“Mechanical Design and Development of Passive, Assistive and Rehabilitative Tendon Driven Device for Enhancing Grasping Capabilities”

Author

Waleed Bin Mehdi

2021-NUST-MS-Mech-00000205512

Supervisor

Dr. Sajid Ullah Butt

DEPARTMENT OF MECHANICAL ENGINEERING

COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

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Waleed Bin Mehdi

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Thesis Supervisor

Dr. Sajid Ullah Butt

Thesis Supervisor's Signature: ___________________________________

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COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

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ISLAMABAD

DECEMBER, 2021

DECLARATION

It is hereby solemnly declared that the whole work in this project report of "*Mechanical Design and Development of Passive, Assistive and Rehabilitative Tendon Driven Device for Enhancing Grasping Capabilities*", which is submitted to National University of Sciences and Technology (NUST)'s affiliated institution, College of Electrical & Mechanical Engineering, is based upon the work carried out by us after the proper literature review of books and under the supervision of our supervisor and co-supervisor. I further certify that no piece of this work is presented in any other Project Thesis or Report of any degree program in any university of the world. If any plagiarism from the students" papers regarding the technical work is found then we solemnly are ready to face the consequences.

LANGUAGE CORRECTNESS CERTIFICATE

It is solemnly certified that this thesis has been properly read by a linguistics expert and is free from any kind of grammatical, typing, semantic, syntax, and spelling errors. Also this thesis is in accordance with the guidelines and formatting provided by the university.

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The working over the thesis opens the creative minds of the students which lets them think outside the box and the regular studies. The postgraduate studies provide deep knowledge of the respective field and provide a thorough go through of the field and let the students discover their new set of skills. It requires a great determination from the students‟ side and great guidance from the mentors. In this journey of a few years of the postgraduate program and the thesis, a number of people helped me to get through my goals; who continuously encouraged me to achieve my goals and provided me guidance through all my way. With their help, I am able to accomplish this piece of work, for which we would like to pay our gratitude to them:

- First of all, I am thankful to my Creator Allah Almighty, who has guided me throughout my life and specially this work at each and every little step and thinking, which my creator set-up in my mind and improved it. Indeed, I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.
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ABSTRACT

The human body is properly functional if it does not face any kind of issue like a stroke or an accident. The stroke can result in drastically hampering the hand motor function of the human body. Passive and active assistive devices are getting common day by day to help get back lost-hand strength and agility. Soft robotics is employed in the project which is an amalgamated discipline of classical robotics' principles and soft materials. It can make way to a new plethora of passive assistive devices which can also rehabilitative in nature. Soft robotic passive assistive devices can bring a human robot interaction with the use of compliant and frivolous structures. The domain of this work was to show that a light weight, compliant and cable driven fabric based soft robotic glove (a mobile device designed for home use) can assist and also rehabilitate people effected by spinal cord injury in daily life work. Mechanical exo-gloves have gotten an expanded enthusiasm throughout the most recent decade mainly due to their appreciation by the users. Potential uses of these frameworks extend from increasing the capacities of reestablishing the versatility of people that experience the ill effects of loss of motion or stroke and the people who have lost one or both of their limbs. In spite of the critical advancement in the field, most existing arrangements still require an outside power source to work, and they are not comfortable to wear. In this research work, we center around the design of a versatile (autonomous and consistent), tendon driven, wearable exo-gloves and we propose a conservative, reasonable, and lightweight assistive gadget that enhance the handling abilities of the patients. The gadgets are tentatively tried and their effectiveness is approved through clinical testing on patients with disability of one and two limbs. The gadgets can fundamentally improve the grasp force of the client. This body-fueled device has long life and low expense and hence provides an effective solution.

Key words: Soft Robotic, Glove, Passive exoskeleton Tendon based drive, Differential Drive

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CHAPTER 1: INTRODUCTION

The human arm is one of the most complex organs in the human body. It is because of a number of reasons; first the human arm starts from the shoulder with a ball and socket joint, which is capable of showing a 360^0 movement. Then there is an elbow to support the 360^0 movement and give the revolution from the shoulder a shape and direction. After the elbow, the wrist joint further extends the capability of the human hand to reach some specific place to do the human-desired operation. For such a complex mechanism there is a very detailed mechanism of muscles, bones to support the whole movement.

Because of some unforeseen incidents or some natural calamity, the movement of human arm is interrupted and gives a huge set-back to the life of a person because all the major operations of the human body are done with the help of hands and without the proper functioning of hands, a person requires assistance in doing the normal life operations.

Science and technology has developed over the centuries to provide the best possible services to the human beings and to facilitate them in their lives. Going towards future, human beings are in greater need of complex working mechanism in every field, either technical or non-technical. Everything is getting complex and each complexity can’t be solved by merely human beings and the supportive human person. Therefore at this place, some need of some machine or technical device, which would help the humans in doing their life tasks and assisting them by providing them a helping hand in doing and carrying on their daily life operations.

1.1 Background, Scope and Motivation

Worldwide Stroke (cerebrovascular disease) is the second main leading cause of death and the third main leading cause of disability [1]. In lower-middle income countries like Pakistan, non-infectious diseases like stroke are the leading killers [2, 3]. Stroke is a neurological disease which results in the loss of brain function. It occurs when a clot blocks the supply of oxygen and nutrition to the blood vessel leading to the brain or when a blood vessel ruptures and bleeds in the brain. Due to this, some part of brain cannot get the required amount of blood (containing oxygen and nutrients); as a result brain cells begin to die within a short span of time [4].

Due to advancement in the medical area, death rate of the stroke patients has decreased with time. Sensorimotor impairment of limbs is considered as one of the major sequel of stroke.

Upper limb sensorimotor impairment is observed amongst almost 66 percent of stroke patients [5]. Unable to perform the basic daily life activities not only affect the patient physically but also leave a psychology mark disturbing the way of life in general.

Such patients need immediate attention if not granted at early stages might lead to bigger issues including complete inability to perform physiotherapy procedures which ultimately leads to permanent loss. Rehabilitation process becomes an immediate necessity. Such rehabilitation processes are found to be more effective if the patient performs daily activities instead of high repetitive tasks [6], which highlight the importance of one such gadget.

The sort of devices we already have for such purposes include either autonomous which normally demand the installment of additional apparatus alongside; heavy which makes it uncomfortable and in some cases frustrating for the patient to use them; or demand external power source which makes it costly posing other relevant issues like mobility etc. Moreover, most of such devices are rehabilitative devices making them really hard to use all the time.

Currently hand movements can be enhanced by the use of robotics, namely exoskeletons. Multiple upper limb exoskeletons have been designed over the past years which can be classified based on their complexity, functions, size, weight, actuation principles, and materials employed. Most of these exoskeletons are rigid and require careful alignment with the limbs which would otherwise damage them. Rigid exoskeletons are useful for challenging clinical scenarios e.g. rehabilitation of wrist [7], the hand [8, 9], and the individual fingers [10, 11, 12]. However these are not portable due to their heavy and rigid frames. As a result most of these training systems are stationary and require experienced personnel to oversee the patients‟ safety during usage.

An alternate option is to relocate the rigid exoskeletons to convenient locations [13-17] or using soft robotics based exoskeletons i.e. polymer-based [18] or fabric based [19-24] hence maximizing the portability, usability and comfort while reducing weight. This can be done at the cost of power and precision. In recent times, textiles [23] and elastomers [25] have been used instead of rigid actuators. They have created a new class of

Wearable soft robotic devices. They provide a safe, comfortable, light, portable and relatively cheaper alternative to rigid exoskeletons.

1.2 Objectives

Our main purpose is to devise a gadget which is assistive and rehabilitative both in nature making the rehabilitation process simpler. The aim is to come up with a body powered device using the principles of mechanical amplification.

The aim of this project is to demonstrate that a multi-posture soft robotic glove offers a better alternative to the rigid exoskeletons currently in use for people with limited hand dexterity and strength. As opposed to the rigid version, they do not require you to stay in a place and personnel overlooking you. They can be used in everyday life to enhance the productivity and rehabilitate the impaired individual at the same time. The device will focus on low power input making it easy to use for the patients whose both upper limbs are affected.

1.3 Outlining the Thesis Report

The report of the thesis “Optimization of feature extraction and reduction techniques for improved control in assistive hand” is divided into a number of chapters; each chapter provides a topic, upon which it discusses the literature and relevant details.

Chapter 1 briefly describes the introduction of the need to the project and the basic theory behind the project, like what is its background; what was the need; what is the motivation; and what is the future? This chapter also provides the scope and objective of this thesis project and how can we achieve the desired objectives.

Chapter 2 describes the literature review that we have done and important parameters needed for understanding the need of this project, and the design criterion.

Chapter 3 focuses on the methodology; it provides an overview of how the working needs to be done; what is the background scenario and how the force transmits. Then what are the experimental parameters that are going to be watched. Apart from this, the selection of materials and the designing background also.

Chapter 4 presents the mechanical design and the material properties used for the project. Along with the modeling, another feature of this chapter is the simulation.

Finally, the last section that is the **Chapter 5** includes a conclusion and a few future work recommendations that how in future students may carry upon my work.

CHAPTER 2: LITERATURE REVIEW

The history of mankind is distinguished by the relentless fight of human for the survival; which means that he has to conquer or overthrow what threatens the human existence: for instance natural catastrophes, aggressive animals, and others. Sometimes because of the age or because of some accident, the human needs assistance in their working. This leads to our project about providing assistance to humans in their daily life operations.

2.1 Stroke

Stroke, throughout the world, is the second leading cause of death above the age of 60 years and the fifth leading cause of death for people aged between 15 and 59 years (stroke a brain attack). Stroke is third leading cause of disability also [26].One out of 6 people will suffer from stroke in their life time. According to the survey of World Health Organization, on worldwide level 15 million people suffered with stroke every year, out of 15 million 5 million patients die and 5 million suffered permanent disabilities [27]. In the developed countries, one out of 10 deaths is due to stroke so it is the third most common cause of death [28]. Stroke is also known as brain attack, usually happens when vessel supplying blood to the brain is block by a clot or when a blood vessel in the brain bursts [29].Stroke can be considered as the most dangerous disease of brain whish results loss in functionality. As we know, all the multiple complex functions of the body are controlled by the brain as it is the main central information – processing organ. Without supply of blood to the brain, cerebral infraction (death of blood cells) can occur, which may lead to the brain damage. During a stroke, the risk of brain damage and disability increases which further leads to death as approximately two million brain cells dies in every minute [30]. The level of disability depends on condition of patients, type of stroke, affected part of brain and the size of the affected area [31].

Two major sub-types of stroke are ischemic and hemorrhagic: Ischemic stroke occurs when the flow of blood to the brain cell is reduced due to narrowed or blocked arteries. About 85 % of stroke patients suffer with ischemic stroke [32]. An ischemic stroke is further sub divided in two types according to the way it occurs. One is Embolic stroke and other is thrombotic stroke [33]. Embolic stroke occur when a clot of blood travels along the blood stream through the blood vessels from any part body to your brain blocking the blood vessel and cut off the blood supply [34]. Thrombotic stroke occurs by an impaired flow of blood because of blockage of the one or more arteries supplying blood to the brain. Blockage of blood vessels also occurs because of the fatty deposits and cholesterol. Thrombotic stroke is further classified in two types: large vessel disease and small vessel disease [35]. Hemorrhagic stroke is usually caused by the breakage or blowout of a blood vessel in the human brain. Due to the breakage of blood vessel, the amount of blood increases in the brain. Hemorrhagic stroke is further categorized in two types: subarachnoid and intra-cerebral [36]. Subarachnoid hemorrhagic stroke occurs when an aneurysm burst in a large blood artery or in the thin membrane surrounding the brain, causing the accumulation blood-contained fluid around the brain. While intra-cerebral hemorrhagic stroke occurs by the bleeding from the blood vessel with in the brain, 20 % of all strokes are hemorrhagic stroke [37]

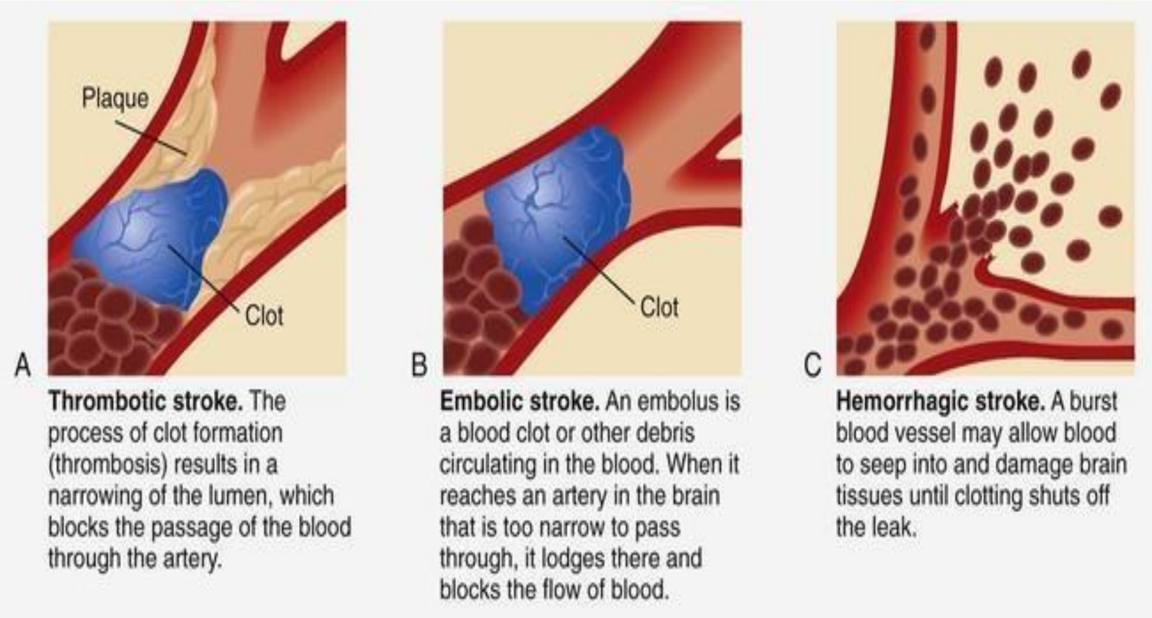

Figure 2.1 The three types of Strokes: Thrombotic Stroke, Embolic Stroke, and Hemorrhagic Stroke[37].

