Progressive Rehabilitation in Stroke Patients Using EMG Controlled Exoskeleton

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Copyright Statement

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Abstract

The nervous system's interaction with other body parts and the environment to achieve desired and coordinated actions is known as motor control. It is a reflex and decision-based system that systematically regulates movement functions. If the contact is weakened or interrupted, a variety of neurological problems such as apraxia, tremors, and neurological and neuromuscular strokes may result. To improve hand function in stroke patients, new medical technology such as wearable gadgets and rehabilitative therapies are being developed. Because three-dimensional (3D) printing allows for the creation of low-cost, individualized devices, interest in applying this technology in rehabilitation equipment is developing in line with scientific discoveries. A novel electromyography (EMG)-controlled 3D-printed hand orthosis is demonstrated in this study. Force transfer is a major worry for these gadgets that are worn on the user's hand. The orthosis is designed to help stroke survivors recover their grip ability. As a result, active and passive devices can be utilized to perform a range of rehabilitation activities to regain or strengthen lost or compromised control while also improving strength, mobility, and motor conditions. Active devices are controlled devices used in rehabilitation to improve muscle function and restore appropriate biomechanics by providing stability, maintaining posture, and maintaining joint alignment. This device allows the wrist and fingers to move in specific directions depending on their degree of flexibility, allowing patients to do daily tasks more easily. Finger extension and flexion (hand opening and closing) and wrist extension are among the motions performed by stroke patients.

Key Words: Rehabilitation; Orthotic Device; 3D-Printing; Electromyography (EMG); Design and Simulation of Exoskeleton (DSE)

Table of Contents

List of Figures

List of Tables

1 Chapter 1: Introduction

Hand function, which includes dedicated finger flexion and extension movements, is critical for performing daily tasks including holding a glass of water, picking up a fork, and holding a pen. The ability to be autonomous is harmed by impaired hand function [1]. Patients with brain injury-induced hand function impairment are unable to interact autonomously with their surroundings, lowering their quality of life significantly[1][2]. The motor capabilities and mobility of stroke patients are frequently compromised. 70% to 80% of stroke survivors require long-term medical care[3] and have a low quality of life (QOL)[4]. These patients require hospital rehabilitation[5] and daily assistance from their families, resulting in expensive medical and care costs[6]. For patients with a hemiparetic arm, restoring hand function is a significant therapy goal to improve recovery outcomes[7].

Some stroke survivors who completed an upper extremity rehabilitation program were able to regain some proximal motor capabilities at the shoulder and elbow joints, but hand and wrist joint recovery was limited [8][9]. Hand skills such as opening and closing the hand are important for many daily tasks, however, developing an effective training device for hand function rehabilitation has proven difficult. For individuals with unilateral hemiparesis or hemiplegia, bilateral hand training is a viable rehabilitation approach [10][11]. When performing a task, such as holding an object, both hands are employed symmetrically. Bilateral hand training, therefore, improves the affected hand's performance. According to research, bilateral arm motions across the hemispheres stimulate additional brain circuits, such as the supplementary motor area and primary motor cortex, which aid in the motor recovery of the damaged hand [12]. In patients with unilateral hemiplegia, using the less-affected arm makes it easier to regain hand function. As a result, in a rehabilitation program, excellent bilateral hand training is sought to recover patients' hand function and allow them to conduct daily activities independently.

The method used for additive manufacturing of objects from verity of materials [13][14]. Because of its cost-effectiveness, adaptability, and increased productivity, this technology has sparked a lot of interest in the biomedical field [15][16]. In the early 2000s, it was first used to produce dental implants. Since then, the technology's biomedical applications have been divided into other fields, including rehabilitation engineering [17]. Furthermore, when compared to earlier metal orthoses, additive manufacturing technique used for manufacturing orthotics is regarded as a viable option for economical and speedy fabrication. The bulk of the studies compared lower limb orthotics, to traditional techniques [18]. Abdallah et al. proposed an additive manufactured electromyographic prosthesis that can assist stroke victims with finger movement. They demonstrated in the study that the developed orthosis improved finger motion. They proposed classifying the system as a continuous passive motion device [19].

The demand for new hand orthoses is increasing as technology advances. We presented a revolutionary electromyographic hand orthosis for stroke paralyzed patients that use 3D printing and given functioning grasp. Using additive manufacturing, an inexpensive orthosis that is appropriate all stroke patients and preserving necessary functions. In addition, the controller's input was surface EMG signal. The apparatus makeup is such that it can interact with a customized EMG setup, allowing it to identify and manage the user more intuitively. The study's purpose is to demonstrate how a 3D-printed myoelectric orthosis impacted stroke victims.

1.1.Background

Rehabilitation robotics is a new and quickly expanding area that is beginning to make its way into therapeutic settings. The discovery of training-induced restoration of sensory function in animal models with central nervous system injury in the late 1980s and early 1990s sparked a series of key technological improvements [20]. The goal was to increase the training program's effectiveness by gradually increasing treatment intensity and giving responsive help.

The concept of utilizing robots to assist with rehabilitation has been around for a while. Theodor Büdingen proposed movement cure equipment,' a motor-driven mechanism that would control and assist walking motions in heart patients, in a patent issued in 1910. Richard Scherb invented the Meridian,' a cable-driven or orthopedic treatment device, in the 1930s.

In 1989, a new era of neuro-rehabilitation robots began with the introduction of the MIT-MANUS [21], which was first evaluated clinically in 1994. This planar manipulandum has a low mechanical power output frequency-dependent impedance to motion experienced during the interaction between the human user and the robot system, in comparison to industrial manipulators. Around the same time, the Mirror Image Motion Enabler (MIME) was introduced, allowing a stiff industrial robot to control paretic limb motions via a motion encoder (mirror-image therapy mode).

Since these groundbreaking discoveries, innovative rehabilitation robots have developed to include both the upper and lower extremities and can be divided into three types: grounded exoskeletons, grounded end-effector devices, and wearing exoskeletons. Exoskeletons have a serial kinematic structure, in which proximal joints must move distal joints, have better motion dynamics and can match a larger variety of impedances than grounded end-effector devices [22].

The usage of neuroplasticity is required for the restoration of motor function following CNS injury [23] [24]. To produce effective arm and hand motions, scientists combine physiological limb stimulation and stimulation of critical peripheral receptors during mechanically executed leg movements like walking. As a result, rehabilitation robots should be able to aid and facilitate this kind of training.

1.2.Problem Statement

Motor control is lost as a result of numerous impairments in neurological and musculoskeletal systems, which can lead to neurological illnesses, strokes, and deformities. As a result, various exercises are conducted utilizing various types of active and passive equipment to recuperate lost or weak muscle control and increase muscular strength, mobility, and motor coordination. This device permits the wrist and fingers to actively execute a motion in a certain direction based on their degrees of freedom, assisting the patient in performing daily activities. It was ensured that the design is ethically sound, comfortable to wear, non-hazardous, and devoid of hazards and electric shocks.

1.3.Objectives

Design a controllable and user-friendly home-based physiotherapy equipment for opening and closing hand and wrist motion that is cost-effective, ergonomic, properly operating, easy to manage, and provides the needed motion, mobility, and coordination.

1.4.Areas of Application

Hospitals, physiotherapy units, rehabilitation centers, and educational institutions can all benefit from the system.

1.5.Thesis Overview

This dissertation has six chapters. Chapter 1 presents the research topic and discusses the problem statement, significance, and research objectives. Chapter 2 provides a thorough review of the literature, such as the anatomy and physiology of the human hand, as well as needs and limitations. Chapter 3 discusses the modified methodology used in the device's development. The chapter develops the software design and system components sequentially, including block diagrams, drawings, and electrical and mechanical details. Chapter 4 discusses the device's merits and drawbacks. Chapter 5 illustrates the analysis' findings and additional observations. Chapter 6 concludes the project and makes recommendations for improving the developed study It also talks about future improvements.

Chapter 2: Literature Review

A stroke is caused by an unexpected interruption or disruption in blood flow to the brain, which distributes important nutrients and oxygen to brain tissues via blood arteries and is required for brain cells to perform certain functions [25]. When the brain's blood supply is cut off for 4 to 8 minutes, brain tissue starts to die [26].

The brain is organized into several parts, each of which performs a specific function. As the tissue dies, the brain loses some of its functions. Some of the cells may survive and regenerate if blood flow is restored. A stroke is defined as a condition that lasts more than or equal to 24 hours, whereas a Transient Ischemic Attack lasts less than or equal to 24 hours. According to the WHO, stroke affects more than 15 million individuals worldwide each year. Whereas 33% of sufferers are chronically incapacitated, 34% recover, and 33% decrease [27].

There are two categories of risk variables: modifiable risk factors and non-modifiable risk factors. Non-modifiable features include genetics, age, race, and low birth weight, to name a few. Independent predictors include hypertension, diabetics, diabetes mellitus, LV dysfunction, alcohol misuse, drug use, asymptomatic carotid stenosis, hyperlipidemia, and migraine [28].

2.1. Stroke Classification/ Types of Strokes

Stroke is divided into two main groups, which are discussed below:

2.1.1. Ischemic Stroke

Ischemic stroke occurs when the blood flow is disrupted due to partial or total obstruction of blood arteries. Ischemic strokes are caused by blockages inside or outside the brain (other parts of the body) and account for the majority of strokes worldwide. Atherosclerosis is a disorder in which the walls of blood arteries narrow due to the accumulation of fat and other substances [29].

