DEVELOPMENT OF PNEUMATIC REHABILITATION GLOVES BASED ON MCKIBBEN ACTUATOR (HELPING HAND)

MOHAMMED IQBAL BIN ARIFIN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF PNEUMATIC REHABILITATION GLOVES BASED ON MCKIBBEN ACTUATOR
(HELPING HAND)

MOHAMMED IQBAL BIN ARIFIN

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours

Faculty of Electronics and Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJURUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Development of Pneumatic Rehabilitation Gloves Based on McKibben Actuator (Helping Hand)

Sesi Pengajian : 2024

Saya MOHAMMED IQBAL BIN ARIFIN mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐	**SULIT***	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	**TERHAD***	(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.
✓	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS) (COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: ....
....
....
....

Tarikh : 18 May 2024 Tarikh : 18 May 2024

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled DEVELOPMENT OF PNEUMATIC REHABILITATION GLOVE BASED ON MCKIBBEN ACTUATOR (HELPING HAND) is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Student Name	:	MOHAMMED IQBAL BIN ARIFIN
Date	:	18 May 2024

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours.

Signature :

Supervisor Name : DR. FARID ARAFAT BIN AZIDIN

Date : 18 May 2024

Signature :

Co-Supervisor Name (if any) : NOT APPLICABLE

Date :

DEDICATION

For people that lend a hand, who give support, and who stay till the end:

This honest thesis is devoted to the soul of compassion and the firm dedication to creating the earth a greater place. The Development of Pneumatic Rehabilitation Gloves Based on McKibben Actuator project embodies the essence of selflessness, resilience, and community. May its impact ripple far beyond these pages, inspiring countless others to reach out, lift up, and create positive change.

To my adviser, companion, and families. Thank you for accompany me on this long journey. Your support and encouragement are truly my steering stars.

And to those who will carry this good deed, hope you keep up to open up your heart, share your brain, and be the beacon of aspiration to the people in need.

May the Development of the Pneumatic Rehabilitation Gloves Based on McKibben Actuator shine a light on the transformative potential for those in need.

ABSTRACT

In past few years, stroke is said to be Malaysia's third leading cause of death, with a considerable percentage of survivors suffering hand and arm dysfunction. For the past few year, there is a positive development of hand rehabilitation gloves to help stroke survivor to conduct ADL task. Nevertheless, few research have discovered that the past hand rehabilitation gloves are expansive and heavy in weight that are not suitable for daily use of the stroke survivor therapy. Thus, this research aims to improve the hand rehabilitation system by reducing the cost and weight of the gloves or system that are easy to used for daily rehabilitiation therapy. Firstly, the hardware design are made such as the major and minor component of the system to make sure the component are carefully and suitably selected. Secondly, the software design is also made using Arduino IDE to programme the source code that are responsible for the motion of the system. The parameter of 'Helping Hand' is also set up to measure the related data that need to be record and analysed to test the effectiveness of the system. The study method can make the 'Helping Hand' glove to aid an assistance for the stroke survivor to fulfil the ADL needs in addition to the cost and weight reduced gloves. This research and developement of '*Helping Hand*' gloves show it importance aspect in hand rehabilitation gloves field. This research promotes the application of simple yet cost effective and weight reduced gloves or system in stroke rehabilitation.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, strok dikatakan menjadi punca kematian ketiga utama di Malaysia, dengan peratusan besar mangsa yang mengalami disfungsi tangan dan lengan. Sejak beberapa tahun kebelakangan ini, terdapat perkembangan positif sarung tangan pemulihan tangan untuk membantu mangsa strok menjalankan tugas ADL. Walau bagaimanapun, beberapa kajian telah mendapati bahawa sarung tangan pemulihan tangan sebelum ini adalah mahal dan agak berat serta tidak sesuai untuk kegunaan harian untuk terapi harian strok. Oleh itu, penyelidikan ini bertujuan untuk meningkatkan sistem pemulihan tangan dengan mengurangkan kos dan berat sarung tangan atau sistem yang digunakan setiap hari. Pertama, reka bentuk perkakasan dibuat untuk komponen utama dan kecil sistem untuk memastikan komponen dipilih dengan teliti dan sesuai. Kedua, reka bentuk perisian juga dibuat menggunakan Arduino IDE untuk memprogramkan kod sumber yang digunakan untuk sistem. Parameter ‘Tangan Tolong’ juga disediakan untuk mengukur data berkaitan yang perlu direkodkan dan dianalisis untuk menguji keberkesanan sistem. Kaedah ini boleh menjadikan sarung tangan *‘Tangan Tolong’* satu sistem yang membantu mangsa strok memenuhi keperluan ADL selain kos dan berat sarung tangan yang dikurangkan. Penyelidikan dan pembangunan sarung tangan ‘Tangan Tolong’ ini menunjukkan aspek penting dalam bidang sarung tangan pemulihan tangan. Penyelidikan ini menekankan kepada penggunaan sarung tangan atau sistem yang mudah serta mesra kos dan sarung tangan atau sistem yang dikurangkan berat dalam membantu proses rehabilitasi strok.

