A Soft Pneumatic Robotic Glove for Hand Rehabilitation of Hemiplegic Patients after Stroke

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Abstract. Stroke-induced hemiplegia frequently causes reduced hand function, which has a substantial impact on patients' quality of life. Traditional rehabilitation methods often fail to offer targeted, intensive, and engaging therapy. In response, this study presents a novel strategy that employs a soft pneumatic robotic glove specifically built for hand rehabilitation in hemiplegic stroke patients. 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. Preliminary research shows promising results in increasing hand motor function, range of motion, and grip strength in hemiplegic stroke patients. The robotic glove prioritizes comfort and non-invasiveness, ensuring that patients can wear it for extended periods without discomfort. The glove can be used with other techniques such as physical and occupational therapy for a comprehensive approach to hand rehabilitation. Overall, the soft pneumatic robotic glove is a potential improvement in hand rehabilitation technology, providing a personalized and participatory approach to hemiplegic stroke recovery. Additional research and clinical trials are required to evaluate its efficacy and investigate its potential as a standard rehabilitation aid in clinical settings.

Keywords: Stroke Rehabilitation, Hemiplegia, Soft Pneumatic Glove, Mirror Therapy, Hand Function Recovery, Neuroplasticity

1 Introduction

According to data about stroke rate in Pakistan it is 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. A stroke is considered a critical medical situation that happens when the blood flow to the brain is disrupted or diminished, causing harm to brain cells. There are two primary categories of strokes: ischemic stroke and hemorrhagic stroke. Ischemic strokes occur when a blood clot blocks a blood vessel in the brain, while hemorrhagic strokes occur when a

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variety of complications, including physical impairments such as weakness or paralysis. There are various types of paralysis including full paralysis, partial paralysis (also referred to as paresis), and generalized paralysis. The specific type of paralysis depends on the region of the brain or spinal cord impacted. For instance, diplegia affects corresponding areas on both sides of the body, quadriplegia impacts all four limbs, and hemiplegia influences just one side of the body [1]. According to the patient distribution of stroke, around 73.30% experience hemiplegia (where one side of the body gets affected) following stroke. A survey conducted at our university, LUMHS Jamshoro, in the Department of Physiotherapy, involving 8-10 patients also revealed that most stroke patients ended up with left-sided hemiplegia and highlighted a significant need for new rehabilitation solutions. For individuals with hemiplegia and hand dysfunction, daily life becomes more demanding. To enhance hand functions, the implementation of RTP (Return to Play) rehabilitation is essential [2]. This strategy involves breaking tasks into discrete movements and engaging in exercises, often under the guidance of a therapist. The objective is to improve hand strength, precision, and range of motion [3]. The main motivation for this glove development is to facilitate such patients for assistive therapy at home as old methods are labor-intensive, costly, and slow.

This paper introduces an innovative rehabilitation system utilizing soft pneumatic tubes "A Soft Pneumatic Robotic Glove for Hand Rehabilitation for Hemiplegic Patients after Stroke" which 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.

2 System Description

The development of the soft pneumatic robotic glove consists of two modes: the rehabilitation mode and the mirror therapy mode. The whole system is divided into three components: the rehabilitation glove system, the pneumatic control system, and the sensory glove system, which are demonstrated below in detail [4].

2.1 Rehabilitation glove system

The rehabilitation glove, powered by micro motors, assists disabled hands in training activities and aids stroke patients in maintaining hand strength and comfort. The glove uses pneumatic actuators, bellow-shaped, attached to the dorsal side of the glove, which are made of compatible resin fiber.

The air gas valve, with a 4mm diameter, is connected to a pump capable of generating positive pressure (1.2 Kpa) and negative pressure (0.5 Kpa). The soft pneumatic robotic glove features positive-negative pneumatic actuators (PNPA) for hand rehabilitation, focusing on flexion and extension movements. Flexion/extension actuators are permanently attached to the fingers. Positive pressure extends the fingers, while nega-3

tive pressure flexes them. This dual-pressure functionality supports comprehensive rehabilitation exercises, particularly for stroke patients [5]. The glove's ability to operate aid recovery.

2.2 Pneumatic control system

A pneumatic-based control system has been developed to improve the operational control of the REHAB Glove for rehabilitation. Each robotic glove finger has its own set of solenoid valves and pressure sensors for independent control and monitoring. The system includes a 12V DC air pump, five KSVO5A DC 3V-5V micro mini electric solenoid valves for controlling flexion and extension sequences, and five sphygmomanometer pressure sensors for monitoring. The operation and data logging are managed using a microcontroller ESP-WROOM-32 and the related control algorithm. The control system includes 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. The microcontroller controls the measured air pressure to track the intended air pressure and uses it to activate and deactivate the valves and pump. The angle of flexion/extension of the rehab glove is set for the affected hand of the patients, and the pressure sensor readings are displayed on an LCD. The schematic diagram of the pneumatic control system is demonstrated in (fig.1)

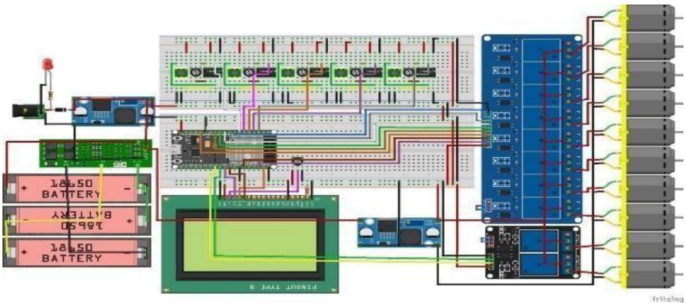

Fig. 1. Schematic diagram of Pneumatic control system

2.3 Sensory glove system

The circuit of the sensory glove consists of a flex sensor and ESP32 WROOM the sensory glove is specially designed for the mirror therapy technique the sensory glove is worn in a healthy hand and by the use of a flex sensor and microcontroller the input signal and analog values of sensor transmitted through one way communication between sensory circuit and the pneumatic control box system.

