Modeling and Simulation of Rehabilitation/Assistive Device for Stroke Effected Hand

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We hereby recommend that the dissertation prepared under our supervision by **Muhammad Sohaib Faiz Registration No. 00000274319** titled **Modeling and Simulation of Rehabilitation/Assistive Device for Stroke effected Hand** be accepted in partial fulfillment of the requirements for the award of MS Biomedical Engineering degree with Grade (___).

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I certify that this research work titled "*Modeling and Simulation of Rehabilitation/Assistive Device for Stroke effected Hand*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Acknowledgements

بِسْمِ اللّٰهِ الرَّحْمَنِ الرَّحِيم

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Dedicated to my incomparable parents and venerated siblings

Abstract

With the intent of enhancing the rehabilitation and training of stroke patients, we present the design and validation of cost-effective, configurable, lightweight, and convenient rehabilitation equipment for the hand. The goal of this research is to decrease spasticity, paresis, and muscular tone immediately following a stroke. This rehabilitation gadget can do opening/closing, pronation/supination of the hand, and flexion/extension of the arm and hand. This concept is based on earlier Slider propelled hand exoskeleton work with the similar kinematics, but with a focus on improving DOF, economic viability, and some design modifications to make assembly easier. 3 Four distinct movements were achieved using servo motors and an actuator. The components were designed in 3-D using PTC Creo2.0 software. The same software was used for assembly, simulation, and investigations such as kinematic, dynamic, and static. The preliminary findings are given. The highest angular velocity obtained to curl and open fingers is 12.77deg/sec with a force equivalent to 1.5N per finger, and the allowed Range of Motion (ROM) is -30^{o} for supination and 90^{o} for pronation with this device. The highest von-Mises stresses operating on the finger mechanism are 3.14e^{+2} kPa, with a deflection of 1.37e^{-5} mm, according to static analysis.

Key Words: *Actuated Exoskeleton (AE), Design and Simulation of Exoskeleton (DSE), Rehab Device (RD)*

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CHAPTER 1: INTRODUCTION

Stroke is one of the most widespread causes of impairment in adults, since it is induced by a sudden restriction of nutrients to the brain, leading to loss of sensorial, cognitive, and motor skills, as well as mortality[1]. It places a significant financial burden on a government as well as the relatives of the victims. It is crucial for the people surviving stroke to rehabilitate their effected parts soon after the attack[2][3] to completely or partially recover the movements otherwise, due to increase in spasticity with the passage of time the effected muscle gets stiffer that results in losing some particular movements[4].

Rehabilitation deals with the recovery of focused goals like decreasing spasticity, muscle weakness, joint range of motion, activation of mirror neurons[5], motor, visual, and speech, psychological and other therapies related to physical disabilities[6]. Each goal deals with specific type of therapy. Physical therapy is commonly done by Professional physiotherapist[7]. It is very helpful to reduce the limitations consequential from disorder. Physical therapy involves different kind of treatments to overcome the effects of stroke comprising massage, muscle re-education, joint manipulation to decrease pain, electrical stimulation and different exercises for strengthening of muscles and deep breathing[8] to overcome particular problems.

Robot assisted Orthotic devices on other hand are devices that help patients to do exercises without the regular help of traditional physical therapists. These kind of devices are recommended by therapists to aid in the recovery and to refrain from permanent disabilities[9]. These devices are modified to adopt neurophysiologic principles of humans for the purpose of recovery. These devices are used for correction or prevention of deformity and to stabilize the halt parts of the body as well[10]. There are three factors to decide the time period for how long the device is going to be used[11];

i. Current Condition of the patient

ii. How severe part of the body is affected

iii. Recommendations from the professional therapist

While adopting advanced technologies for rehabilitation is economical, most effective and fast as compared to the typical one[12]. Moreover, countries like Pakistan where professional therapist are not in reach of common people whether due to lack of professionals or of money[13]to see them it is most convenient to have these kind of devices. Orthotic devices have the most possibility to reach maximum people without increasing the number of therapists and without any limitations of time. Patients can use these devices at their homes as well without travelling to distant locations to see therapists saving time and money.

Human hand has very complex structure. It has more than 20 DOF which make it more flexible than other parts of body[14]this is the reason very little work has been done for rehabilitation of hand. Current devices available for rehabilitation are bulky, expensive and they have less DOF.

Orthotic devices can interface with computers and other electronic controllers that greatly benefits performance[15].Task oriented games and interactive challenges with feedback of the performance are really helpful for the fast recovery of patients. It also promotes patients involvement in the recovery process and motivates the patient to do more[16]. These orthotic devises can be programmed for some motions as well by keeping certain limitations in mind for specific patients and for specific parts of body. So, it can be used for a specific group of people without losing time and in a matter of minutes. In this way, a single device can be used for multiple patients over the period of time.

Another technique is to use EMG signals from the healthy parts of body and then amplify and filter them to use it to actuate the electronic devices[17]. This technique is more effective if it is combined with Mirror Therapy that is useful for the activation of mirror neurons proven in clinical trials[18]. The purpose behind this work was to develop a low cost multi-dimensional exoskeleton for stroke affected upper limb (Hand) to be actuated by servo-motors. This work will focus for designing and manufacturing a prototype for hand exoskeleton. Mechanical design analysis was carried out using Pro-Engineer and Creo2.0.

1.1 Background, Scope and Motivation

Rehabilitation robotics is a new and fast expanding discipline that is finding its way into therapeutic settings. The discovery of training-induced restoration of sensory function in animal models with central nervous system injury sparked a series of groundbreaking technical advances in the late 1980s and early 1990s [19]. The objective was to boost the effects of training program by gradually increasing treatment intensity and providing responsive assistance.

The concept of employing robots for rehabilitation has been around for a long time. Theodor Büdingen suggested a 'movement cure apparatus,' a mechanism motor driven that would direct and assist stepping motions in heart patients, in a patent issued in 1910. Richard Scherb invented the 'meridian,' cable-driven equipment for orthopedic treatment, in the 1930s.

With the invention of the MIT-MANUS [20], which first assessed clinically in 1994, a new age of neuro-rehabilitation robotics began in 1989. This planar manipulandum has a low mechanical power output frequency-dependent impedance to motion experienced at the interaction between the human user and the robot system) as compared to industrial manipulators. The Mirror Image Motion Enabler (MIME), which enabled paretic limb motions with a rigid industrial robot commanded by the non-paretic limb through a motion encoder, was launched about the same time (mirror-image therapy mode).

Since these groundbreaking discoveries, there has been an expansion of innovative rehabilitation robots for both the upper and lower extremities, which may be divided into three categories: grounded exoskeletons, grounded end-effector devices, and wearing exoskeletons. Exoskeleton devices having a serial kinematic structure, in which proximal joints must move distal joints, would generally achieve greater motion dynamics and allow the depiction of a larger range of impedance matching than grounded end-effector devices [21,22].

Restoration of motor function following injury to the central nervous system (CNS) is dependent on the use of neuroplasticity, according to data from research non-human primates[23] and humans[24]. During the training of efficient arm and hand motions, it relies on physiological limb stimulation, as well as stimulation of relevant peripheral receptors during automatically executed leg movements like walking. As a result, rehabilitation robots should be able to facilitate and assist this type of training program.

CHAPTER 2: LITERATURE REVIEW

A stroke is caused by unexpected stoppage or disturbance in the flow of blood flow to the brain, which transports vital nutrients and oxygen through blood arteries to brain tissues and is required for brain cells to execute specific functions [25]. If the blood supply to the brain is cut off for 4 to 8 minutes, brain tissue begins to die [26].

The brain is divided into many sections, each of which is responsible for a distinct function. When tissue die, the brain loses some functions as a result. And, if blood flow is restored, some of the cells may survive and regenerate. Stroke is defined as a condition that lasts for more than or equal to 24 hours, whereas Transient Ischemic Attack is defined as a condition that lasts for less than or equal to 24 hours. More than 15 million people around the world are affected by stroke each year according to WHO. Where 33% of the victims are permanently disabled, 34% recover and about 33% decease [27].

Modifiable risk factors and non-modifiable risk factors are two types of risk factors. Genetics, age, race, and low birth weight are examples of non-modifiable traits that can't be changed. Hypertension, diabetics, diabetes mellitus, LV dysfunction, alcoholic abuse and drug use, asymptomatic carotid stenosis, hyperlipidemia and migraine are all independent predictors [28].

2.1 Stroke classification

Stroke is classified into two main categories as described below:

2.1.1 Ischemic Stroke

If the supply of blood is interrupted due to the blockage of blood vessels partially or complete it is known as ischemic stroke. Major portion of stokes worldwide are ischemic strokes caused due to the formation of clog inside or outside the brain (other parts of body). Atherosclerosis is a condition when blood vessels are narrowed down due to the clogging of fat and other substances on the walls of vessels.