ACKNOWLEDGEMENTS

Firstly, I really would love to extend heartfelt gratefulness to everyone that have contributed to the realization of the Development of Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand) research project. Their unwavering encouragement, expertise, and support have been instrumental in shaping this work to success.

Secondly, I would like to thank my Supervisor, Dr Farid Arafat bin Azidin, your patience, advice, and insightful feedback have been very invaluable. Thank you for steering me in the right direction and helping me to make the greatest decision regarding the project.

Thirdly, for my precious UTeM, I greatly thank you for providing the necessary resources, infrastructure, and funding. Your belief in my vision empowered me to explore new horizons.

Last but not least, to my family, who patiently endured my late nights and celebrated the victories, your unwavering support means the world to me. Plus, to my friends, who cheered me on, proofread drafts, and shared my excitement, your comradeship kept me going.

To conclude all, this paper stands as a testament to collective effort, compassion, and the pursuit of meaningful innovation. May the Helping Hand continue to make a difference in the lives of many.

May this acknowledgment, honour the collaborative spirit that drives the impactful to the research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

v	-	voltage
+	-	positive

LIST OF ABBREVIATIONS

V	-	Voltage
Gnd	-	Ground
PB	-	Push Button
PAM	-	Pneumatic Artificial Muscle

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

In this chapter, the explanation of project background, the problem statement that led to this project, the objectives that should be achieve, and scope of work are described in detail for the development of Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand).

1.1 Background

In past few years, stroke is said the Malaysia's third leading cause of death [1], with a considerable percentage of survivors suffering hand and arm dysfunction. A stroke can have serious complications, frequently limiting one's capacity to carry out everyday tasks on their own. As instance, during the year 2019 about 47 911 occurrences related to stroke case, 19 928 loss of life, 443 995 common cases and 512 726 Disability Adjusted Life Years (DALYs) lost related to stroke[1]. Regaining hand function is vital for stroke survivors mainly because their recovery has a big impact on their independence and quality of living. For stroke survivor, repetitive movements are crucial to functional rehabilitation [1].

However, the traditional method of recovery often are resources intensive and the rehabilitation are often costly [2]. There is a dire need for easier and more effective methods since the cases of individuals with stroke especially with hand injuries or suffering from a condition arthritis and also carpal syndrome carry on to increase and there are insufficient rehabilitation specialists to handle the demand.

This is where the development of Helping Hand becomes essential. The Helping Hand project aims to address these challenges by developing a state-of-the-art pneumatic rehabilitation glove that leverages McKibben actuators, also known as pneumatic artificial muscles (PAMs). So, the rehabilitation process is improved much more by using the system, which have demonstrated clinical efficacy for assisting repetitive movement activities. Among them, exoskeletons gloves for hand rehabilitation have become more and more well-liked because of their construction, which is modeled after the human body. So, the McKibben actuator is well likely suitable for this project because they are used for the high power-to-weight ratio, ability to mimic the natural muscle movement of human and very flexible.

A simple, adaptable, and affordable exoskeleton gloves such as McKibben actuator for hand rehabilitation can be created with the a very affordable item that is called braided sleeve, long type air ballon, aquarium clear hose and cable tie. Plus, the system is controlled using Arduino Uno, a microcontroller board well-known for its functionality. The primary aim of this project is to produce a hand rehabilitation device or gloves that is weight and cost reduce which can help stroke sufferers regain their functional skills by utilizing the Arduino Uno's ability to practice repeated motions intensively.

1.2 Problem Statement

The primary global cause of disabilities is often called for stroke, a lot of survivors suffering from hand and arm movement problems [3] Therefore, the disabilities will limit the individual’s ability to do the daily activities independently. Each hour, six new incidents of strokes are reported in Malaysia alone and about 15% of patients who pass away within 30 days are having a stroke, these people are reported to have mild to severe disabilities and need ongoing therapy.[4]

Conventional rehabilitation devices are usually resource-intensive[5], sometimes expensive[6], and need the ongoing presence of a physiotherapist[7]. Some of the smaller government hospitals have poor facilities compared to tertiary hospitals, which provide enhanced equipment and treatment alternatives. Stroke patients from low- and middle-class backgrounds frequently lack the financial resources available in general hospitals to participate in an extensive and ongoing program of professional rehabilitation that are provide in the tertiary hospital.