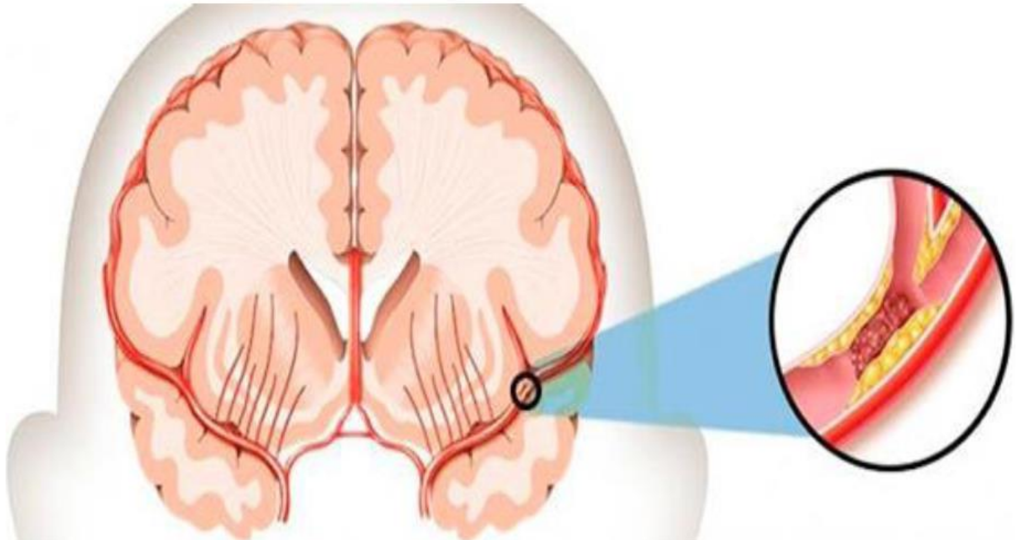

Figure 1 : Clot formation within the vessel

2.1.2. Hemorrhagic Stroke

The supply of blood to the brain tissues is cut off if a blood artery within or outside the brain bursts. As a result of the lack of nutrition and oxygen, necrosis of brain tissue develops. Hemorrhagic stroke accounts for 30% of all strokes globally and has the highest death rate [30]. The hemorrhagic stroke inside the brain is depicted in the diagram below:

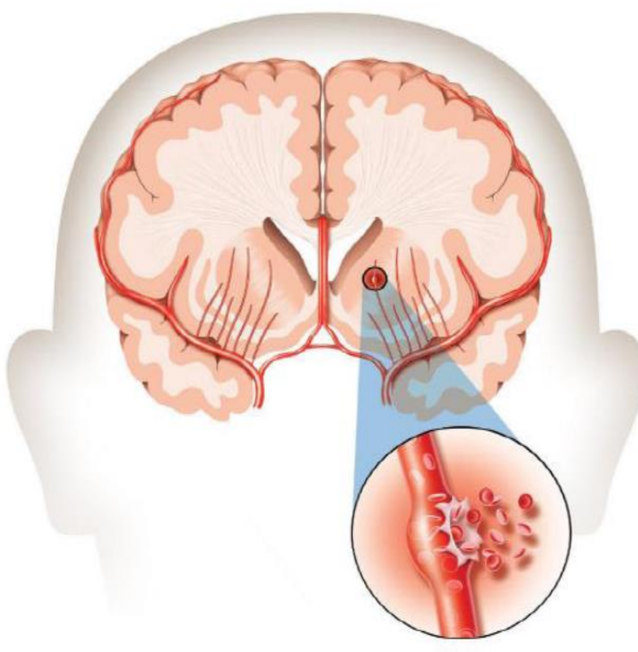

Figure 2: Vessel Rupture within the Brain

2.2. Effects of Stroke

Stroke is the world's second leading cause of death [31]. Similarly, many stroke survivors require rehabilitation to return to normal life. The very first stage of rehabilitation is to determine the damage caused by the stroke to a specific part of the brain, including the functions and abilities lost as a result of it. The right and left hemispheres, the brain stem, and the cerebellum are the four parts of the human brain [32].

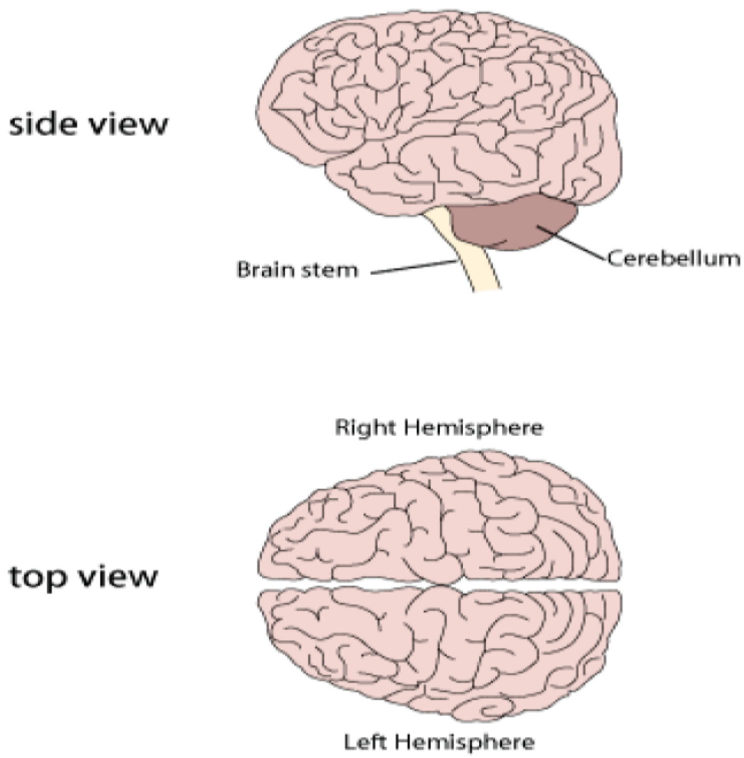

Figure 3: Different Brain Sections

2.2.1. Right Hemisphere Damage

The right hemisphere controls the movements of the left side of the body. Short-term memory loss, difficulties judging distances, size, and speed (Spatial abilities), difficulties 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 are all caused by damage to this part of the brain (Impulsive behavior).

2.2.2. Left Hemisphere Damage

The left hemisphere of the brain controls vocalizations, words, and right-side movements. Injury to this area can result in trepidation, difficulty forming sentences, difficulty comprehending words in reading and writing, paralysis of the right side of the body (Right Hemiplegia), and memory loss.

2.2.3. Brain Stem Damage

Damage to the brain stem is dangerous because it administers unintentional functions of the body. It controls breathing, heartbeat, and blood pressure. Eating, moving the eyes, hearing, and speaking are some of the other functions. Coma, double vision, and total paralysis on either side of the body can all result from damage to this area of the brain.

2.2.4. Cerebellum Damage

This area of the brain is in charge of balance, bodily coordination, and many-body reflexes. Dizziness, nausea, and slurred speech are all symptoms of cerebellar damage.

2.3. Recovery

After a stroke, the brain and body begin to repair in the first few hours after the patient has been stabilized. The first few weeks of this process are critical because this is when the body recovers the fastest. The first two weeks will account for more than half of the recovery in the first three months [32]. Interconnected social, psychological, and physical aspects influence the patient's results during the healing process. Because the relationship between these variables and their relevance is unknown, numerous theories on how the brain reacts after a stroke has evolved.

2.3.1. Reduction of Brain Swelling

The natural response of the body to tissue death is to fill it with water and white cells. Because the injury occurs within the brain, the tiny gap between the brain and the cranium is filled, increasing pressure on healthy tissue. Extreme pressure and a lack of nourishment cause certain brain functional regions to shut down. As a result, some functions have been disabled. When the edema begins to fade and the dead tissue is naturally cleared, the patient's damaged functions are restored, and a visible recovery occurs. This only applies to healthy tissue not affected by the stroke.

2.3.2. Possible Growth of Nerve Axons

Although only a small percentage of injured brain tissue regenerates, it can help restore some lost functions. Neural precursor cells multiply and develop into new neurons near the injured area, forming new circuits that did not exist before the stroke. This occurs 7 to 10 days after the stroke [33].

2.3.3. Use of Other Parts of the Brain

Normal brain regions (those that were not used to perform the lost functions) adjust in this situation to deal with the stroke-affected connections and processes. Neuroplasticity is gaining traction in the scientific community, with significant advances made in recent decades. Still, a thorough understanding of the mechanisms at work is lacking.

2.3.4. Coping with the Disability and Adaptation by Others

Individuals can learn new ways to perform activities with the help of other parts of their body, external equipment, or people. This method is critical because the individual may be able to live with the impairment while performing "routine" tasks. Family members, friends, and doctors are all involved in this procedure and are always willing to help the patients.

2.4. Post Stroke Rehabilitation

Rehabilitation is an essential component of a patient's return to normal life. It could focus on motor, speech, vision, neurological, psychological, or any other treatment related to the impairments caused by the incident. Because the brain responds faster and repairs itself more quickly after a stroke [34], it is critical to begin rehabilitation as soon as possible. The patient's rehabilitation varies depending on how long it has been since the stroke, including intensity, concentration, length, and type of activity, among other factors. As a result, the treatment is divided into four distinct phases:

- **Acute phase**

This phase covers the first few hours to a week following a stroke. Rehabilitation is carried out with a focus on respiratory function, coughing, and swallowing abilities.

- **Subacute Phase**

From the second to the fourth week following the stroke, the main focus of therapy is on motor and verbal control.

- **Chronic Phase**

After six months, the chronic phase of the stroke begins. During this phase, task-oriented exercises are undertaken to help the patient achieve long-term independence. Rehabilitation includes not only healing but also reintegration into society and achieving the highest level of independence possible. The patient's family and therapists must work hard to keep the patient stimulated and focused on the therapeutic goals. Because many obstacles may not become obvious for months after a stroke, a constant assessment of rehabilitation should be documented and used to develop new strategies and goals.

2.5. Anatomy of Upper Limb

The region stretching from the deltoid region to the hand, comprising the arm, axilla, and shoulder, is known as the upper limb or upper extremity. [35].

The upper limb of a human being consists of the following parts:

- Shoulder

Connected with the pectoral girdle and forearm.

- Arm (Humerus)

Connected with shoulder and elbow.

- Elbow

Connects forearm and arm.

- Forearm (radius and ulna)

Connects with the wrist and elbow

- Wrist

Connects with hand and arm

- Hand (palm and fingers)

Connected with the wrist.

