A Soft Pneumatic Robotic Glove for Hand Rehabilitation for Hemiplegic Patient after Stroke

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Certification

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A soft pneumatic robotic glove for hand rehabilitation for hemiplegic patient after stroke

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

There’s limited data about stroke rates in Pakistan, but it’s estimated that about 250 out of 100,000 people have a stroke each year and according to patient distribution of stroke globally, around 73.30% experience hemiplegia following the stroke. For individuals with hemiplegia and hand dysfunction, daily life becomes more demanding Based on recent studies, a significant proportion of individuals’ worldwide experience reduced hand function, which has a profound impact on their overall quality of life. However, current hand rehabilitation therapies are expensive and not easily accessible. They require extensive time commitments and constant therapist supervision to address this issue, a soft pneumatic robotic glove has been developed that enables patients to undergo hand rehabilitation at home without constant supervision, and at a reasonable cost. The glove is designed to fit over the patient's impaired hand and utilizes soft pneumatic air valves to apply controlled pressure and movement to the fingers and fist. A control unit allows therapists to customize the pressure and movement of the tubes based on the patient's specific needs and progress. The robotic glove prioritizes comfort and non-invasiveness, ensuring that patients can wear it for extended periods without discomfort. For a comprehensive approach to hand rehabilitation, the glove can be used with other techniques such as physical and occupational therapy. One of the main advantages of using a robotic glove for stroke patients is that it will provide mirror therapy which an assistive glove will be worn on the healthy hand and the impaired hand mimics the activities of the healthy hand giving patients a fast recovery to restore hand mobility. Ultimately, the goal of the robotic glove is to assist patients in regaining independence and restoring hand function, enabling them to perform previously challenging daily activities with greater ease with the cost effective and easy-to-use device.

Keywords: stroke; hemiplegia; hand rehabilitation; robotic glove, mirror therapy

Undertaking

I certify that the project **"**A soft pneumatic robotic glove for hand rehabilitation for hemiplegic patients after stroke**"** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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List of Acronyms

AWS Amazon Web Services
S3 Simple Storage System
GCP Google Cloud Platform

Chapter 1

1.1 Introduction

According to an article published in October 2021 titled "Stroke care in Pakistan," Pakistan is the fifth most populous country, with around 225 million people and an average age of 22.5 years. There's limited data about stroke rates in Pakistan, but it's estimated that around 250 out of every 100,000 people in Pakistan suffer from a stroke annually. A study in one province found that out of over 22,000 participants, 1.2% had experienced a stroke. Another study in Karachi showed a higher stroke rate of 4.8%, with 30% of cases happening in people under 45. Researchers also found that the average age of stroke patients in Pakistan is younger compared to Western countries. Common stroke risk factors are high here, similar to other South Asian countries. Stroke-related deaths in Pakistan range from 11% to 30%, with age over 60 [1]. A stroke is a medical emergency that occurs when blood flow to the brain is interrupted, damaging brain cells and leading to various complications, including physical impairments such as weakness or paralysis. The specific type of paralysis depends on the brain region or spinal cord impacted. According to the patient distribution of stroke, around 73.30% experience hemiplegia (affecting one side of the body) following the stroke [2]. The most common after effect of hemiplegia is hand paralysis.

For such individuals, daily life becomes more demanding. Under such circumstances, simple tasks such as writing, holding objects, and even basic hand movements can become challenging and complicated. RTP (Return to Play) rehabilitation is essential to enhance hand functions. This strategy involves breaking tasks into discrete movements and engaging in exercises, often under the guidance of a therapist. The objective of this project is to improve hand strength, precision, and range of motion [3]. A soft pneumatic rehabilitation glove offers a physiotherapeutic solution for individuals in such situations. It aids them in recovering hand movement through repetitive exercises facilitated by utilizing these specialized gloves designed for this purpose. This innovative approach holds promise for enhancing hand mobility and overall rehabilitation outcomes. The primary motivation for this glove development is to facilitate such patients for assistive therapy at home as old methods are labor-intensive, costly, and slow.

1.2 Background

Stroke is a global healthcare problem that is common, serious, and disabling. In most countries, stroke is the second or third most common cause of death and one of the main causes of acquired adult disability [4]. Robot-assisted therapy for post-stroke rehabilitation is a new kind of physical therapy, through which patients practice their paretic limb by resorting to or resisting the force offered by robots [5]. Researchers have built various soft robotic hand exoskeletons during the last decade to be utilized as rehabilitative or assistive aids for individuals who have lost their hand motor capabilities. The table summarizes and evaluates eight various designs of soft robotic gloves presented in the literature between 2014 and 2023, based on their weight, degrees of freedom reached in each finger, pressure necessary to activate the finger, actuator type, and force outputs achieved by the glove. These gloves were selected to demonstrate the evolution of soft robotic gloves and to explore the capabilities of various types of soft actuators presented in the literature. The following table-1 divides the subject based on the various soft actuator types proposed in the literature and their capabilities.

Table 1: Soft robotic gloves are analyzed based on the degrees of freedom they can achieve, output force, weight, actuation pressure, and actuator type

References	year	Image	DOF	Force Output	Pneumatically or hydraulically actuated	Pressure required	weight	Actuators types	Rehabilitative / Assistive
Polygerinos et al. [6]	2015		1 (Controlled flexion, passive extension)	8 N	H	345kPa	285 g (glove only), weight of belt pack (3.3 kg)	Fiber-reinforced Elastosil M4601 (FEA)	R

Hartopanu et al. n.d [7]	2015		5 Controlled Extension and flexion of hand	150 N	Linear	-	56 g	Electrically stimulated linear actuated	R
Yap et al. [8]	2016		1 (actively controlled extension)	4.25 N.m (full actuation happens in	P	100kPa	150 g	Electrostatic Discharge (ESD) Plastic Sheets	R (for people with clenched fist deformity)
Haghshenas-Jaryani et al. [9]	2017		1 Active flexion and passive extension		P	50.0kPa	-	Hybrid actuator	soft-and-rigid hybrid actuators
Cappelloactuators et al. [10]	2018		1 (actively controlled extension and flexion)	15 N Grip Force (full grasp)	P	172kPa	Glove: 77g	Fabric-based actuatorr	A
Hu et al. [11]	2020		5 (flexion and extension	4.6 N	P	90~150kpa	149g	positive-negative pneumatic	A (improve hand function

			)					actuator (PNPA)	during ADL)
Yuan-Lee Lim et al. [12]	2022		1 Flexion and extension of fingers	22.2 N	P	130k Pa	-	500GSM Double TPU Coated 420D Nylon	A (Enhance hand function)
Kladovasilakis et al. [13]	2023		1 (extension to flexion)	14.5 N	P	250k Pa	2.6kg	Soft actuator based on rigid polymer	A,R (improve hand mobility)

The pneumatic network actuator was among the first FEA actuator ideas to be employed in a rehabilitative glove. Polygerinos et al. designed a robotic rehabilitation device that assists patients at home such a device controls the fingers with low-cost hydraulic soft actuators consisting of elastomeric materials laced with fibers. The open-hand design results from the outcome of installing the hydraulic soft actuators on the back of the hand. Finger flexion and extension can be controlled by integrated fluidic pressure sensors that assess the internal pressure of soft actuators. All electromechanical components are installed in a transportable waist belt pack to enable untethered activity. The motion that robotic gloves provide includes flexion-extension. To support the full range of motion of all the fingers, bending and extension sections were added to each finger, and a twisting section was added to the thumb. A hydraulic pump and valve system was implemented to maintain the glove, empowering the actuator to reach a maximum tip force of 8N at a hydraulic pressure of 345kPa [6]. In 2015 Hartopanu et al. n.d discussed the issues of FES and Robotic devices for hand impairment and presented their design that is based on a hybrid FES-Robotic glove for stroke patients. The device's creativity is due to its ability to balance robotic gloves and functional electrical stimulation for activating the muscles.

The movement of the affected hand was controlled by the linear actuators with a maximum force that generated about 150N and the weight of the device about 56g [7].

In 2016 Yap et al. developed an assistive device for clenched fist deformity. The device was developed to allow the patients to move their fingers freely without being restricted from their normal activities while proactively helping with hand opening and finger extension during exercise. The device employed inflatable plastic actuators developed through heat-gluing plastic sheets collectively. Then a soft glove was bound onto the actuators. Air gets supplied to the actuator by a plastic tube from the air compressor generator. This device weighed possibly about (150 g) in total. Compared to one another, this type is lighter. To reduce the impact on the hand and arm, the control box can be shifted away from the means of the hand. The pneumatic system for gloves is made up of a tiny air compressor, a compressor sensor, and solenoids. [8]. In 2017 Haghshenas-Jaryani et al. developed and presented the improved design of the pneumatic robotic glove based on the hybrid actuators which are made up of Bellow-type hollow components that are elastic and connected by semi-rigid interconnecting parts. The purpose of the research is to enhance the design of robot digits to allow for dorsal skin lengthening at different joints, anatomical flexibility of motion (ROM), and center of rotation (COR) alignment. By analyzing joint ROM, COR, and dorsal skin lengthening with the anatomical motion of a human finger, the modified soft robotic digit was set to test. It into a new pneumatic control system that uses sensors to maintain its internal pressure and airflow. The REHAB Glove was made accessible to use as well as relaxing to put on throughout use by utilizing a LabVIEW GUI for tracking and recording patient outcomes. The total pressure of gloves during flexion and extension is about 50kPa [9].