There a few devices that have been design and produce to help the stroke survivor focusing on the hand rehabilitation recovery but there are a disadvantages and problem with the existing hand device. As instance, the Hand Extension Robot Orthosis (HERO) [8] is an advance device engineered to facilitate hand rehabilitation. However, it does come with a few noticeable drawbacks. One of the main disadvantages is the placement of the battery on the glove itself, which can increase the overall weight of the object which can make it heavy to be accommodate by the patient hand. Thus, this can possibly cause discomfort for the user during rehabilitation process and potentially limit the duration of effective therapy sessions. The device also incorporates a micro actuator, although precise, is considerably more expensive than a pneumatic actuator, making the device less accessible for some users due to cost constraints. Furthermore, the micro actuator is not suitable for all conditions as it tends to overheat, which could lead to performance issues and even pose a safety risk. Therefore, the existing devices, HERO have a lot of disadvantages, so the kind of factors should be carefully considered when evaluating its overall effectiveness and suitableness for different users and conditions.

1.3 Project Objective

The primary focus of the project is to develop a pneumatic rehabilitation glove based on McKibben actuator system or device. Specifically, the objectives are as follows:

a) To develop a device that use Arduino based microcontroller with a particular focus on reducing the weight of the rehabilitation gloves.

b) To develop a cost effective and user friendly device that is easily utilized by patient that use McKibben actuator.

c) To analyze data on the effectiveness of the pneumatic rehabilitation glove based on McKibben actuator, providing valuable insights for further improvements.

1.4 Scope of Project

There is a numerous scope of the Helping Hand that contain the design, development, and testing of the pneumatic rehabilitation glove that use the McKibben actuator to aid in hand therapy and rehabilitation process, the scope is stated below:

a) Literature review about design of the glove and the function of the existing rehabilitation.

b) The existing rehabilitation glove will be analyzed and the new initial design concept of the pneumatic rehabilitation glove based on McKibben will be created.

c) Selection of the appropriate materials and components for the devices and the glove which includes the McKibben actuator.

d) The functionality of the device will be programmed and tested using Arduino IDE with the use of Arduino Uno.

e) Create a user interface that allow patient to easily operate the glove and select the therapy setting.

f) The McKibben actuator will be tested and will be implemented onto the designed glove.

g) Detailed documentation will be produced for every design possibility, development procedures, and data analysis. This will act as a reference for next future project and a record of the completed work.

h) The project's outcomes will be published via the proper channels. Public device tests, academic presentations, and scholarly papers will be included in the project report.

1.5 Expected Outcome of the Pneumatic Rehabilitation Glove Based on McKibben Actuator

Considering that the focus of the project is to enable user to perform a therapeutic exercise that use Arduino based microcontroller based on McKibben actuator. The table 1.1 explain the details the expected outcomes for the Helping Hand project. These outcomes serve as the foundation for creating a device that not only meets therapeutic needs but also ensures comfort, safety, and user acceptance.

Idea	Description
Comfortable to wear (Weight reduced factor)	Develop a glove design that ensures a comfortable to be wear by the patient. Use lightweight and breathable materials. Provide adjustable fasteners at the wrist for a secure the glove onto the hand.
Reliable Actuation (Cost reduced factor)	Integrate McKibben actuators to provide smooth, natural, and precise hand movements. Ensure actuators are positioned to mimic natural muscle contractions effectively.
User-Friendly Control System (Easily accessible factor)	Design a control system for easy operation and adjustment of therapy settings. The compact and lightweight control unit are separated from the glove and the air flow are supplied by a clear hose.

Table 1. 1: Expected Outcome for Helping Hand project

CHAPTER 2

LITERATURE REVIEW

This chapter provides a broad overview of the project related to the topic in this report. Besides, the relevant literature is critically discussed and presented later in table for this chapter.

2.1 Introduction

In the context of hand rehabilitation for stroke patients, this literature review investigates the relationship of rehabilitation treatment and rehabilitation devices or system. It starts out with an outline of the effects of stroke, pointing out hand-related motor problems. The restrictions or the disadvantages of conventional approaches are explored, along with the important of hand rehabilitation and the function which repeated movements serve in functional recovery. The research focuses to the possible applications of technology in stroke rehabilitation, with the focus on the development of hand rehabilitation devices using Arduino Uno. The review also intends to give a comprehensive understanding of the state of stroke rehabilitation today and the possibilities of Arduino Uno in this domain by looking at the aspects.