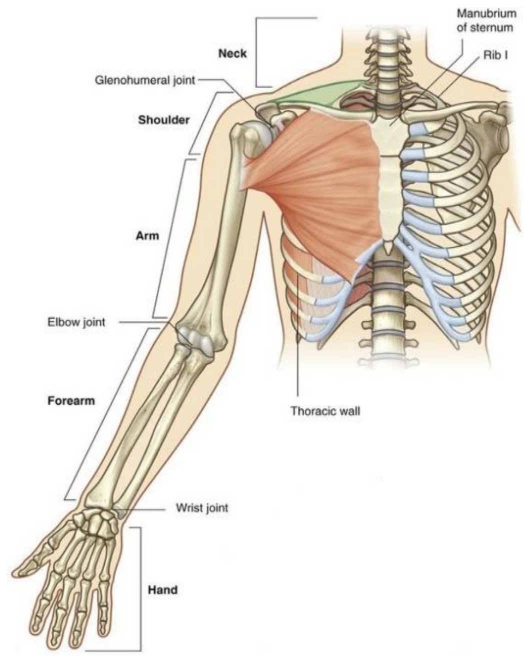

Figure 4: Anatomy of Upper Limb

The hand and wrist anatomy are intricate, complex, and fascinating. Its consistency is quite useful in regular living functions.

2.6. Anatomy of Hand

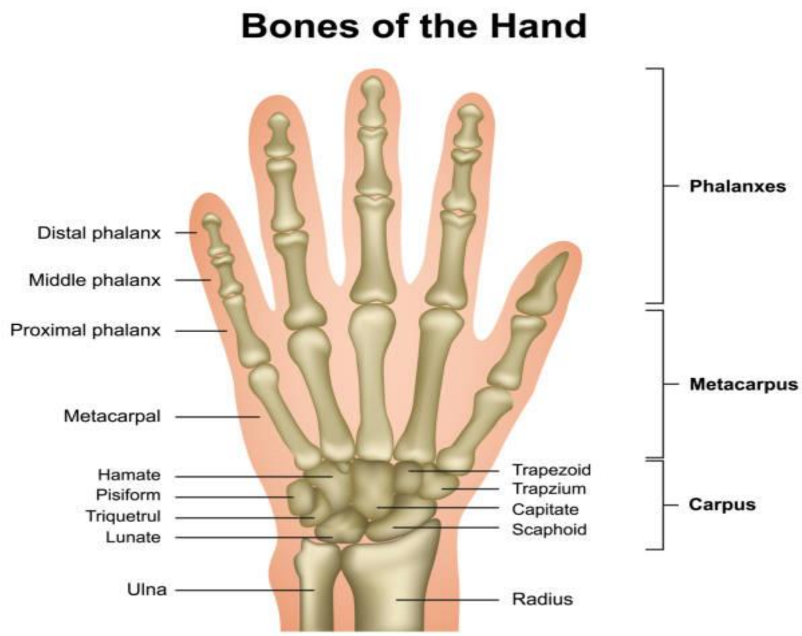

Figure 5: Joints in Hand

The hand and wrist skeleton of a human being is made up of 27 bones [36]. There are five metacarpal bones in total. A metacarpal is distinguished by its base, shaft, neck, and head. The thumb is the shortest and most movable of the metacarpal bones. The trapezium articulates with it proximally, whereas the trapezoid, capitates, and hamate articulate with it near the base. The heads of each metacarpal articulate distally with the proximal phalanges of each digit. In a human hand, there are fourteen phalanges. Each finger has three phalanges with the names proximal, middle, and distal, except the thumb, which has just two. Instead of being referred to by its numerical value, each digit is given the names thumb, index, long, ring, and tiny.

2.7. Movements and motions

Muscles and tendons are responsible for hand movement [36]. These are the tissues that form the link between bone and muscle. When the muscle contracts, the bone is pulled. The fingers move as a result of this pull. The forearm contains the muscles that control the movement of the thumb and finger. Long tendons originate and stretch from these muscles, connecting the tiny bones of the thumb and finger and flowing through the wrist.

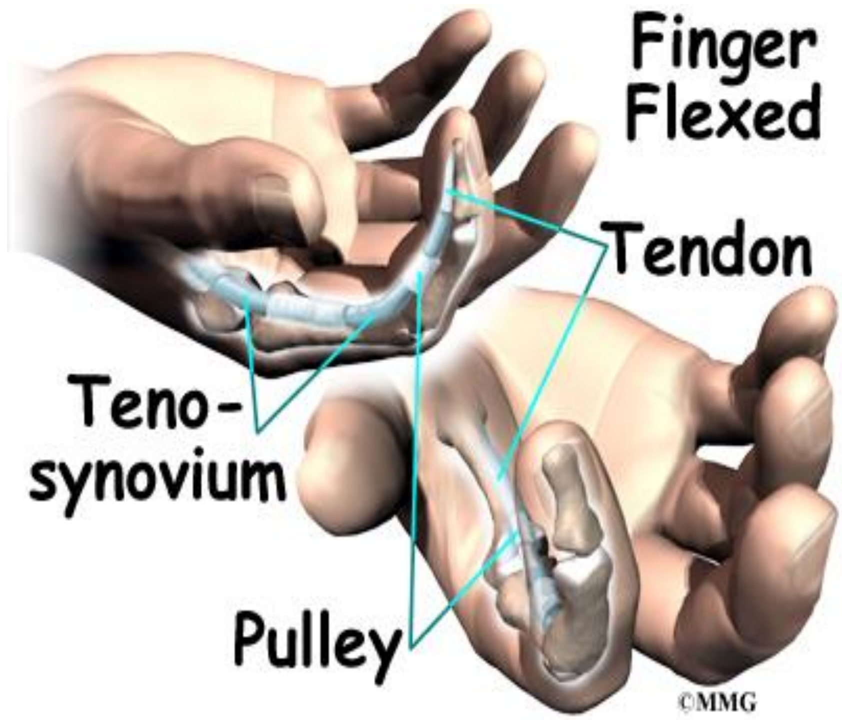

Figure 6: Tendons for Movement

2.7.1. Extensor Tendons

The tendons on the top of the hand help to strengthen the fingers. Extensor tendons are the name for these sorts of tendons.

2.7.2. Flexor Tendons

The flexor tendons are the tendons that help you bend your fingers. The flexing tendons moving through the singing tunnels hold the tendons located near the bones in place when the finger is flexed or straightened through the tendon sheath. [36].

Table 1: Hand movements fingers Flexion and Extension

Fingers motion	Images	Description
Closed Hand (Flexed Fingers)		Flexed fingers are defined as the folding of the fingertips and finger joints from a straight position into the palmer creases.
Opened hand (Extended fingers)		Straightening the fingers outwards away from the palmer creases is accomplished by moving the fingertips back to the starting place.

2.8. Physical Therapy

Physical therapy is mostly used to assist stroke victims in regaining their independence and mobility. This is done with the support of a skilled therapist, who assists the patient in overcoming the limits and debilitating effects of their sickness. It's important to remember that physical therapy doesn't try to "cure" the ailment. It merely aims to improve the disorder's functional limitations.

The first step in physical therapy is to evaluate the patient's condition from multiple angles, including the range of motion, strength, sensation, muscle tone, mobility, motor status, balance, and respiratory status [37].

2.9. Orthotic Devices

As part of the rehabilitation process, therapists may recommend orthotic devices to help address persistent impairments or boost recovery chances. The orthotics for stroke therapy has been updated to follow the neurophysiological principles of recovery.

These devices can also be used to stabilize or immobilize bodily components and repair or prevent abnormalities. They may be used for short-term or long-term rehabilitation, depending on the patient's condition. These gadgets are classified into three groups.

- **Assistive**

  These gadgets are used to help people with spasticity and joint functioning.

- **Protective**

  The primary goal of these devices is to limit joint range of motion to minimize tissue rupture, prevent deformity, and support unstable joints, bones, and muscles.

- **Corrective**

  These devices aid in the correction of joint, bone, and tendon contractures.

2.10. Robotic Orthotic Devices

In recent decades, there has been an increase in the number of orthotic devices that use electrical and mechanical components to perform their functions. This is because introducing innovative technological advancements in the field of rehabilitation enables the implementation of more efficient and cost-effective rehabilitation programs. Work has been completed on the loss of functions caused by neurological disorders, stroke patients, paralysis, and so on. For patients with post-stroke conditions, a device called HANDEXOS [38] was developed. The primary goal of the exoskeleton was to teach the impaired hand a safe motion. Training or exercises can be carried out in medical facilities as well as in people's homes.

In a world where specialist labor costs are rising, robotic orthotics offer a fantastic opportunity to reach more patients without increasing the number of therapists and to keep patients motivated without the need for direct directions. Furthermore, automated orthotics provide rigorous and continuous therapy without tiring out the therapist, eliminating the risk of human error caused by repeated and consistent efforts to move the patient. Robotics [21] has played a significant role in physical therapy for stroke patients, such as the hand Gripper. This allows the hand the opportunity to practice gripping and grasping techniques.

Patients who are unable to visit a therapist's center or office may benefit from a robotic orthotic device that can be adjusted to their specific needs during their leisure time. In this case, a therapist may make frequent visits to assess progress and make any necessary changes to keep the programmer running.

2.11. Electromyography (EMG)

Electromyography is a graphical method for quantifying electrical impulses delivered to muscle fibers by motor neurons, allowing researchers to study muscle activation in a variety of situations [39]. In general, fatigue studies have shown that EMG data increases during a fatiguing procedure, but fatigued individuals activate fewer muscle fibers in power tests [40][41].

When measuring fatigue with EMG, median power frequency is commonly utilized. Raw EMG data is filtered and processed to remove noise, after which appropriate time frames are obtained [42][43].

The median frequency is calculated for each data window. In terms of time, a drop in the median frequency is a sign of exhaustion [44][45]. Motor unit action potentials have a similar repolarization pattern, with quicker motor neurons acting first and then decreasing, and nervous system propagation rate decreasing over time, both of which contribute to fatigue [46].

2.12. Summery

The chapter includes a comprehensive assessment of the literature on the subject. It goes through the anatomy and physiology of the human hand and wrist and how they move.