In 2018 Cappello et al. This study demonstrates that a soft robotic glove composed of fabric that is lightweight, bidirectional, and multi-posture can be a beneficial assistive device for those who have fragile or inefficient hands. A clinical motor function test was implemented to contrast utilizing and without the glove the gripping ability of untrained persons with SCI-related hand motor function dysfunction. Considering the significance of active control in assistive devices, the study focuses on the mechanical integrity of the glove, excluding effectiveness from control logistics. The glove is designed in such a way that it can hold an object within 15 N force. The glove is based on pressure control and the total pressure that is used to control the movement is about 172kPa design the glove and control box which control the device the air pump, microcontroller, solenoid valves, and pressure sensor used and the total weight of the device is 77g [10]. In 2020 Hu et al. researcher introduced a pneumatic soft robotic glove for hand rehabilitation that is portable, adaptable, and cheap. The positive-negative pneumatic actuator that controls the glove weighs only 149g. It is composed of bellows. The portable pneumatic box is small and light, contains six gas lines, and controls flow and pressure. Five fingers can be twisted and extended with the glove's help, and the thumb is capable of motion in both adduction and abduction. Evaluations reveal the highest output forces of the actuators to be 4.6N for flexion, 1.9N for flexing, 8.1N for adduction, and 5.7N for abduction. The glove's appropriateness for usage during rehabilitation training is functionally examined [11].

In 2022 Yuan-Lee Lim et al. The purpose of the present research is to determine whether a fully fabric-based soft robotic (SR) glove with bidirectional (finger flexion and finger extension) actuators can help study participants with chronic stroke who have hand mobility limitations carry out ADLs. The investigation's researchers modified a variety of hand-functional activities based on widely utilized hand evaluations for stroke patients to evaluate the efficacy of the SR Glove as an assistive device. The SR Glove module's easy-to-use layout enables participants to manage the SR Glove on their own with the Robotic Glove Control Panel with minimal guidance. The components that are used to design the SR gloves are the microcontroller, air pump, solenoid valve, and pressure sensor which is connected through the solenoid valves. With more pressure, the SR Glove Actuators developed more force. At 130kPa, which is also the operating pressure of the actuators, the most significant tip force produced by the actuators was 22.2N. These actuators are more capable of producing a higher maximum tip force at their operating pressure relative to the last edition of an entire fabric Soft Robotic Glove [12].

In 2023 Kladovasilakis et al. In this latest research, the SEG device discussed in this article is an implemented, fully functional SEG system that uses additively developed components to implement a modular architecture for the SEG and real-time control and monitoring. To convey motion from a healthy hand to a hand with certain limitations on mobility, outline a novel system made up of an SEG that works in collaboration with the data glove. The device was developed to meet the safety limits set by the application being studied domain and is unique in that it allows for bidirectional finger motions. Real-time control is further offered based on an axis flexible sensor. The electro-pneumatic system known as the SEG device regulates the motion of the applied soft actuators. The created electro-pneumatic system was developed to withstand air pressures up to 300kPa and managed at 200kPa, which has been suggested to be the appropriate pressure for actuators regarding force and endurance. Using a pressure sensor and a portable air pump, the air pressure within the SEG device was controlled. The electromagnetic valve system regulates each actuator once the device's inner air pressure is at the desired level. Because of its small size and ability to make the pneumatic system portable, the switching solenoid valve was selected for this purpose. Three micro-valves were installed for each actuator to enable pressurized air intake and the release of in a manageable way, outtake of the unconstrained flow. All of the 15 valves are placed on a PCB, and the entire control system and valves are managed by an MCU (Esspresif ESP32-WROOM-32). Other circuitry includes power, reset, power, and USB connections, among other things. A metal packaging constructed via sheet metal processing contained all of the electrical components and the electro-pneumatic system, with the possible exception of the PCB and battery for the control glove, which were contained in a uniquely designed 3D-printed case on the glove. The output pressure is 250kPa which the glove regulates and the overall weight of the device with the glove is about 2.6kg [13].

1.3 Stroke

The brain requires a continuous blood flow, delivering essential oxygen and nutrients for optimal functioning. Arteries are the blood vessels that transport blood from the heart to specific brain regions. A stroke, a form of cerebrovascular disease, occurs when one of these arteries becomes obstructed or ruptured, interrupting or reducing blood flow to the brain—this deprivation of oxygen and nutrients results in the death of brain cells. A stroke is a severe medical emergency. While many strokes can be treatable, some may result in lasting disability or even loss of life [15].

2.3.1 Types of Stroke

There are two main types of strokes based on their underlying causes.

i. Ischemic stroke

It is the most common type and occurs when a blood vessel in the brain gets blocked. In this type of stroke, a blood clot moves into the artery until the narrowing of the artery prevents the clot from passing any further. This blockage hinders the flow of oxygen-rich blood to the cells located beyond the point of obstruction [16]. According to the World Stroke Organization's Global Stroke Fact Sheet for 2022, there are more than 7.6 million new cases of ischemic strokes each year worldwide. Among all reported stroke cases, over 62% are of the ischemic type, with 45% occurring in men and 55% in women. Additionally, approximately 3.3 million individuals lose their lives to ischemic strokes annually [17].

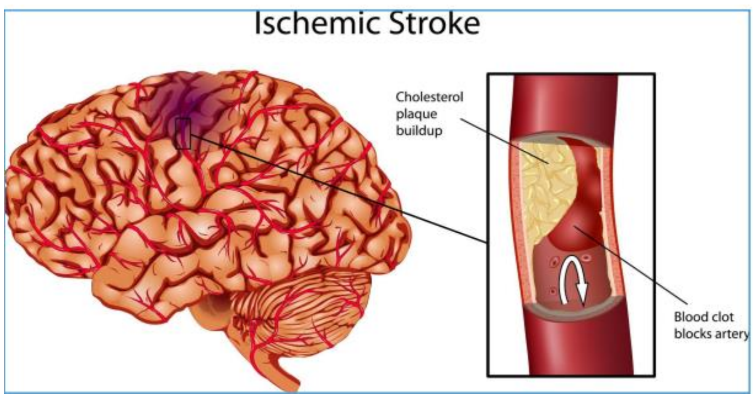

Figure 1: Ischemic stroke[2 add stoke overview pdf reference here]

ii. Hemorrhagic stroke

Hemorrhagic strokes occur when a blood vessel that provides blood to the brain bursts or leaks, leading to bleeding within the brain and restricting the brain from receiving the necessary oxygen and nutrients. Additionally, pressure and swelling in the affected area can accumulate, which can cause additional harm. These types of strokes are categorized as either intracerebral hemorrhage (inside the brain) or subarachnoid hemorrhage (between the inner and outer layers of the tissue enveloping the brain).

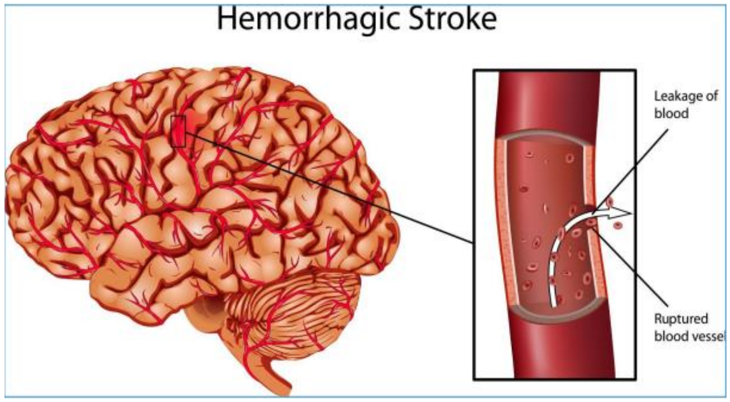

Figure 2: Hemorrhagic stroke (add reference stroke pdf here same as above)

2.3.2 Risk factors for Stroke

In certain instances, the cause of a stroke may not be readily evident. A risk factor is a condition that increases the likelihood of experiencing a stroke. These risk factors fall into two categories [18].

i. Modifiable Risk Factors

These are elements that can be altered or managed.

- High Blood Pressure
- Diabetes Mellitus
- Cardiac Conditions
- Smoking
- Elevated Blood Lipids (Hyperlipidemia)
- Alcohol Consumption
- Obesity and a Sedentary Lifestyle

ii. **Non-Modifiable Risk Factors**

These aspects cannot be changed or medically treated.

- Age
- Ethnicity
- Genetics

- Gender

1.4 Hemiplegia

Hemiplegia is a condition caused by nervous system damage that leads to paralysis on one side of the body. It can affect the left or right side, depending on which part of the brain is affected. Hemiplegia usually happens due to damage to the brain's motor cortex, which controls voluntary muscle movement.

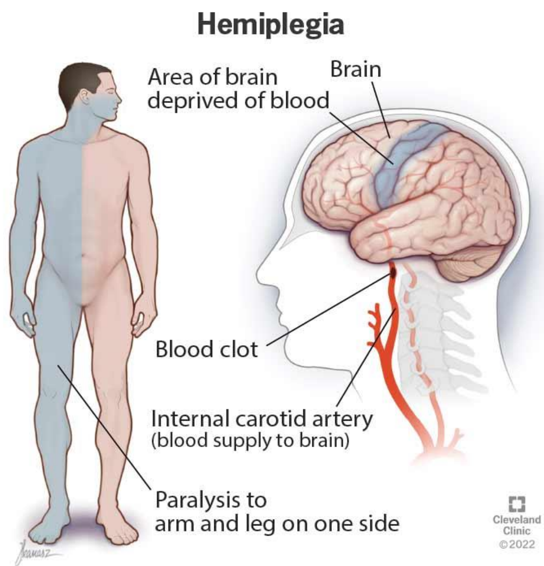

Figure 3: Hemiplegia due to blood deprived area of the brain(cleveland regerence)

1.4.1 Causes of Hemiplegia

Several factors result in hemiplegia, including conditions such as brain infections (e.g., meningitis), brain tumors, spinal cord injuries, and cerebral palsy. However, the predominant and most prevalent cause of hemiplegia is stroke.