When stroke happens, brain damage occurs as brain cells die. As some area of brain is damaged during the stroke therefore the abilities associated with this specific area are lost; which may include speech, memory, and movement etc. as shown in Figure 2.1. The amount of abilities lost depends upon the area in which stroke occurs and the amount of damage. For example, a patient suffering from a small stroke may experience minor problems including weakness of arm and legs. Patients having larger stroke may lose their speaking ability or may be paralyzed one half side on body.

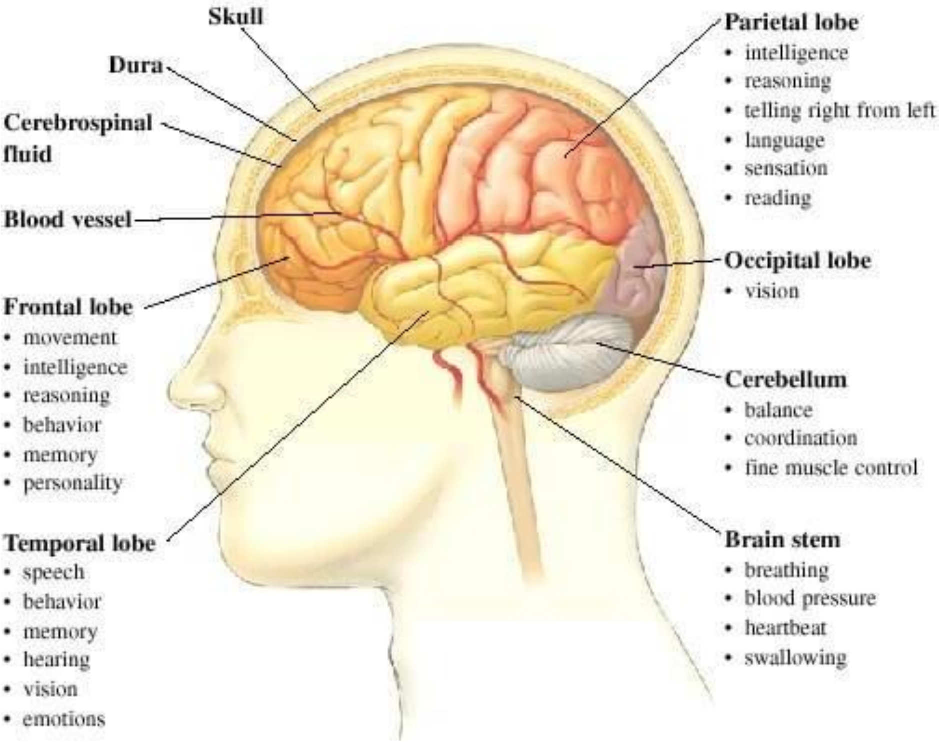

Figure 2.2 Anatomy of Brain [27]

Some patient's recovers completely depending upon the rehabilitation process they go for but according to survey more than sixty-six percent of the survivors will have some type of disability [38]. Chances of rehabilitation depend on two things; the affected area of brain and the duration of stroke [35].

2.2 Effects of Stroke on Human Body

After a stroke a patient life may not return to normal as during stroke oxygen cannot reach to brain which was previously controlling everything including speech, memory and movement .Stroke patients face a greater range of disabilities than any other disease [39]. It can effect speech, talking, balance, walking, co-ordination, vision, swallowing, spatial awareness, bladder control and bowel control etc. as shown in Table 2.3:

Difficulty	% of people affected
Upper limb/arm weakness 40	77%
Lower limb/ leg weakness 40	72%
Visual problem 41	60%
Facial problem 42	54%
Slurred speech 42	50%
Bladder control 43	50%

Swallowing 40	45%
Aphasia 44 45 46	33%
Depression 47	33%
Bowel control 42	33%
Dementia 48	30%
Inattention /neglect 42	28%
Emotionalism within six months 49	20%
Emotionalism post six months 49	10%

Table 2.1People with Difficulties with respect to their respective percentage

2.3 Stroke and Upper Limbs/Arm Weakness

Worldwide, the second reason of mortality and third reason of long –term disability is stroke with only 33 million survivors [50, 51]. A majority of patients suffer with hemispheric stroke and which limits their usability of upper limb. 80% of the stroke patients fears about post stroke upper limb insufficiencies [52] while 30% to 60% stroke patients face insufficiencies in upper limb capability remaining for at least 6 month after stroke [53,54]. After one year of stroke, due to deficits in upper limb, patients face higher level of anxiety and depression [55], lower observed health-associated quality of life [56]. Therefore the major therapeutic target in improving upper limb capacity is stroke rehabilitation [57, 58].

World health organization designed a scheme of classification of Activities (disability), impairment and participation (handicap) to accurately examine the impact of stroke on an individual life or a population [59]. In an experimental research show that 77% of the people affected with stroke experienced post-stroke upper limb/arm weakness [40]; thus the major therapeutic target is improving upper limb capacity in stroke rehabilitation.

2.4 Stroke Rehabilitation Therapy

After a stroke a patient life may not return to normal as during stroke oxygen cannot reach to brain controlling everything including speech, memory and movement. As a life changing event, stroke patients require emergency treatment and rehabilitation care afterword. Many stroke patients need regular rehabilitation program including physiotherapy and occupational therapy. These rehabilitation processes helps the patient to regain their lost abilities. In physiotherapy, mobility science is used to train the stroke survivor to regain the functionality and usually done in a clinical environment. In occupational therapy, patients performed activities of daily living (ADLs) [60, 61]. Therefore the occupational theory involves performing of real world activities to regain the lost functions of affected body limbs. Rewiring of affected area of brain for motor skill recovery is the main aim of both rehabilitation techniques. Repetitive, enormous and task oriented rehabilitation therapy is most effective for stroke survivors [63].

2.5 Human Hand and Its Anatomy

A human body function like a responsive, ever- evolving and sublime machine. While each organ is vital for executing daily function, hand surpasses all of them in terms of movement, implementation and performance. Study of hand anatomy was necessary to understand the working of human hand and to design a device which not only assist the natural motion of human hand but also act as a rehabilitation device. Human hand anatomy is quite unique, a very intricate structure which consists of 27 bones, 17 joints and more than 20 DOFs. Bones of the hand are divided into three groups called carpals, metacarpals and phalanges. Cluster of bones in Carpals is responsible for the to- fro and back-forth motion of the wrist. Central part of the hand in made up of 5 metacarpals bones; while remaining 14 bones are known as phalanges.

Name of bone in Carpals Group	Name of bones in Metacarpals group	Name of bones in Phalanges
Scaphoid	First metacarpal (Thumb)	Proximal
Lunate	Second metacarpal (Index finger)	Medical
Triquetrum	Third metacarpal (Middle Finger)	Distal
Pisiform	Fourth metacarpal (Ring finger)	
Trapezium	Fifth metacarpal (Little finger)	
Trapezoid		
Capitate		
Hamate		

Table 2.2 The name and number of bones in a Human Hand

Muscles of hands are like building blocks placed on the bones. These muscles play a vital role in hand’s movement and robustness of hand in gripping. Hand motion is totally dependent on tendon, and the tough cords of tissue, as it is a connecter between muscle and bones.

Finger Joints	Range of Motion of the Joint
Distal Interphalangeal Joint (DIP)	0-82
Proximal Interphalangeal Joint (PIP)	0-105
Metacarpophalangeal Joint (MCP)	0-100

Table 2.3 The Joints of the fingers of Human Hand with their respective range of motion

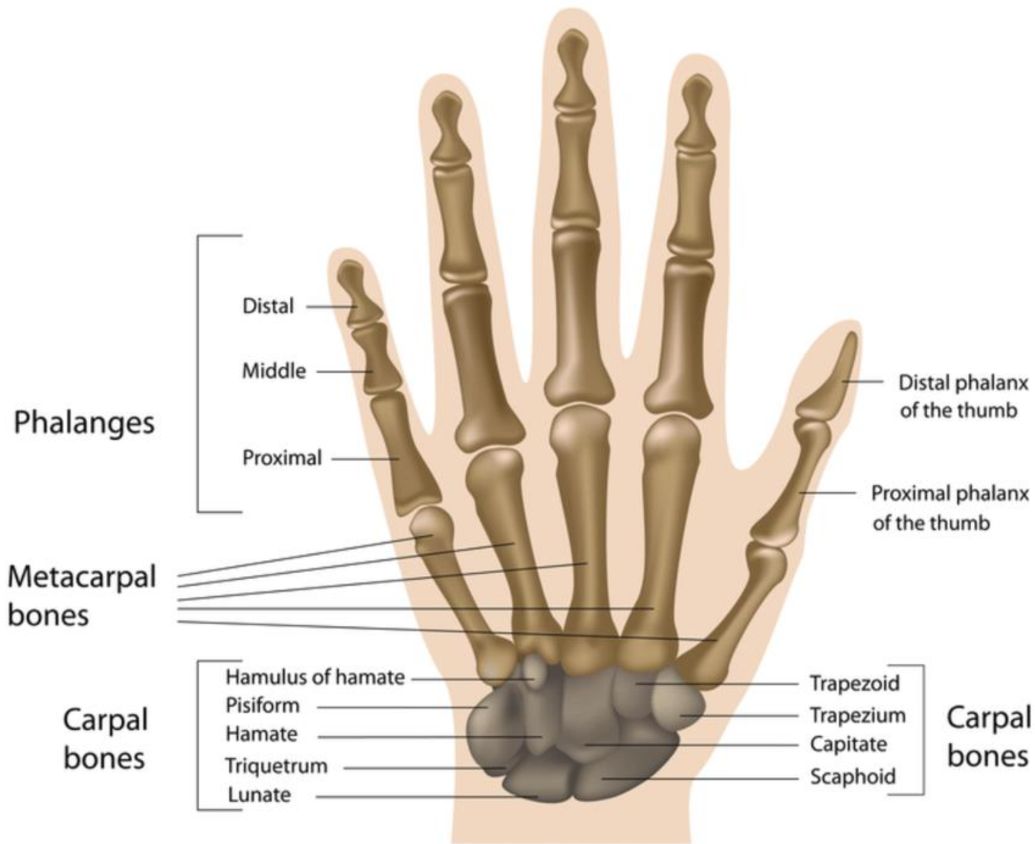

Figure 2.3 The Anatomy of Human Hand[63]

In the recent years, there has been great progress in the development of novel rehabilitation devices. A brief over view of the design, specification and performance of these devices is given below.

2.6 Hand Exoskeleton Rehabilitation Robot (HEXORR)

HEXORR [64] was mainly developed to help therapists in the rehabilitation of the patients. This robotic device is also capable of performing the extension and flexion motion of the thumb. To prevent hyperextension or hyper flexion, mechanical end-stops were added for safety purposes. HERORR is mainly a bulky device as it consists of

Metallic linkage and is uncomfortable to wear. It’s not portable and works like a rehabilitation device only.

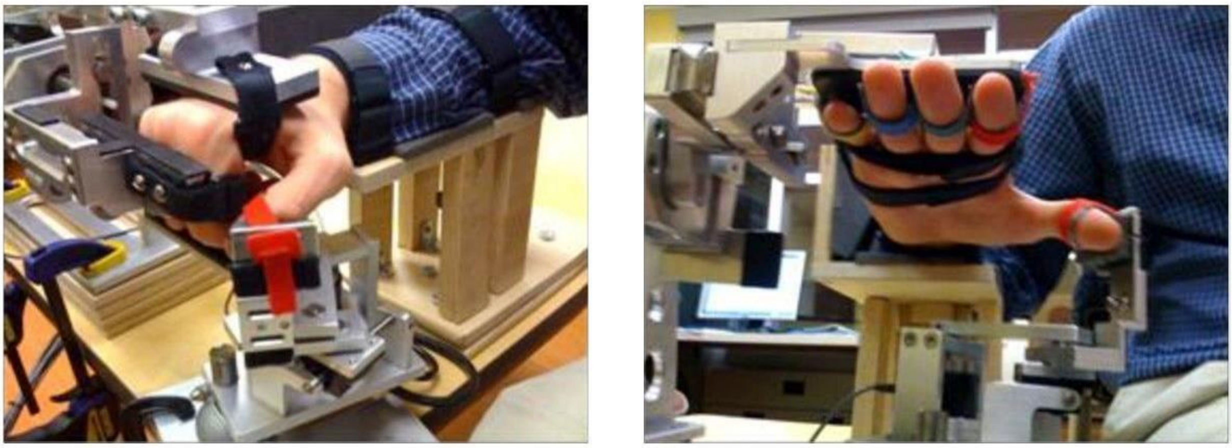

Figure 2.4 Hand Exoskeleton Rehabilitation Robot (HEXORR)[64]

2.6.1 Hand Exoskeleton

In [65] Hand Exoskeleton, a unique mechanism which exert controlled amount of forces on the finger tip of index and thumb are used. Optimization of accuracy and mechanical performance is also done in this device. The linkages designed in this device follow the movement path of the operator. Using linkagesand mother, Hand Exoskeleton can exert a force of 5N.

The main issue of this devise is its weight; it is 1.1kg so the patient feels burden and some fatigue in his fingers. While using Hand Exoskeleton, it is difficult to execute daily life activities.