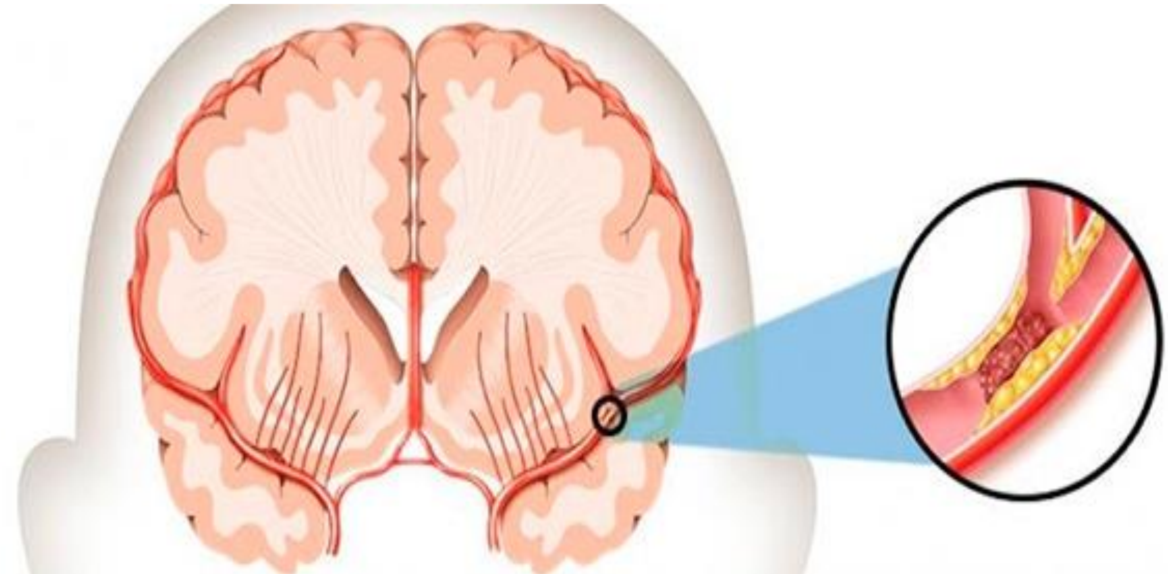

Figure 1: Clot build up inside the vessel (Ischemic Stroke) [29]

Types of ischemic stroke are described below:

- **Embolic**

  If clot is formed outside the brain in circulatory system commonly inside heart, then travels to the brain where it is stuck inside the vessels having smaller diameter. It blocks the flow of blood so that the brain cells can't get enough oxygen and nutrients so they start dying.

- **Atherothrombotic**

  It is caused due to the formation of a clot in an artery inside brain which is previously narrowed down by Atherosclerosis resulting partial to complete obstruction of the blood supply to the neural cells. It can be diagnosed early as complete blockage of artery will take time.

- **Lacunar**

  Blockage of blood supply from a single piercing artery inside white and gray matter causes death of a tissue with damaged zone of diameter about 3-10 mm [30].

2.1.2 Hemorrhagic stroke

If a blood vessel within or outside the brain bursts so that the supply of blood to the brain tissues is cut off. As a result, necrosis of brain tissue starts due to cease of nutrients and oxygen.

Hemorrhagic stroke accounts 30% of the total strokes worldwide with highest fatality rate [31,32]. Following figure shows the hemorrhagic stroke inside brain;

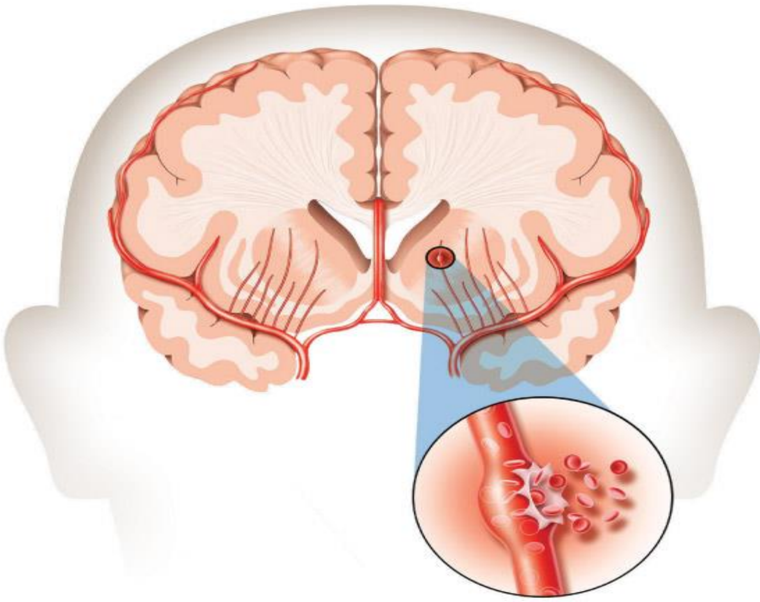

Figure 2: Vessel rupture inside the brain (Brain hemorrhagic) [29]

Hemorrhagic stroke is further subdivided into the following types according to the effected zone:

- **Subarachnoid**

  If the rupture occurs in between brain and skull this kind of stroke is called subarachnoid. It happens very often due to the burst of cerebral aneurysm.

- **Intra-cerebral**

  If rupture of vessels takes place inside the brain commonly caused by the high pressure of the blood inside vessels already narrowed down due to atherosclerosis. Bleeding starts and creates pressure inside brain, brain tissues are suppressed so that they lose functionality this condition leads to intra-cerebral hemorrhagic.

2.2 Effects of Stroke

Worldwide, stroke is the second most cause of death [33]. In the same way there are many survivors of the stroke that need rehabilitation process to come back in the normal life. The very first stage of the rehabilitation is to determine the damage caused by the stroke to a specific part of the brain including the functions and abilities lost due to it.

The human brain consists of four portions: Right and Left Hemisphere, Brain stem and Cerebellum.

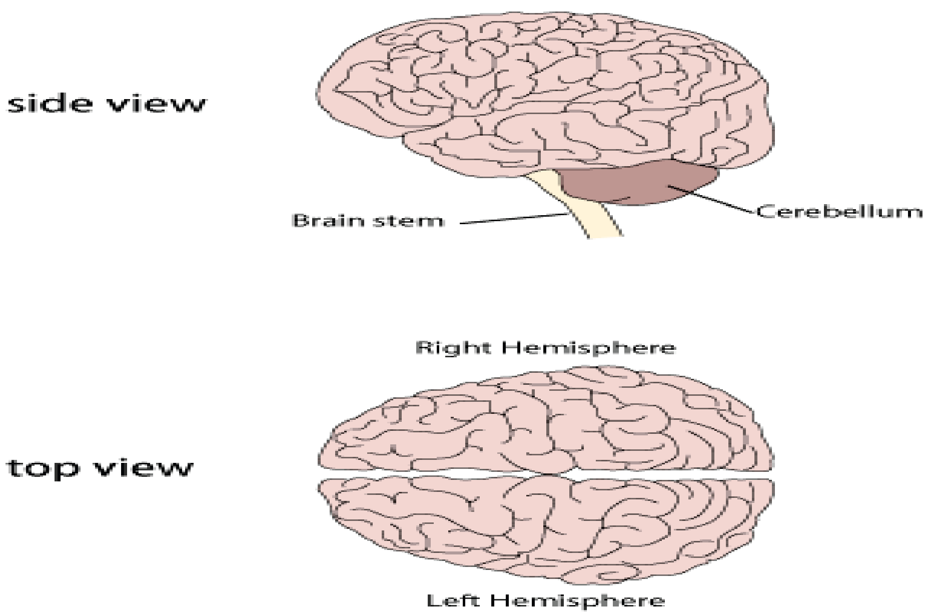

Figure 3: Different Parts of the brain [34]

2.2.1 Right Hemisphere Damage

The movements of the left side of the body are controlled by the Right hemisphere. Damage to this part of brain causes short term memory loss, troubles with judging distances, size and speed (Spatial abilities), difficulties in telling up from down and left from right (Perceptual abilities), Paralysis of the left side of the body (Left Hemiplegia) and Judgment difficulties in everyday life (Impulsive behavior).

2.2.2 Left Hemisphere Damage

Left hemisphere of the brain manages vocalizations, words and movements of the right portion of the body. Injury to this area can cause: Precautious behavior, troubles in formulating a sentence, difficulties to comprehend words in reading and writing, paralysis of the right side of the body (Right Hemiplegia) and memory loss.

2.2.3 Brain Stem Damage

Brain stem administers unintentional functions of the body therefore this part of the brain is dangerous in case it is damaged. It controls breathing, heart beat and blood pressure. Other functions include swallowing of food, eye movements, hearing and speech. Damage to this part of the brain can also cause Coma, double vision and total paralysis on either side of the body.

2.2.4 Cerebellum Damage

This part of the brain controls balancing, coordination between parts of the body and many body reflexes. Damage to cerebellum causes dizziness, nausea and indistinct speech.

2.3 Recovery

The brain and body begin to heal in the first hours after a stroke has occurred and the patient has been stabilized. The first few weeks are crucial in this process since they are when the body recovers the most quickly. Over half of the entire recovery in the first three months will have happened in the first two weeks [35].

The healing procedure engages interconnected social, psychological, and physical variables that influence the patient's final outcome. Because the link and significance of these variables are not entirely known, several ideas about how the brain reacts after a stroke have emerged.

2.3.1 Reduction of brain swelling

After tissue death, the body's normal response is to fill up it with water and white cells. The tiny gap in between the brain and the cranium is filled, and pressure rises on the healthy tissue since the injury is inside the brain. Due to the severe pressure and decrease of the supply of nutrients, certain functioning regions of the brain stop working. As a result, some functions are blocked. The patient's impaired functions are recovered and there is a perceptible recovery when the edema begins to diminish and the dead tissue is naturally eliminated. This is true only in the case of healthy tissue that was not damaged by the stroke.

2.3.2 Possible growth of nerve axons

Although there is only a little sum of regeneration of injured brain tissues, it can assist to restore certain lost functions to some extent. Near the injured area, neural precursor cells multiply and develop into new neurons, forming new circuits that did not prevail before the stroke happened. This process takes place within 7 to 10 days following the stroke [36].