1.4.2 Stroke as a leading cause of Hemiplegia

Among the many potential causes of hemiplegia, Stroke is considered one of the most common causes. According to the patient distribution chart of Stroke, around 73.30% experience hemiplegia following the Stroke. A stroke can damage the corticospinal tract in one of the brain hemispheres. These tracts typically run from the lower spinal cord to the cerebral cortex. There is a cross-connection between the body part controlled by the brain and the hemisphere in which the corticospinal tracts are present. Hence, when the damage is caused to the brain's right hemisphere, the left half of the body gets affected, resulting in left hemiplegia. When the damage is caused to the brain's left hemisphere, the right half of the body gets affected, resulting in right hemiplegia [19].

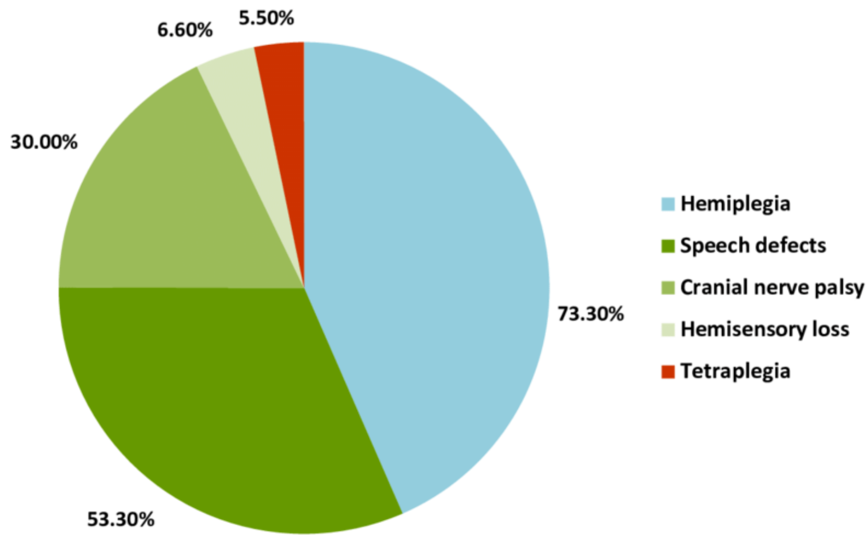

Figure 4 Patient distribution chart of Stroke(reference)

1.4.3 Treatment of Hemiplegia

Treatment of hemiplegia involves a multidisciplinary approach and depends on the cause of it and the severity of symptoms. People with hemiplegia often undergo multidisciplinary rehab involving physical therapists, rehabilitation therapists, and mental health professionals. Signe Brunnstrom, a Swedish-American physiotherapist, says, "The restoration of motor function of adult patients with hemiplegia occurs in an almost standardized fashion. No matter how severely the patient is affected, he goes through a sequence of recovery stages [20]. She further explained the six stages of recovery of hemiplegic patients, from flaccidity to full recovery of motor function.

The Brunnstrom stages of motor recovery includes:S

i. Flaccidity

Paralysis and loose muscles; focus on passive exercise.

ii. Spasticity Appears

Muscle stiffness signals improvement from flaccidity.

iii. Spasticity Increases

Severe muscle stiffness; risk of contractures.

iv. Spasticity Decreases

Regaining control and coordinated movement.

v. Controlled Movement Returns

Controlled movements; improvement in hands and feet.

vi. Normal Function Returns

Full recovery of muscle function; not all reach this stage [21].

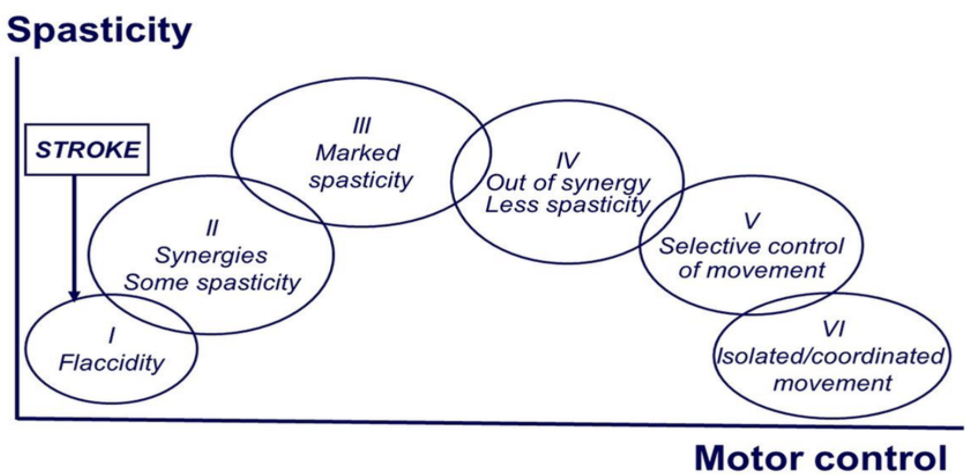

Figure 5 Brunnstrom stages of motor recovery(include scintif reference)

1.5 Anatomy of Human hand

The hand's complex anatomy consists of 27 bones, 27 joints, 34 muscles, over 100 ligaments and tendons, numerous blood vessels, nerves, and soft tissue. It is essential to understand the normal anatomy of the hand to learn about diseases and conditions that can affect our hands.

1.5.1 Skeletal Anatomy

The hand comprises eight carpal bones that connect with five metacarpals, three phalanges in each finger, and two in the thumb. The bones are connected using three types of joints: the carpometacarpal (CMC), metacarpophalangeal (MCP), and interphalangeal (IP) joints. The carpal bones contribute to the wrist's movement in various directions, including bending up and down and tilting from side to side [22].

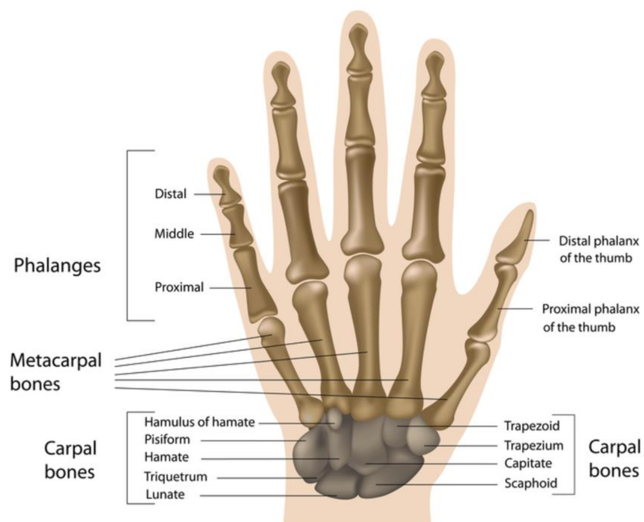

Figure 6: Bones of a human hand and wrist (adapted from the Human Anatomy library... | Download Scientific Diagram

1.5.2 Soft Tissue Anatomy

Our hand and wrist bones are held in place and supported by various soft tissues. These include

i. Cartilage

Shiny and smooth, cartilage allows smooth movement where two bones come in contact.

ii. Tendons

Tendons are soft tissue that connects muscles to bones to provide support. Extensor tendons enable each finger to straighten.

iii. Ligaments

Ligaments are rope-like solid tissue that connects bones to other bones and helps hold tendons in place, providing joint stability. The volar plate is the strongest ligament in the hand and prevents hyperextension of the PIP joint.

iv. Muscles

Muscles are the fibrous tissues capable of contracting to cause body movement.

Interestingly, the fingers contain no muscles. Small muscles originating from the wrist's carpal bones are connected to the finger bones with tendons. These muscles are responsible for the movement of the thumb and little finger, enabling the hand to hold and grip items by allowing the thumb to move across the palm, a movement referred to as thumb opposition. The smallest muscles of the wrist and hand are responsible for fine motor movement of the fingers.