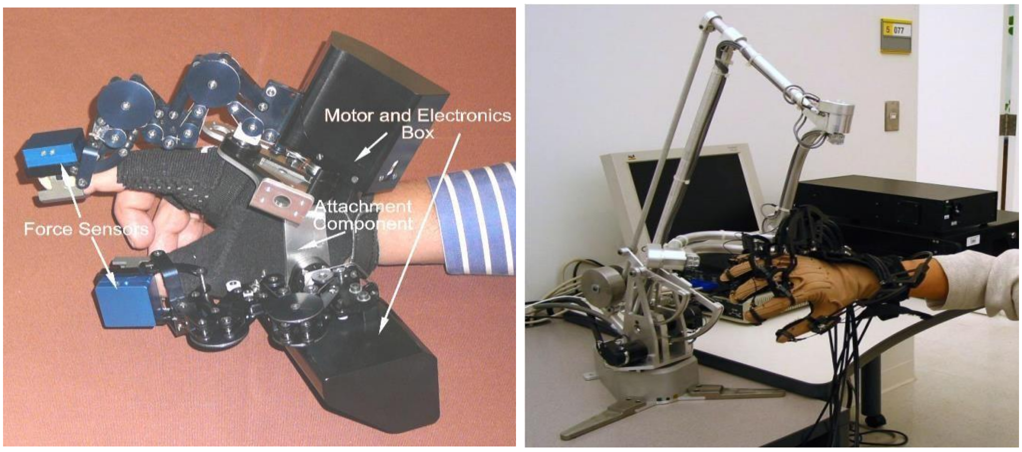

Figure 2.5Hand Exoskeleton Demonstrated[65]

2.6.2 Rehab Robot Ottawa

In university of Ottawa a robotic system was designed for the rehabilitation of the stroke patient suffering impairment of upper limbs [66]. The developer team used the technology of Virtual Reality (VR) haptic feed for the training of patients. The robotic rehab device consisted of a glove, an exoskeleton and an armature .The main issue of this robotic system is the impropriate design of glove as it is difficult for the trainer to place the glove on the patients and it faces limitation to fit on the hands of different sizes. As the robotic system is non-portable so it is difficult for the stroke patient to perform ADLs. Some patients felt fatigue in their arm during rehabilitation as the arm is held in unsupportive manners by the device. Due to non-portability the robotic device had a limited range of motion (ROM).

2.6.3 Exo-Glove Poly

A wearable tendon driven soft robotic exo-glove was designed by a group of students [67]. This device used a battery powered actuation unit and was capable of exerting a pinch force of 20 N and a 40 N warp grasp force. The total weight of this system exceeded 1.5 kg. The main issue of the proposed system is its weight and no autonomy.

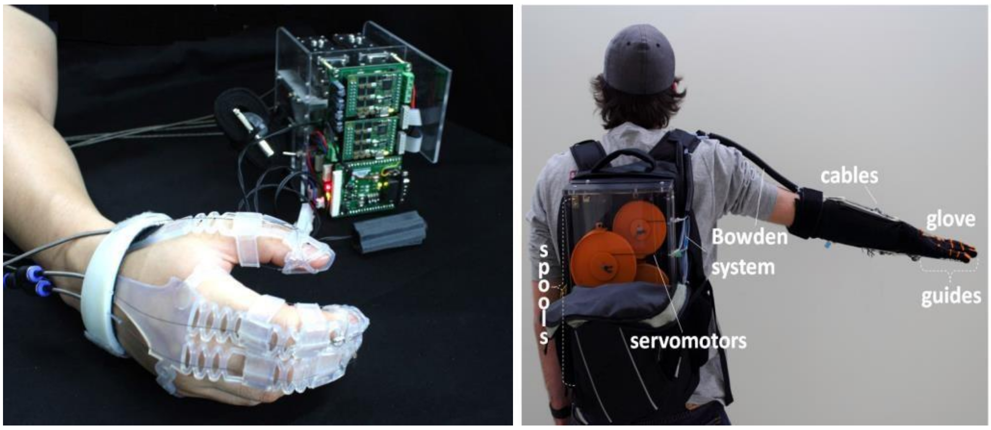

Figure 2.6 Exo-Glove Poly Demonstrated[67]

2.6.4 Exo-Musculature Glove

Exo-musculate glove uses the concept of soft robotic [68]. The primary Purpose of this device is to assist the patient in the coordination of gripping exercises. In the proposed devise, cable system was used for the opening and closing of the patient hand and these cables are operated by servo motors. This robotic glove is capable of exerting a grip force of 15N on fingertip. This whole device is portable and packed in a back pack weighing round about 6kg. The main issue related with this device is the weight of back pack as patient will suffer with back pain or muscle fatigue with time.

2.6.5 SEM Gloves

SEM is basically a tendon-based assistive glove. It is capable of exerting a force of 4N in the fingertips. A battery is used in device for the actuation of the tendons. The main issue with this device is the low autonomy as their battery lasts approximately one day and cost of the battery which is more than $4,000 [69].

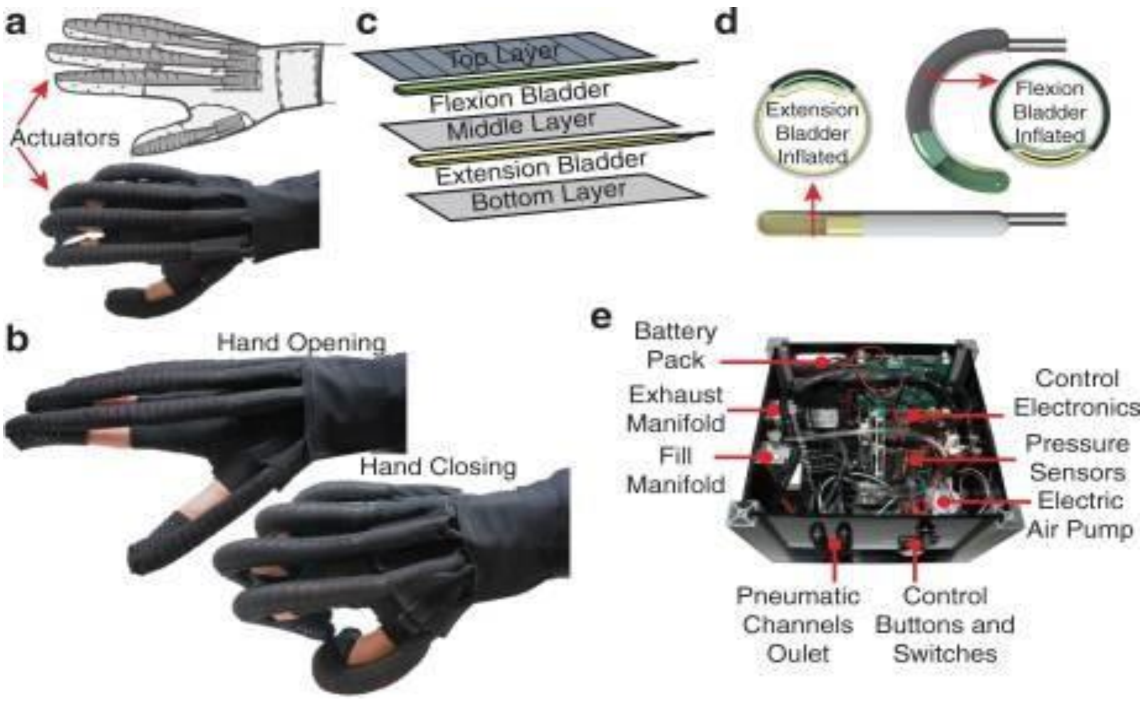

Figure 2.7 SEM Gloves[69]

2.6.6 Exo Glove

An exo-glove is designed by a team of students from School of Engineering and Applied Sciences, Harvard University. This devise can assist the patients to exert a force of 8 N. The device consists of a belt pack with a battery and uses a hydraulicsystem for actuation having a weight of 3.3. The battery timing is only two hours [70].

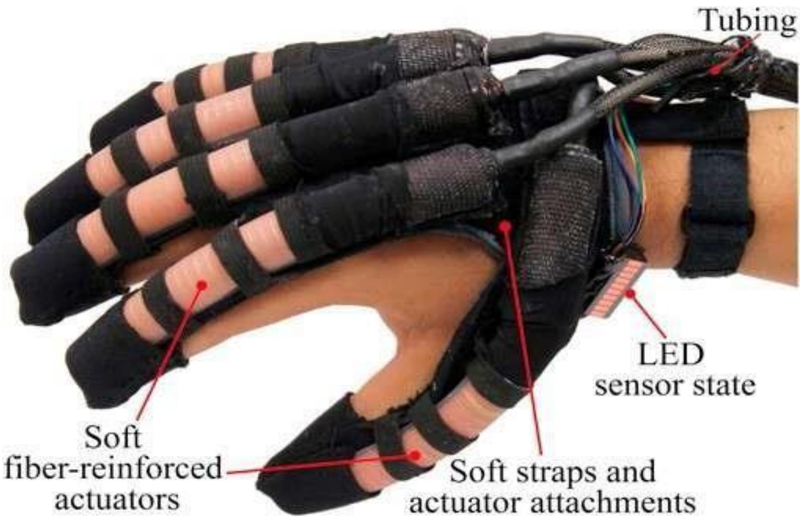

Figure 2.8 Exo Glove[70]

2.6.7 Actuated Hand Skeleton

A group of students developed an actuated hand exoskeleton in NUST, Pakistan [71]. The proposed structure is made up of aluminum including metal linkages. DC motors are used for the conversation of rotational motion of the motor into the linear motion of the linkages. The designed system had 4 degrees of freedom (DOF). The system in only rehabilitative in nature as it cannot assist the patient in everyday activities because of its weight. The wear ability of the exoskeleton is limited as there is a separate motor for each finger.

As all the assistive devices can help the patient to improve his physical condition and quality of life but all the devices designed till date have several limitations.

- These devices are operated by some external power source. As a result, their autonomy becomes limited.
- These devices mainly use multiple motors, actuators and sophisticated sensors. As a result, cost of the device increases considerably.
- Due to the addition of motors and different sensors the total weight of the device also increases. As a result, the device becomes uncomfortable for the patient.
- Mostly current wearable devices operate on batteries so they do not offer a long operation time.

Figure 2.9 Actuated Hand Skeleton[71]

2.7 Soft Robotics

The RoboSoft Coordination Action Community defines Soft Robotic as "Soft robots are devices which can actively interact with environment and which can undergo „large" deformation relying on inherent or structural compliance"[72]. The structures, actuators and linkages used in soft robotics are easily deformable because of low modulus of elasticity (less than 10GPa) and density (less than 1000Kgm^{-3}).

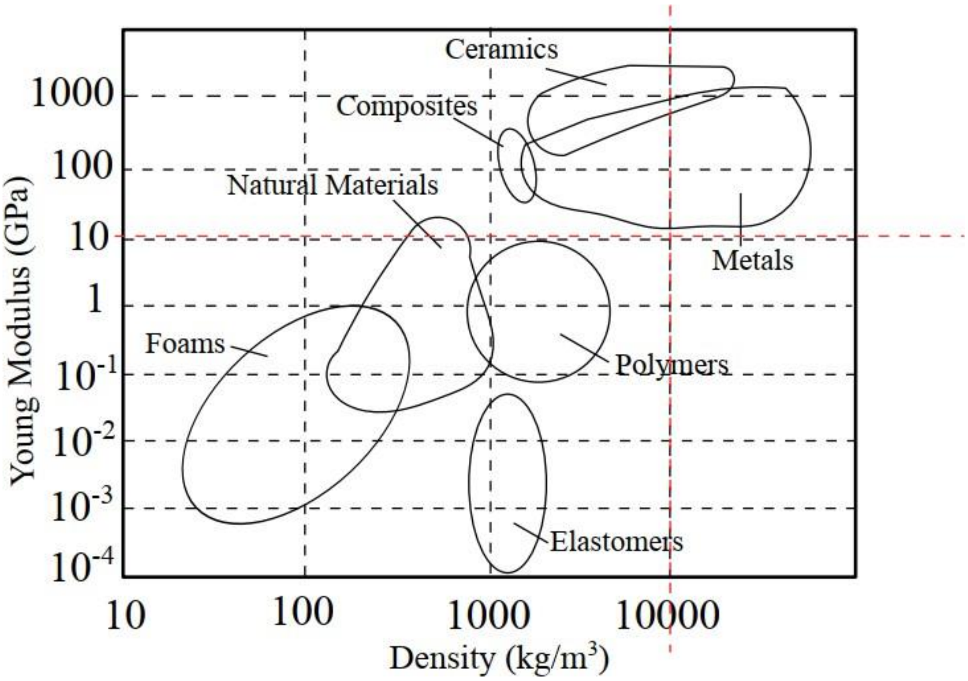

Figure 2.10 The comparison of the Young's Modulus of different materials in relation to their density

Modern development in the rehabilitation technologies led to the use of soft robotic to aid the patient limbs in their natural motion. Now a day's development in the field of robotic is mostly focused on design show resemblance to human or animals. We see the use soft material is greater than stiff material in human and animal body so this excess use of soft material helps the humans and animals to adapt continuously changing environment. Involuntary muscles like heart and voluntary muscles of different limb are common examples of soft material.

Cable pulley drive mechanism is correspondent to musculoskeletal structure as muscles are analogous to actuators, tendons are the cables and joints behave like pulleys. Mostly the Skelton system is made up of soft material. Young's Modulus of human's bones ranges between 20 to 30 GPa.

In animals, hydrostatic skeletons are present which are correspondent to hydraulic and pneumatic drives. Different complex movement such as elongation, squids, torsion and bending occurs due to the change in pressure of fluids that is present inside the Skelton.

2.7.1 Benefits of Soft Robotics

Soft robots offer following benefits

- Sift robots offer extra safety because of high compliance.
- Due to high compliance Soft robot can be used in both indoor and outdoor environment as they efficiently interact with objects
- Soft robots offer high power to weight ratio as they have low height due to soft actuation mechanism.
- Soft material have very high shock absorbing characteristics
- Soft robots are easily manufacture able and do not need any type of special CNC milling methods
- Soft robots are capable of doing complex maneuvers.