2.2 Type of Stroke

Stroke is the major cause of loss of life and impairment around the world. There are three type of stroke that is ischemic [9], hemorrhagic [10] and transient ischemic attack (TIA) [11]. When a blockage cuts off the blood supply to part of your brain, an ischemic stroke happens which kill the brain cells [9]. The injury that happens to the brain cells can influence on how the body function. Plus, it can also transform on how you feel and think. While, hemorrhagic stroke take place if you own a bleeding around or in the brain [10]. This damages the cells of your brain, and can influence on how your body works, as well as how you feel and think. Plus, a TIA are also the same as a stroke, yet the sign last for a short term time [11]. The people can get stroke sign because the blood clot is blocking the oxygen supply to your brain. When the clot has moves away from the path, the stroke sign stop.

2.3 Understanding the effect of stroke

Stroke is a critical global health subject with a lot of negative impact on individual. As stated by the World Stroke Organization (WSO), stroke is the third primary source of loss of life and disability in the world and in Malaysia [12]. The stroke occurred when the blood path to the brain is obstructed and clogged which can lead to various physical and cognitive impairment [9], [10], [11]. As instance, hemiparesis, which is the loss of motor function on one side of body [13]. Depending on the intensity, location, and type of the stroke in the brain, the consequences might differ significantly. Therefore, stroke have a lot of negative effect on human. Other effect of stroke on human body are shown in Table 2.1.

Effect	Description
Physical [14]	Reduced range of motion (ROM), compensatory movement, muscle stiffness, sensory changes, coordination challenges and muscle weakness. [14]
Cognitive [15]	Unable to learn new knowledge and languages, lack of attention and memory. Having a disorder that can affect a person's ability to write, speak, and comprehend language. [15]

Emotional [16]	Having behavioral and emotional changes. Such as anxiety, sadness, rage and regretting. [16]
Vision [7]	Loss of vision, difficulty in focusing, and difficulty in identifying object. [7]

Table 2. 1: Effect of Stroke

2.4 Stroke impact on hand function

The primary cause of death and disability in the world are often related to stroke, it often resulting to motor deficits, including upper extremity impairment such as hemiparesis [17], which significantly affects hand mobility. This impairment can be debilitating, as it hinders the ability to perform daily activities, thereby impacting the quality of life.

Restoring hand function post-stroke is considered a high priority for individuals, because the hand have a very importance role in performing tasks that require fine motor skills [18]. These tasks range from basic activities such as eating and dressing to more complex ones like writing or operating machinery. The ability to perform these tasks independently contributes significantly to an individual's self-esteem and overall quality of life.

Hand rehabilitation for stroke patients is therefore of paramount importance. It involves a series of therapeutic exercises[19] and activities designed to regain hand function and improve motor skills in the upper extremity [17]. These rehabilitation programs are typically design and construct to the individual's specific demand, abilities and can involve physical therapy, occupational therapy, and the use of assistive devices.

Rehabilitation exercises focus on improving strength, flexibility, coordination, and fine motor skills. They may involve tasks that mimic daily activities, such as gripping objects, buttoning clothes, or using utensils, to help the patient regain independence. In addition, emerging technologies such as robotics and virtual reality are being incorporated into rehabilitation programs to provide more intensive, repetitive, and task-specific training.

In conclusion, hand rehabilitation is a critical component of stroke recovery. It not only helps stroke survivors regain their hand function and independence but also significantly improves their overall quality of life. As research in this field continues to advance, it is hoped that more effective strategies for hand rehabilitation will be developed, further enhancing the recovery outcomes for stroke survivors.

2.5 Past Hand Rehabilitation Glove

2.5.1 A Hybrid Arm-Hand Rehabilitation Robot With EMG-Based Admittance Controller

According to Xie et al. 2021, the ability to perform reach-and-grasp activities give a critical importance in the everyday lives of individuals, particularly for those who have experienced a stroke. Despite its significance, there is a lack of rehabilitation robots capable of providing comprehensive training for the arm and hand to aid in improving post-stroke mobility. This study presents the development of a revolutionary hybrid arm-hand rehabilitation robot (HAHRR) specifically tailored for the grasp and reach task as shown in Figure 2.1.

The HAHRR's innovative design (see Figure 2.2) encompasses a cable based module for an exoskeleton and enabling 3D arm motion for aiding the hand movement. This unique structure allows for simultaneous assistance for both the arm and hand during rehabilitation exercises. To enhance its functionality, an Electromyography (EMG) based admittance controller is integrated into the HAHRR, enabling active compliance control throughout the rehabilitation process.