2.3.3 Use of other parts of the brain

Normal regions of the brain (the ones that were not used to accomplish the lost functions) adjust in this situation to handle the stroke-affected connections and processes. The topic of neuroplasticity is gaining traction in the scientific world, and significant advances have been made in recent decades. Still, a complete understanding of the mechanisms involved is lacking.

2.3.4 Coping with the disability and adaptation by others

With the support of other portions of their body, external equipment, or a person, the individual is able to learn new methods to execute activities. This approach is critical because the individual may be able to live with the impairment while still doing “routine” duties. Family members, friends, and physicians are all involved in this procedure and are for all time willing to lend a hand to aid the patients.

2.4 Post stroke rehabilitation

Rehabilitation is an important part of a patient's recovery to the normal life. It might be centered on motor, speech, vision, neurological, psychological, or any other treatment linked to the impairments that occurred as a result of the incident. Because the brain responds faster and repairs more during the initial weeks following a stroke [37], it is critical to begin rehabilitation as soon as possible.

The patient's rehabilitation differs depending on how long has passed after the stroke, including intensity, concentration, length, and types of activities, among other things. As a result, the therapy is split into four distinct phases:

- **Acute phase**

The initial few hours to a week after a stroke are covered in this phase. Rehabilitation with an emphasis on respiratory function, coughing, and swallowing abilities is carried out.

- **Sub-acute Phase**

  Phase from the second to the fourth week after the stroke and main focus during the therapy is on motor and verbal control.

- **Chronic Phase**

After six month of the stroke chronic phase starts. During this phase rehabilitation of task-oriented exercises are performed to get long term independence of the patient.

Rehabilitation encompasses not just healing but also reintegration into society and attaining the maximum level of autonomy possible. The patient's family and therapists must work hard to keep the patient provoked and focused on the goals stated at the start of therapy. Because many difficulties may not become apparent until many months after the stroke, a continuous evaluation of recovery should be documented and utilized to adopt new tactics and goals.

2.5 Physical Therapy

Physical therapy is mostly used to help stroke patients regain their independence and movement. This is accomplished with the assistance of a competent therapist, who helps the individual overcome the limitations and devastating effects of their illness. It's critical to note that physical therapy does not attempt to "cure" the disease. It simply makes an attempt to alleviate the disorder's functional limits.

The initial stage in physical rehabilitation is to assess the patient's condition from several perspectives like range of motion, strength, sensation, muscle tone, mobility, motor status, balance and respiratory status[38].

2.6 Orthotic Devices

Therapists may prescribe the use of orthotic devices as part of the rehabilitation procedure to improve the probability of recovery or to help with persistent impairments. In the case of stroke rehabilitation orthotics, they are altered to conform to the neurophysiological principles of person revival.

These devices can also be used to repair or prevent deformities, as well as to stabilize or immobilized bodily parts. Depending on the patient's condition, they might be utilized for short-term or long-term rehabilitation. These devices are divided into three categories.

- **Assistive**

  These devices are used to overcome spasticity, and assist in joint functions.
- **Protective**

  The main purpose of these devices is to restrict range of motion of the joints to avoid any kind of rupture in the tissues, prevent deformity and to support unstable joint, bones and muscles.
- **Corrective**

  These devices aid to correct contracture of joints, bones and tendons.

2.7 Robotic Orthotic Devices

Many orthotic devices that employ electrical and mechanical components to fulfill their tasks have increased in recent decades. This is because implementing new technology in the field of rehabilitation allows for the implementation of more efficient and cheap rehabilitation programs.

Robotic orthotics provide a fantastic chance to reach more patients without expanding the number of therapists, and to keep patients motivated without the requirement of direct directions in a world where specialist labor costs are on the rise. Furthermore, automated orthotics provides rigorous and continuous therapy without exhausting the therapist, obviating the risk of human mistake caused by recurring and consistent effort to move the patient.

Patients who are unable to attend a therapist's center or office may benefit from a robotic orthotic device at home, which may be adjusted to their specific needs during their leisure time. In this scenario, a therapist might make frequent visits to assess progress and make any required adjustments to keep the program going.

CHAPTER 3: METHODOLOGY

Rehabilitation orthotic devices are difficult to design as compared to the prosthetic devices. Constraints of space as well as the limitations of natural movements of different joints are to be integrated at the same time. While for prosthetic devices there is no limitation of space one can place motors or other things where they want. Here are some design parameters for the exoskeleton:

i. It should have maximum range of motion
ii. It should be light weight and portable as well as durable
iii. It should provide continuous motion
iv. It should be user friendly and safe to use
v. It should have Multiple degrees of freedom

3.1 Biomechanics of Hand

It is compulsory to study the biomechanics of the wrist and hand to execute any design for hand. The wrist is very important structure that interfaces the hand to the lower arm. It is a collection of many bones joints and muscles involved in to perform most complex movements of the body. It is a bunch of complex arrangement of joints that are connected around the carpal bones and further more to the radius and ulna bones. A wrist involves in flexion and extension of the hand as well as abduction and adduction.

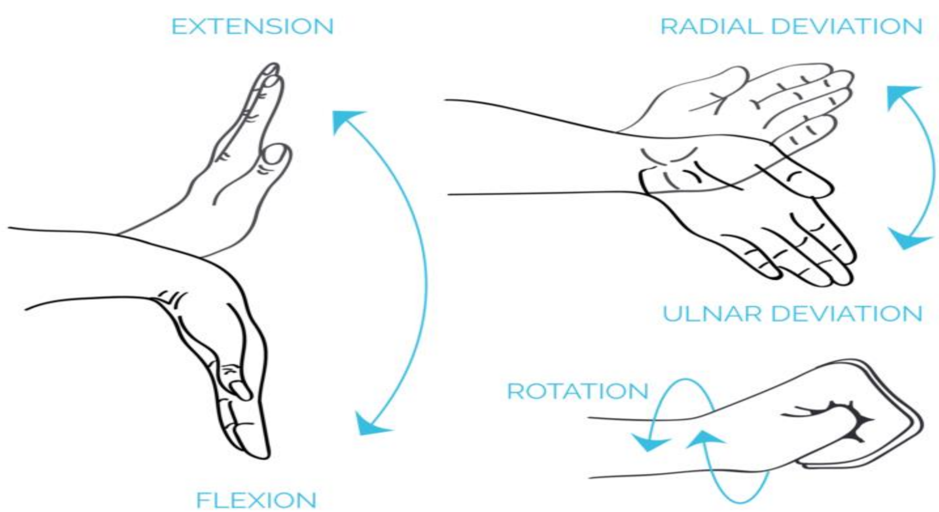

Figure 4: Different movements of wrist

For a stroke affected body the muscles become stiffer with the passage of time commonly known as spasticity so it becomes difficult for the subject to move the affected parts. If it is not dealt with care the muscle breakage can occur. Therefore, it becomes crucial to know the range of motion of the joints. Following table shows us some of the important range of motion of the normal persons for different joints;

Table 1: Range of Motion (ROM) for wrist and arm

Joints	**Motion**	**Range of Motion (deg)**
Wrist	Flexion Extension Pronation Supination	50-60 80-90 90 90
Arm	Flexion Extension	0 120

Similarly, table below shows range of motion for remaining joints;

Table 2: Range of Motion (ROM) of Fingers

Joint Name	**Motions**	**Index (deg)**	**Middle (deg)**	**Ring (deg)**	**Pinky (deg)**
Distal Inter-Phalangeal (DIP)	Flexion Extension	73 11	80 11	75 11	78 11
Proximal Inter Phalangeal (PIP)	Flexion Extension	101 12	103 12	105 12	103 07
Metacarpo-Phalangeal (MCP)	Flexion Extension	88 -20	90 -22	88 -22	90 -24

As exoskeleton is intended to perform opening/closing of the hand, Flexion/Extension of the hand and arm as well as to twist the wrist clockwise (Supination) and anticlockwise (Pronation) so, we divide the design into four portions:

a) Closing/opening of hand

This portion consists of metallic finger assembly and a single actuator

b) Supination/Pronation of hand

This portion of the design is related to the twisting of the hand. It consists of a motor

c) Flexion and Extension of Hand

d) Flexion and Extension of Arm

3.2 Closing/opening of hand

Keeping the natural rotation of the fingers in view a virtual center of rotation was supposed at each joint of the finger. Starting from MCP, slots are designed in the 1st hub keeping origin of the curves at MCP joint. Slider inside the hub is set to provide force at a suitable distance tangent to the epicenter constraining its rotation about its own axis by putting a 2nd slot after the slot1and then connecting it with slider. Similar operation was done for the 2nd hub slots. Afterwards 1st hub is connected to the crank of the 2nd hub to provide a suitable force to move the slider 2.