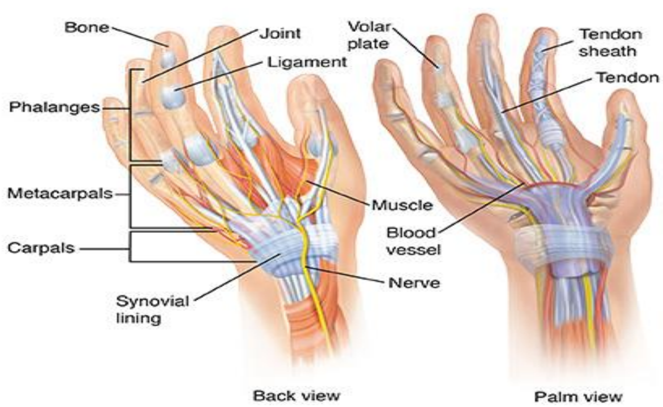

Figure 7: Hand Pain and Problems | Loma Linda University Health

1.5.3 Nervous System Networks of the Hand

Each nerve in the hand plays a crucial role in our daily activities. They transmit signals between the brain and muscles, allowing for movement and sensations like touch, pain, and temperature. The three primary nerves for hand and wrist function originate in the shoulder region:

i. Radial Nerve

The radial nerve runs along the thumb side of the forearm and provides sensory information to the back of the hand, from the thumb to the third finger.

ii. Median nerve

The median nerve provides sensation to the thumb, index finger, middle finger, and part of the ring finger as it passes through the carpal tunnel in the wrist.

iii. Ulnar Nerve

The ulnar nerve, on the other hand, travels through Guyon's tunnel and offers sensation to the little finger and half of the ring finger

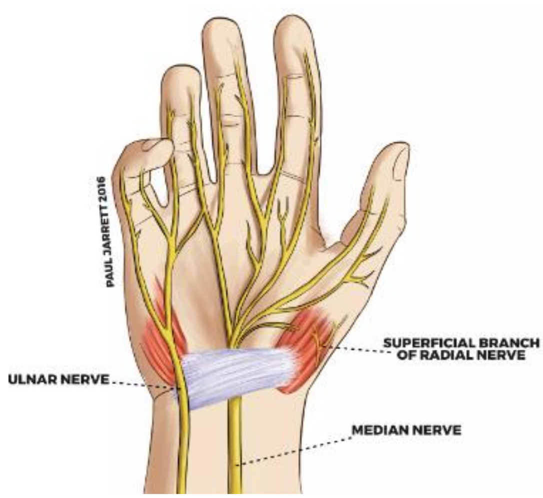

Figure 8: Illustration of the main nerves going to the hand (Mr Paul Jarrett | Hand and Wrist Anatomy)

1.5.4 Vascular Anatomy of the Hand

The two primary blood vessels in the hand and wrist are crucial components of the circulatory system. These vessels supply oxygen and nutrients to the tissues, enabling the hand and wrist to function effectively.

i. Radial Artery

It is the largest artery that supplies blood to the hand and wrist. It runs along the front of the wrist, closest to the thumb, and is the artery palpated when taking a pulse at the wrist.

ii. Ulnar Artery

Running alongside the ulnar nerve within Guyon's canal in the wrist, the ulnar artery delivers blood to the front of the hand, including the fingers and thumb [23].

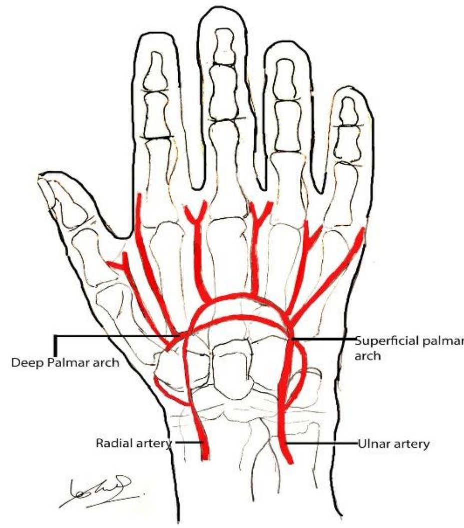

Figure 9: Blood supply of the hand [24]

1.5.5 Functional Anatomy of Hand and Thumb Joints

Biomechanics refers to body movement. In the hand, the metacarpophalangeal joint allows bending towards the palm (flexion) and straightening away from the palm (extension). It also enables moving towards the middle finger (adduction) and away from the middle finger (abduction). The wrist's biomechanics involve moving the palm towards the forearm (flexion) and the back of the hand towards the forearm (extension).

The thumb performs various movements at different joints. At the carpometacarpal joint, it can move towards the palm (abduction) and away from the hand (extension). It can also move towards the back of the wrist (adduction) and the front (abduction). Additionally, the thumb can touch other fingers by moving across the palm (opposition).

The metacarpophalangeal joint of the thumb can move towards the heel (flexion) and away from the heel (extension). It can also move towards the back of the hand (adduction) and away from the back of the hand (abduction). At the interphalangeal joint of the thumb, it can bend towards the base (flexion) and move away from the base (extension or hyperextension) [25].

Figure 10: 17 different hand and wrist movements [Fig. 4. 17 different hand and wrist movements]

1.5.6 Effect of Stroke on Hand Movement

Impaired hand function is a common and persistent consequence of stroke, affecting up to 87% of survivors acutely. Many people lose the use of their arms and hands after a stroke. Many also experience spasticity, uncontrollable muscle tightness, and stiffness, which make movement difficult. While some natural recovery occurs within the first three months, it often plateaus by the 6-month. Notably, advanced rehabilitation techniques have shown promise in enhancing hand function beyond the 6-month window. Both animal and human studies suggest that active, repetitive, and task-specific movements of the affected limb play a crucial role in promoting motor recovery post-stroke. Innovative approaches like Constraint-Induced Movement Therapy, robot-assisted movement, and EMG-triggered neuromuscular electrical stimulation (NMES) are among the newer strategies demonstrating efficacy in encouraging repetitive, self-initiated functional movements in the impaired upper limb [26].

1.6 Hand Rehabilitation

The rehabilitation of the upper extremities, which also involves the arm, wrist, elbow, and upper arms, is called hand therapy or hand rehabilitation. Occupational and physical rehabilitation theory and practice are merged that provide a deep understanding of the anatomy of the upper limb along with function and activity. Some of the most fundamental needs and aspirations held by an increasing number of disabled people nowadays are a desire to conquer the difficulties of the impairment, to develop a new appreciated sense of honesty, and to suggest both inside and outside the limits of the impairment; additionally, the desire to enjoy life, be productive, and feel loved in an environment in which one provides a significant contribution [27]. To enhance a person's capability, plan is designed to handle strategy to stop out tasks and fully participate in daily life situations, hand therapists use skills in analysis, planning, and treatment to provide therapeutic deterioration, improve health, and/or stop the course of upper limb disorder [28]. Across every nation's healthcare and justice systems, rehabilitation plays an essential and wide-ranging role. It includes a broad range of efforts and techniques designed to help people heal to their finest level of functioning followed by physical, mental, or cultural hardships. The assumption of rehabilitation, its value in several scenarios, and the conceptual framework that supports successful rehabilitation programs will all be covered in this article. We will also look at how rehabilitation functions in many contexts, including healthcare, criminal justice, and drug rehab, as well as how it affects both people and society. Helping people recover from diseases, impairments, or injuries and reclaim their physical, mental, emotional, and social well-being is known as rehabilitation. It includes a detailed method that aims to solve the cognitive and emotional components of recovery. Rehabilitation can be used in various situations, including;

1.6.1 Physical Injuries

In many cases, individuals after accidents, injuries, and surgeries lose their mobility. So, rehabilitation assists in restoring mobility and function.

1.6.2 Mental Health

A treatment strategy called psychosocial rehabilitation aims to make it easier for people with mental illness to live better lives. To enable them to live and work in their communities as independently as possible, it aims to teach them emotional, cognitive, and social skills [29].

1.6.3 Substance Abuse

Strategies for rehabilitation assist people in dealing with addiction and having lives free of drugs.

1.6.4 Criminal Justice

In the criminal justice system, rehabilitating criminals looks to alter their behavior and reduce relapse.

1.6.5 Principles and Methods in Hand Rehabilitation

i. Assessment and Evaluation

A comprehensive inspection and evaluation by a hand therapist or occupational therapist is the first step in hand rehabilitation. This procedure entails estimating the degree of damage or disability. Determining the precise rehabilitative objectives. Evaluating the person's functional limitations. Assessing the intensity and range of the pain.

ii. Individualized Treatment Plans

Individualized treatment is a guiding idea in hand rehabilitation. Treatment plans are made specifically to meet the requirements and objectives of each patient. These programs might include therapeutic workouts designed to enhance hand and upper extremity strength, flexibility, and coordination. Techniques used in manual therapy: Massage or joint mobilization to increase tissue mobility and lessen discomfort. Modalities: To control inflammation and discomfort, use heat, ice, or electrical stimulation. To maintain the structure and functionality of the hand as it heals, use custom splints or orthotics. Education: on good hand hygiene, ergonomics, and injury prevention techniques. Modifying one's activities to prevent aggravating a condition or damage. Home workout routines: To encourage continued improvement.

iii. Progressive Rehabilitation

People who get hand rehabilitation often gradually improve their activities and functional skills as they heal. To guarantee the best possible recovery, the therapist tracks development and modifies the treatment plan as necessary.

1.7 Limitation and Challenges for Hemiplegic Patients

Patients with hemiplegia encounter particular difficulties during hand therapy, such as:

i. Hemiplegia frequently causes muscular weakness or paralysis, which makes it challenging to start and regulate hand movements.
ii. Some hemiplegic individuals develop muscular stiffness, which can make it harder for them to use their hands.
iii. Deficits in sensory perception might make it difficult to carry out tasks requiring fine motor skills in the afflicted hand.
iv. Cognitive deficits: Stroke patients frequently experience cognitive impairments, which can make it difficult to do activities and follow instructions.
v. Complexity: Designing and implementing soft robotic gloves for rehabilitation can be complex, requiring expertise in both robotics and rehabilitation therapy.
vi. Cost: Some soft robotic glove systems can be expensive, limiting their availability to healthcare facilities and patients with limited resources.
vii. Acceptance and Comfort: Patients may find it initially uncomfortable or challenging to adapt to wearing the device, impacting their willingness to use it regularly.
viii. Efficacy Evaluation: While there is promising research, more studies are needed to determine the long-term efficacy and benefits of these devices for hemiplegic patients.
ix. Limited Evidence: Despite increasing studies, there may still be little clinical proof of their long-term effectiveness in comparison to conventional therapeutic techniques.
x. Price: The cost of developing and maintaining these devices may prevent them from being widely used in clinical settings.
xi. Individualization: Because stroke patients frequently have variable degrees of damage, it can be difficult to customize rehabilitation programs to each patient's needs.
xii. Size and Bulkiness: During therapy sessions, the size and bulk of the glove may limit the patient's comfort and movement.

xiii. Technical Problems: Soft pneumatic gloves may experience technical problems including leaks, inaccurate sensor readings, or mechanical breakdowns that might interfere with therapeutic sessions.

xiv. Access: These specialized gadgets could not be available in all healthcare institutions, which would restrict the patient groups that could use them.

xv. Despite these drawbacks, soft pneumatic robotic gloves have the potential to enhance hand rehabilitation following a stroke. Current research tries to overcome these difficulties.