2.7.2 Actuation Methods

Previously Composites, rubber, polymer and silicones were commonly used in the manufacturing of soft robots. Metals are rarely used in the manufacturing of soft robots but in some cases we use metal in liquid form and very less quantity for soft material actuation.

The actuation of these soft materials can be done by chemical, thermal, electrical or mechanical means. Some robots have air cavities within them where air can be filled or sucked to produce actuation. Similar is the case with hydraulic bots. There are multiple new actuation fields, which are being developed due to research but pneumatic and hydraulic actuation are the most common techniques to date.

2.7.3 Fabrication Techniques

The methods used for the creation of soft materials to be used in soft robots are different from the traditional methods which are used to manufacture metals. The fabrication method influences the composition of the material of the soft robot. Welding and casting and moulding are the most common fabrication methods. Some robots are even sewn together as they are fabric based. The latest trend in soft robot creation is FDM (fuse deposition modeling) or SLA (stereo lithography) and 3D printing of flexible materials. The below table summarizes all the previously used manufacturing processes.

2.7.4 Moulding

The process of pouring the soft material into a preheated cavity to create specific shapes is called moulding. After pouring the material in the cavity, the mould is closed and compresses the molten material inside it. After that the molten metrial is cooled and it solidifies.

In case of moulding, we require moulds of specific geometry. This leads to the drawback that some types of designs cannot be created but as this process is fast, it can be used for mass production.

2.7.5 Casting

Casting is similar to moulding in a way that both require cavities. In case of casting, a mold is made of the negative of the geometry of the desired shape. After that the molten material is poured in the cavity which is then solidified. This technique is mostly used for silicones. Since the material is being poured in the cavity, it should have low viscosity which would allow it to easily move inside the mould and occupy all the space inside completely. Two types of casting are mainly used.

2.7.5.1 Soft Lithography

It is a technique similar to compression moulding without requiring the high pressure and the specialized equipment. The mould is 3D printed which has the inner cavity of the required shape. Two part mould is made so that it can be easily opened to extract the resulting shape from the mould. This causes the design variations of the model to be limited.

This is a low cost process which does not require much labor but requires time for the material to solidify. This makes it unsuitable for mass production. The object can also undergo failure at the point of separation from the two part mould.

2.7.5.2 Low Wax Casting

In this type of casting, the object is casted as a single piece and does not require the two part mould which results in greater mechanical strength. In low wax casting, first the mould is created using rubber. Then a hollow wax or paraffin cast is made using the mould. This cast is then covered with a final fireproof mould and a fireproof core. The mould is then heated in an oven which causes all the wax to melt out leaving us with only the mould which can now be used to manufacture the soft robot.

2.7.6 Additive Manufacturing

Additive manufacturing (also known as 3D printing) is an extremely convenient method used to prototype soft robots. This is a low cost and quick solution.

Mainly two techniques are used in additive manufacturing.

- Stereolithography – It uses UV light to harden the resin to create the desired shape.
- Fused Deposition Modeling – It melts the flexible filament and deposits it layer by layer.

Thermoplastic Poly Elastomer and Thermoplastic Polyurethane is used for 3D printing of soft robots. These materials have low shore hardness, typically in the range of 70A to 95A on durometer scale. They do not undergo plastic deformation while bending, stretching and folding. Sometimes a specific extruder is required to 3D print with these materials [73]. These materials have high impact resistance and strength [74].

2.7.7 Challenges on Soft Structure

Along with the advantages, there are also multiple drawbacks of the soft materials. The drawbacks faced during this research are given below.

2.7.7.1 Design

The degrees of freedom given by soft materials are infinite as opposed to the conventional rigid joints of the rigid robots. Due to the multiple degrees of freedom, soft devices exhibit hysteresis and non-linearity.

2.7.7.2 Fabrication

Development of soft robots is mostly done through casting which requires us to make a negative mould of the shape first and then pouring in the molten soft material. This is a tedious process and compared to the conventional milling of a rigid metal based robot, its takes more time.

This issue was solved using 3D printing the robots with flexible polymers but the commercially available flexible materials are limited. Only Thermoplastic Polyurethane and Thermoplastic Poly Elastomer are commercially available filaments which can be used to 3D print the robot with the required flexibility [73].

2.7.7.3 Strength

Soft robots are mostly actuated using electromechanical, pneumatic or hydraulic methods but the amount of torque produced is limited as compared to rigid robots.

2.7.7.4 Control

Soft materials offer infinite degrees of freedom so precise control over these robots is an extremely difficult task.

A closed loop feedback system may be employed for stable control but stable control system for precise motion of these devices is still a challenge.

2.8 Soft Robotic Exoskeleton

Exoskeletons have two types, one being active and the other being passive, for active type hands, external power source like batteries has to be used and passive ones are operated through physical body movements. When compared with passive type exoskeletons, the active type exoskeletons come with a number of disadvantages, first being the resistance to mobility because of its added power source, weight and size, also great care is required to keep the batteries up and running throughout the day as electronic actuators then take a lot of battery power to operate and batteries discharge really quickly. All these factors tend to make active type exoskeletons really expensive and hard to maintain for day to day use, however the passive ones do not require any external maintenance and are comparatively very low cost for its manual nature operated through amputee's body movement and non-electronic type.

2.8.1 Problem faced by Patients in Rehabilitation

If the process of rehabilitation is delayed, discharge duration increases, the activities are curbed, health is negatively affected, and dependency on assistive measures increases [75, 76]. These negative results can cast widespread social and financial problems for individuals as well as communities [77, 78].

The World Health Organization (WHO) and the International Society for Prosthetics and Orthotics (ISPO) have stated with the help of an approximation that people who are in need of prosthetics make 1/2 percent of the population in developed countries. But this figure gives an alarming situation when we see 30 million people in Latin America, Africa, and Asia to be in need of approximately 180,000 rehabilitation specialists to help them in their daily life processes and operations. In 2005, there were twenty-four prosthetic and orthotic schools in developed countries of the world, which were producing almost four hundred graduates per annum. But in contrast with the necessity of the time, the current orthotic facilities are in significant deficit [79].

The general lack of access to recovery in every health sector was identified by a survey conducted in Slovenia, Croatia, Slovakia, Hungary, and Czech Republic [61]. Shortage and the lower rehabilitation experts in the rural and the remote areas are recorded in developed countries such as the United States of America, Canada, and Australia [80]. Another new detailed rehabilitation study in Ghana revealed that there is no rehabilitation doctor or occupational therapy in the country; and a very few prostheses, orthotics and physical therapists have been shown in comparison to the need in that country [81].

Another research revealed that there are just six rehabilitation doctors available for the 780 million population of South Africa in the sub-Saharan Africa [82]. Female physiotherapists cannot engage and restrict the opportunity of women to access their homes in recovery careers and their societal views towards the gender market [83]. In both high-income and low-income economies, the cost of recovery can be a challenge for individuals with handicaps. And where financing is available from states, insurance agencies and NGOs, the burden of recovery cannot be adequately met. Disabled people have poor wages and are frequently unemployed; thus, employer-sponsored health benefits or private charitablehealth programs are not likely to cover them. More than half of the aid systems are bought directly from disabled persons and their families.

Two thirds of the assist users reported paid for their devices by a domestic survey in India.

Lack of access to prophesized facilities in Haiti was partly due to consumers who did not pay. Key centers for recovery are typically situated in urban cities; rural areas often do not even have basic therapy care [84]. It can be expensive and time consuming to connect to secondary or tertiary facilities, and sometimes public transit is not tailored for those with mobility issues. Rehabilitation efforts, including home-based facilities and classrooms, are increasingly versatile. Rehabilitation programs should be made available as close to the homes and neighborhoods of individuals as possible [85].

The research carried out in 1505 patients in the U.S. found that 23 percent were fearful of visiting the nursing home or other rehabilitative services [86].

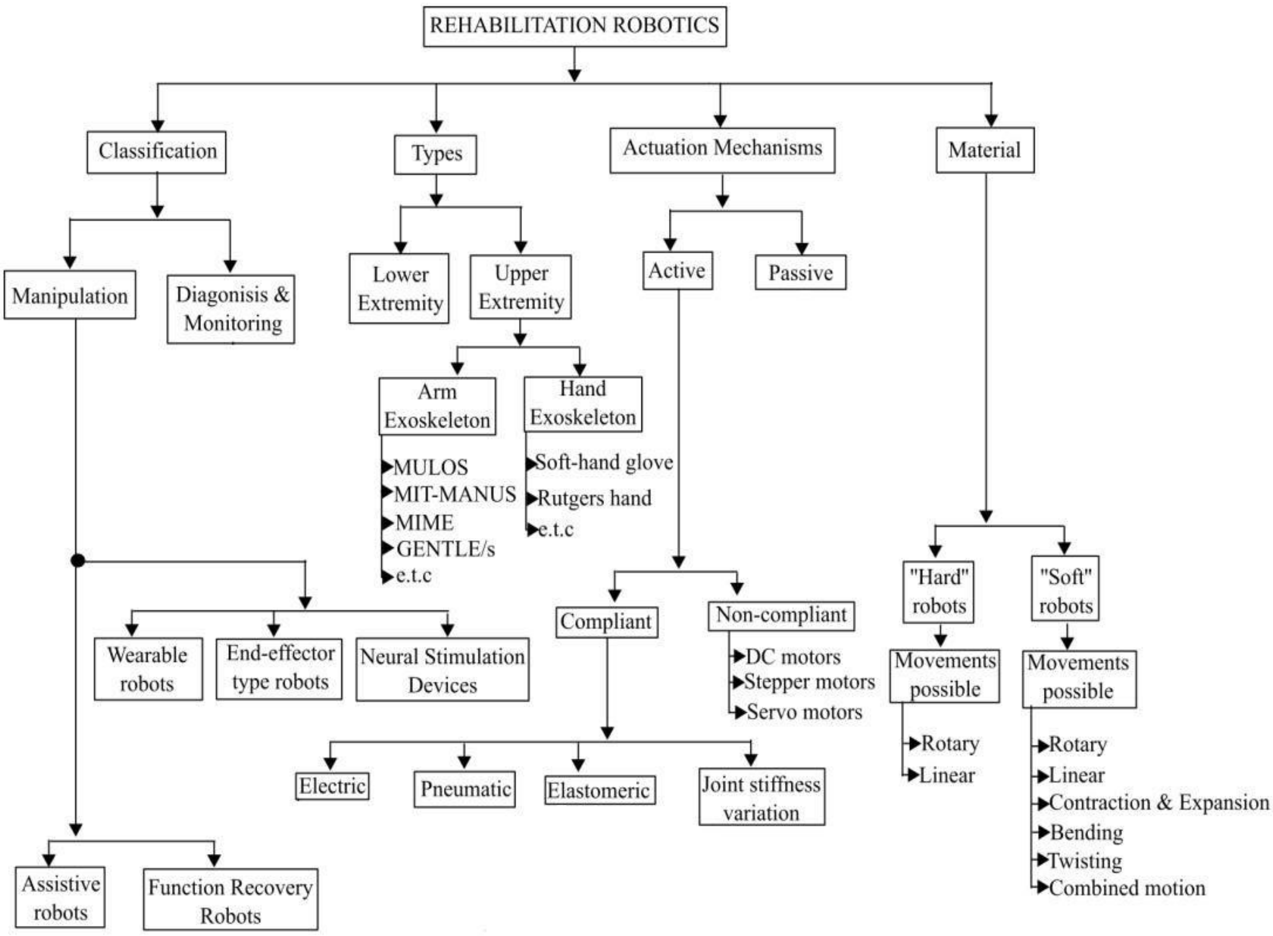

Figure 2.11 Overview of the Rehabilitation Robotic[45]

2.9 Our Goal

Robotics is being proposed as a non-invasive solution to enhance the functionality of hands by means of wearable exoskeletons which enables the disabled users to move their hands. A number of robotic exoskeletons have been developed over the past years which can be classified based on their actuation principles materials, complexity and functions. Most of these devices are rigid and require careful alignment with joints for safe use. Rigid exoskeletons are useful for challenging clinical scenarios under expert supervision but aren't portable due to their size and weight. Consequently, most of them are stationary and designed for in-clinic use.

We have designed and developed a novel passive type exoskeleton, the primary purpose for its Research and Development was to assist such patients who are suffering from paralysis because of certain body paralyzing strokes and cannot afford to have expensive active type exoskeletons. Moreover, our device also acts as a rehabilitative device for the patient while preserving its assistive nature and making sure patient is performing his/her day-to-day activities well. It's a one of a kind 2 in 1 device offering therapy and assistance that does not require any external therapist to operate and can be used anywhere. It's a light weight device, easy to wear and has a high mobility with no maintenance requirements and extended life span.

CHAPTER 3: METHODOLOGY AND MODELING

In this section, we present the methodology used in designing and developing of a passive body-powered exo-glove that meets the objectives discussed above. Hardware design to control the actuation is also outlined.