Chapter 3: Methodology

In comparison to prosthetic devices, rehabilitative orthotic devices are more challenging to create. Space constraints as well as the restrictions of normal joint movements must all be considered. When it comes to prosthetic devices, there are no restrictions on where motors or other components can be placed. The following are some exoskeleton design parameters:

1. It should have the greatest range of motion possible.
2. It should be lightweight, portable, and long-lasting.
3. It should be able to move indefinitely.
4. It should be simple to use and secure.
5. There should be a variety of degrees of freedom.

3.1. Motion and Angular Study of Hand

It is vital to research a device in all of its connected elements before constructing it. The required relative hand motions and angles were investigated with the help of a 'Gloreha Sinfonia' [47]. The spring-loaded gadget was worn on the wrist in conjunction with the arm and fingers.

3.1.1. Biomechanics of Hand

To develop any design for the hand, it is necessary to examine the biomechanical structure of the wrist and hand. The wrist connects the palm to the arm and is an important component. It is a combination of multiple bones, joints, and muscles that work together to accomplish the body's most complicated movements. It consists of a complicated network of joints that connect the carpal bones to the radius and ulna bones. The wrist is responsible for hand flexion and extension.

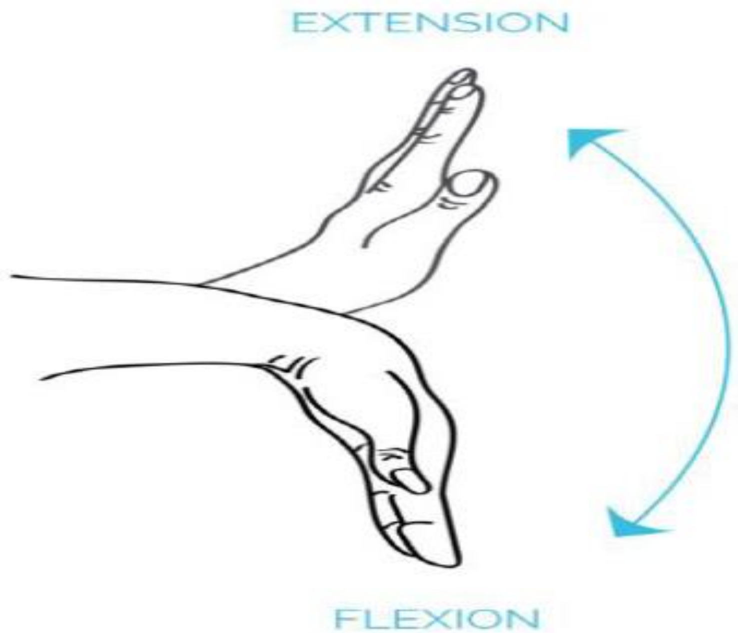

Figure 7: Wrist Flexion and Extension

The muscles in a stroke victim's body stiffen over time, a condition known as spasticity, making it difficult for the person to function with the affected part of the body. Muscle breakage might occur if it is not treated properly. As a result, knowing the joint's mobility/ range of motion (ROM) of the joints is critical. The table below depicts some of the most important ranges of mobility for various joints in the human hand.

Table 2: Range of Motion (ROM) of Wrist in Human Hand

Joints Under observation	Motion Description	Range of motion (ROM) in degrees
Wrist	Flexion Extension	50-60 80-90

In the same way, the table below displays the range of motion (ROM) for the joints in the fingers of the human hand.

Table 3: Range of Motion of Fingers in human Hand

Name of the Joints of the finger	Motion Description	Index ROM in Degrees	Middle ROM in Degrees	Ring ROM in Degrees	Pinky ROM in Degrees	Thumb ROM in Degrees
DIP	Flexion Extension	73 11	80 11	75 11	78 11	74 11
PIP	Flexion Extension	101 12	103 12	105 12	103 07	100 07
MCP	Flexion Extension	88 -20	90 -22	88 -22	90 -24	90 -24

DIP: distal interphalangeal, PIP: Proximal interphalangeal, MCP: metacarpophalangeal

3.2. Material Selection and Design

A variety of hand orthotics can help patients with hand restrictions. The majority of orthotics, on the other hand, are made in a mold and are meant for the treatment of hand malformations while limiting functional movements [48]. Patients rarely utilize the flexor hinge splint, a traditional metal tenodesis splint, to improve prehension grasp because of its expensive cost and difficult construction. Because it is easier to make and cheaper, it can only be used by those who can stretch their wrists against gravity [49]. Furthermore, despite the implementation of novel robotic exoskeletons, electrically actuated orthoses are rarely profit-oriented because they are expensive. Broadened Horizons, Minnesota, USA (Power Grasp) has commercialized an electrically driven functional hand orthosis, however, it costs more than $5000 [50].

3.3. Mechanical Design

The computer-aided design software was used to model orthosis's' 3D architecture (Pro-Engineer). The arm, wrist, and finger ring pieces make up the intended orthosis. The forearm cuff is divided into two parts: a lateral and an anterolateral forearm splint. A linear actuator is attached to the dorsal forearm splint to regulate wrist extension. With a stroke length of 41mm, it can generate 30 Newtons of force. A Velcro strap connects the lateral forearm splint to the anterolateral arm splint, allowing it to be fitted to the participant's forearm. The linear actuator is coupled to the hand component, which is wrapped around the hand. The wrist component is dragged toward the forearm when the motor is turned on, causing the wrist to expand. The ring fitted on the finger is joined to anterolateral arm splint with the help of a string.

The string tightens when the linear actuator extends the wrist, strengthening the grip. Every finger's interphalangeal and metacarpophalangeal joints, including the thumbs, flex at the same moment when the wrist is extended. When the wrist is extended, the amount of nylon string is adjusted so that the ring sections of the fingers can be pulled sufficiently. This is a crucial aspect of orthosis that allows it to be used for stroke therapy by more patients. The length of the nylon string is changed as the wrist is extended to give enough pulling on the finger ring sections.

To make the orthosis, the breadth and length of each joint was assessed before additive manufacturing. The distance across the palm from the index to the little finger metacarpal-phalangeal joints is the handbreadth [53]. Because PLA is a thermoplastic, all 3D-printed parts were warmed with torch gas and fine-tuned to the specific hand shape. To prevent skin erosion, the self-adhesive patch is affixed inside the hand after re-adjustment. The orthosis is meant to use the patient's joint rather than any mechanical joint. The gadget can accept any such wrist deviation by removing the orthosis' artificial joints.

3.4. Electronics of Orthosis

The designed myoelectric exoskeleton is designed to be controlled by surface EMG obtained in the unaffected hand muscles of stroke patients. So, when EMG output reached the predetermined threshold, the control unit activated the linear actuator. The position of the EMG electrodes is adjusted based on the severity of the damage and the subject's comfort to obtain accurate signals. We must identify suitable muscles that are both accessible and conserved. The flexor digitorum superficialis, flexor digitorum profound, and flexor policies longus of the patient's unaffected hand were chosen to implant the electrodes for surface EMG in this study. According to the surface EMG guidelines for noninvasive muscle assessment, two electrodes should be placed on the most conspicuous protrusion of the muscle belly, with an interelectrode distance of 2 cm [51]. The wrist of the unaffected hand contains a ground electrode.

The surface EMG signal is processed before the orthosis is applied, 1000-fold signal amplification is performed, and background noise is eliminated using a filter. The surface EMG signal is the most used and is related to load and muscular contraction, the root means square (RMS) is the parameter for regulating the linear actuator [52][53]. Figure 8 depicts the raw surface EMG signal as well as the RMS for each condition. To separate signals from unwanted movements, the on/off threshold in RMS is adjusted to 80% of the maximum contraction level. The individuals were, however, free to change the threshold value until they were satisfied. As a result, the threshold might be tailored to the users' abilities and injury state. The RMS could be stated in the following as:

$$\boldsymbol{RMS} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} \boldsymbol{X}_{\boldsymbol{i}}^{\mathbf{2}}}$$

A microcontroller board called Arduino is used. It had an analog input with a resolution of 10 bits and a frequency of 1000 Hz. The control unit and the linear actuator were powered by a 12-volt rechargeable lithium-ion battery. To enhance portability, the controlling unit is designed to be as tiny as feasible. The control box's size and weight are determined by the patients' requirements.

The myoelectric exoskeleton activates and the exoskeleton flexes the fingers when the RMS value is obtained of the surface EMG signal surpasses. If the signal rises above the threshold, the orthosis reverses and the fingers are extended back to their position.