Through the experimental findings revealed, the HAHRR, equipped with the EMG based admittance controller, plus, successfully facilitated the subject in completing the grasp and reach task, yet also generated swift trajectories when measured to the force-sensing-based admittance controller. The results underscore the potential efficacy of the proposed approach in post-stroke arm-hand rehabilitation training and its capacity to contribute to improved patient outcomes. This research shows an important step forward in the development of hand rehabilitation gloves or system and holds promise for improving the quality of life for individuals undergoing stroke recovery. [20]

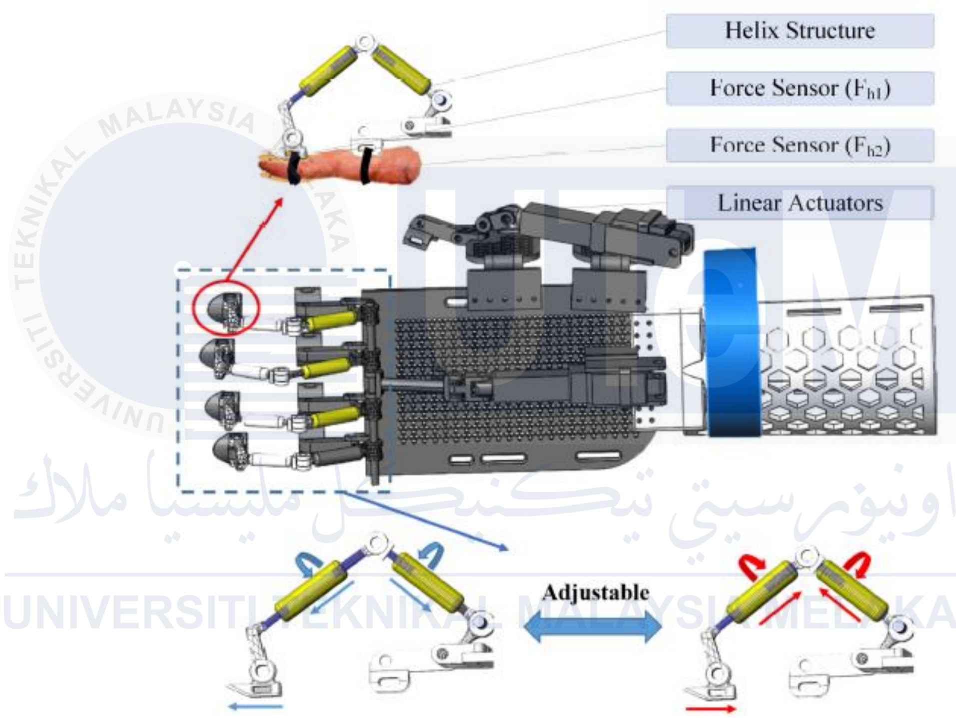


Figure 2. 1: The schematic of hand exoskeleton [20]

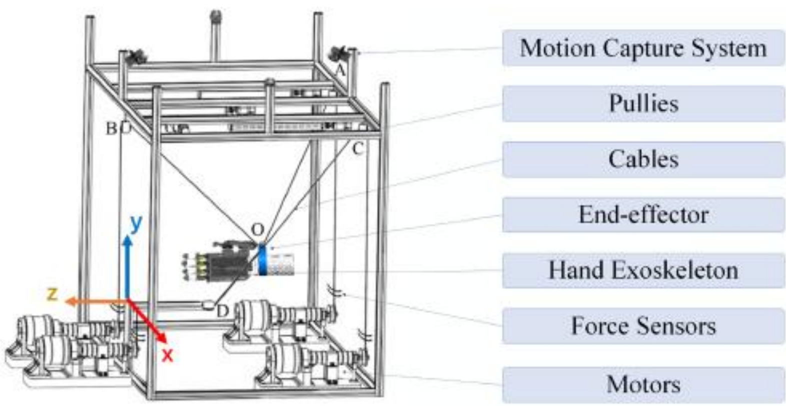


Figure 2. 2: The schematic of the HAHRR [20]

2.5.2 A Wearable Hand Rehabilitation System With Soft Gloves

Based on Chen et al. 2021, the article introduces a novel wearable hand rehabilitation system aimed at addressing hand paralysis, a common complication in stroke patients. This system is designed to support each task oriented therapy and mirror therapy. It comprises two of gloves that is a sensory glove [see Figure 2.4 (a), (b)] and a motor glove [see Figure 2.4 (c), (d)].