3.1 Design Approach

Following steps were used for the system design**:**

- Latest design and fabrication trends were considered and applied as considered appropriate
- The needs of the system were kept in mind to determine the design criteria and requirements
- The selection of best mechanism meeting the requirements of the user with best power to weight ratio
- Selection of appropriate and inexpensive techniques for the fabrication of the device prototype
- Testing various performance parameters through different methods
- Repeated testing for the confirmation of design
- Using the results to iterate the design to come up with the best design to be further used for testing**.**

3.2 Design Constraints

The design followed for the design of the device includes:

- The device should have less weight of the whole system to avoid fatigue
- It should have low maintenance cost
- It should have high autonomy
- It should be easily useable for patient to do daily life activities
- It should be comfortable to wear and may not cause skin damage

3.3 Design Criterion

The design criteria for the device are:

- The device should provide at least 10 N of pinch force to help the patient in daily activities

- The device should help the patient a certain range of motion without causing hyper flexion or hypertension
- The glove should have little effect when exposed to water so that it can be easily cleaned
- The system should be reliable and stable

3.4 Modeling

Modeling is one of the basic and foundation steps of any project, which we attempt it and will show how it all went. To help and expand the grasping capabilities of the user (i.e., a patient) we designed a body-powered exo-glove, which has a numerous advantages for the user except enhancing his grabbing capabilities. First of all, it provides the process's intuitiveness, easiness, cheaper and easy to afford, no maintenance required, and a perfect long tenure of autonomy. Elaborating this device, we model the whole phenomenon into four different and discrete parts, which are:

1. The differential module
2. The tendon tensioning
3. The adjustment mechanism
4. The harness
5. The soft glove

Figure 3.1 Annotated presentation of the body-powered device[87]

The figure 3.1 shows the model our project, where all the five parts of our project are displayed and how a user will have utility of this project. The major parts of this device includes, artificial tendons and tendon routing tubes, adjustment mechanism of the tendon tensioning, the differential mechanism (which we would manly focus), the glove, and the harness.

With the help of tendon-routing system, the body powered mechanism of this whole process depends on the transfer of pressures from the upper limb of the human body, i.e., the shoulder in our case, which is transferred towards the fingers to move according to the movement of the shoulder to move the fingers and thus help in grabbing. Because of the simple body movements, the stress on the movement of tendon will increase, and thus it will actuate the soft exo-glove. This is the mechanism, which can be used to equally distinguish the forces in the distribution between every participating finger to help in providing a better grabbing capability.

3.4.1 Differential Module

For the tendon stress and equal distribution of forces among the finger and to achieve an adjustable gripping power, the differential module provides a viable solution. Similar prosthetic and orthotic structures may also be used with the same differential process. In under-actuated robot hands, the differential system based on the whiffle-tree system can also be utilized as shown in Figure 3.2 to enhance the grabbing process in such a way that even if the shoulder is moved back to its location (which provides the main force in this process), the hand will stay on the position, i.e., has grabbed the thing that a patient requires.

The suggested differential loading spring system is a solution that can not only be extended to assistant exotic gloves but also to robots and prosthetic devices, like prosthetic hands and arms for terminating the tendon tensioning process, the stress, and the locking of motion to enhance the gripping process. The definition of this process is based is based on the equally distribution process, which is achieved with the help of whiffle-tree process, which helps to provide the body powers to the participating finger tendons. A locking heel and the linear ratchet will lock the differential easily in various positions. The locking Mechanism is pushed against the teeth of the linear ratchet by a spring until the device is locked in place. On the whiffle-tree differential mechanism the finger tendons are associated with the proposed capture system. The picture of the suggested solution is annotated in Figure 3.2, as below.

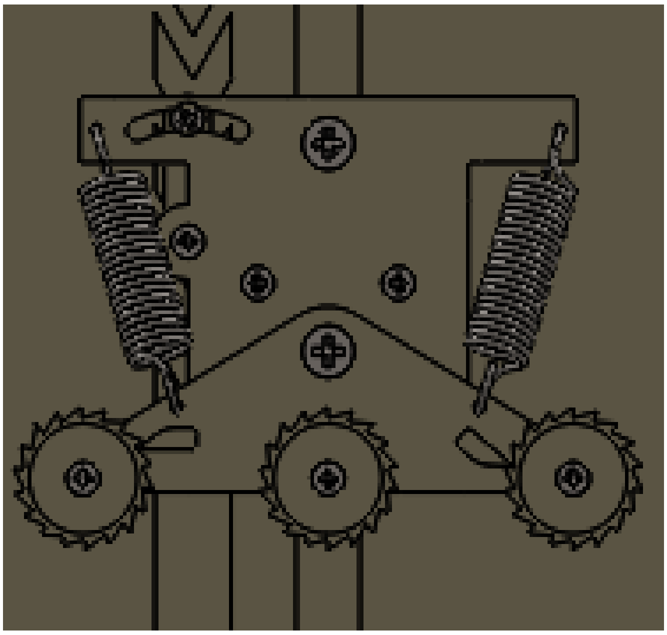

Figure 3.2 The Differential Mechanism, a proposed solution

The differential mechanism itself is divided into numerous portions, as illustrated above in the Figure 3.2, which are:

1. The spring loaded whiffle-tree mechanism to provide the locking mechanism to the movement of the fingers in various positions according to the desires of the user (i.e., the patient).The locking Mechanism pushes against the teeth of the linear ratchet by a spring until the device is locked in place.
2. The linear ratchet, which helps to constraint the moment in one direction. The movement of linear ratchet with the help three smaller pulley(s) helps to provide a fine and adjustable tendon strength to the fingers of the user to enhance the grabbing capability.
3. The ratchet clutch, which includes the whole process of tendon wrapping with the help of pulley blocks.

3.4.1.1 Ratchet Pulley Block

The mechanism of ratchet clutch contains a “ratchet pulley block”, which aims to wrap the tendon around it, a “pawl” which helps to block the ratchet in one direction and a spring-style, elastic part, pressing a pawl against the ratchet teeth and restricting its movement in the opposite direction. The mechanism guarantees that the length of the tendon is accurately and precisely calibrated. The goal of this ratchet club is basically to change the length of several tendons that are guided by the tendon routing tubes to meet the glove. A linear ratchet was used to sustain the tendon stress for a long time.

3.4.1.2 V Shaped Teeth

This system ensures that the tendon is locked in one position before the mechanism is continuously employed. The mechanism is composed of different teeth in the shape of "V", which are arranged on a base, a rail, a lever, a row, and the two springs. The rail is connected by screw to the differential modular mechanism and the base can be glued onto the rail so that the base rotation only takes place on one axis. Once the top cable is removed, the heel is forced to the desired position by a spring against its teeth. The lever then pushes into one of the "V" teeth to secure the valve to sustain a constant tension.

3.4.1.3 Pulling the Lever Back

The lever is pushed to the channel once again as the mechanism re-engaged and a spring linking the base with the differential module walls tightens the base to the lowest position and the tendon returns to its original tensed position. The cycle is reset as the top cable is pulled out. For low-actuation and body powered systems, the need to keep the tendons tensioned for long stretches of time is paramount as in most of the mechanized solutions operated by the tendons (for example, the fully-actuated systems), the motors will change the tendon tensioning and hold the charge as the objects are grasped and handled.

3.4.1.4 Distribution of Force to the Fingers

This body powered mechanism helps the stresses to be transferred by the tendon routing device from the upper limb of the body (i.e., the shoulder) to the fingers of the hand on the other side, i.e., the index finger, the middle finger, and most importantly the thumb. The strain in the tendon, triggering the vulnerable exo-glove may be improved by quick gestures. The differential system is used to disperse the forces equally to your fingers. This cable needs to be tightened specifically and a tension control system has been established for this purpose. The mechanism consists of a foundation with a retractable reel, a cover, a rectangular teethed pulley, and the lever.

3.4.1.5 Utilizing the Body Powered Mechanism

When the mechanism is worn and utilized by the user, i.e., the patient, the person pushes the button and the cord rotates in the counter-clockwise direction (separate from the tendon), wrapping and tensioning the tendon around the actuator. The plastic cover means that the pulley and the cord will not separate from each other, i.e., the casing retains them intact. For the body driven system the suggested brace was selected because it is secure and helps to hold the shoulders in alignment. When transmitting pressures to the main cord, the right arm or shoulders pull the differential, and resultantly we can see the artificial tendons to give a force to the fingers to grab and tighten of the fingers for the product they want to grab in their hand.

3.4.1.6 Ultra-High Molecular Weight Polyethylene

These tendons move the fingers, which are made up of the braided fiber which offers almost zero friction and offers high performance. The material for fiber is suggested to be "Ultra-High Molecular Weight Polyethylene" (UHMWPE). One end of this string is connected to the differential process and the other end is attached at each fingertip by a stainless-steel structure. It has to be remembered that performing tasks with the body-powered system takes longer since the exo-glove has to be controlled by longer body compensation movements.

The body-powered mechanism of the exo-glove was designed to be as quick and convenient as possible to use without intensive preparation. The system is adaptable to all forms and sizes of the human-body. The individualization takes place only on the handle and harness because the size of these objects depends on the height and weight of the user. The body-powered mechanism's prototype costs on the whole a very small value and is also very much light-weighted and easy to handle by the user, i.e., the patient, in terms of comfort. This is the most light-weighted of all the assistive and actuated exo-gloves in the literature presently available to our full knowledge. It should be stressed that this approach can be applied to multiple actuators.

3.5 Soft Exo-Glove

3.5.1 Fabric Basic Soft Glove

A light-weighted, tightly fit, extremely sensitive glove, with 3 anchor systems (i.e., for the index finger, the middle finger, and the thumb), three artificial tendons, the five soft anchor points, and one cable reinforcement are all used to shape the soft glove framework. This soft glove can be originated from a simple soft glove, for instance the golf glove. The framework was developed to optimize the sensitivity, ability and grasp powers that users will practice when executing tasks. A rubber-covered glove has been picked to improve the contact between the object and the exo-glove. The use of internal tendons in the glove is a special design function of this approach. When grabbing, harms or reduces the functionality of the system, external cables can be obstructed. At the fingertip, as seen in Figure 3.3, an anchor framework of stainless steel was stitched to the back of the glove. Due to their relevance for most everyday activities, the design decision was based only on three fingers (i.e., the index finger, the middle finger, and the thumb).

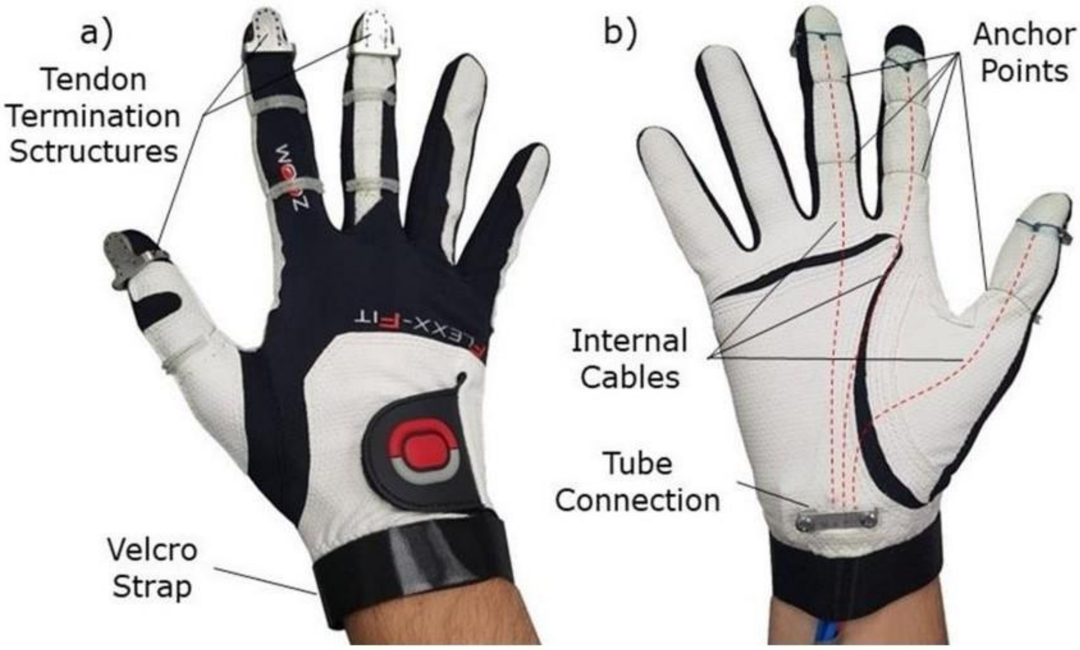

Figure 3.3 Annotated View of the Soft Gloves utilized by the body-powered mechanism[87]

3.5.2 3D Printed Soft Glove

The soft glove used in this system is a custom designed and 3D printed flexible glove. The material used for this glove is the flexible Thermoplastic Poly Urethane (TPU) which is a flexible polymer. The glove is a single printed part that consists of thimbles for the two fingers and the routing pathways for tendons. TEFLON tubes were embedded within the design to minimize the friction of tendon cables for maximized efficiency and power transmission. The salient features of the design are as follows:

- The system was designed in such a way that it helps stroke patients to maximize the tactile sensitivity by removing material from the parts where finger interact with the object it holds.
- Glove features embedded pathways for tendon cables. External cables can get stuck in any object causing self-damage.

- The glove features Rhombus shaped pattern which increases the compliance of the glove and its easier for the glove to aid the hand in its natural motion.
- Rhombus structure was chosen because it offers 1 Degree of Freedom in longitudinal direction. This decreases the structural rigidity and hence offers more compliance in longitudinal direction. So, we can do not require removal of material to increase compliance, unlike in case of circular or any other structure.
- This is further illustrated in figure 3.5. Testing was done and it was proved that the rhombus structure has the most tensile strength while offering similar compliance. The test results are displayed in Results section of this study.
- The glove was designed in such a way that it is easily 3D-Printable with Thermoplastic Poly Urethane (TPU) which is one of the hardest material to 3D Print with.
- All the angles in the thimbles were set to less than 60 degrees at unbridged areas.
- A total of 3 straps were 3D printed and integrated within the design make the glove easy to don on and off by the stroke patients.
- ∞ shaped design was implemented in the straps to make it ultra-stretchable for hands of various sizes.
- Decision for actuation of only middle and index fingers was based on the usefulness of only these two fingers in most of the tasks needed to perform activities of daily living (ADLs).
- The tendon pathways for flexion of fingers feature a novel arrangement through which under-actuation of the fingers is achieved. The arrangement acts as a mechanical differential drive but does not uses any extra gears or any complex mechanism.
- There are two separate tendon pathways for extension and flexion tendons.
- TEFLON tubes were also embedded in the thimbles for reduced friction when under-actuation is required.
- The CAD Model is displayed in Figure 3.4.