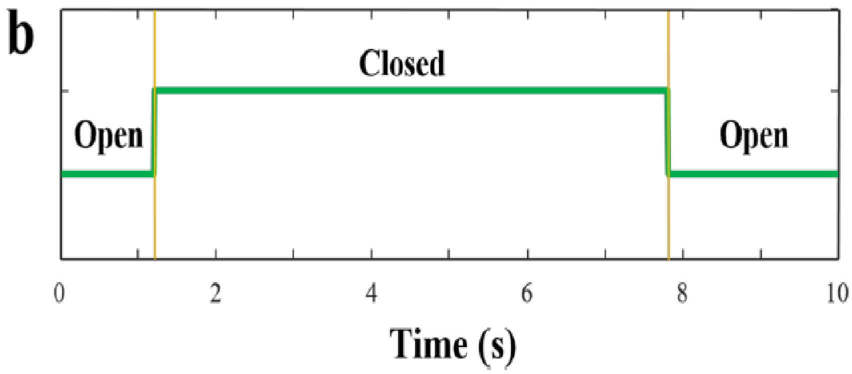

Figure 8: Opening and Closing of Hand

3.5. Circuit Block Diagram

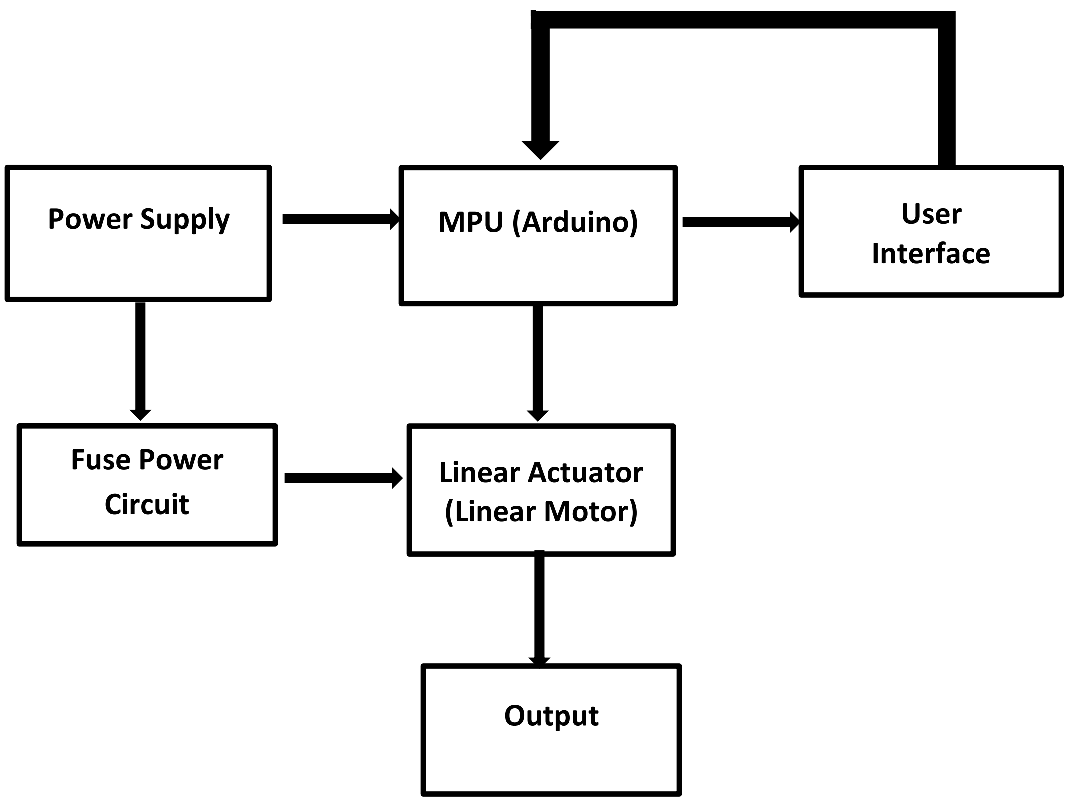

Figure 9: Device Circuit Block Diagram

3.6. Participants Selection

• Cognitive Ability: Individuals ought to have sufficient cognitive and linguistic abilities to focus on the task for at least 10 minutes and follow the therapist's directions.

• Vision: The psychotherapist should assess whether or not the individual can see a detailed vision of the work at hand

• Trunk Control: During treatment, the patient can sit independently in a wheelchair or regular chair.

• Non-affected Limb: The non-affected arm should have a normal range of motion and be pain-free.

3.7. Components

The device's main structure and design are made of Polylactic acid (PLA) filament, which is commonly used in 3D printing.

3.7.1. Polylactic acid (PLA)

PLA (polylactic acid) is a biodegradable polymer used in a wide range of clinical applications. For bone repair and reconstruction, PLA is routinely machined into complicated shapes. Solid freeform fabrication technologies like 3D printing may generate complex-shaped things straight from a CAD model. Polylactides are biodegradable polyesters used in a variety of medical uses. Surgical materials, bone repair and regeneration, delivery of drug gadgets, nerve regenerating guides, and ligament reconstruction all use polylactides. PLA may provide an advantage over rigid fixation systems made of metals like stainless steel for bone fixation and reconstruction.

3.7.2. Attachment Rings

The connection rings are made to order according to the patient's demands, including which side of the brain is affected and which hand will be recovered. The ring is designed using 3D CAD software and then 3D printed, enabling it to fit the thickness of the digit. PLA is the material used in 3D printing.

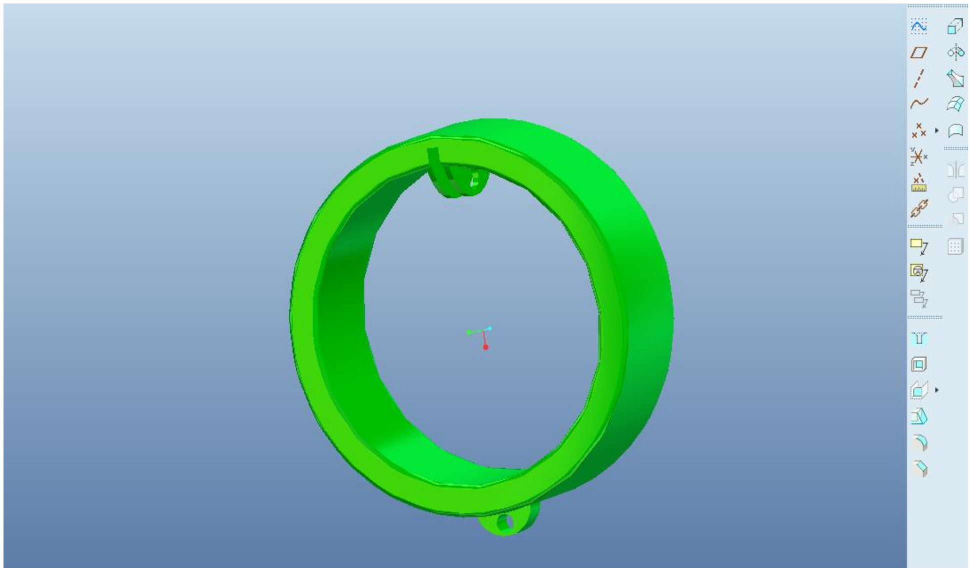

Figure 10: Attachment Ring

3.7.3. Linear Actuator Assembly

There are two pieces to the forearm cuff: a lateral and anterolateral forearm splint. To control wrist extension, a linear actuator is coupled to the anterior forearm splint. It can create 30 Newtons of force with a stroke length of 41 mm. The forearm splint is connected as an anterolateral splint by a Velcro strap, allowing for forearm modification. The manual component that surrounds the linear actuator is connected to it. When the actuator is turned on, the wrist piece is dragged into the forearm, allowing the wrist to extend.

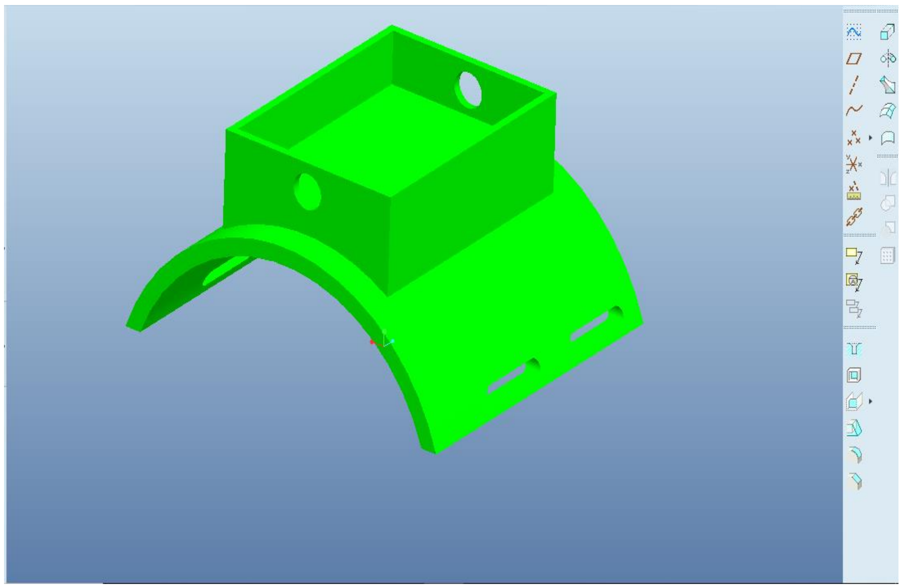

Figure 11: (a) Anterior Arm Splint

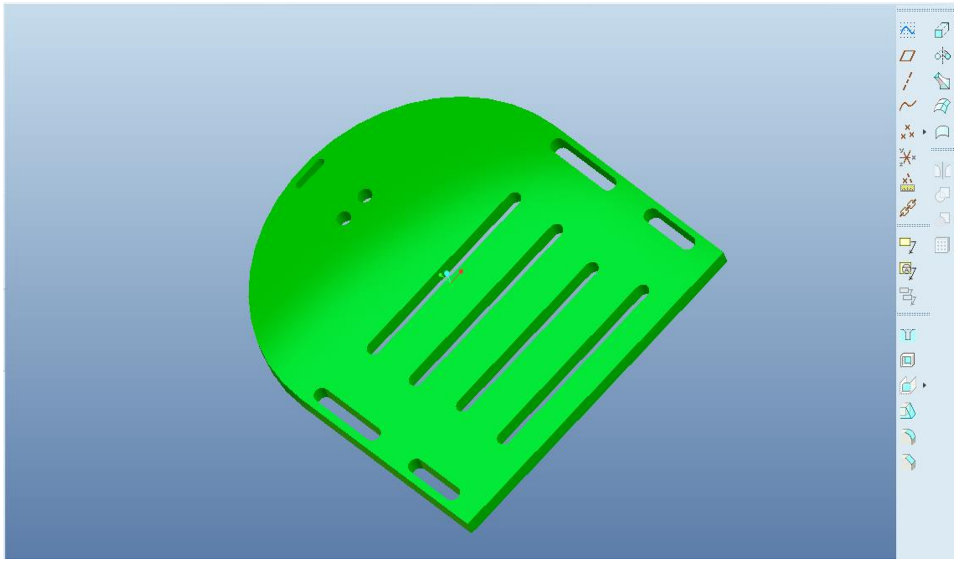

Figure 11: (b) Part of Splints

3.7.4. Linear Actuator

In this orthosis, the linear actuator extends the wrist to an angle of 60 degrees from its normal position, allowing the fingers to be flexed because the patient's fingers are connected to the splint with nylon strings. The linear actuator applies force to the patient's wrist; during initial training, the speed of the linear actuator is kept slow so that the patient can adjust to the exercise; after training, the speed can be adjusted according to the patient's needs.

Figure 12: Linear Actuator

3.7.5. Spring System

A spring mechanism is used to extend the fingers from their flexed position because a stroke patient cannot move their hand without external assistance, so a spring with a constant of 0.5 K/mm is used. [54].