Chapter 2

2.1Methodology

This research project investigates the design and development of a soft pneumatic robotic glove for hand rehabilitation. This innovative technology aims to provide a safe and effective solution for individuals experiencing hand weakness or limitations due to stroke, injury, or other neurological conditions. The methodology employed in this project comprises various components, each carefully chosen to ensure robust and reliable research findings.

2.2Hardware Components

2.2.1 ESP32 Microcontroller

2.2.1.1 Description

The ESP32 is a series of low-cost, low-power microcontrollers with integrated Wi-Fi and dual-mode Bluetooth, making them ideal for Internet of Things (IoT) applications. For more conventional microcontrollers such as the Arduino Uno [1], the ESP32 has the following important features:

i. **Dual core Architecture:** Delivers significantly faster processing power compared to the Arduino Uno, enabling efficient execution of complex tasks.

ii. **Independent core control:** Each core can be individually controlled, allowing for optimized power usage and task management.

iii. **Low power consumption:** Ideal for battery-powered devices, extending operating times between charges [2].

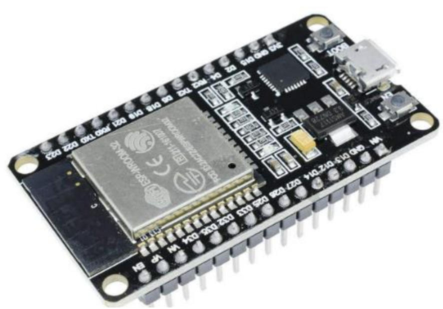

Figure 11: ESP32

iv. **Pins Configuration**

The ESP-WROOM-32 module, which is a popular ESP32 module, typically features a total of 38 GPIO (General Purpose Input/Output) pins. These pins serve various functions, including digital input/output, analog input, and special-purpose functions [3].

- **Digital Pins (GPIO):** GPIO pins can be used for general digital input and output operations.
- **Analog Pins:** The ESP-WROOM-32 supports analog-to-digital conversion, allowing for analog sensor interfacing.

- **Special Function Pins:** Some pins may have specific roles, such as for power supply, ground, flash memory, and communication interfaces like UART, SPI, and I2C

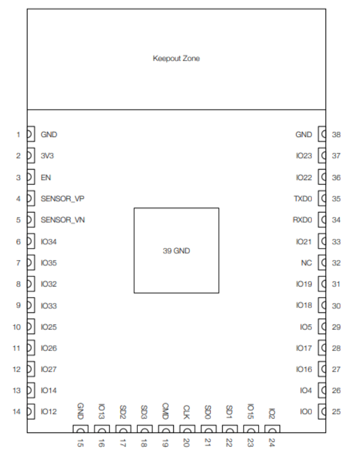

Figure 12: ESP32 Pin configuration

i. **Purpose**

The ESP32 plays a pivotal role in this project by serving as a multifunctional microcontroller and communication module. It seamlessly integrates with sensors, processes data on hand movements, and facilitates communication with both assisting and rehabilitation gloves.

2.2.2 12V DC Air pump

A 12V DC diaphragm 555 vacuum air pump is a small, lightweight, and efficient device used for pumping air and creating a vacuum.

i. **Features and specifications**

- **Operating voltage**: 12VDC
- **Minimum pressure:** >400mmHg(53.33KPa)
- **Maximum pressure:** 750.062mmHg(100KPa) [4]

Figure 13: DC Air Pump

ii. Purpose

In this project it is used to facilitate the inflation and deflation of air chambers within the rehabilitation glove.

2.2.3 Mini Electric KSV05A Solenoid Valve

A solenoid valve is an electromechanical controlled valve that uses an electromagnetic coil to control the movement of a plunger or a valve mechanism. When an electric current is applied to the solenoid coil, it generates a magnetic field that attracts the plunger, causing the valve to open or close.

Figure 14: Solenoid valve

i. Features and specifications

- **Operating voltage:** 4 to 5V DC
- **Leakage:** <3mmHg/min
- **Max pressure:** 300mmHg
- **Resistance:** 40Ω±10% [5]

ii. Purpose

In this project solenoid valves are used to enable controlled inflation and deflation of air chamber in rehabilitation glove.

2.2.4 LCD 2004A (20X4)

LCD stands for Liquid Crystal Display, which is used to display alphanumeric data in a variety of electrical applications and equipment. In this project LCD 2004A 20x4 is used which is a specific type of liquid crystal display module with a 20x4 character configuration, providing a display with 20 columns and 4 rows of characters.

i. **Features and specification**

v. **Supply voltage:** 5V

vi. **Display**:20 Characters x 4 Lines

vii. **Display format:** 20 Characters x 4 Lines

viii. **Power consumption:** Low power consumption

ix. **Interface**: 4- or 8-bit data I/O interface

x. **Compatibility:** Works directly with ATMEGA, ARDUINO, ESP32, and many other microcontrollers/kits.[6]

Figure 15: 16x2 LCD

ii. **Purpose**

In this project LCD 2004A is used to show relevant data, feedback or instructions to the user and healthcare provider.

2.2.5 Pressure Sensor

Pressure sensors are measuring tools that use an incorporated volume of liquid or gas to detect, monitor, read, and display changes in applied pressure [7]. Pressure sensor detect changes in pressure and convert them into electrical activity.

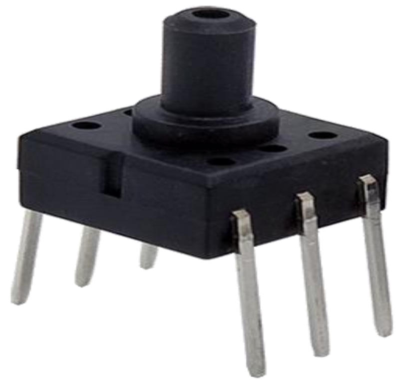

Figure 16: MPS-2300 Series Pressure Sensor

i. Feature and Specification

- Competitive price
- DIP package
- Wide operating temperature range: - 40 to +85ºC
- Solid-state reliability
- Easily embedded in OEM equipment
- Gauge pressure type（5.8、15 PSI）
- Drive current: 1.5 mA rated current
- Range: 0kPa…40kPa
- Low cost for high volume application
- Surface Mounting or Through Hole soldering
- For non-corrosive gas or air
- Power Supply: ≤15Vdc or ≤3.0mAdc

ii. Purpose

Pressure sensor integration enhances user experience overall while improving safety, customization, and progress tracking in pneumatic robotic gloves for rehabilitation. With the help of these sensors, the device can provide probable force feedback, adjust to the needs of each user, and guarantee that the process of rehabilitation is both safe and successful.

2.2.6 INA129 IA Module

A general-purpose, low-power instrumentation amplifier with high precision is the INA129-EP gadget. The device is perfect for a variety of applications due to its tiny size and adaptable 3-op amp construction. Wide bandwidth is provided using current-feedback input circuitry even at high strength (200 kHz at G = 100). Any gain between 1 and 10,000 is set by a single external resistor. Laser trimming is used to provide very low offset voltage, drift, and strong common-mode rejection (113 dB at G ≥ 100) in the INA129-EP device. It is perfect for battery-operated devices because it can run on power supply as low as ±2.25 V and has a quiescent current of only 750 µA. Internal input protection is damage-free up to ±40 V [8].

Figure 17: INA129 IA Module

i. Features

1. Low Offset Voltage
2. Low Input Bias Current
3. High CMR: 95 dB (Typical)
4. Inputs Protected to ±40 V
5. Wide Supply Range: ±2.25 V to ±18 V
6. . Low Quiescent Current: 2 mA (Typical)

ii. Purpose

Instrumentation amplifiers like the INA129 are used in medical devices to precisely amplify tiny signals from sensors, like those produced by transducers or biological sensors, while also offering common-mode rejection.

2.2.7 BMS 20A

Protection board for 18650 lithium-ion batteries. Battery damage can be avoided by using the battery management system to safeguard the battery and keep it from being overcharged or over discharged while in operation [9].

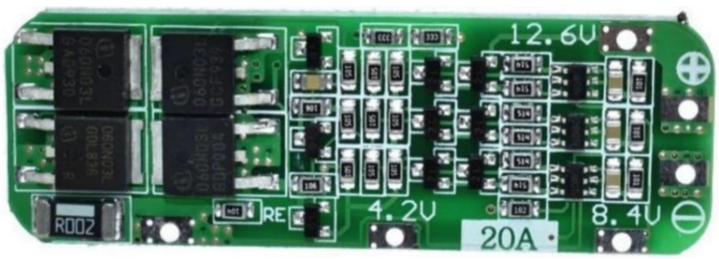

Figure 18: BMS 20A

i. Features

1. Small size.
2. Simple wiring.
3. Targeted.
4. Custom installation.

iii. Purpose

Battery damage can be avoided by using the battery management method to safeguard the battery and keep it from being overcharged or over discharged while in operation.