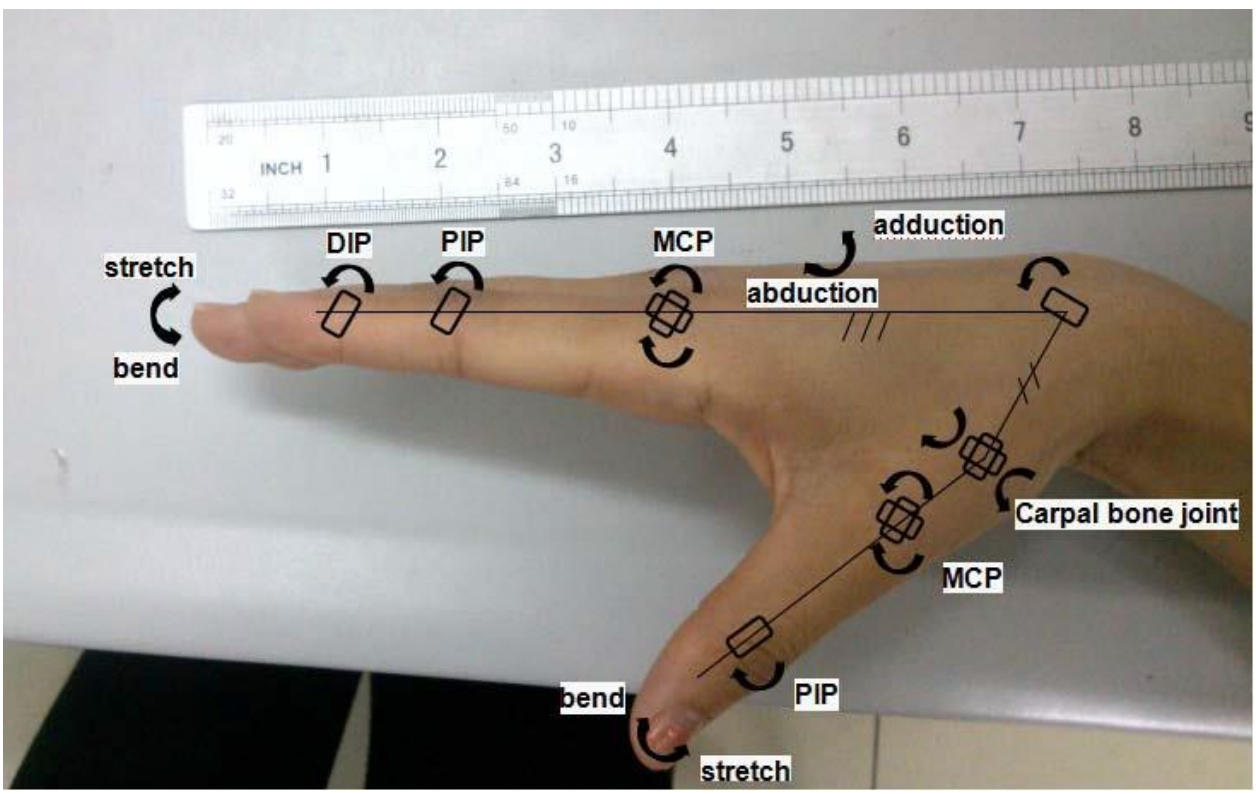

Figure 5: Location of Joints in a hand

This whole assembly mechanism can close or open a finger. Each finger mechanism provides 2 DOF. Each component of the mechanism is shown in details below;