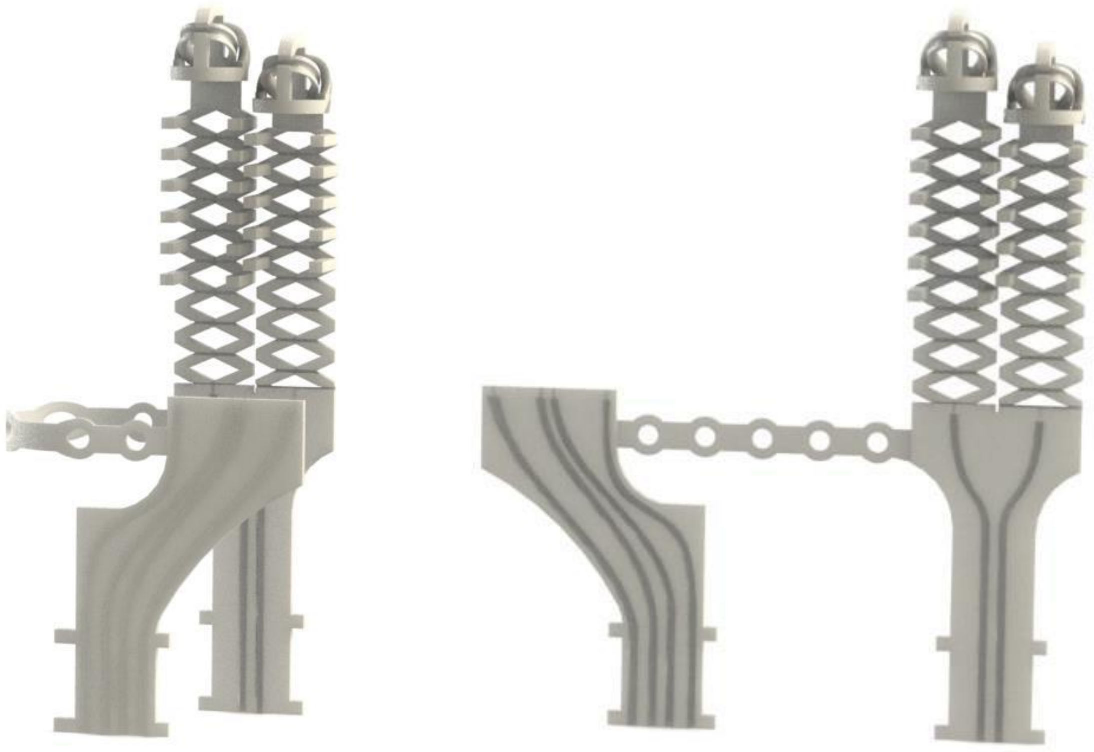

Figure 3.4 CAD Model

Figure 3.4 Different glove designs for testing mechanical strength while keeping the compliance constant

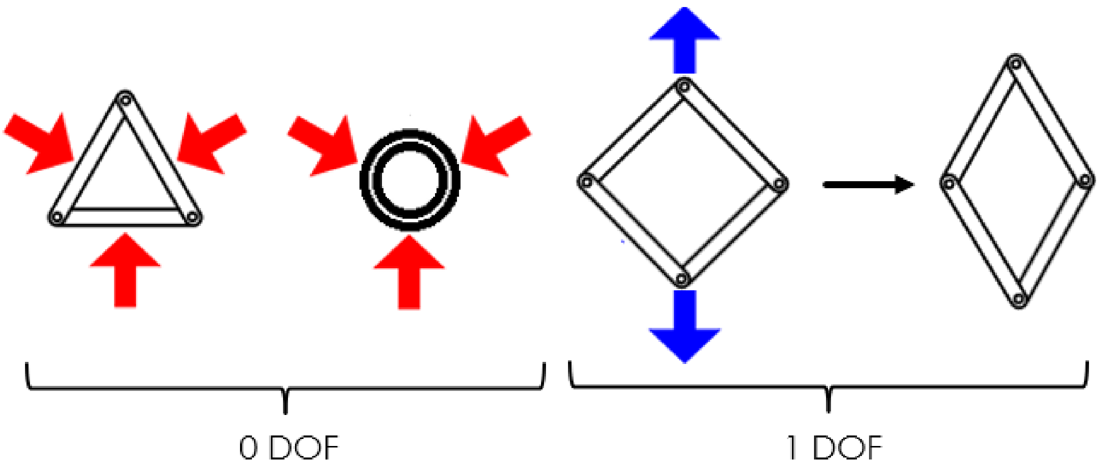

Figure 3.5 Compliance of Rhombus structure is greater in longitudinal direction as it offers 1DOF

3.6 Gear Transmission

Gear transmission in the differential system is utilized to achieve the goals of giving an elevated motion to the later part of the mechanism, with a slight movement in the first part. To explain my point, the mechanism can be seen with the help of "Gear Train Mechanism"; when the two gears are mounted into each other in such a way that their teeth engage to give the small movement in the first gear, a larger movement in the second gear.

The first wheel is regarded as the driver wheel, which provides the input to the gear transmission mechanism and the second wheel is regarded as the driven wheel, which follows the input to provide the output at the other edge. To provide a higher speed advantage at the output with respect to the input, we use the gear assembly in such a way that the driver while is smaller, with less number of teeth, which leads to lesser speed and less power required for moving that gear.

Now when the motion is transferred with the help of gear transmission process to the next gear, i.e., the driven gear (larger in size with more number of teeth), the smaller motion in the first gear (driver) provides a larger motion in the second gear (driven). The gear assembly for the proposed solution is shown as following in figure 3.4, 3.5, and 3.6.

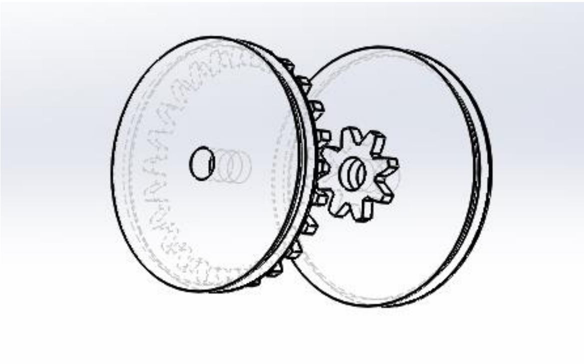

Figure 3.4 The Gear Transmission for the Proposed Solution

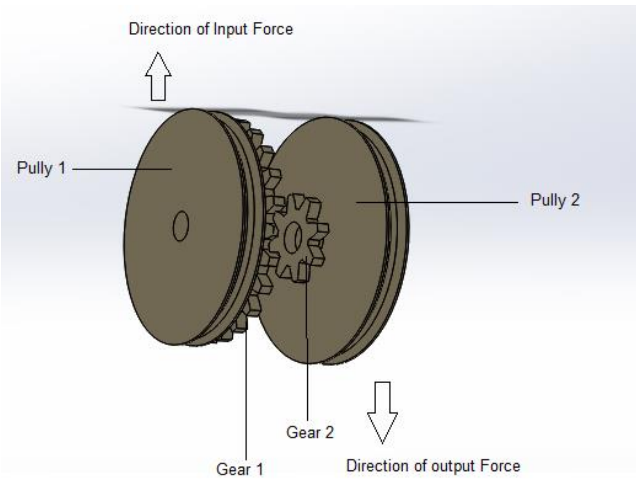

Figure 3.5 The Larger Driver Gear (right) and The smaller Driven Gear (right)

CHAPTER 4: DESIGNING AND SIMULATIONS

4.1 Mechanical Design Overview

The project report is based on the "Mechanical Design and Development of Passive, Assistive and Rehabilitative Tendon Driven Device for Enhancing Grasping Capabilities"; for the designing of this body powered mechanism, the mechanical design is the necessary factor, which provides the shape and structure of the whole mechanism by designing each and every small linkage and connecting them with the cord to provide the effective movement of each finger and help in grabbing the products.

Designing is one of the major and the most important step of any technical project; and it is because of the reason that it shows the actual working behind the project; it also tells how the project will actually function and how it can be possible to work in the prescribed working environment.

The advance design standards and principles of modeling and design were followed for this stage of the process. The body-controlled exo-glove was targeted to upgrade the grasping abilities of the person, giving effortlessness and instinct of activity, with long autonomy, low support, and minimal effort. The device consists of four distinct parts: the tendon tensioning and adjustment part, the soft glove, the differential module, and the outfit.

The differential module is responsible for tendon tensioning and even appropriation distribution of forces for the partaking fingers. The specific differential mechanism can likewise be applied to various under-actuated prosthetic and orthotic frameworks. Differentials dependent on the whiffletree mechanism are broadly utilized in under-actuated robot hands [20, 19].

4.2 Solid Modeling (3D Model)

The three dimensional design of the whole body powered mechanism was devised and designed to give a practical shape to the product, such that we can be able to even fabricate the product with some specific techniques like 3D Printing, casting and moulding etc. The 3D design of the product is shown as following.