On the non-affected hand, the sensory glove is worn that is equipped with the flex and force sensor that are utilize in measuring the bending angle and force of gripping of each joint of the finger that are used for motion diagnosis. The motor on the glove is powered by micromotors which are providing the affected hand with supporting driving force to run a rehabilitation tasks. What makes this system unique is the use of machine learning to accept gestures from the sensory glove, allowing for fine-grained gesture recognition that have an impressive precision rate of 93.32%. This feature enables stroke survivor to utilize precise finger gestures for repetitive task of multiple finger or single fingers in coordination using the mirror therapy.

Furthermore, the system provides an additional unique task oriented rehabilitation during the mirror therapy, offering six types of training tasks [see Figure 2.3]. These tasks achieve an average real-time accuracy of 89.4%, enhancing the overall effectiveness of the rehabilitation process. [13]

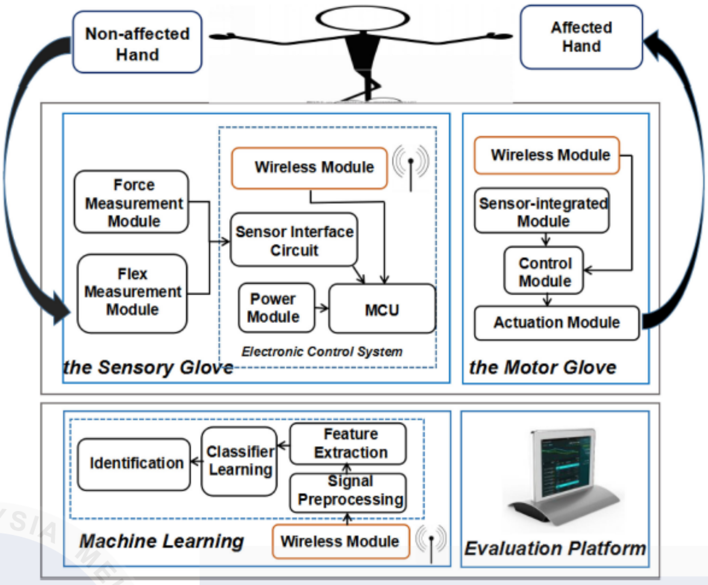


Figure 2. 3: Architecture of the proposed hand rehabilitation system. [13]

Figure 2. 4: Design of the glove hardware. [13] (a) Dorsal side of the sensory glove, (b) Palm side of the sensory glove, (c) Motor glove, (d) Motor glove with animation of tendon design.

2.5.3 Cooperative Hand Therapy via a Soft, Wearable, and Unilateral Telerobotic System

According to Kim et al. 2023, the process of rehabilitating hand function is intricate and challenging, requiring a high amount for degrees of freedom. While soft wearable hand rehabilitation robots have been developed to help hand motion with a solid design, the key to successful rehabilitation lies in having an instinctive control system which can handle multiple degrees of freedom and enable interaction with an occupational therapist. In response to this need, a soft wearable unilateral telerobotic system has been created to allow for numerous grasping tasks and collaborative interaction between the survivor and therapist. This device comprises a sensor on glove that tracks the occupational therapist's hand position and a soft robotic glove [see Figure 2.6 (a), (b)] that assists the survivor's hand movements, including adjustments to the coordination of the fingers and movements of the thumb. The soft robotic glove replicates the patient's hand movements according on the data collected from the sensor on glove.

Furthermore, a telerobotic impedance-control scheme [see Figure 2.5] provides instinctive instruction for fingertip-force vector control and different hand postures. The effectiveness and achievement of the system were evaluated on a healthy individual and a post-stroke survivor. The results demonstrated that the system enabled the therapist to significantly expand the survivor thumb workspace and have control over the fingertip-force direction, thereby facilitating stable object grasping in various postures. This innovative rehabilitation system is well-suited for non-contact telehealth care, enhancing patient-therapist interactions. [14]

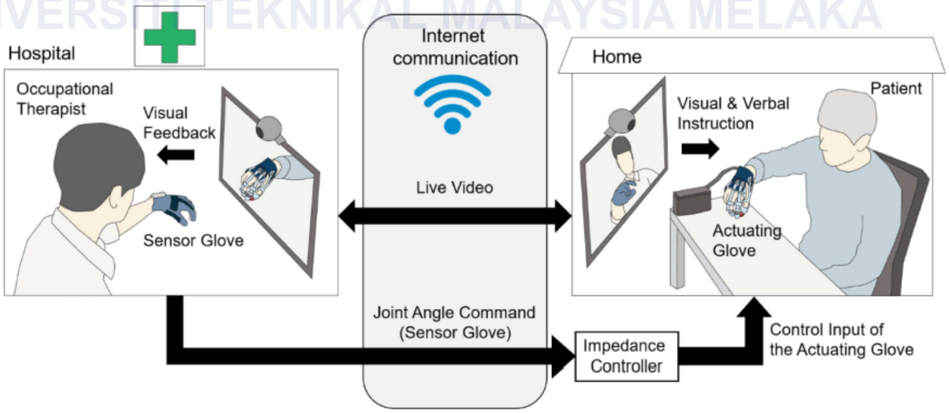


Figure 2. 5: Overview of the soft wearable unilateral teleoperation system for hand rehabilitation. [14]