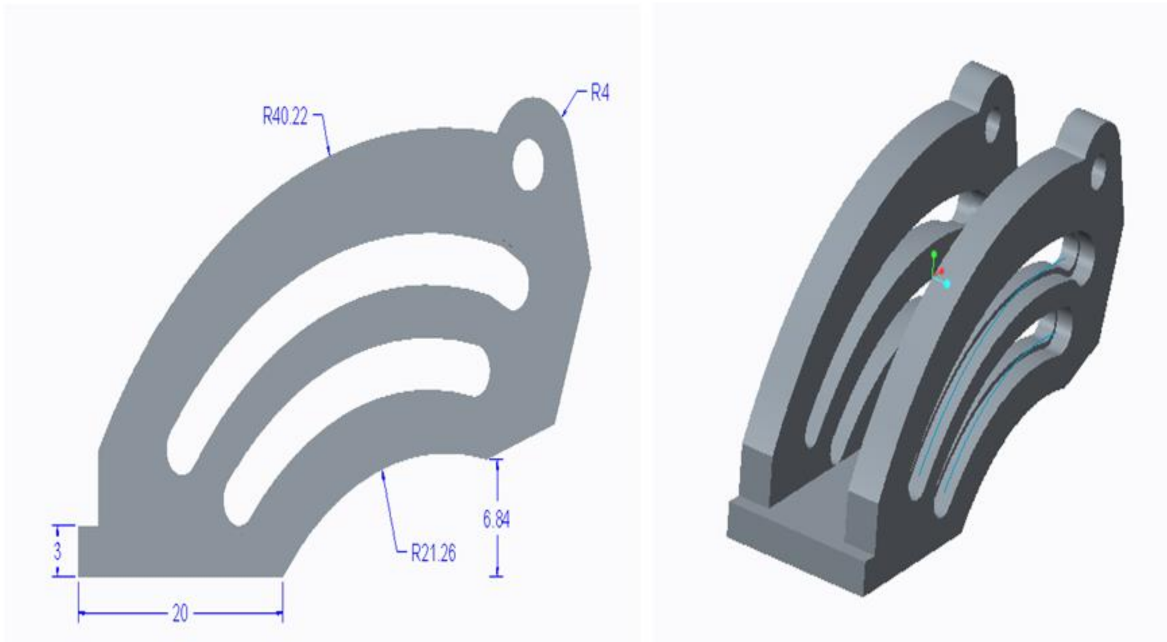

Figure 6: Slot “1”, 2D drawing with 3D object

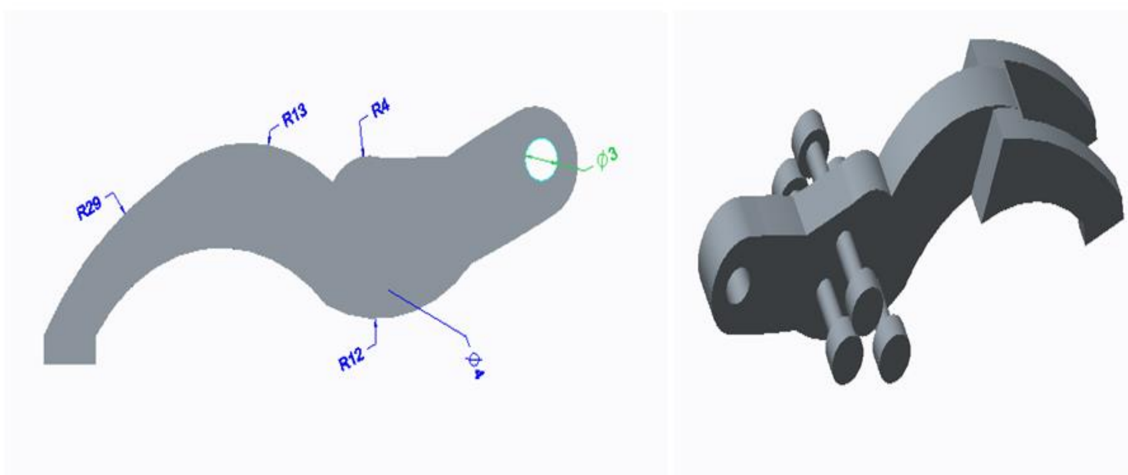

Figure 7: Slider “A”, 2D drawing with 3D object

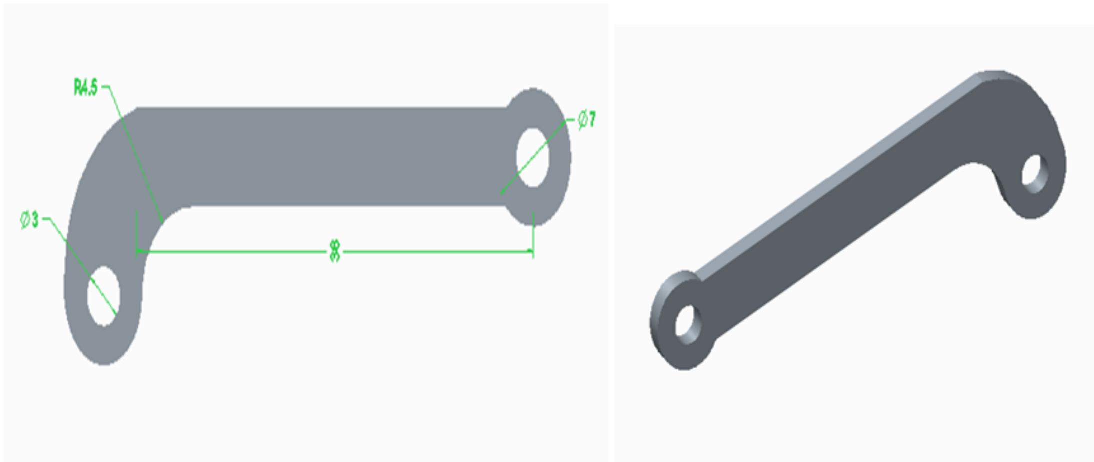

Figure 8: Link between Slot "1" and Crank

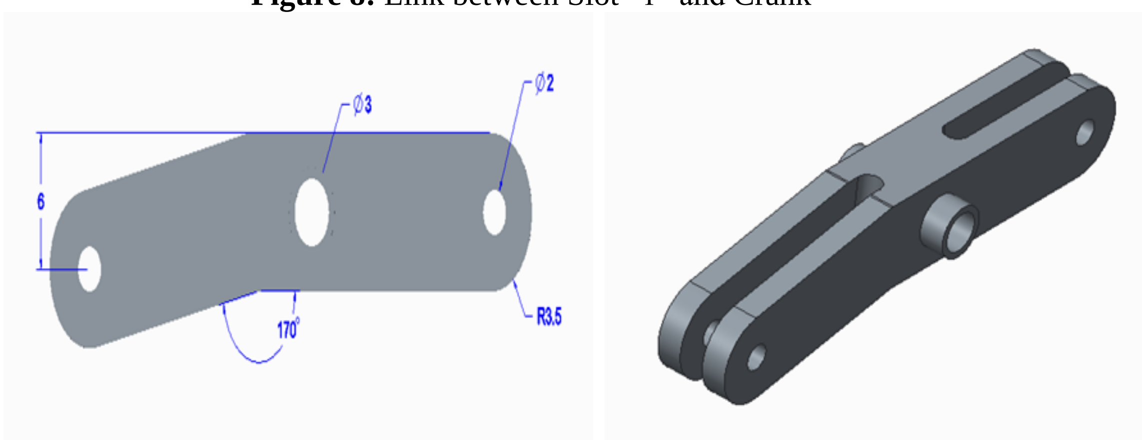

Figure 9: Crank, 2D drawing with 3D object

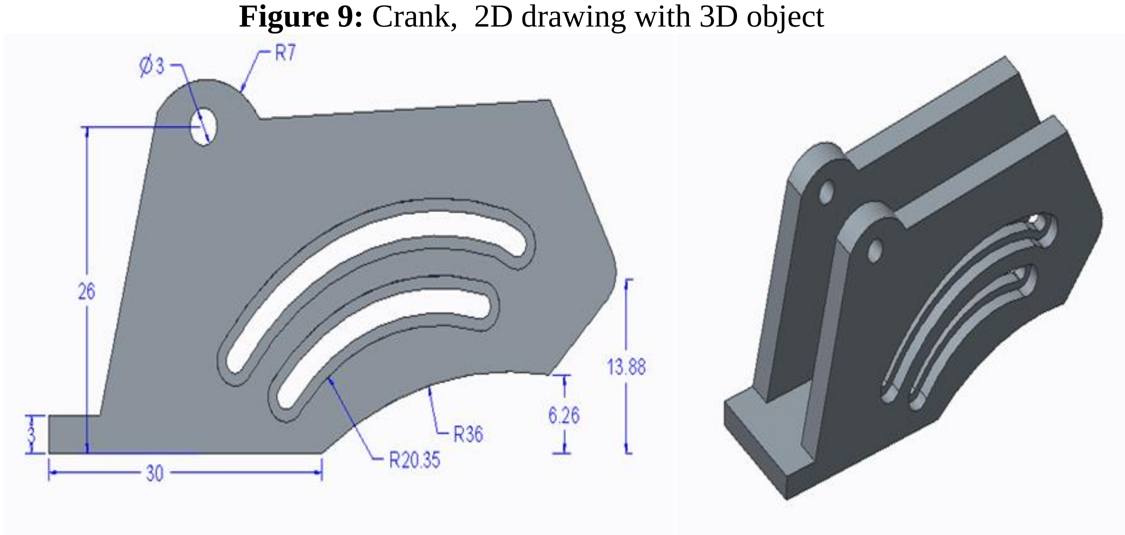

Figure 10: Slot "2", 2D drawing with 3D view

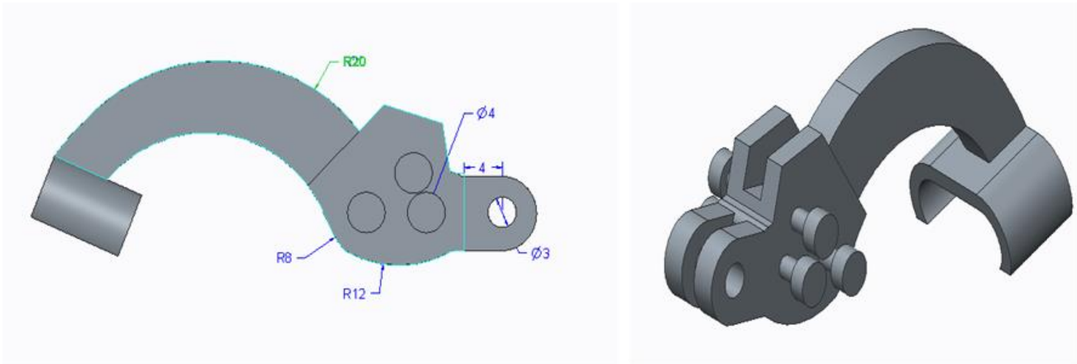

Figure 11: Slider “B”, 2D drawing with 3D view

To attain first requirement assembly is adjusted so that it would provide maximum range of rotation to the finger (55¬¬ degrees for MCP and 65 degrees for PIP). Each assembly of the finger has 2 rings to be attached with the subject finger. Aluminum was selected for the purpose of manufacturing due to its light weightiness and strength. It meets our 2nd requirement. Further challenge was to reduce friction and to provide continuous motion. Since, the hub was made of aluminum; steel rod and wheel is proposed to be used in the slider to move over the slot track as friction between aluminum and steel is lesser compared to aluminum verses aluminum.

Parts of the fingers were designed in order that they can be adjusted with the different span of the fingers. Each finger is connected with the base of the assembly having grooves at its end marking a place where finger assembly is to be connected. The two hub slots are inter connected with a link that is further connected with a crank. When slider of the 1st slot hub is pushed forward, it provides a necessary force to curve the finger about MCP joint. The 2nd slot hub is fixed on the finger and a crank link is pinned on it. Due to rotation of the finger about MCP joint the crank inside the slot hub2 is pushed by the interconnecting link to rotate about it axis. Slider of the slot hub 2 is connected with the crank. As the crank rotates the slider is pushed forward that curls the distal phalanges about PIP joint. It aligns the extension and flexion of the finger assembly with the extension and flexion of the finger. All the fingers except the thumb finger were actuated by a single actuator.

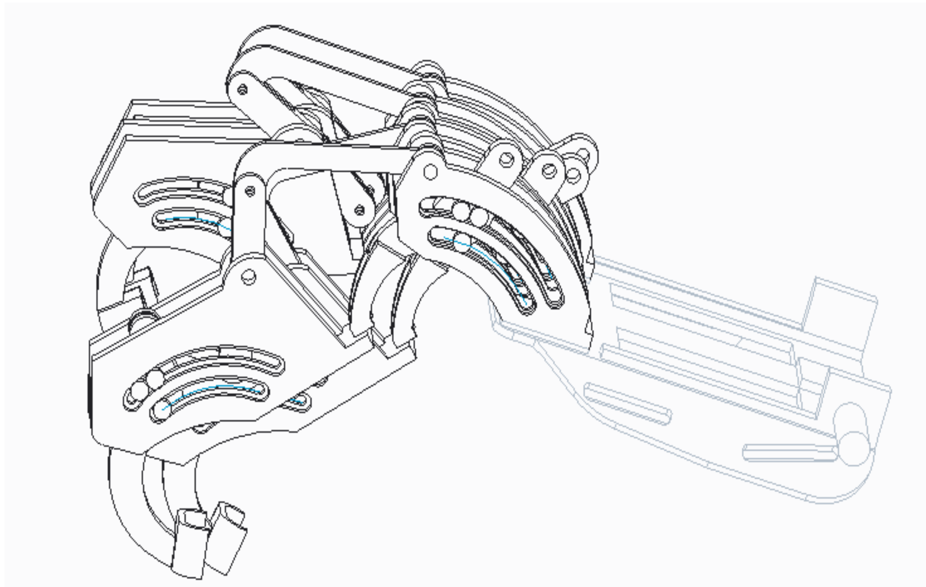

Figure 12: Assembly view of the parts

The platform was made with acrylic material. It was heated and curved to give it shape like hand. Foam was attached inside to give comfort to the subject hand. Velcro straps were used to attach the hand of the subject with the exoskeleton.

It requires about 10N of force to completely close/open hand. So an actuator producing such force is required to push the slider to close and open hand.

3.3 Supination and pronation of hand

Two mechanisms in the upper body are involved in rotation of hand and it defines the proper functioning of hand. First mechanism is one in which two joints are involved in rotation of the hand: The superior radio-ulnar and the inferior radio-ulnar. In this mechanism ulna is locked to its place and radius slides on its surface while rotation takes place at the inferior radio-ulnar joint. The second mechanism which involves shoulder joint (Glen humeral joint), increases its range of rotation. Therefore, Supination and pronation is considered only for the first mechanism.

This part of motion was acquired by connecting the platform with a link bar that is further connected with a servo motor. It provides required torque to rotate the platform along with the subject's hand. Angle of the rotation is variable in between 0^o to 130^o and it is adjustable according to the patient needs, where 0^o is neutral axis of the hand. Aluminum was selected as a material for that link because of its high weight to strength ratio. The link was joined with the platform at the point of virtual axis of the wrist. This will allow the subject to move finger and wrist at the same time.