4.2.1 The Description of Parts

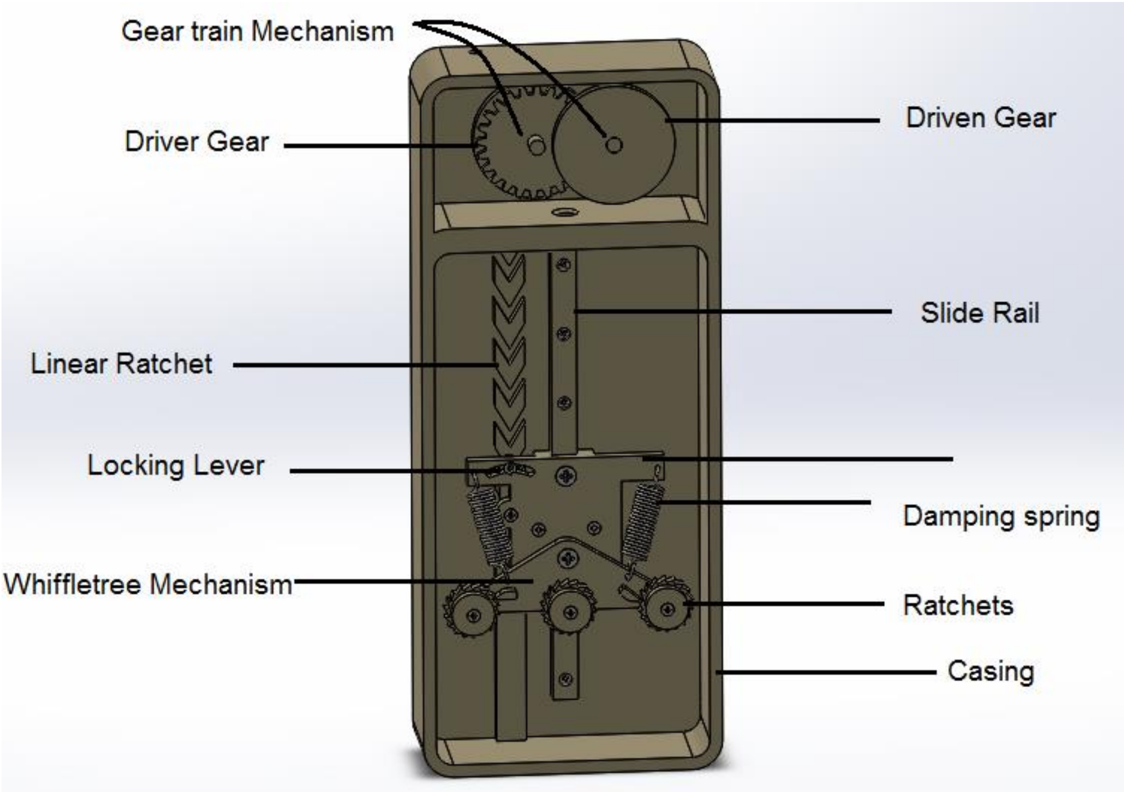

Figure 4.1 Proposed Mechanism – Parts Illustrated

4.2.2 Isometric View of the Designed Mechanism

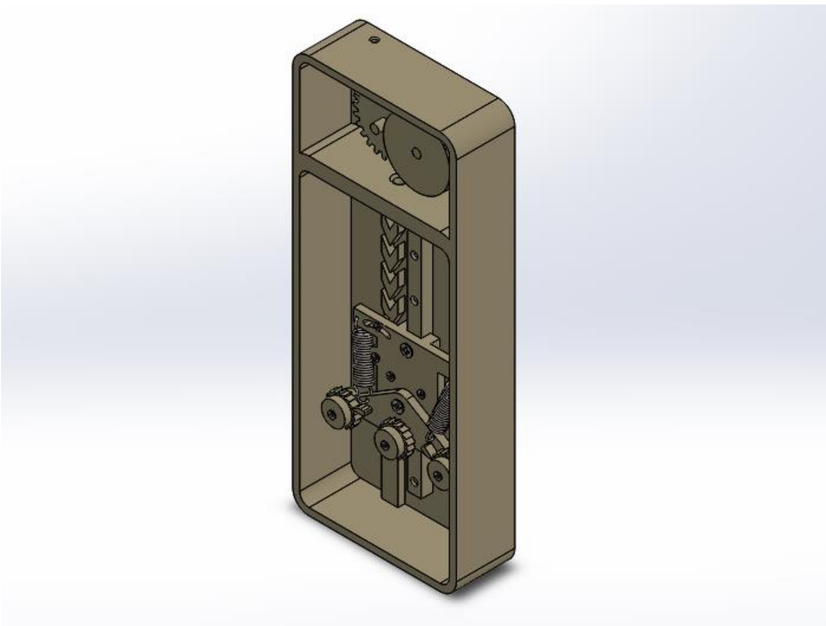

Figure 4.2 The Isometric View of the Proposed Mechanism

4.2.3 Front View of the Differential Mechanism

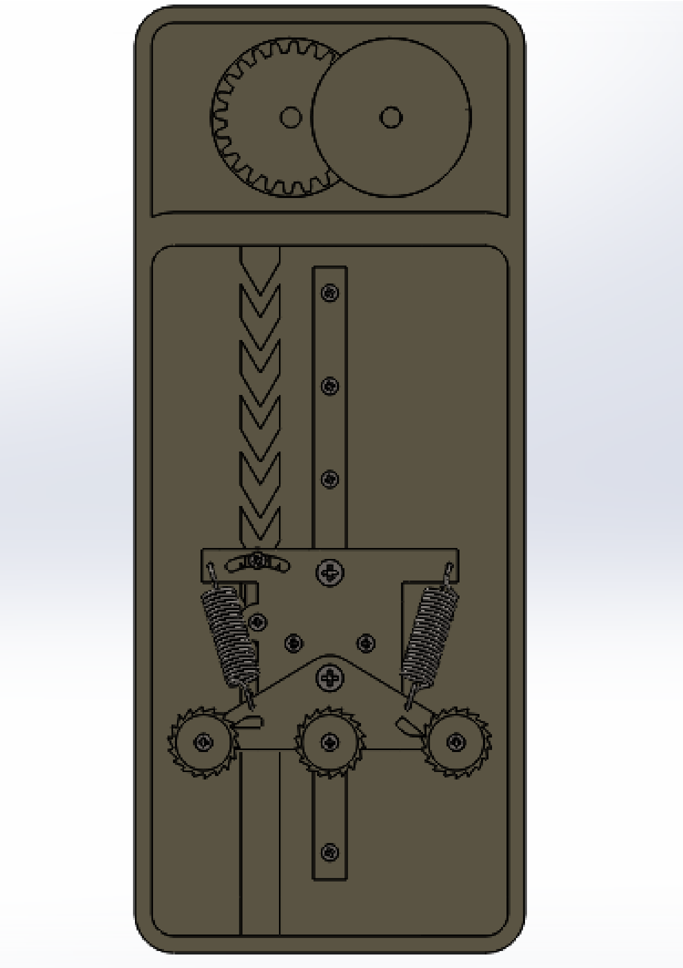

Figure 4.3 Front View of the Proposed Mechanism

4.2.4 Isometric View of the Gear Transmission

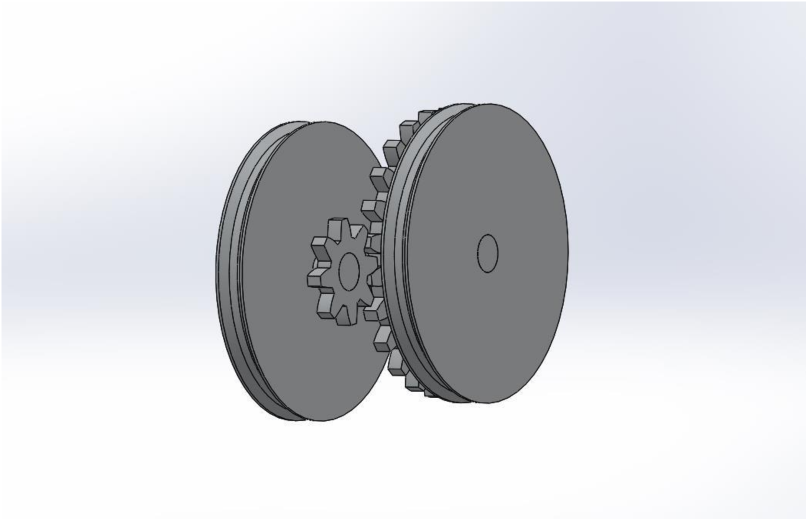

Figure 4.4 Isometric View of the Gear Transmission

4.2.5 Side View of the Gear Transmission

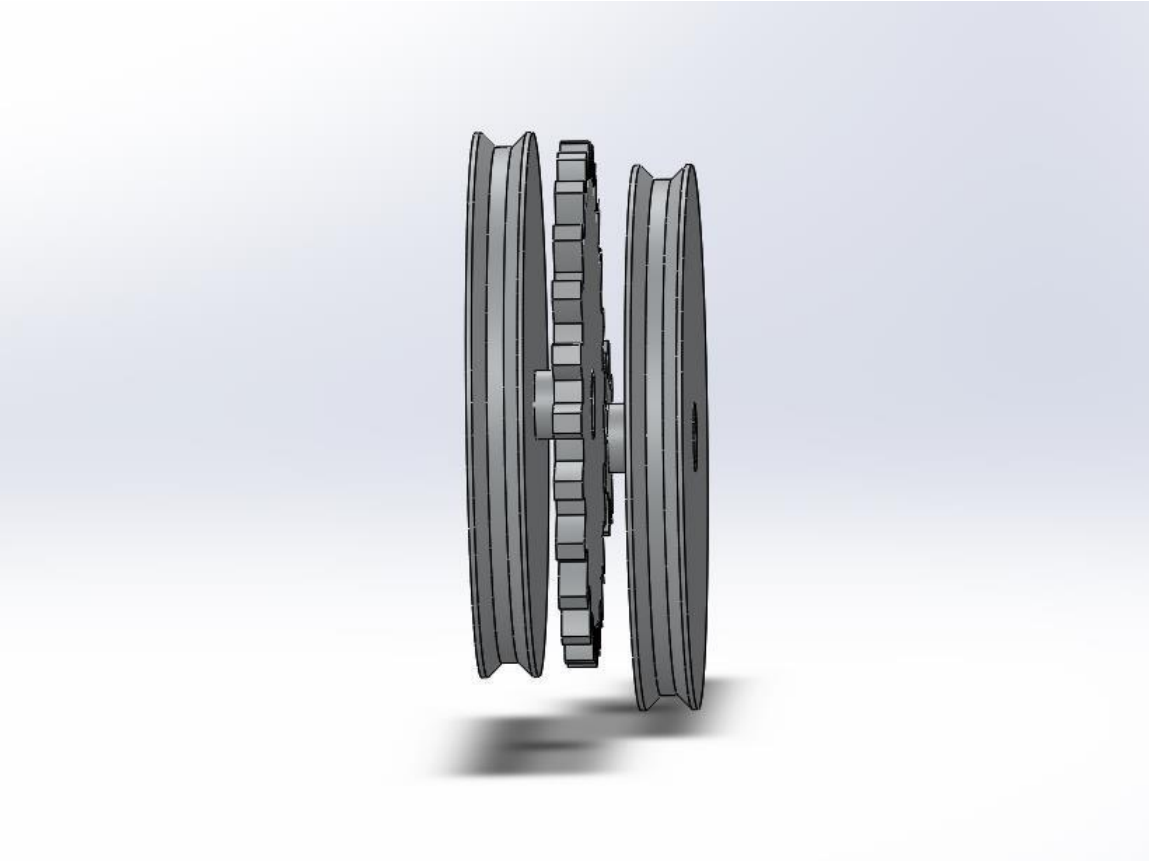

Figure 4.5 Side View of the Gear Transmission

4.2.6 Top View of the Gear Transmission

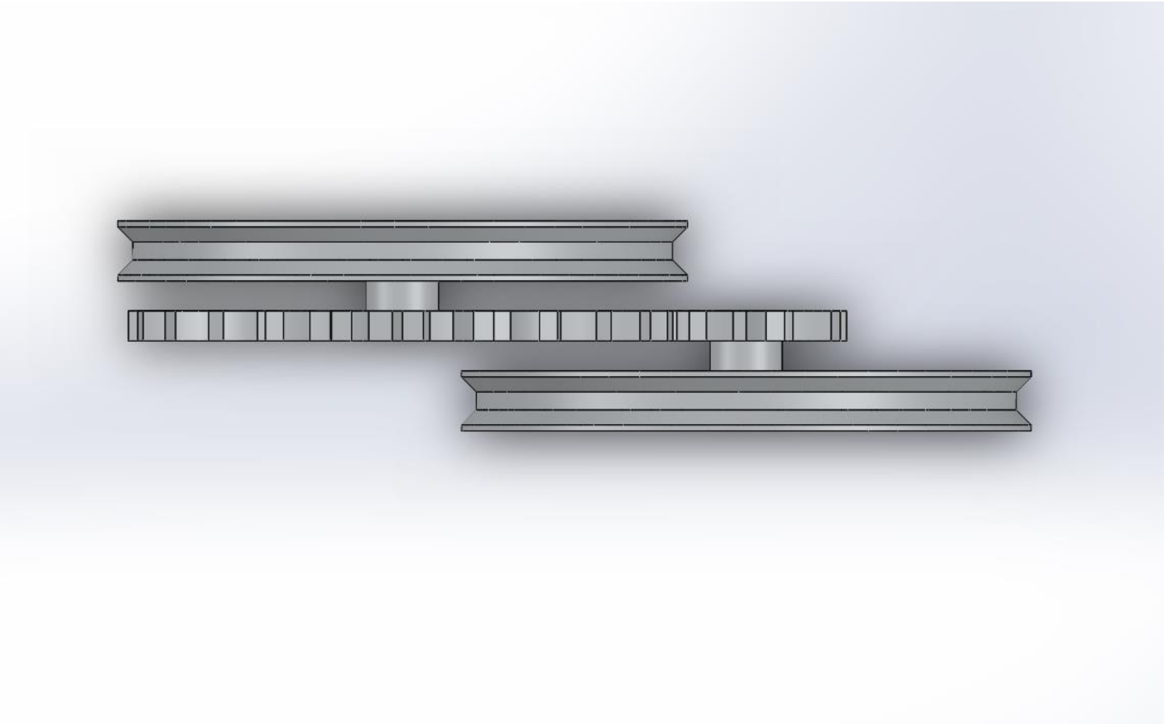

Figure 4.6 Top View of the Gear Transmission

4.2.7 Whiffle-Tree Mechanism

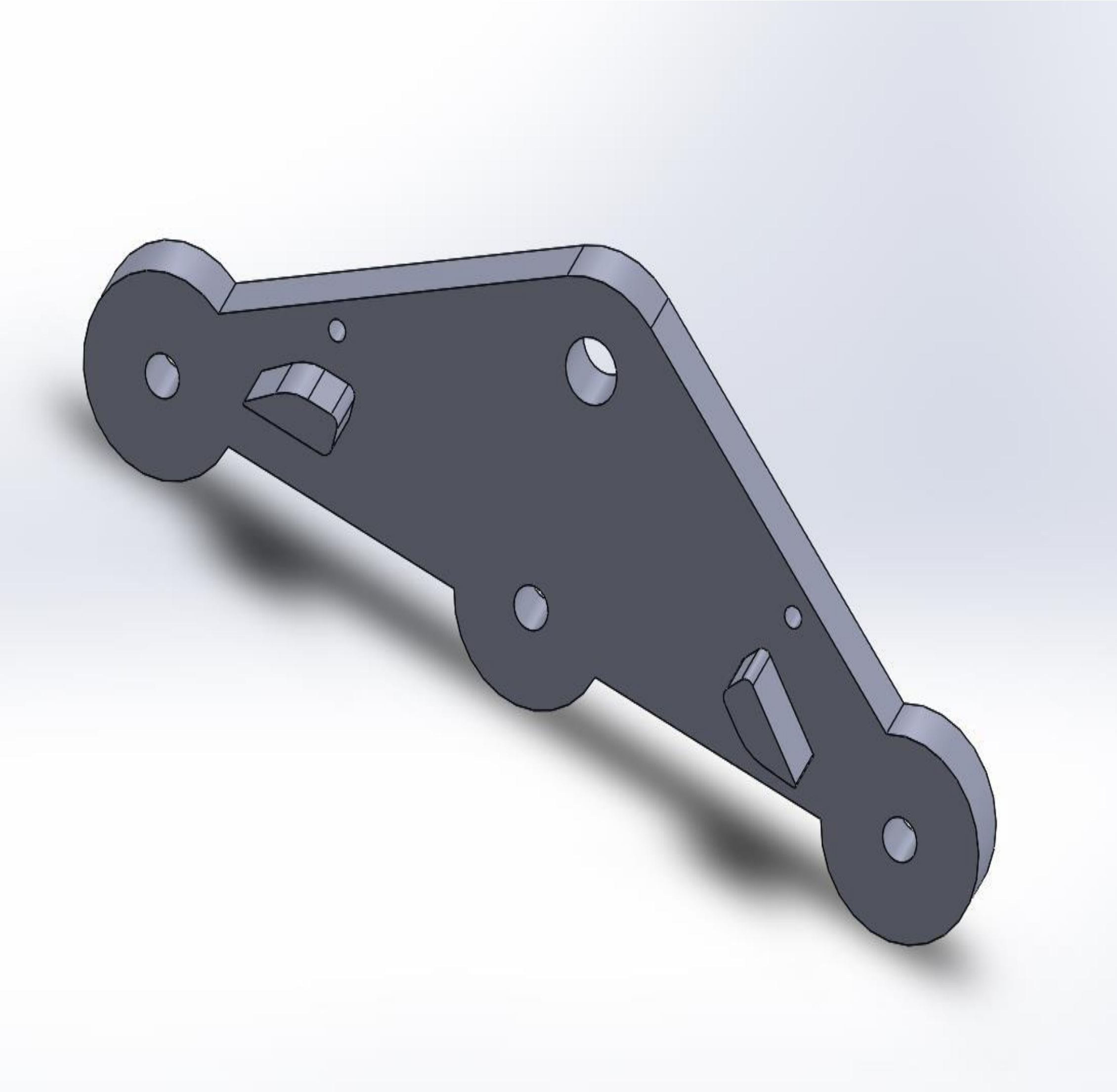

Figure 4.7 Whiffle-Tree Mechanism

4.2.8 Casing Covering for the Differential Mechanism

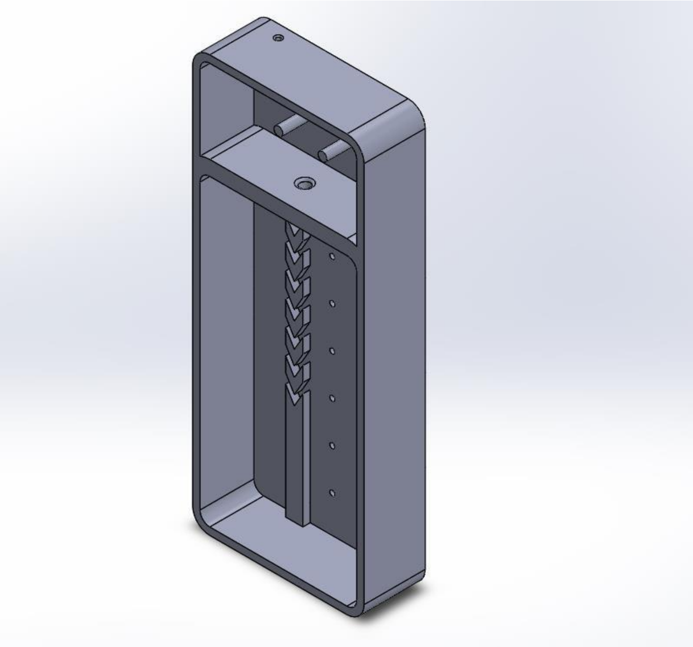

Figure 4.8 Casing Covering of the Proposed Mechanism

4.3 Mathematical modeling

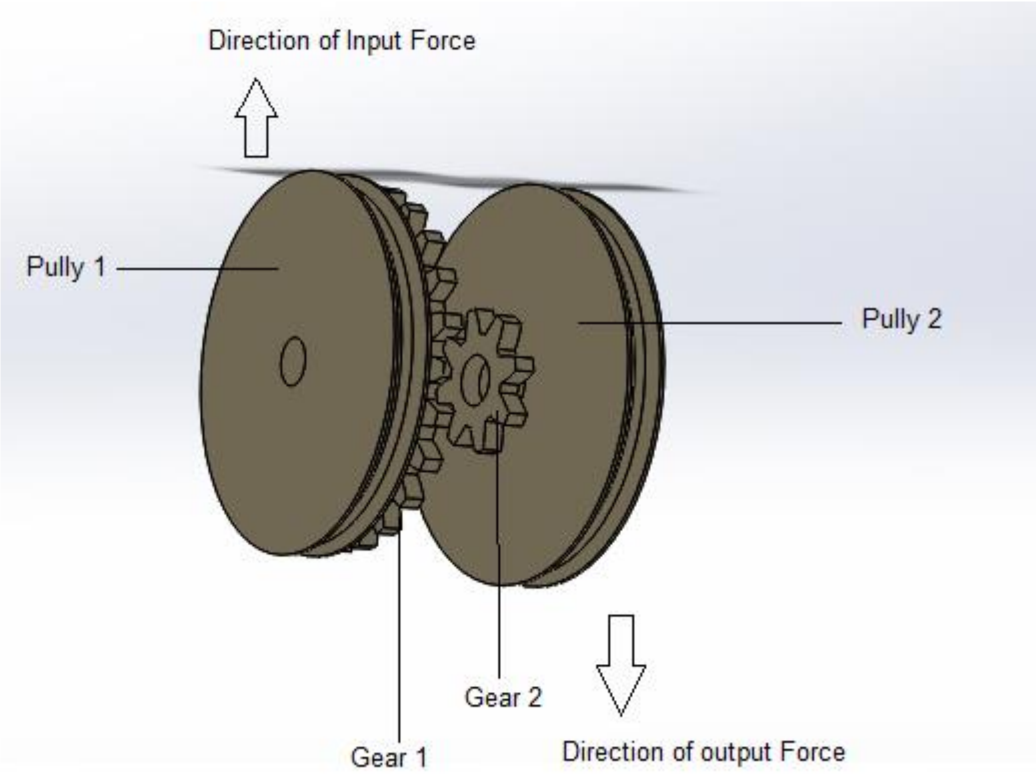

Figure 4.9 Proposed Mechanism

Design gear, such that the applied force become three times at the output.

Torque and angular velocity remains the same, on the same shaft. i.e.

$(T)_{P1} = (T)_{G1}$ $(T)_{G2} = (T)_{P2}$

$(W)_{P1} = (W)_{G1}$ $(W)_{P2} = (W)_{P2}$

Now, velocity ration is given by;

$W_1 / W_2 = r_2 / r_1 = D_2 / D_1 = N_2 / N_1$

For G_2 to complete three rotations on one rotation of G_1, we will have

$$R_1 / R_2 = D_1 / D_2 = N_1 / N_2 = 3$$

Now assuming, D1 = 6 cm. Then, $D_2 = D_1 / 3 = 6$ cm / 3 = 2 cm. Thus, $D_2 = 2$ cm.

Now $R_{P1} \times F_{P1} = Ra_1 \times F a_1$

$F_{G1} = R_{P1} F_{P1} / R_{G1}$

Assuming $D_{P1} = D_{P2} = 6$ cm So,

$F_{G1} = (3) \times F_{P1} / (3) = F_{P1}$

Thus, $F_{G1} = F_{P1}$

Now, $Fa_1 = Fa_2 = F_{P1}$ (meshed gears), and,

$T_{G1} = T_{P1}$

$R_{G1} \times F_{G1} = R_{P1} \times F_{P1}$

$F_{P1} = R_{G1} \times F_{G1} / R_{P1}$ OR $FP1 = \frac{RG1 \times FG1}{RP1} = 6/2 \times FG2$

Now $F_{P1} = 3 \times F_{G2}$

It means that the force will increased three times the applied force. For example, if 20 N force is applied at P_2 i.e. Pulley 2, then, $F_{G1} = F_{P1} = 20$ N $= Fa_2$. So, $F_{P1} = 3$

FP2 = 3(20) = 60 N

$F_{P1} = 60$ N.

4.3.1 Number of teeth(s)

To specify the number of teeth, we have to assume the module (m) of the two gears.

Assuming, module (m) = 1 and we know that $m = \frac{D}{N}$

For meshing, the module of both gears should be same. Thus

$m = m_{G2} = 1$ mm where

$$\frac{DG1}{NG1} = \frac{DG2}{NG2} = \mathbf{1}$$

Now, $N_{G1} = D_{G1} = (60) \times (1) = 60$ teeth's and

$N_{G2} = D_{G2} = (20) \times (1) = 20$ teeth's

4.4 Experimentation and Results of the Design

To evaluate performance parameters of the soft exoskeleton glove, different quantitative analyses were performed. These tests were done to ensure the ability of the device to rehabilitate the patients.

4.4.1 UTM Testing

One of the main design objective of this study was to develop a high strength polymer based glove that is also compliant to aid the fingers in their natural motion. Rhombus based structure was chosen for the glove as discussed in the Methodology section of this study because it offers 1 degree of Freedom in longitudinal direction. Hence more material can be placed at high stress points to increase strength while keeping the compliance constant.

Tensile testing of different design iterations which offer similar compliance was done on a Universal Testing Machine (UTM). It can be seen from the graph in figure 4.10 that the iteration 3 (Rhombus Structure) offers greatest strength among Rev1 and Rev2.

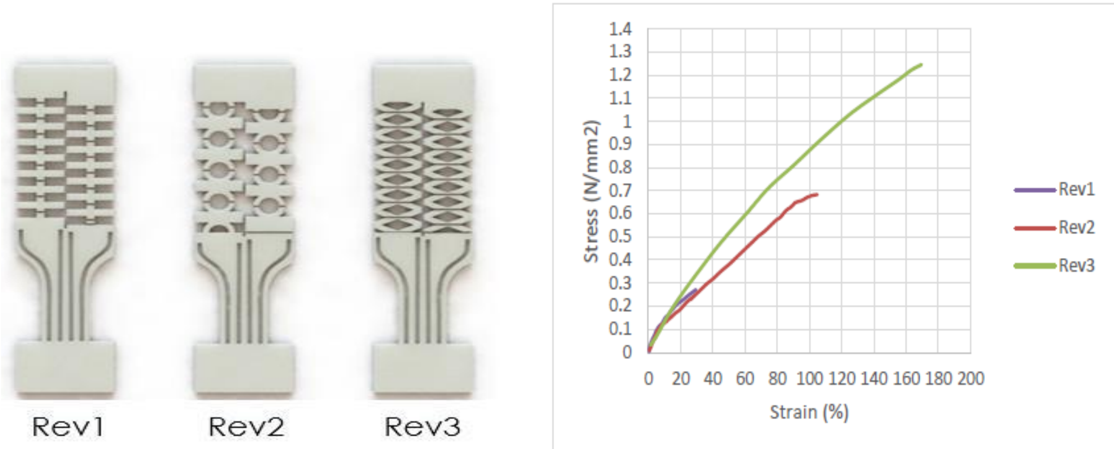

Figure 4.10 Stress – Strain graph of design iteration

4.4.2 Motion Tracking