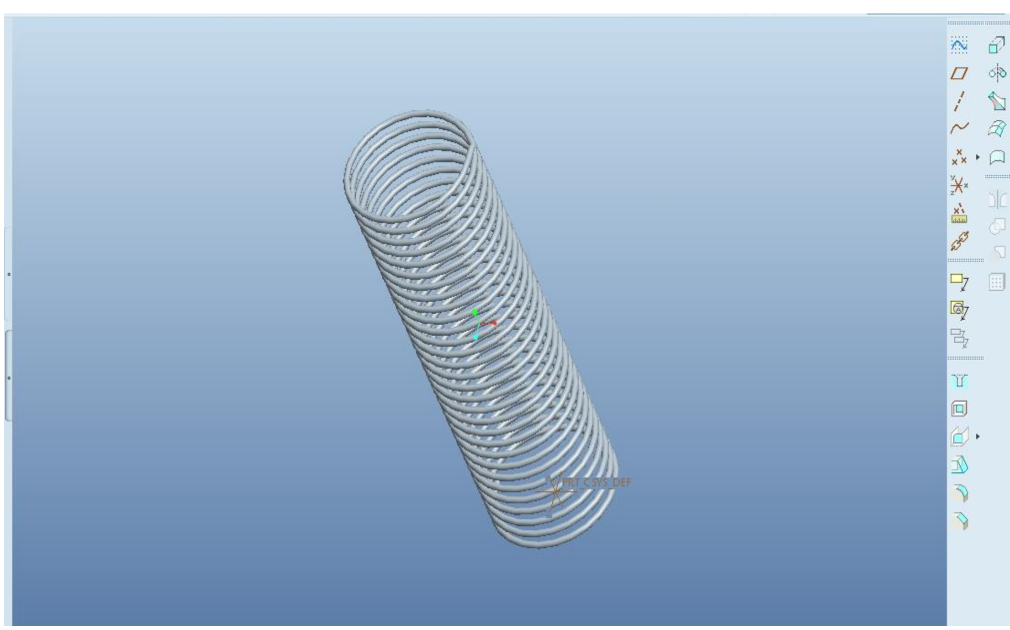

Figure 13: Spring Used for Extension of Fingers

3.7.6. Threads

The linear actuator is attached to the hand unit by a thread, enabling it to tug the wrist, and flex the fingers. The hand assembly connects the finger rings to the anterolateral forearm splint, so that when the linear actuator pulls on the palm, the fingers flex, allowing patients to exercise.

3.7.7. Power Supply

The device is powered by a 12v power supply that can run a linear actuator.

3.7.8. Arduino

An Arduino is an electrical system that is accepted worldwide hardware and software that is simple to use. The Arduino can simply read inputs, such as a light on a sensor, and convert them to outputs, such as a motor or a turned-on LED. The Arduino is instructed by sending a series of instructions to its microprocessor. Programming is done in the Arduino software language on the IDE Arduino software for this purpose. They are costly, cross-platform, simple and provide a simple programming model, and include software and hardware that can be expanded. It has been classified into various sorts based on the requirements.

Table 4: Arduino Classification

Arduino Board	Processer	Analogue I/O
Arduino UNO	16MhzATmega328	6 inputs, 0 output
Arduino Due	84MHzAT91SAM3X8E	12 inputs, 2 outputs
Arduino Mega	16MHzATmega2560	16 inputs, 0 output
Arduino Leonardo	16MHzATmega32u4	12 inputs, 0 output

The Arduino Mega is used in this rehabilitation equipment since the requirements were met by its specifications.

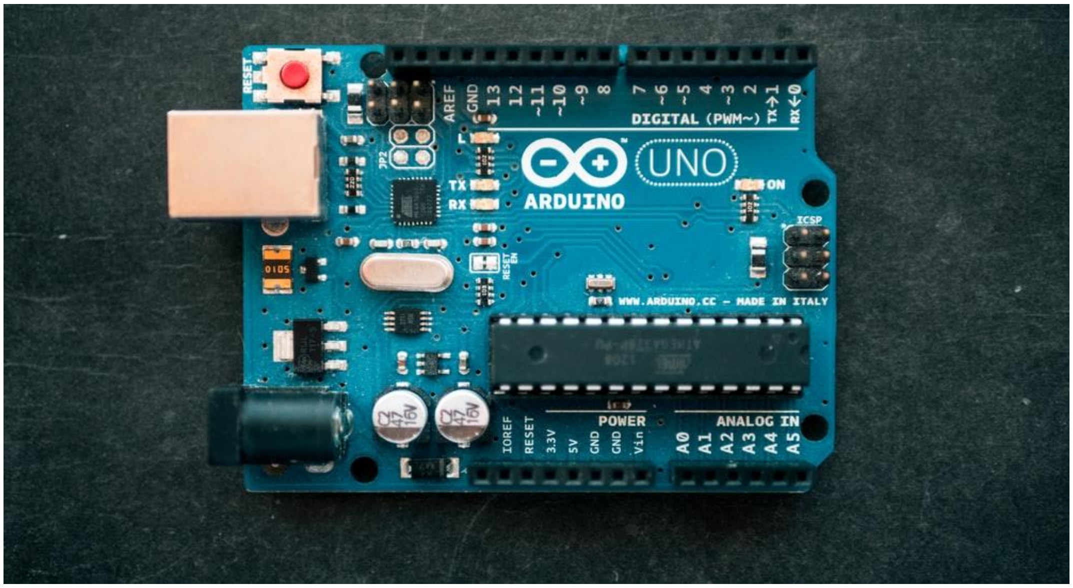

Figure 14: Arduino UNO

3.7.9. Safety

One of the most important considerations is safety. Safety elements ensure that the work platform, in this example, the rehabilitation gadget, is safe. This physiotherapy gadget has an emergency button that protects it against high voltage, shock, and other hazards. It is connected between both the circuit's power source and the power on.

3.8. Summary

This chapter covers the device's entire approach as well as user experience. It also provides the entire study strategy as well as a circuit block diagram. It outlines the significance and function of each component in the gadget.

Chapter 4: Benefits and Objectives

4.1. Benefits

Because the rehabilitation is active and regulated, we can control the linear actuator. The flexion and extension of the fingers are done on stroke patients for rehabilitation whenever the linear actuator detects the surface EMG signal. Before turning on the device, the patient can try to flex and extend their fingers without the help of the linear actuator as a passive action. The device can be 3D printed for both hands of a stroke patient, depending on which side of the brain is affected. Patients with various movement impairments and stiffness can wear the device because of its design.

4.2. Limitations

Every useful device has some limitations. The user data in this device is not saved in the record. Angle measurement with movement other than the visual method, as in this case, is also not possible. Another factor in the device is force, which cannot be recorded or applied in the opposite direction while the device is running. The device only allows finger flexion and extension, but the wrist can only extend.

4.3. Social Aspect

The device will be extremely beneficial to people suffering from neurological and musculoskeletal disorders. This is inexpensive and simple to install in medical centers, physiotherapy centers, rehabilitation centers, hospitals, and homes. The cost chart is written as follows:

Table 5: Device Cast

Sr #	Item	Price in PKR
1.	PLA filament (1000 g)	2600
2.	Linear Actuator	5000
3.	Arduino	2000
4.	12 V battery	1000
5.	Straps of Velcro	500
6.	Strings made of nylon	200
7.	Surface EMG electrodes	500
8.	EMG sensor kit	4900
9.	Self-adhesive pad	200
10.	**Total**	16900

4.4. Summery

This chapter has discussed the device's advantages, disadvantages, and social aspects. It offers a detailed device expense chart that is simple to use.

Chapter 5: Results and Discussion

The simulation was carried out using PTC Pro/Engineer. Because this software was used to create the entire assembly, it was simple to complete all of the required tasks with it. A linear actuator is connected to the pin joint (wrist). In the simulation setup, the motion mechanism for linear displacement was divided into forwarding and backward movements. Each activity was first simulated and then represented by a curve that depicted the path of motion as well as the maximum range of motion. With the suggested device, you can close and open your hand, flex and extend your fingers, and extend your wrist.

5.1. Experimental Results

The suggested mechanism is designed to produce 60 degrees of angular rotation for a wrist that is initially in a normal position.