An average torque of 42Nm is required to perform supination and pronation. Mechanism for supimation and pronation is shown below:

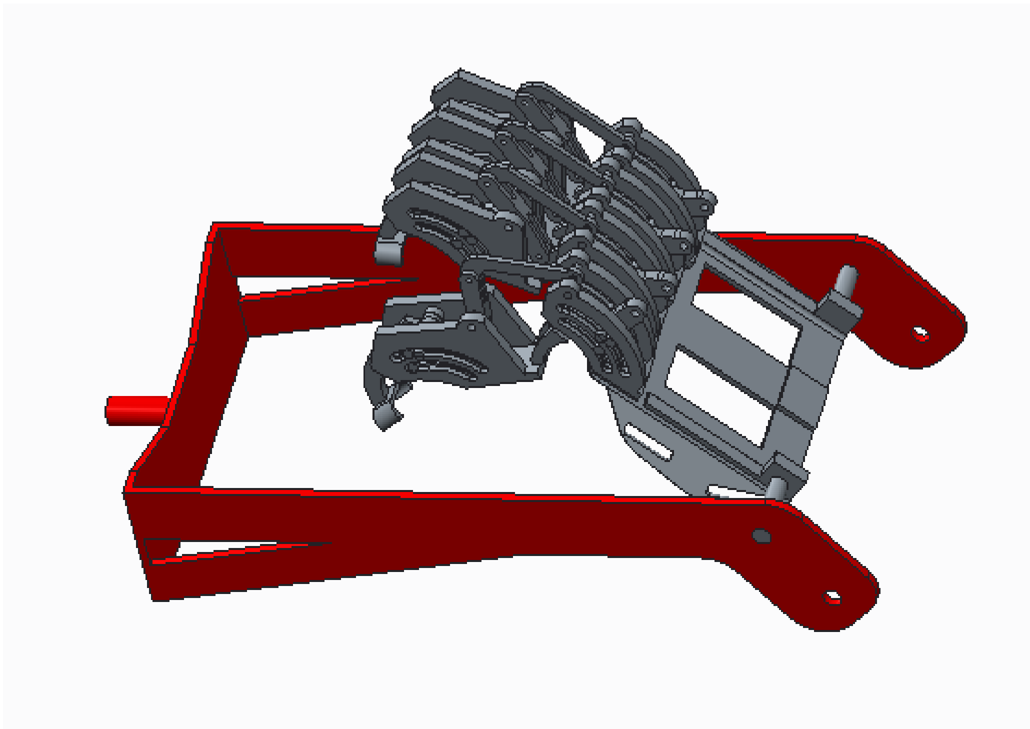

Figure 13: Supination and pronation Mechanism

3.4 Flexion and Extension of Hand

Human wrist consist of lots of bones and joints in a very small area, therefore, it requires a lot of care to be taken. It is required that the axis of rotation of the radiocarpal joint in wrist should not be disturbed for smooth and safe flexion and extension of the hand, therefore, servo motor is placed at the link attached to the platform taking virtual axes of the wrist in view both have the same axis of rotation. Furthermore, servo motor is connected with "U" shape bar to push the palm. Neutral position of the hand is considered at 0^o of angle while, for flexion its maximum range is -25^o and for extension it is 45^o. The subject hand is pushed with a bar (attached with a servo motor from) from below to upwards to achieve flexion and extension.

To achieve required movement of the wrist it is compulsory to provide the required force in such a direction that the axis of rotation of the wrist should remain the same throughout the motion. Therefore, the bar below the palm of the hand has axis of rotation right in front of the axis of the rotation of the wrist.

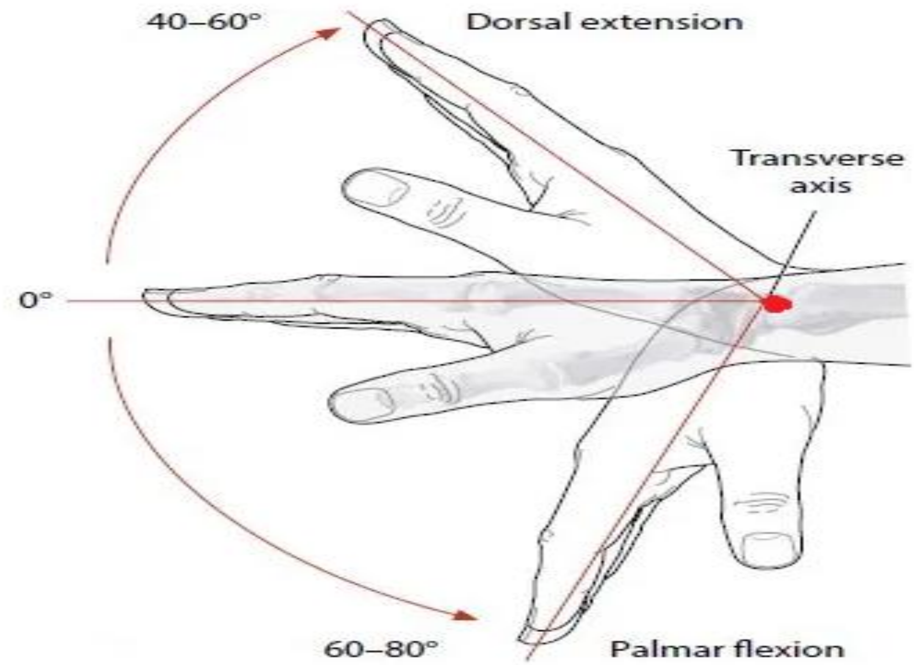

Figure 14: ROM of the wrist

The torque required to perform flexion and extension should be greater than the torque produced due to the combined weight of hand and its exoskeleton. So, the minimum torque required is:

$Hand_{mass} \approx$ 0.5kg

$Hand_{Length} \approx$ 19.42cm

Mass of $Exoskeleton_{Hand} \approx 4(0.030)+0.02+0.058+0.6 \approx 0.798$ kg

Required $Torque_{Hand} \approx (0.5+0.798)x0.1x9.81 \approx 1.27Nm$

So, a motor producing torque more than 1.27Nm is required to perform flexion and extension of the hand.

Figure below shows the mechanism of the flexion and extension of hand.

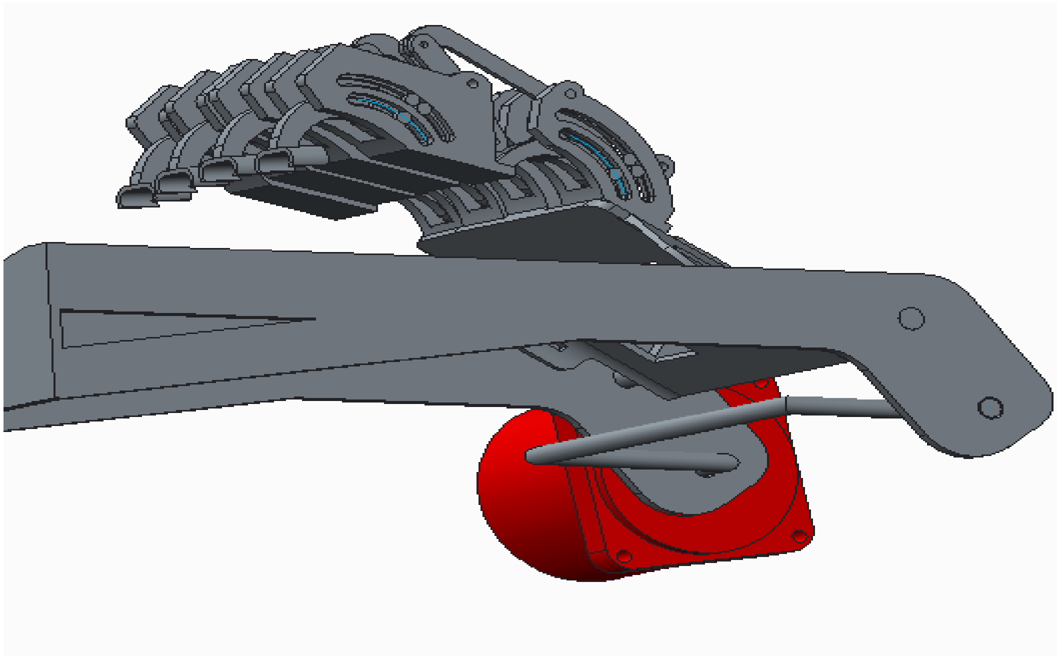

Figure 15: Flexion and Extension of the hand Mechanism

3.5 Flexion and Extension of Arm

Arm rest is provided along with Velcro strips to fix arm position. A servo motor is placed right in front of the elbow joint axis. An adjustable angle between 0^o to 110^o is selected according to the movement range of the subject arm to perform a suitable extension/flexion while keeping neutral axis of the arm at 0^o.

Minimum torque required to move an arm should be greater than the torque produced due to the combined weight of the subject's forearm and the exoskeleton. We take average weight and the length of the whole arm (including hand) [19] and exoskeleton to calculate torque force required:

Mass of Exoskeleton= 3.5+1.2+0.2+0.058+4(0.030)+0.02+0.6+0.3=5.99 kg

$\text{Fore arm}_{mass} \approx 1.30$ kg

$\text{Fore arm}_{Length} \approx 28.08$cm

$\text{Hand}_{mass} \approx 0.5$ kg

$\text{Hand}_{Length} \approx 19.42$cm

$\text{Required Torque}_{arm} \approx 9.81(1.30+0.5+5.99) \times ((28.08+19.42)/2x100) \approx 18.15$Nm

Therefore, a motor producing torque more than 18.15Nm is required to perform flexion and extension of the arm.

CHAPTER 4: RESULTS AND DISCUSSION

PTC Creo2.0 was used to do the kinematic simulation. Because the entire assembly was created with this software, it was simple to do all needed tasks with it. Each rotatory component was connected with a servo motor one by one. For linear displacement, the motion mechanism was split into forward and backward movement, as well as clockwise and anticlockwise motion in the simulation setup. Each activity was first simulated, and then portrayed by a curve that depicted the route of motion as well as the greatest range of motion. Closing/opening of the hand, flexion/extension of the hand, supination/pronation, and flexion and extension of the arm are all possible with the suggested device.