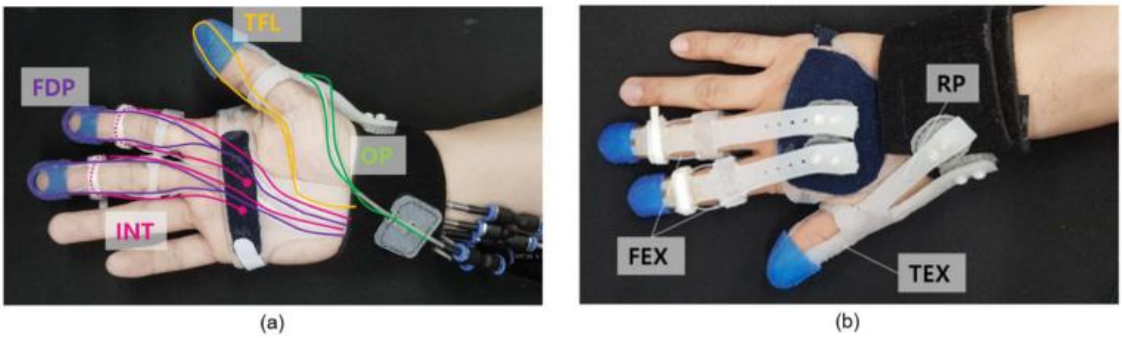


Figure 2. 6: Design overview and exotendon routing scheme of the soft robotic glove: (a) Palmar view of the soft robotic glove showing active exotendon routing, and (b) Dorsal view of the soft robotic glove showing passive exotendon routing. The dashed lines in (a) indicate the routing of the active exotendons along the dorsal aspect. [14]

2.5.4 Design and Analysis of the M3Rob: A Robotic Platform for Wrist and Hand Rehabilitation

As stated by Alonso-Linaje et al. 2024, physical therapy is essential for recovering motor functions, and the use of rehabilitation robots has significantly improved the ability to provide repetitious therapeutic interventions in both home and clinical settings. This article focuses on introducing the M3Rob device [see Figure 2.7(b)], which is a 3-DoF wrist exoskeleton [see Figure 2.7(a)] integrated with a force sensor. The device enables the implementation of real therapies known for their productiveness in hand recovery. It utilizes a joint space target trajectory and close loop admittance control system as input, which has been thoroughly tested across three levels of assistance. Additionally, the device has the capability to integrate a hand exoskeleton, allowing for concurrent wrist and hand rehabilitation to target activities involved in daily living. With a wide range of motion of 180° for supination/ pronation, 120° for extension/flexion, and 75° for radial/ ulnar deviation, as well as joint torques spanning from 7.85 to 43.86 Nm, this device engulf the full range of motions and forces necessary for daily activities. In summary, the shown device provides an effective solution for hand and wrist rehabilitation, productively solving crucial problem in hand rehabilitation recovery. [21]

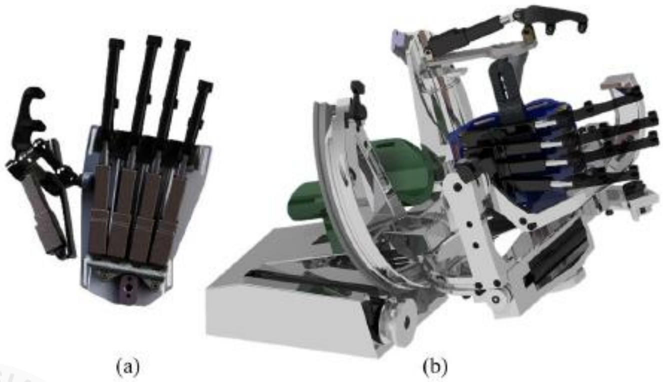


Figure 2. 7: The RobHand exoskeleton for hand rehabilitation (a) CAD model (b) Assembly onto the M3Rob device. [21]

2.5.5 Hand Extension Robot Orthosis (HERO) Glove: Development and Testing With Stroke Survivors With Severe Hand Impairment

As explained by Yurkewich et al. 2019, the Hand Extension Robot Orthosis (HERO) glove [see Figure 8] was developed through a creative design process in collaboration with real therapists and stroke patients. The goal was to create a solution that would enable individuals with terrible hand disfunction due to stroke to effectively hold and grasp everyday objects. The HERO glove [see Figure 2.8] was designed to be lightweight, mobile and easy to set up. The glove contained of a batting glove with machine made tendons embedded in the fingers. These tendons are controlled by an actuator that have linear type movement, allowing the fingers to be extended and flexed as needed. The finger grasping and extension assistance are self-activated using signal thresholds from an inertial measurement unit.