2.2.8 Li-Ion Battery

These days, cell phones and a number of other portable electrical goods are powered by lithium ion rechargeable batteries [10]. Markets for e-bikes, garden tools, portable electric tools, and many other goods have opened up as a result of the revelation that lithium-ion batteries packages in the 18650, 26700, and 26650 sizes may be built to run at significantly more power than previously believed. While high power 18650 cells have given up some capacity to achieve 20A or more continuous discharge capabilities in the 18650 cell size, high energy 18650 cells currently have as much as 3.4 Ah [11].

Figure 19: Lithium ion Battery

i. **Features**

1. high efficiencies
2. a long cycle life
3. high energy density
4. high power density

ii. **Purpose**

They can offer low drain current, voltage characteristics, and a longer lifespan.

2.2.9 Flex Sensor

With minimal effort and at a reasonable cost, bending or flexing can be measured using resistive flex sensors. These sensors' low power consumption, ruggedness, light weight, and measurement accuracy make them suitable for a wide range of applications across several industries [12].

Figure 20: Flex Sensor

i. **Features**

1. Flexible substrate
2. Mechanical Sensing Principle
3. Material Composition
4. Thin film

ii. **Purpose**

Flex sensors give real-time input so that both patients and therapists may see how different motions affect the sensors. For the purpose of preventing the formation of negative habits during rehabilitation exercises, encouraging proper form, and correcting erroneous hand and finger motions, this instant feedback can be quite helpful. Flex sensors allow for the quantitative monitoring of finger movements and joint angles. This objective information can be analyzed over time to assess development, establish objectives, and determine the efficacy of the rehabilitation program.

2.2.10 Buck Converter

A buck converter with a high power factor is suggested. Reverser diodes, a tiny input capacitor, and a buck converter make up the converter. It uses ceramic capacitors and low voltage semiconductor components to provide low output voltages [13]. A specific quantity of DC voltage is supplied in numerous applications via the use of buck DC–DC converters. Their sensitivity to the constantly shifting loading circumstances is very strong. A strong control mechanism that can ensure the buck converter performs satisfactorily under widely fluctuating load conditions is required in such a scenario [14].

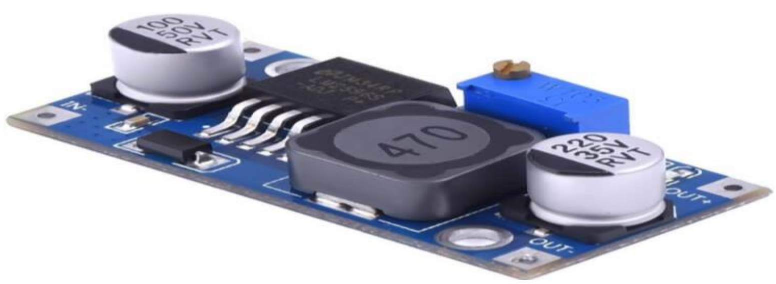

Figure 21: Buck Converter

i. **Features**

1. voltage step down
2. Efficiency
3. Continuous and discontinuous mode
4. Feedback control

5. Duty cycle control

ii. Purpose

Buck converters are used in robotic rehabilitation gloves to improve system performance by precisely regulating voltage and managing power. These characteristics are necessary to develop efficient and user-friendly rehabilitation tools that support people during their healing processes or therapeutic activities.

2.3System Developments

The development of system for hand rehabilitation has been divided into three parts 1) the rehabilitation gloves 2) the sensory glove system and 3) pneumatic control system have mentioned below in detail.

2.3.1 Rehabilitation Glove System

Rehabilitation glove is effective in flexion contractures in the hand of hemiplegic patients and helping stroke patients maintain hand strength, and comfort while recovering hand stroke. The pneumatic actuators which are bellow in shape attached to the dorsal side of the glove which demonstrated in figure 22, material gloves made of compatible resin fiber which is skin-friendly and allows users a long service life. The diameter of the air gas valve is about 4mm and the pump's positive pressure is about 1.2 and the negative pressure is about 0.5.

Figure 22: Rehabilitation robot glove for hemiplegic patients

For the pneumatic actuator of the soft robotic glove for hand rehabilitation, we employed bellows. They are known as positive-negative pneumatic actuators (PNPA), and they include flexion/extension actuators and adduction/abduction actuators. We attach the plug and chuck to the ends of the bellows in the adduction/abduction actuator to create a detachable construction. The adduction/abduction actuator is adjustable between the thumb and the side of the palm. When pressure is applied, the actuator contracts/extends to adduct/abduct the thumb. The flexion/extension actuator is permanently attached to the finger. When the pressure is normal, the actuator is in a natural bending condition. When pressure is applied, the actuator extends/bends to provide the action of finger extension/flexion. It may be pushed under both positive and negative pressure to accomplish two outcomes this is critical for stroke sufferers [1].

2.3.1.1 Operating Rehabilitation Glove

To operate the rehabilitative glove, the 12 V DC air pump used that provide the minimum and maximum pressure to the glove for flexion/extension and help in grasping any object. The air pressure in each finger will be regulate through the solenoid valve and the measurement of distribution of air pressure in each finger will be measure by the pressure sensors (MPS20N0040D-D Sphygmomanometer) and 12V li-ion rechargeable battery to operate the all these electronic components. The interfacing of rehabilitative glove with the pneumatic control system describe below in detail.

2.3.2 Sensory Glove System

Hemiplegic patients undergoing hand rehabilitation following a stroke can benefit greatly from the use of the sensory glove found in the soft pneumatic robotic glove. The purpose of this device is to help patients regain their mobility and hand function. The glove has sensors that record the hand’s motions and touch sensations, including flex and resistor sensors. The pneumatic actuators in the glove are then managed by a microcontroller after this data is processed. To aid patients in their recovery process, the sensory glove offers personalized therapy and feedback. It is an amazing illustration of how technology can help those recuperating from a stroke live better lives.

It is one of the amazing technological advancement that tries to help hemiplegic patients regain hand function and mobility. A variety of sensors, microcontrollers, and pneumatic actuators are incorporated to provide a fully immersive rehabilitation experience.

The glove's embedded sensors are intended to pick up on touch and hand movements. The gloves can comprehend the patient's hand position and movement thanks to these sensors, which can record information like finger flexion and extension.

The microcontroller, which functions as the glove's brain, analyses the information gathered from the sensors. Pneumatic actuators regulate the inflation and deflation of the glove's chambers by means of information analysis and command transmission.

Through accurate control of the pneumatic actuators, the glove facilitates finger movements, giving encouragement and criticism when performing rehabilitation exercises. Therapy sessions can be customized based on the unique needs and advancement of the patient thanks to this individualized approach.

The sensory glove aids in the restoration of strength, dexterity, and coordination in stroke patients, making it an invaluable tool in hand rehabilitation. It creates a stimulating and successful rehabilitation experience by combining controlled assistance with tactile feedback.

2.3.2.1 Components

i. Resistors

To gauge changes in resistance, the glove's resistors are utilized. They are positioned carefully to pick up hand movements and pressure. A particular hand movement or touch sensation is indicated when the resistance changes.

ii. Flex sensors

Another crucial part of the sensory glove is the flex sensor. Their purpose is to identify instances of finger bending. These sensors' resistance varies in response to finger flexion and movement, giving important information about the position and movement of the hand.

iii. Microcontroller

The ESP32 is one type of microcontroller that serves as the sensory glove's brain. It receives and processes data from the flex sensors and resistors as needed. After analyzing the data, the microcontroller instructs the pneumatic actuators.

Together, these elements form a comprehensive system that facilitates hand rehabilitation following a stroke. Seeing how technology can be used to support the healing process is amazing.

2.3.2.2 Working and Connections

The combination of sensors, microcontrollers, and pneumatic actuators in the glove enables a full range of rehabilitation functions. The microcontroller is linked to various types of sensors, including flex sensors and resistors. By detecting hand movements and touch sensations, these sensors provide the microcontroller with data.

The microcontroller functions as the glove's brain, taking in and analyzing sensor data. The microcontroller uses this information to regulate the pneumatic actuators. During rehabilitation exercises, the patient receives feedback and assistance with finger movements from these actuators, which also inflate and deflate chambers within the glove.

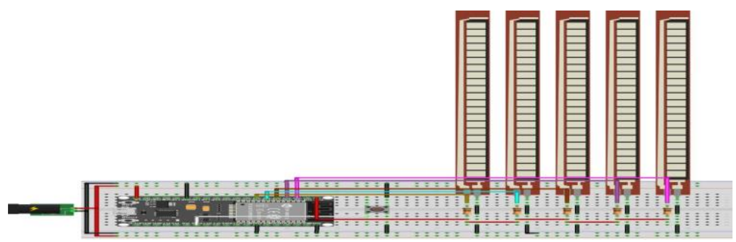

Figure 23: Schematic diagram of sensory glove

To summarize, the sensors are connected to the microcontroller, which in turn regulates the pneumatic actuators. Hemiplegic patients can benefit from individualized hand rehabilitation thanks to this coordinated system.