4.1 Experimental results

The suggested mechanism is designed to produce a 90^o angular rotation for an arm that is initially 30^o distant from the body. The graph below depicts the curve as it was followed in real time:

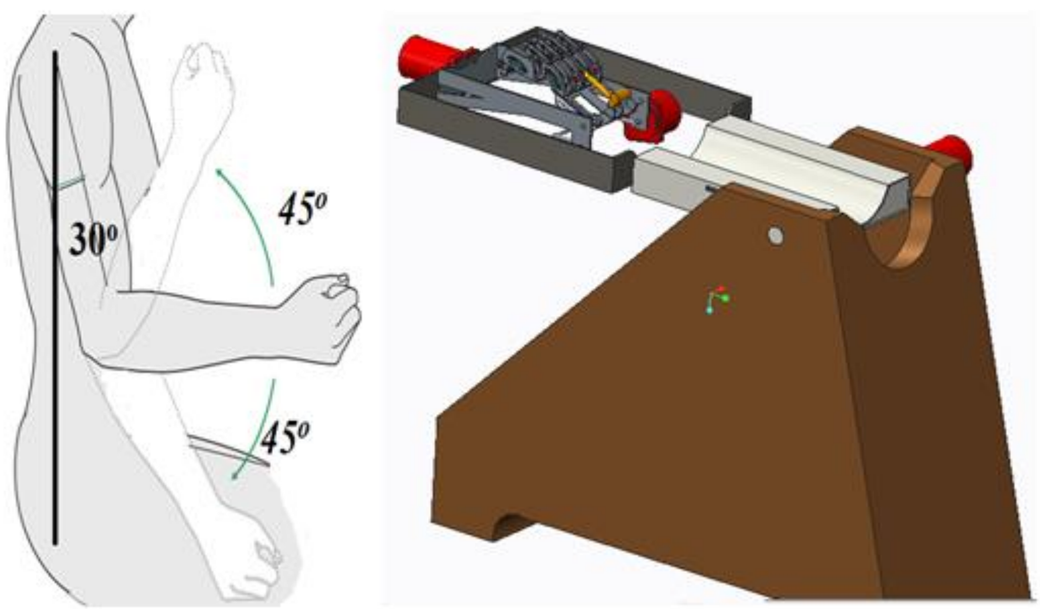

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Figure 16: Flexion and extension of the arm

The most essential and difficult part of this apparatus was the opening and folding of the finger. The slider of the finger was fitted with an actuator capable of delivering a force of more than 10N. Each finger mechanism exerts a 1.5N thrust on the finger. The curve route below demonstrates that the finger can bend and stretch without hitting a dead point, and the journey takes 14 seconds with an average angular velocity of 0.22rad/sec. PIP joint is stable until 2.8 seconds, after which a steady shift in angular velocity continues until time approaches 7 seconds, as seen in the graph. The curving route depicts the exoskeleton's mobility in the image. The exoskeleton is intended to fulfill a rotation of -60^o to 70^o for hand flexion and extension, with the neutral axis at 0^o, and the same is true for supination and pronation. And as per the motion curve, this gadget can rotate from -90 to 30 degrees with 0 degrees at the neutral axis. With an average angular velocity of 0.17rad/sec, the entire motion takes roughly 12 seconds.

Additionally, the model's post-kinematic study explores angle position, angular velocity of the PIP joint, and acceleration. The gadget parts move smoothly, with no jerks or fluctuations. As a result, this gadget can be utilized for rehabilitative purposes.

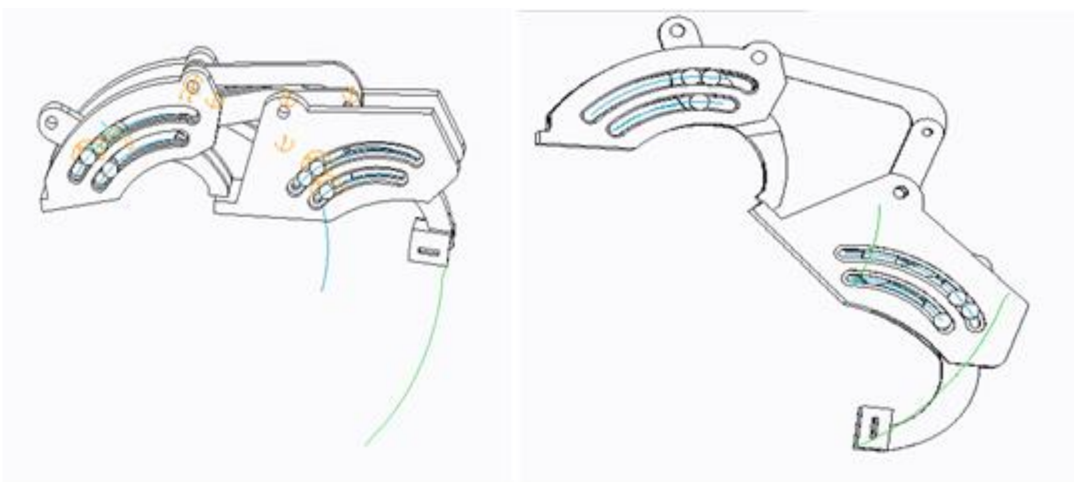

Figure 17: Motion tracking curve of the mechanism to open and close the finger

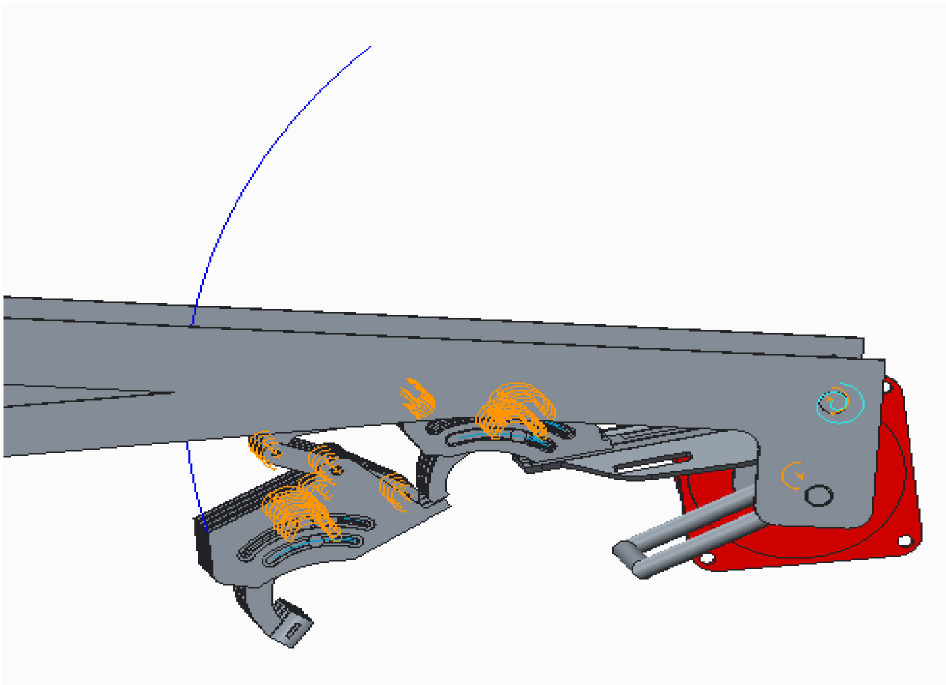

Figure 18: Motion curve of flexion and extension of the hand

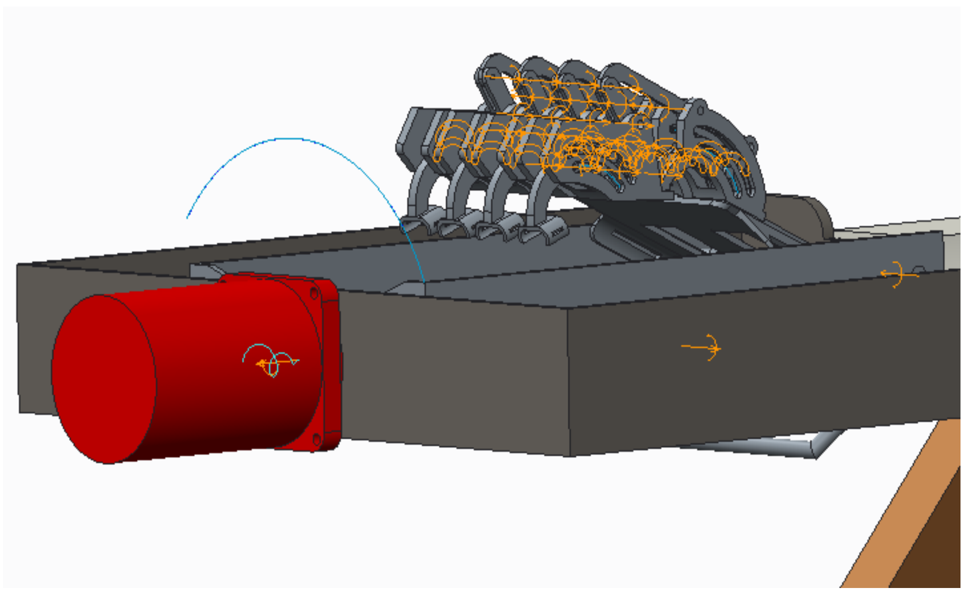

Figure 19: Motion curve for Supination and Pronation of the hand

4.2 Structural Analysis

Static analysis was performed on to analyze deformation and to detect the portions that are under maximum stress in the device. Following portion describe results in detail:

4.2.1 Finger

The peak displacement was 1.37e^{-05}mm, as seen in the Red patterning. The beginning section of the finger, as well as the last piece of the forefinger that is linked to the tip of the finger, will display the most deformity. The highest von-Mises stress value is 2.6e^{+2} kpa, according to these findings. 41.27kPa is the maximum principal stress measurement. 0.00013mm is the maximum displacement.