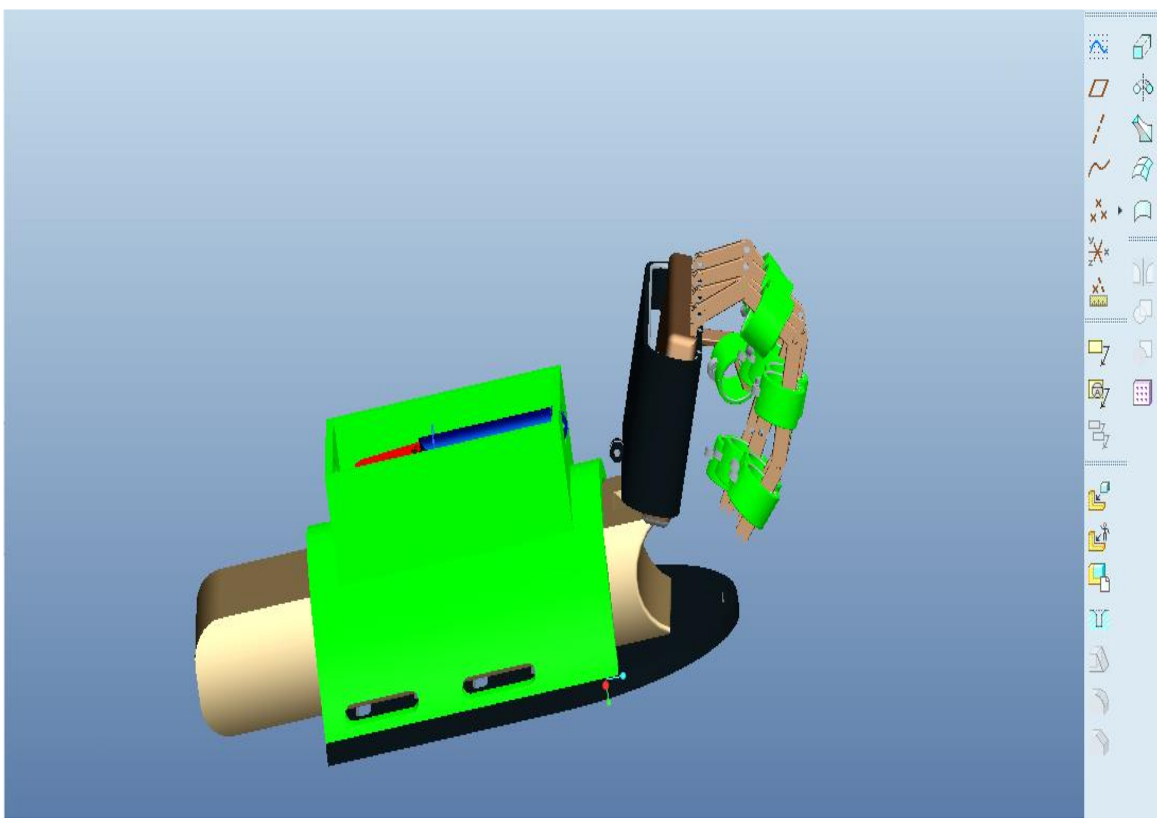

Figure 15: Extended Wrist to 60 Degrees and Flexed Fingers

The extension and flexion of the fingers is the most important and challenging element of this device. The fingers were attached with rings for the individual joints and nylon strings were used to tie all the rings through palm assembly to the arm splint. When the wrist is extended with the help of a linear actuator, the finger can be bent and stretched without striking a dead point as seen below. In the illustration, the exoskeleton's mobility is depicted by the curved course. The exoskeleton is designed to allow for a 60-degree wrist extension rotation, with the neutral axis at zero degrees.

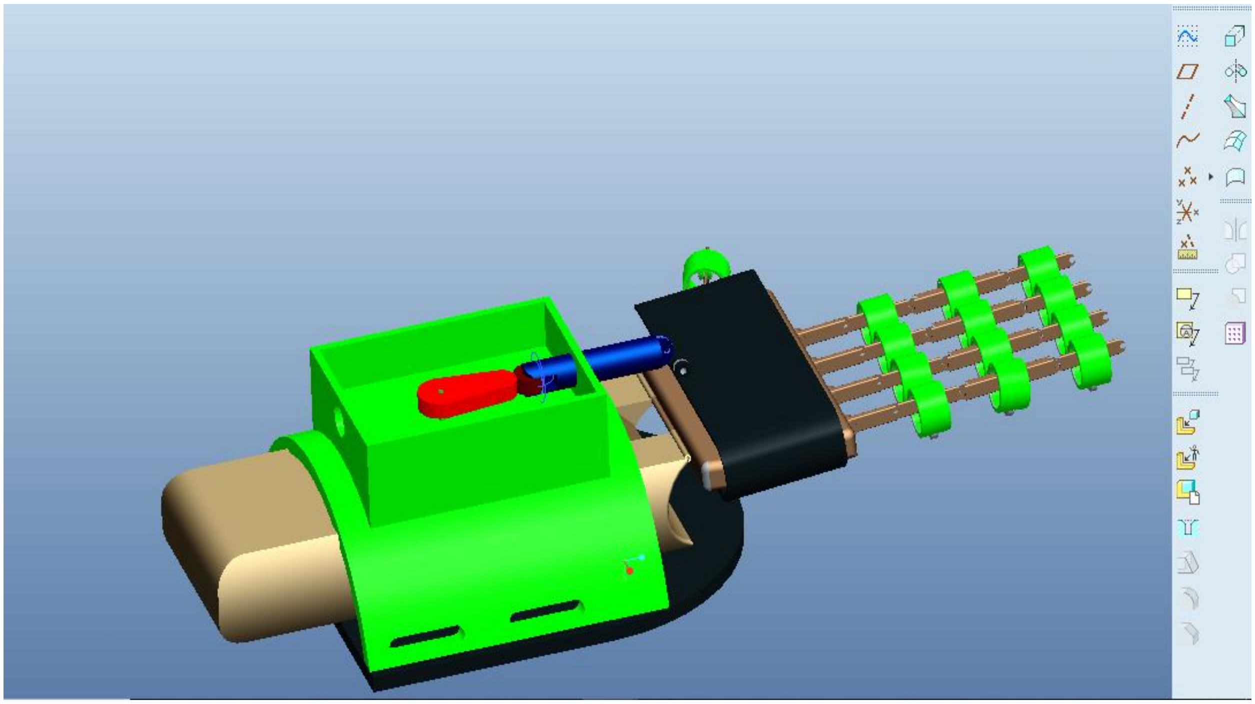

Figure 16: Wrist to Normal Position and Extended Fingers

5.2. Structural Analysis

Static analysis was used to examine the deformation and identify the areas of the device that are under the most stress. The results are detailed in the section that follows.

5.2.1. Finger

The peak displacement of the finger is determined by the user. As long as the wrist is extended, the finger flexes, and nylon strings pull on the finger rings.

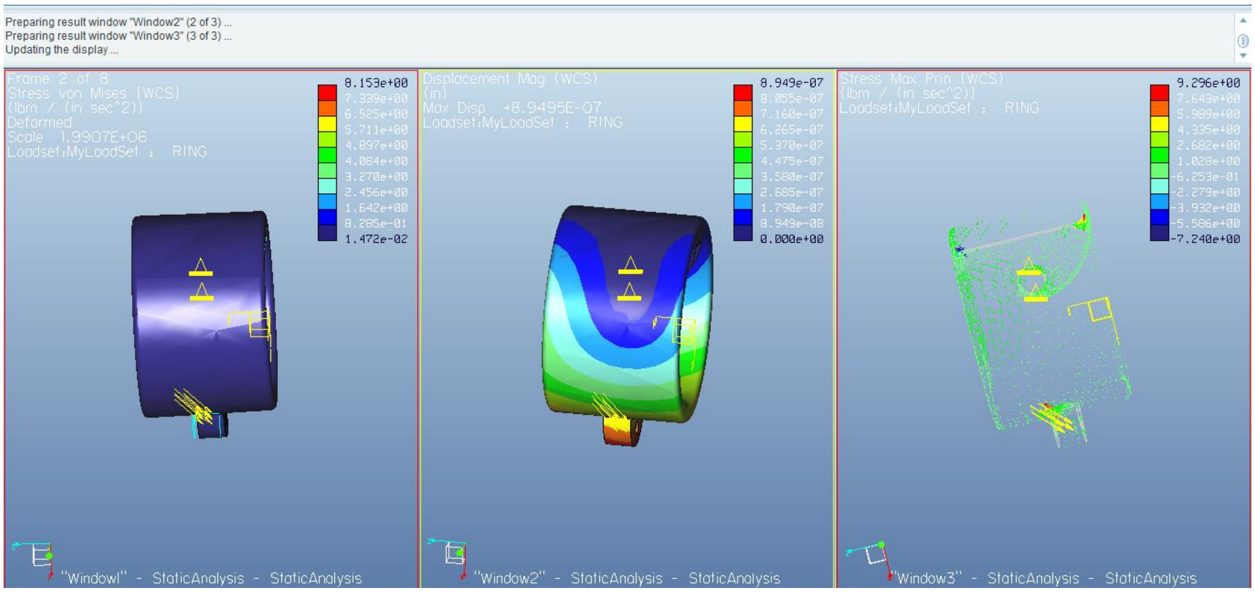

Figure 17: Structural Analysis of the Ring

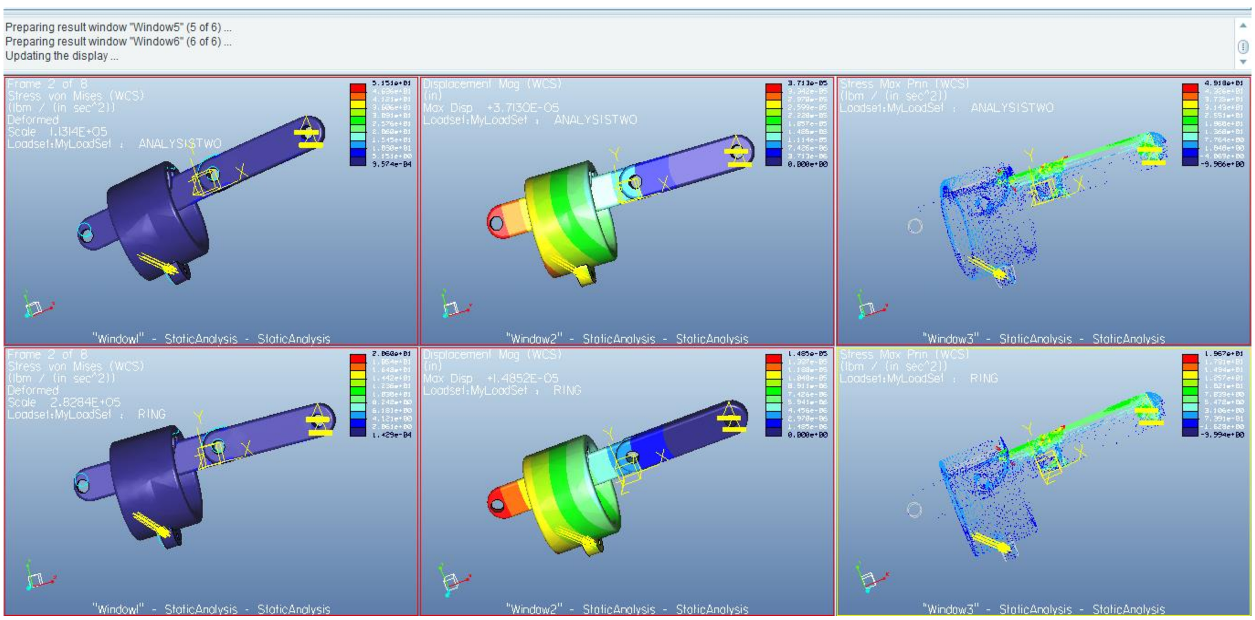

Figure 18: Structural Analysis of the Ring on 3D-CAD joint

5.2.2. Wrist

A linear actuator is used to extend the wrist to an angle of 60 degrees. The linear actuator pulls the wrist towards the anterior forearm. The extended wrist is then pushed back to its normal position, allowing the patient's fingers to extend back to their normal position. This is accomplished with the help of a spring with a constant of 0.5 N/mm.