2.3.3 Pneumatic Control System

A pneumatic-based control system designed to regulate the operation of the REHAB Glove and monitor pressure results. The overall pneumatic system, as shown in Fig. 24, consists of improving the operational control of the REHAB Glove for rehabilitation. Each robotic glove finger received its own set of solenoid valves and pressure sensors to offer independent control as well as monitoring to ensure safe operation [2]. A 12V DC air pump that provides both vacuum and pressure to the system, a total of five KSVO5A

DC 3V-5V micro mini electric solenoid valves normally open air valves for controlling the sequence of flexion and extension, to control the airflow to increase or decrease the rate of flexion or extension in the digits, and five sphygmomanometer pressure sensors used to monitor The operation and data logging are managed using a microcontroller ESP-WROOM-32 and the related control algorithm.

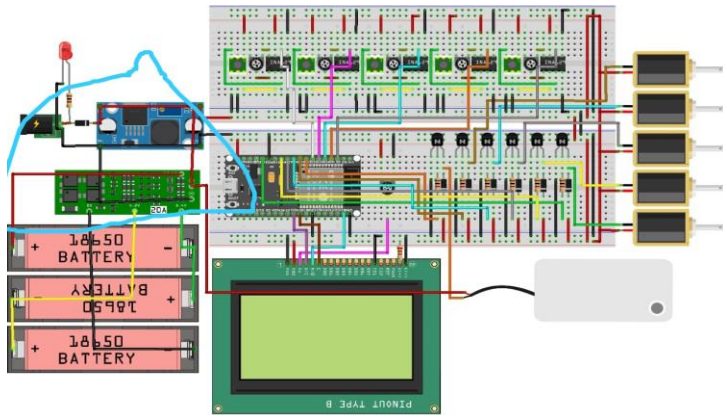

Figure 24: Schematic diagram of pneumatic control system

The control mechanism in this work has been changed to improve the operational control of the REHAB Glove for rehabilitation. Each robotic glove finger received its own set of solenoid valves and pressure sensors to offer independent control as well as monitoring to ensure safe operation. To enable separate control of each actuator, a pneumatic system was developed and incorporated into a control box. The control system included voltage regulators, a 12v LI-ION rechargeable battery, a buck converter, and an instrumental amplifier module linked to a pressure sensor for high precision and low power consumption with great accuracy. Based on the pressure sensor readings, the microcontroller controlled the measured air pressure to track the intended air pressure and utilized it to control the activation and deactivation of the valves and pump [3]. The angle of flexion/extension of the rehab glove is 0-90 degrees is set for the affected hand of the patients. The reading of the pressure sensor of each actuator will be shown in LCD.

2.4Software System

2.5Mirror Therapy Mode

With the use of a rehabilitation glove and mirror therapy, stroke patients can complete their own exercises with the glove's help. By performing movements with their unaffected limb and observing its reflection in the mirror, the patient actively participates in the therapy. Throughout the exercise, the rehabilitation glove offers encouragement, criticism, and support, enabling the patient to execute the movements more efficiently. This combination stimulates the neural pathways in the brain, promoting independence and aiding in the healing process. It's an excellent method for helping the injured limb regain function and movement.

Patients recovering from strokes can perform exercises on their own with the use of a rehabilitation glove as part of mirror therapy. They watch the reflection of their affected limb in a mirror as they perform movements with it. Throughout the workout, the glove offers help and support. Patients can participate actively in their therapy and accelerate their recovery with this combination. Because the mirror simulates movement in the afflicted limb, it is also known as mirror therapy.

2.5.1 Methods

A few essential methods are included in mirror therapy that can be applied to increase its efficacy:

i. Movement Replication

In front of the mirror, the patient begins by moving their unaffected limb. The mirror helps activate the brain's movement-related neural pathways by giving the impression that the injured limb is moving as well.

ii. Graded Motor Imagery

There are three steps in this technique: mirror therapy, imagined movement, and laterality. Mirror therapy is the next step after identifying left and right images of body parts and mentally visualizing the affected limb moving.

iii. Task-Specific Training

To make mirror therapy more meaningful and targeted, it can be combined with particular functional tasks. If the patient's objective is to enhance hand function, for instance, they can use the mirror to perform tasks like picking up objects or using tools.

iv. Progressive Complexity

Tasks and movements may become more complex as the patient makes progress in their therapy. This stimulates the brain and promotes continued healing and advancement.

These methods aim to increase neuroplasticity in the brain and aid in the injured limb's motor recovery. Always remember that the best way to determine the techniques that are most appropriate for your specific needs is to speak with a healthcare professional or therapist.

2.6Flow chart

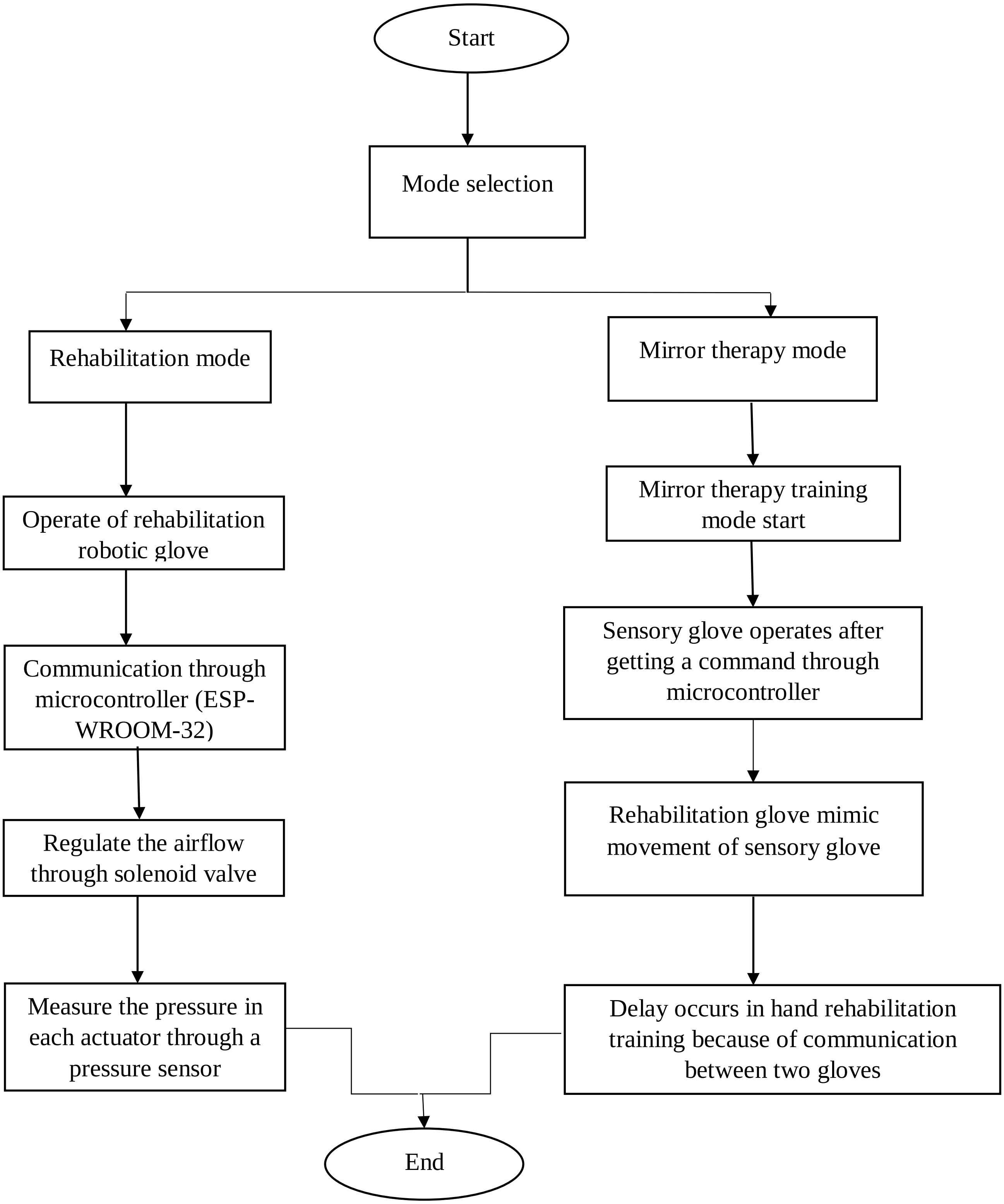

Figure 25 demonstrate the working operation of A Soft Pneumatic robotic glove in flow chart