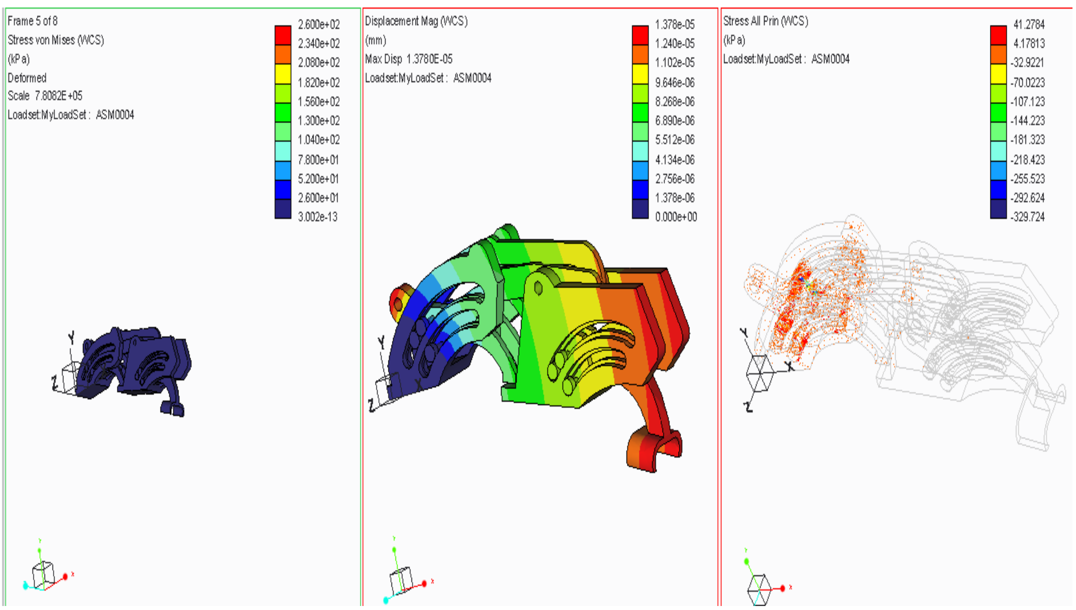

Figure 20: Structural Analysis of the finger Mechanism

4.2.2 Arm rest

To identify stresses and deformation, a similar study was done on the remainder of the device. The results below indicate maximum von-Mises stresses of 21.94MPa and maximum deformation of 0.0379mm. Principal stress reaches a maximum of 11.2676MPa. The findings of the analysis are shown in the diagram below:

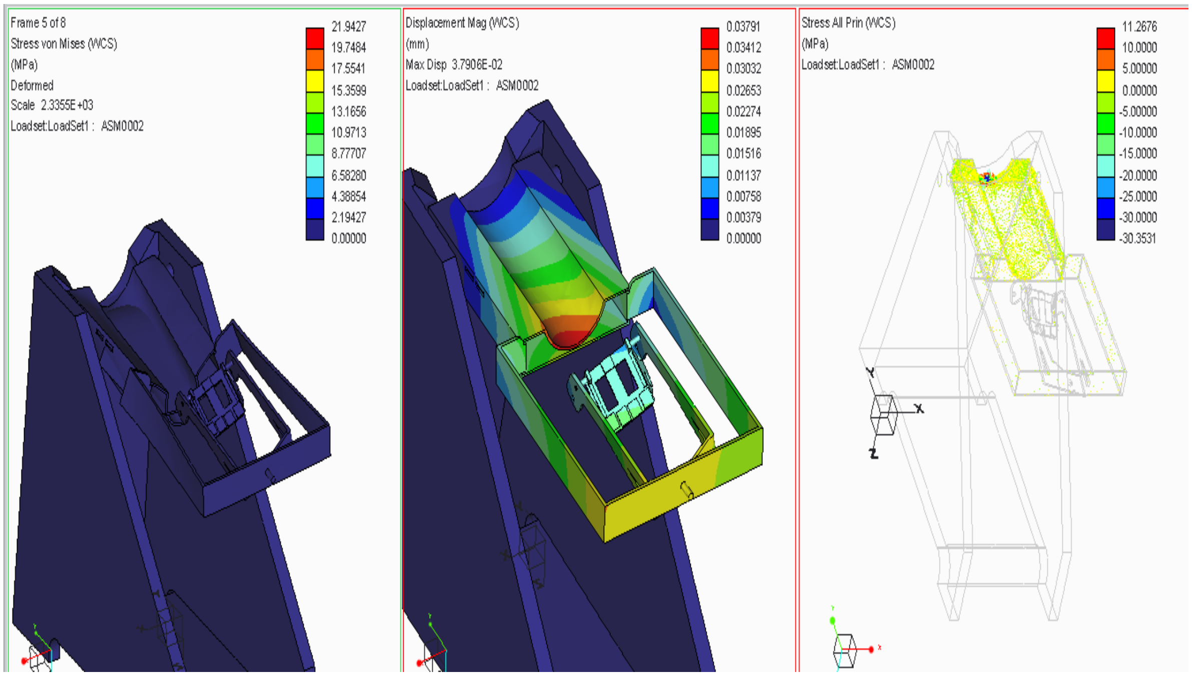

Figure 21: Structural Analysis of Arm rest

4.3 Kinematic and Dynamic Results

The suggested device is designed to accomplish flexion and extension of roughly 90 degrees for an arm that is initially 30 degrees away from the body. The real-time movement is depicted by the green curve as Shown in figure 4. The most essential part of this gadget was the ability to open and close the finger. Each finger's rod connecting slider had a 10N actuator attached to it. With a force of 1.5N, each finger mechanism pushes the finger downward. The folding and extending of the finger without any dead points is confirmed by the curve path in Figure below. In Figure 5 "ä" and "b," the curved route depicts the movement of the finger mechanism. This trip takes 14 seconds and has a max angular velocity of 12.77 degrees per second (figure 8). The following equations indicate the position of the fingertip in the x-y plane at any given time (0-14seconds).

$$x = 0.157t^3 - 3.662t^2 + 12.12t \quad (1)$$

$$y = -1.253t^2 + 21.66t \quad (2)$$

The hand flexion and extension of the exoskeleton is planned to be 60^o (clockwise) to 70^o (anti-clockwise), with the neutral axis at 0^o. The path of the action for flexion and extension of the hand is presented in Figure 6. This device is adjusted to accomplish a rotation of 90^o (anti-clockwise) to 30^o (clock-wise), as per the motion curve produced (Figure 7) having 0^o at neutral axis of the arm. It takes around 12 seconds to complete the maneuver. Furthermore, the model's post kinematic analysis specifies angle position, PIP joint angular velocity, and acceleration. There are no oscillations or shocks in the gadget parts as they move smoothly. As a result, this gadget can be utilized for rehabilitative purposes.

4.4 Discussion

Results above show that this device is able to perform all the tasks as per hypothesis. ROM (Range of Motion) of the device to close and open the finger is increased. Actuators used to open and close the finger is decreased to only one as compared to the four used previously. DOF (Degree of freedom) is increased to 5 while its portability is not compromised. Flexion and extension of the hand is reduced between -30^o to 45^o keeping in view the safety of the hand of the effected subject. Meanwhile, flexion and extension of the arm is set to 90^o from its rest position. Arm and hand and fingers are attached firmly to the exoskeleton with the help of Velcro tapes.

Structural analysis of each mechanism concludes the weakest portion of the mechanism is finger. It comprises of parts with lower thickness value therefore, it is obvious to have high stress values there. Due to higher stress values there are maximum chances of fracture to happen there. Meanwhile, the portion holding arm has lower stress values it predicts there are lesser chances of failure to happen there. Another problem with finger mechanism is limited space availability.

Due to increased spasticity in the effected muscles it is recommended to move the fingers gently. Any abrupt force can cause myorrhexis (rupture of the muscle). The kinematics of the device shows opening or closing of the finger takes 14 seconds to complete the trip with an average angular velocity of 0.22rad/s or 12.77deg/s. Each finger barely requires 1.5N force to perform opening or closing. Therefore, minimum force required to perform this function should be more than 10N. The To and Fro motion is executed without any oscillation and dead points. It completes the trip without any jerks therefore; it is safe to be worn.

Comparing this device with the already available devices in the market it is easy to carry from one place to another. Materials like wood and polymers are cheaper therefore the overall cost of the device is reduced.

CHAPTER 5: CONCLUSION AND FUTURE WORK

A new rehabilitation robotic apparatus is presented in this study to help stroke survivors, osteoarthritis, and muscular dystrophy regain and enhance their hand muscle control. The primary design of the gadget, comprising kinematic and structural analysis, was completed in this thesis. PTC Creo2.0 was used for part design, dynamic analysis, stress analysis, and assembly animation.

The findings show benefits such as enhanced ROM (Range of Motion) of hand closure, reduced number of actuators needed. Expanded degrees of freedom to conduct a variety of additional hand motions including the wrist, and lower production costs thanks to the usage of wood and polymers in the device. Simulations demonstrate that the design has no dead zones and that the motions are perfect. It may be comfortably worn on the hand. Folding and reopening, flexion and extension of the hand, supination and pronation of the hand, as well as flexion and extension of the arm are all actions it may do. It is perfect for completing workout in a short period of time.

To implement controls and other safety systems in the future, a dynamic model of the device will be examined. To avoid subsequent injury to patients participating in trials and coaching, each joint motion will be monitored and evaluated separately.

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