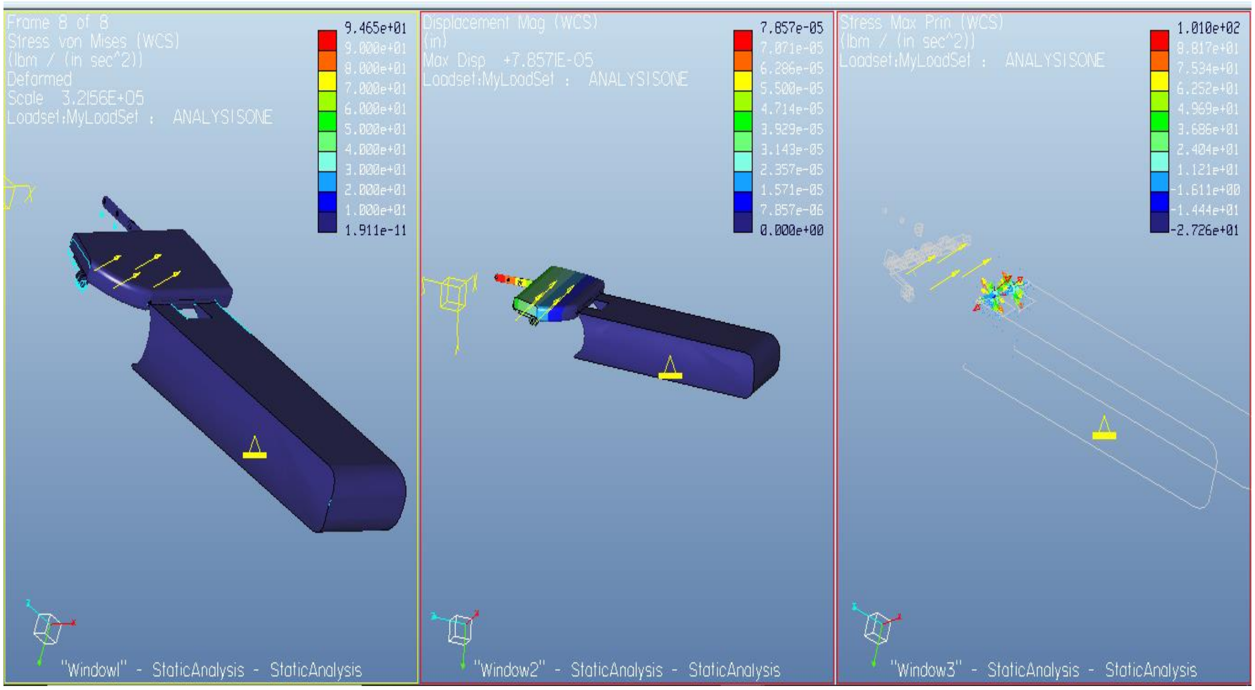

Figure 19: Wrist at Normal Position

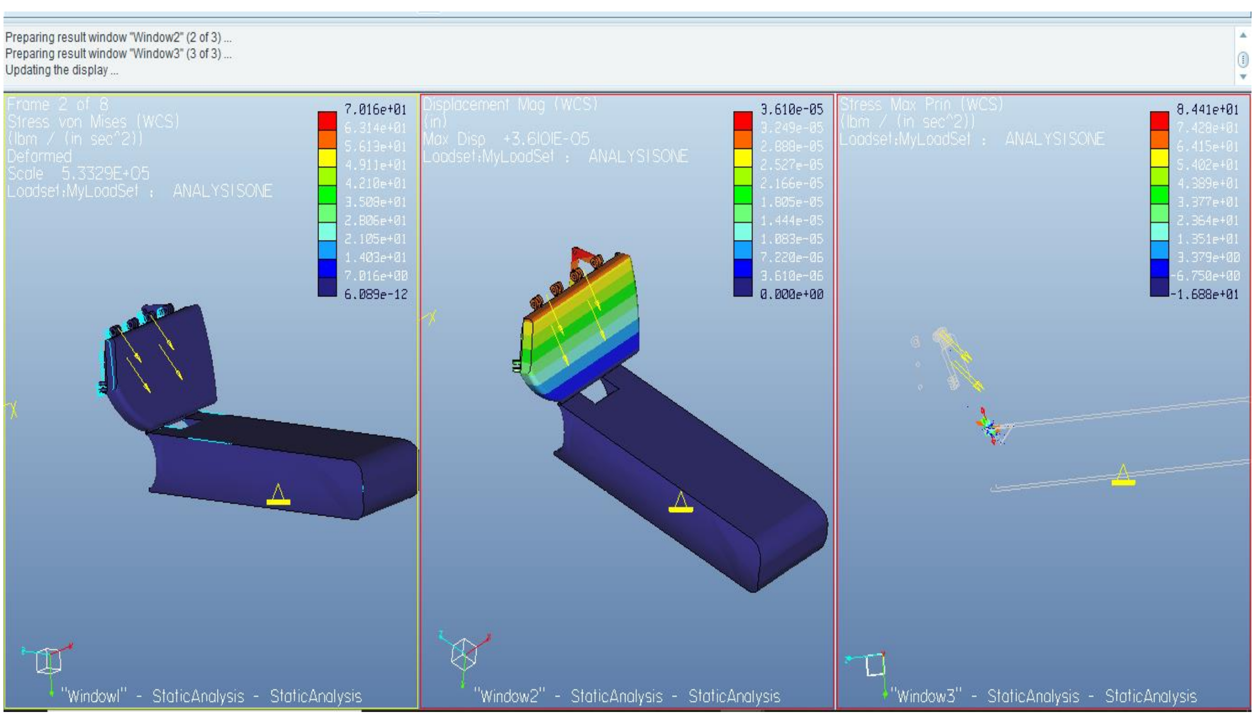

Figure 20: Extended Wrist

5.2. Discussion

A new orthotic device was presented in this study that improved finger extension and flexion and improved users' capacity to execute routine tasks with their hands. The orthosis is designed for stroke patients who are unable to move objects with their hands. Self-care and movement, cannot be made better since they necessitate additional skills. During forceful wrist extension, the muscles flexor digitorum profundus and flexor digitorum superficialis is extended, causing finger flexion. Physical therapists recommend a splint to enhance the efficacy of finger extension and flexion as a corrective latent prehension movement [55].

When compared with other systems currently being developed, the dynamic rehabilitation orthosis produced in this study has unique traits and benefits. The orthosis, for starters, has some structural advantages. Above all, because it was made with 3D printing technology and a simple control method, it weighed less than other recently invented equipment. The orthosis designed in this study weighs about 200g.

The light weight orthotic device was made, weighing less than 50 grams in total. The control box, on the other hand, weighed roughly 930 grams and created to be worn on the patient’s front. As a result, the design was unnecessarily big [58]. Several lightweight hydraulic and pneumatic actuators have also been designed [59][60][61][62].

Structural benefit of rehabilitation orthotic device is the absence of artificial joints to keep the device as basic as feasible. As a result, not only is it possible to minimalize the device's weight, but it is also able to grab objects utilizing the user's joints without changing the finger movement path. Furthermore, the size is simply adjustable and may be adjusted to the patient's hand's condition and size. We could simply make personalized hand orthoses by measuring the width of the hand and the circumference of the fingers.

Second, a myoelectric control system based on surface EMG signals is used to run the orthosis. The electrical impulses of constricted muscles are represented by EMG, which has been extensively researched and is the most often used approach for controlling assistive devices. Despite some challenges, processing of EMG signals and the placement of the electrodes, research has demonstrated that surface EMG can recognize the patients objective and reliable for controlling rehabilitation devices because it shows the muscle activity in form of EMG signal [63][64].

The orthosis additionally uses surface EMG signals from the patients unaffected muscle to control the gadget. This bilateral physiotherapy technique is intuitive and intentional device control, as well as greater patient autonomy. Wearable hand robots that had previously been created were less convenient since they were operated by someone other than the subject [62]. Despite the size of the linear actuator system, an intention button was built to allow users to activate the gadget by pressing it. Pushbutton rehabilitation devices are simple to operate and may be accurately controlled over lengthy periods. Movement artifacts and perspiration, which are two main problems for the myoelectric control system, rarely affect the control signals from the push-button-controlled device. It is, however, less physiological than myoelectric devices because pressing the button may necessitate the use of another hand [65].

The orthosis used in this study, on the other hand, provides control advantages. The gadget might be operated more readily by adjusting the surface EMG threshold level. Because operating the device simply needed a contraction of unaffected muscle, the surface EMG electrodes could be affixed to the unaffected hand, and no training is needed.

5.3. Summery

This chapter illustrates the structural analysis findings and additional observations.

Chapter 6: Conclusion and Future Work

The design of the physiotherapy rehabilitative device mentioned above is unique. Many single-sided designs have been created throughout history, and many of them were passive, unlike this gadget.

6.1. Conclusion

Because the device is active, it may be deduced that it not only permits dual-regulated flexion and extension but can also be utilized by both right- and left-handed stroke patients. It might make it easier and more supportive to move inhibited or stiff muscles. In hospitals, medical facilities, rehabilitation centers, and at home, the device can be very useful. Because each gadget is custom-made using 3D printing, it is simple to use, cost-effective, and can be utilized by people of various hand sizes. As a result, the device will improve the patient's movement range and muscle strength while also giving them fresh hope, boosting their self-esteem and confidence.

6.2. Future Aspects

The device is a flexion/extension device for the hand, but it could be a dual function in the future if a component of the wrist is added. It is possible to create a recording directory and use sensors to record and store force values. The user interface can be integrated within the device, and data storage is also feasible.

6.3. Summery

The benefits and applications of the device in society are discussed in this chapter. It goes over the specs and functions that it can accomplish now and in the future. It could be a genuine and beneficial choice for both patients and physiotherapists.

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