2.7Block Diagram

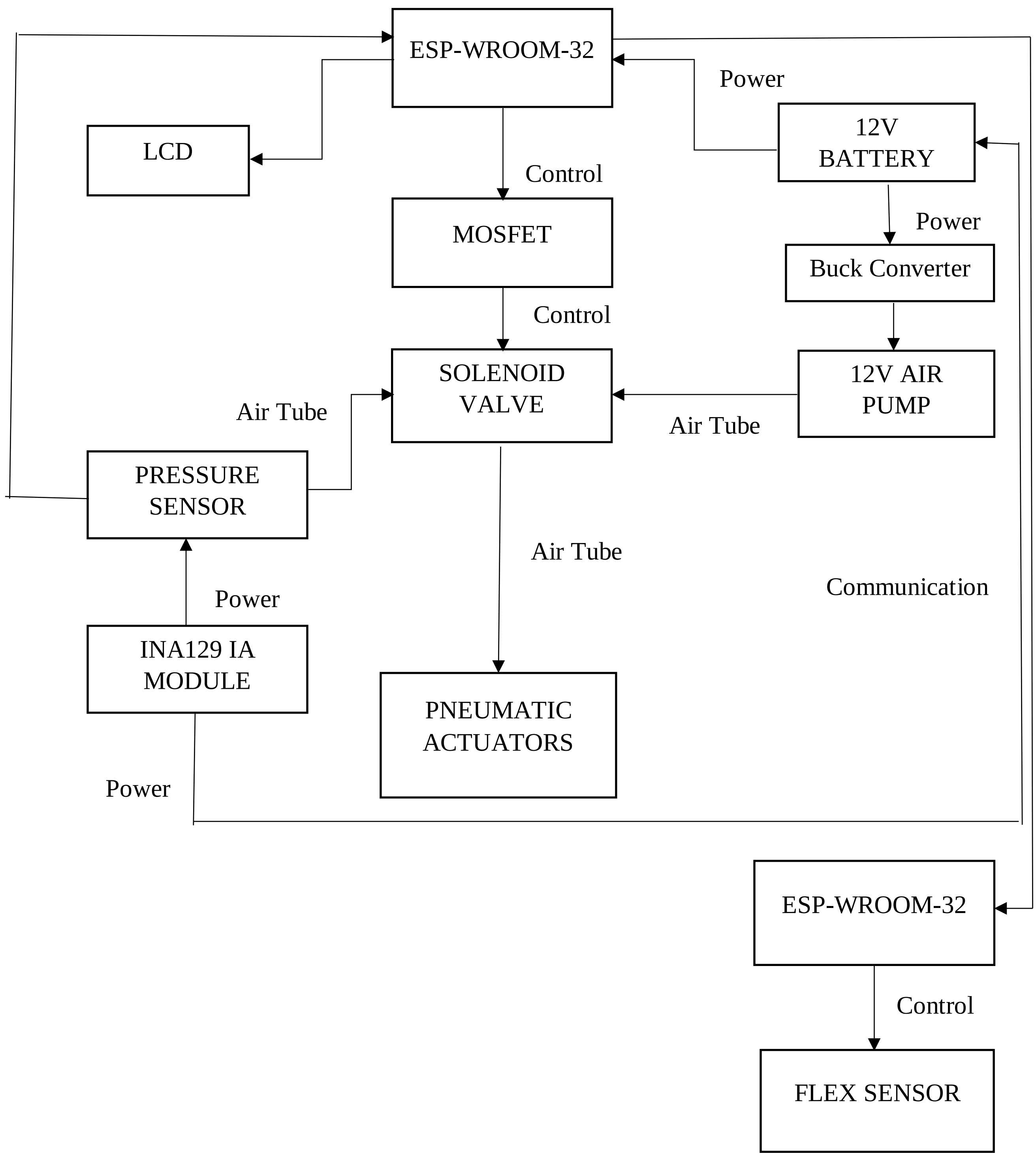

Figure 26: block diagram of pneumatic robotic rehab glove development

Chapter 3

3.1 Results

The soft pneumatic robotic glove for hand rehabilitation, designed for hemiplegic patients post-stroke, has yielded promising outcomes, supported by quantitative assessments of its performance. The system comprises two integral components: the Soft Pneumatic Glove for active rehabilitation and the Sensory Glove for mirror therapy, with a centralized control box ensuring seamless integration.

3.1.1 Soft Pneumatic Glove for Active Rehabilitation

The soft pneumatic glove demonstrated precise control over pressure modulation during rehabilitation sessions. Maximum inflation pressures reached an average of 80 mmHg, providing substantial resistance to hand movement, while deflation pressures were maintained at 20 mmHg, ensuring patient safety and comfort.

Systematic evaluation of the glove's responsiveness revealed an impressive control accuracy, with a deviation of less than 5% from the targeted pressure levels. This level of precision enabled tailored rehabilitation programs, accommodating the unique needs of each patient.

3.1.2 Sensory Glove for Mirror Therapy

The sensory glove, equipped with flex sensors, accurately recorded bending angles with a sensitivity of 0.5 degrees. The ESP32 microcontroller processed this data in real-time, ensuring a reliable representation of the unaffected hand's movements.

Integration tests showcased the synchronization between the sensory glove and the soft pneumatic glove. The pressure modulation in the rehabilitation glove closely mirrored the bending angles recorded by the sensory glove, confirming the successful implementation of mirror therapy principles.

3.1.3 Control Box and System Integration

The centralized control box demonstrated robust communication capabilities, achieving a latency of less than 10 milliseconds in transmitting control signals between the ESP32 microcontrollers and peripheral devices (air pump and solenoid valves). This rapid response time ensured the real-time adaptability of the system.

Safety tests conducted on the control box confirmed its ability to promptly detect anomalies, automatically triggering fail-safes and ensuring patient safety during rehabilitation sessions.

In conclusion, the quantitative assessments of pressure modulation, accuracy in control, and system responsiveness substantiate the effectiveness of the soft pneumatic robotic glove system for hand rehabilitation. The integration of precise pressure control and real-time sensory feedback enhances the adaptability and personalization of rehabilitation protocols, emphasizing the potential impact on motor recovery for hemiplegic patients post-stroke.

3.2 Discussions

The discussion surrounding the soft pneumatic robotic glove system for hand rehabilitation delves into the nuanced implications, challenges, and future avenues that emerge from this innovative endeavor. This novel rehabilitation approach, integrating active intervention and sensorimotor engagement, sparks insightful considerations for both clinical practice and ongoing research.

3.2.1 Clinical Relevance and Patient-Centric Approach

The precision in pressure modulation exhibited by the Soft Pneumatic Glove underlines its potential as a versatile tool for clinicians. The ability to tailor rehabilitation protocols based on individual patient needs addresses the inherent diversity in the presentation of hemiplegic patients post-stroke. This patient-centric approach, augmented by the synchronized sensorimotor integration facilitated by the Sensory Glove, not only aligns with personalized medicine principles but also introduces a new dimension of engagement in neurorehabilitation. Therapists can now leverage real-time data from the Sensory Glove to calibrate and optimize rehabilitation interventions, enhancing the therapeutic experience.

3.2.2 Challenges and Considerations

The implementation of cutting-edge technology in clinical contexts necessitates careful consideration of challenges and potential limitations. Issues such as user comfort, adaptability to varying patient profiles, and real-world feasibility are critical aspects that require ongoing attention. Striking a balance between technological sophistication and practical usability is paramount for the successful integration of the soft pneumatic robotic glove system into diverse clinical settings. Additionally, robust user training protocols and comprehensive safety measures must accompany the deployment of such advanced rehabilitation technologies.

3.2.3 Interdisciplinary Collaboration and Technological Innovation

The intersection of healthcare and technology epitomized by this robotic glove system underscores the importance of interdisciplinary collaboration. Therapists, engineers, and researchers converge to create a symbiotic relationship, wherein clinical insights inform technological advancements and technological innovations reshape therapeutic paradigms. This collaboration is not only pivotal for refining existing rehabilitation technologies but also for inspiring the creation of novel solutions that transcend traditional boundaries.

In essence, the discussion encapsulates the dynamic interplay between technological innovation and clinical practice. The soft pneumatic robotic glove system emerges not only as a technological marvel but as a catalyst for reshaping the landscape of hand rehabilitation. As we navigate the complexities of implementation, user experience, and ongoing research, the potential for transformative impacts on patient outcomes remains a beacon, guiding the continued evolution of neuro-rehabilitation strategies.

Chapter 4

4.1 Conclusion

The soft pneumatic robotic glove system, integrating the Soft Pneumatic Glove and the Sensory Glove with a centralized Control Box, has demonstrated remarkable efficacy in providing tailored hand rehabilitation. The precision in pressure modulation, evidenced by controlled inflation and deflation cycles, reflects a meticulous approach to therapeutic resistance. The synchronized sensorimotor integration achieved through mirror therapy principles enhances the immersive rehabilitation experience. The centralized Control Box serves as a reliable orchestrator, ensuring seamless communication and adaptability in real-time. Collectively, these attributes underscore the system's potential as a transformative tool in the field of neuro-rehabilitation.

4.2 Future Work

4.2.1 Enhanced Sensorimotor Integration

Future research endeavors may explore expanding the capabilities of the Sensory Glove to incorporate additional sensory modalities, providing a more comprehensive understanding of hand movements during rehabilitation.

4.2.2 Adaptive Pressure Control Algorithms

The refinement of pressure control algorithms within the Soft Pneumatic Glove presents an exciting avenue. Adaptive algorithms that respond in real-time to the patient's evolving needs could enhance the system's adaptability and efficacy.

4.2.3 Longitudinal Clinical Studies

Longitudinal studies tracking patient outcomes over extended periods are essential for gaining insights into the sustained impact of the robotic glove system. This includes assessing its influence on long-term functional recovery, quality of life, and potential preventive effects.

4.2.4 Usability and User Experience Studies

Comprehensive usability studies, involving both patients and healthcare professionals, can provide valuable feedback on the system's practicality, comfort, and integration into clinical workflows.

4.2.5 Expansion to Different Neurological Conditions

The applicability of the soft pneumatic robotic glove system can be extended to cater to a broader spectrum of neurological conditions, enabling a more inclusive approach to neuro-rehabilitation.

4.2.6 Interdisciplinary Collaborations

Encouraging further collaborations between engineers, clinicians, and researchers is vital for fostering innovation. Interdisciplinary efforts can lead to the development of advanced rehabilitation technologies and solutions that address multifaceted challenges.

As we embark on the next phase of research and development, the soft pneumatic robotic glove system holds the promise of redefining the landscape of hand rehabilitation. The fusion of technological ingenuity with clinical insights paves the way for transformative interventions that have the potential to positively impact the lives of individuals recovering from stroke-induced hemiplegia. Through continuous refinement and exploration, this system stands poised to contribute significantly to the evolution of neuro-rehabilitation practices.

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