individually as mentioned earlier. The speed of the motor can be varied by altering the pulse of the MATLAB signal. This is done by using the following command

For Example:

```
 s = servo(a, 'D4', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration',
2300*10^-6)
```

Now the pulse duration actually varies the speed of the Servo motor. The motor is attached to the digital port on the Arduino. This is how the speed is varied using MATLAB.

Other Specifications:

Motor

Following are the specifications of the motor used:

Servo Motor (Futaba S3003):

Voltage: 4.8V-6V

Stall Torque: 3.17-4.10 kg-cm

Speed: 0.23 sec/60 degree (variable)

Rotation of our design: 210 degree

Maximum force generated at the end of rack = 27 N

Figure 13. Servo Motor used in the project

Outer Casing:

The design of outer casing to achieve the required arrangement of motors and other 3D parts is as follows:

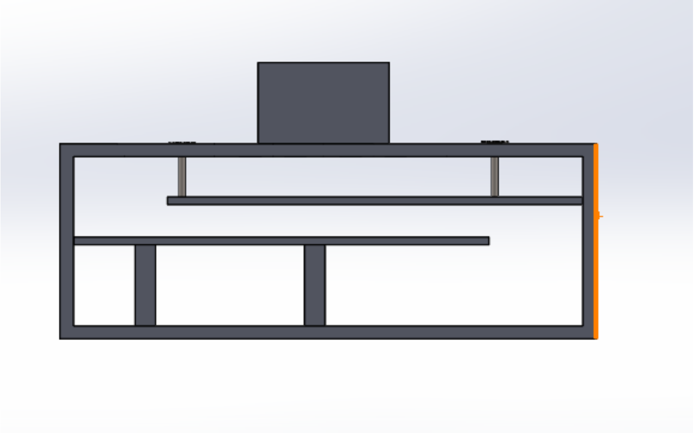


Figure 14. Back View of outer casing

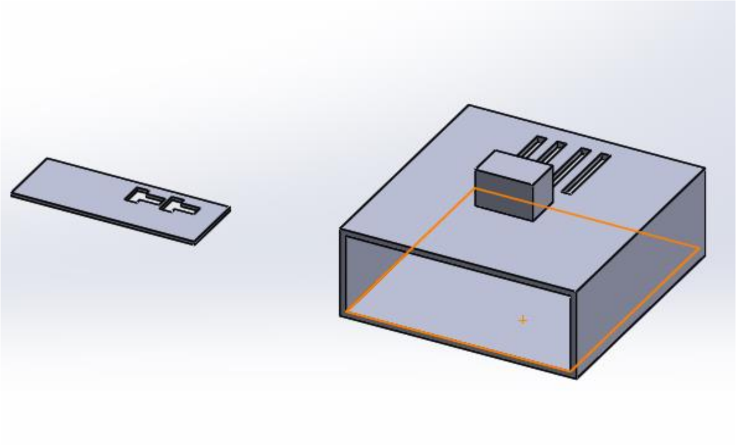


Figure 15. Individual Parts

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Health sector has been revolutionized in the past few years in the past few decades owing to the advances made in science and technology. The field of biomedical has a huge contribution in this sector; especially the work on prosthetics for human body parts and physiotherapy has made lives easier and more comfortable. The physiotherapy has been in use for centuries but the technology replacing the manual labor and the research giving remarkable solutions, exceptional treatments which are highly effective for rehabilitation and follow a specific set of movement for therapy have been developed and are giving phenomenal results. The hand rehabilitation device is an effort by us in this regard and makes patient rehabilitation faster. The design chosen accounts for the factor of cost and has made the process economical and affordable so that a large number of patients could benefit from it.

The model has majority parts made of TLA using 3D printing, thus reducing the cost effectively. But use of a more durable and expensive material could improve the equipment’s life and make it more sustainable. The cost factor would increase due to the demand of skilled labor as the metal parts used are really small and demand a high degree of accuracy from human operator which increases the manufacturing cost. The cost increase would still be marginal as compared to the similar products available in the market hand rehabilitation.

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