Workflow of the system

The soft pneumatic rehabilitation glove aids in restoring limb function after strokes or neurological issues, operating in rehabilitation and mirror therapy modes. The system includes a pneumatic glove for the affected hand, using actuators for finger movements, and a sensory glove for the healthy hand, detecting and mirroring motions. In rehabilitation mode, the pneumatic glove assists with controlled exercises, providing real-time feedback. In mirror therapy mode, the sensory glove captures the healthy hand's movements and the pneumatic glove mimics them on the affected hand, stimulating neural pathways to improve motor function. This flexible design enables shown in (fig.2) which demonstrates the flow chart of an operating glove.

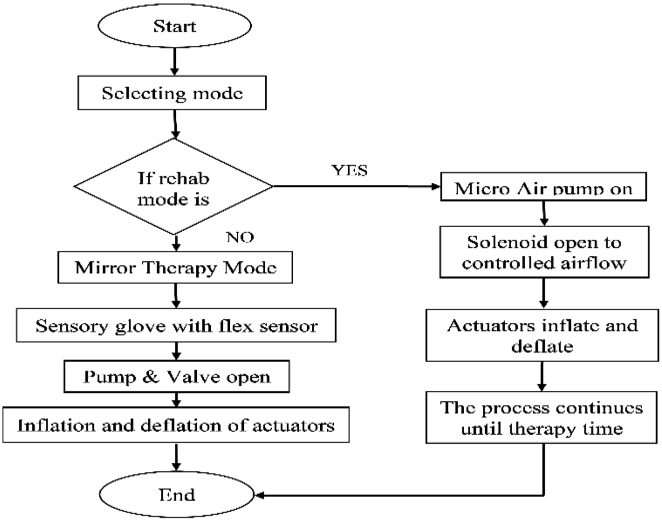

Fig. 2. Workflow of the system

3 Results and Discussion

The rehabilitation glove demonstrated its efficacy in aiding hand mobility restoration through controlled finger flexion and extension. The device utilizes actuators and an air pump to create negative pressure (vacuum) within the actuators, which facilitates precise finger movement. The solenoid valves effectively regulated the airflow, enabling exact control over the finger motions. This mechanism provided consistent and repeatable finger movements, supporting the hand rehabilitation process. The results indicate that the glove can significantly contribute to the rehabilitation of patients by offering regulated and repeated finger exercises and multiple gestures.

3.1 Pressure Measurement

The pressures exerted during finger extension and flexion were measured manually using a sphygmomanometer pressure gauge. This method allowed us to obtain accurate pressure readings for each finger during different movements. Table 1 below summarizes these pressure readings.

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Table 1. Negative and positive pressure in each finger

Fingers	Negative Pressure in kPa	Positive Pressure in kPa
Thumb	34.66 kPa	5.99 kPa
Index Finger	37.19 kPa	6.26 kPa
Middle Finger	37.19 kPa	5.99 kPa

Ring Finger	37.33 kPa	5.46 kPa
Little Finger	37.19 kPa	5.33 kPa

Flexion and extension are displayed in the table. The vacuum that is produced inside the actuators during extension is shown by the negative pressure values, which force the fingers outward. The thumb felt the lowest extension pressure (34.66 kPa), whereas the ring finger had the greatest (37.33 kPa. The total negative pressure applied to the fingers for full extension was observed to be 183.56 kPa, indicating the significant vacuum pressure needed, whereas the positive pressure for full finger flexion into a fist was observed to be 29.03 kPa, indicating that the positive pressure applied by the air pumps is relatively less than the negative pressure show in (fig 3).

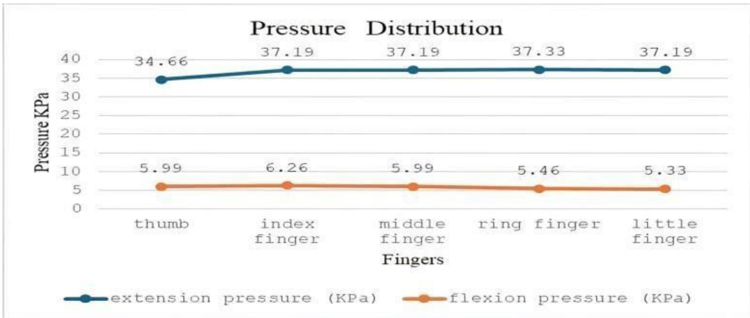

Fig. 3. Graph of pressure distribution during extension and flexion of the hand

4 Conclusion and Future Work

In this paper, we have introduced a prototype of a soft pneumatic robotic system for hand rehabilitation. The system includes a pneumatic soft robotic glove, sensory glove, and pneumatic control box. The pneumatic box can cooperate with the glove to assist hands in achieving a variety of gestures and grasping movements which is shown in (fig 4).

Fig. 4. Multiple gestures of mirror therapy mode during glove operation

In future work, we plan to focus on two main areas of improvement for our soft pneumatic robotic system. Firstly, we aim to enhance customization capabilities by allowing for adjustable pressure settings to accommodate varying patient needs during rehabilitation exercises. Secondly, we will work on refining control algorithms to achieve more precise and controlled finger movements, ensuring that exercises are performed accurately and effectively. Following the outlined improvements, the next goal is to conduct clinical trials to evaluate our device's efficacy and safety. These trials will aim to improve outcomes for hemiplegia patients and integrate our device into standard rehabilitation practices, demonstrating its clinical impact.

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