This test was done to compare the motion pathways of finger with and without the aid of glove. The experiment was done by placing colored markers on Fingertip, PIP and DIP joint and tracking these using MATLAB via image processing. First the analysis was done with the glove put on and then with the glove removed. Then different colored markers were place on the mentioned point and their path was tracked via MATLAB. Image calibration was then performed and the final data was plotted which is displayed in figure 4.11. It can be seen that the finger follows roughly the same path with and without the aid of glove.

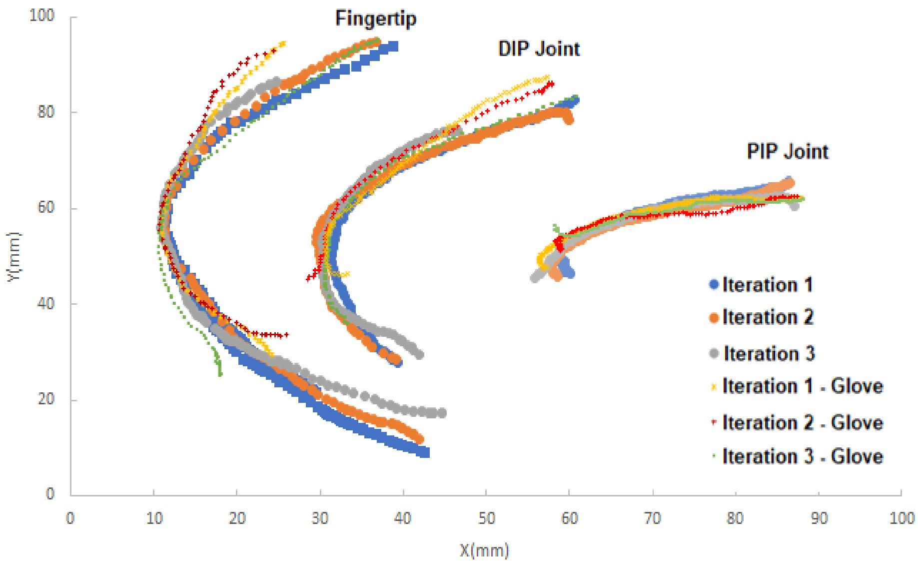

Figure 4.11 Bending Profile of Finger

4.4.3 Customer 3D Test Bench

To test the performance, the custom 3D-Printed test bench displayed in figure 4.12 has two screws connected to the load cells which can be screwed and unscrewed to increase or decrease the length. The test was designed so that there is a gap between the middle and index finger so that the performance of the exo-glove can be tested.

Figure 4.12 Custom 3D printed Test Bench

In future we will be opting different tests for assessing the performance of the device and troubleshooting short comes of our design. In the initial phase, the amount of grasping force generated at the fingertips will evaluated using the proposedtendon routing model.

CHAPTER 5: CONCLUSIONS AND FUTURE RECOMENDATIONS

5.1 Conclusions

The device was made of relatively decent quality material. The device was designed to be assistive in nature for the people with one or both limbs disability and for the people who are unable to perform daily life activities normally. The device can help people in performing most of the daily life chores. The device is body-powered and does not need any additional source for its operation. The device has the potential to transfer the controlled amount of energy to the tendons generated through the tension resulted by the movement of shoulders. The gadget was 3D printed using the light weight material, is quite affordable and is easy to replicate. This device can help people with their independence of actions without the support of people around them.

Despite of the fact that the proposed gadgets have different favorable circumstances as far as the weight, cost, autonomy, and power exertion abilities are considered, they additionally have a few constraints. For the body-controlled gadget, the user must have the option to execute body movements that transmit the powers from the shoulder area to the hand. Patients who experience the ill effects of extreme loss of motion probably won't have the option to execute these movements.

Bending profile of the fingers were found using tracking of colored markers via MATLAB to plot motion pathways of fingers with and without the aid of glove. It was observed that fingers followed approximately the same pathway thus proving that the exoskeletal glove helped movement of the fingers in their natural motion. Testing for material was done using Universal Testing Machine (UTM) and the polymer based glove was found to elongate almost 170% and break at greater than 90 N of force which proves its compliance and strength.

In this work, we presented a body-powered, assistive exo-glove and an under actuated, motorized, assistive exo-glove to augment the grasping capabilities of healthy individuals and to assist patients with physical disabilities.

5.2 Future Work Recommendations

In future, we intend to structure a system that permits controlling both way motion of the all the figures using minimum amount of input and without an external source of energy. We wish to enhance the internal mechanism of the differential through the improved internal setup that would help in making the size more compact and smaller of the device to make it more feasible to use, handier, more comfortable, and more effective.

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CERTIFICATE OF COMPLETENESS

It is hereby certified that the dissertation submitted by **Waleed Bin Mehdi**, Reg. No. **205512**, Titled: **Optimization of feature extraction and reduction techniques for improved control in assistive hand** has been checked/reviewed and its contents are complete in all respects.

Supervisor"s Name: **Dr.Sajid Ullah** Signature: ________________

Date: ________________