In a research study involving five stroke patients (Chedoke McMaster Stroke Assessment – Stage of Hand 1-3), it was observed that these individuals were choose to wear the HERO Glove [see Figure 2.8] in 1-3 minutes with assistance. The results showed that when putting on the glove, the stroke patient conducted remarkable better on the Box and Block Test, transferring an average of 2.8 more blocks ($p < 0.01$) than when not on the glove. Furthermore, four out of the five stroke survivors were only able to transfer blocks while wearing the HERO Glove. The glove enabled these individuals to fully extend their index finger, resulting in an increase of 97.5° ($p < 0.01$). Additionally, three out of the five stroke survivors demonstrated improved ability to grasp a water bottle while wearing the HERO Glove.

Feedback from both therapists and stroke survivors highlighted the need to increase the grip force assistance of the gloves. They also acknowledge the glove's portability, lightweight design, and recognized its future practicality in aiding with task oriented therapy. [8]

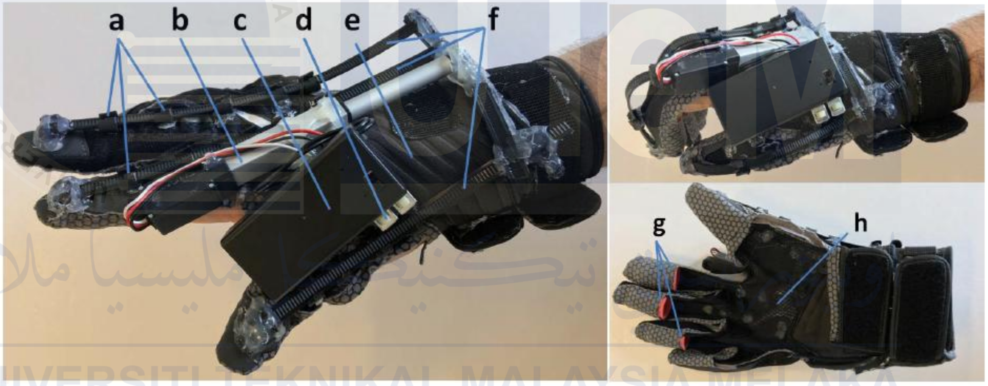


Figure 2. 8: The HERO Glove consists of (a) cable tie pawls, (b) a linear actuator, (c) a 9V battery pack, 9V battery and microcontroller with an inertial measurement unit, (d) buttons to control manual mode and select between the manual and automated modes (e) a batting glove, (f) cable tie tendons, (g) finger thimbles, and (h) an open palm. [8]

2.5.6 Multiple Hand Posture Rehabilitation System Using Vision-Based Intention Detection and Soft-Robotic Glove

Based on Rho et al. 2024, for individuals who have survived a stroke, limited hand function can restrict their ability to perform activities of daily living (ADLs). A recent development in rehabilitation technology involves the use of soft-robotic gloves to assist stroke survivors in actively rehabilitating their hand movements. This is achieved by interpreting their intentions through biofeedback signals such as electromyograms and electroencephalograms.

To enhance the hand functions necessary for ADLs, it's crucial for stroke survivors to actively practice various hand postures. However, accurately detecting these intentions for multiple hand postures has been a challenge, leading to low performance in real-time classification. To address this issue, we propose a hand rehabilitation system that consists of a vision-based intention detection framework and an 8-degree-freedom soft-robotic glove [see Figure 2.9]. Our framework, known as the depth-enhanced hand posture intention network, utilizes images and depth data to observe users' arm behavior and hand-object interactions, allowing it to predict intentions for multiple hand postures.

The 8-degrees-of-freedom soft-robotic glove [see Figure 2.10] enables the flexion and extension of individual fingers, thereby assisting users in performing desired hand postures. In order to actively support rehabilitation, our glove is operated to aid users' finger movements when they make efforts to generate the desired hand postures.

We tested our system in a real-time pick-and-place task that involved five hand postures commonly used in ADLs. Our vision-based system successfully predicted and facilitated the desired hand postures for five healthy individuals and three stroke survivors, with an average accuracy of 90.4% and 80.3% respectively, outperforming methods reported in previous studies. [22]

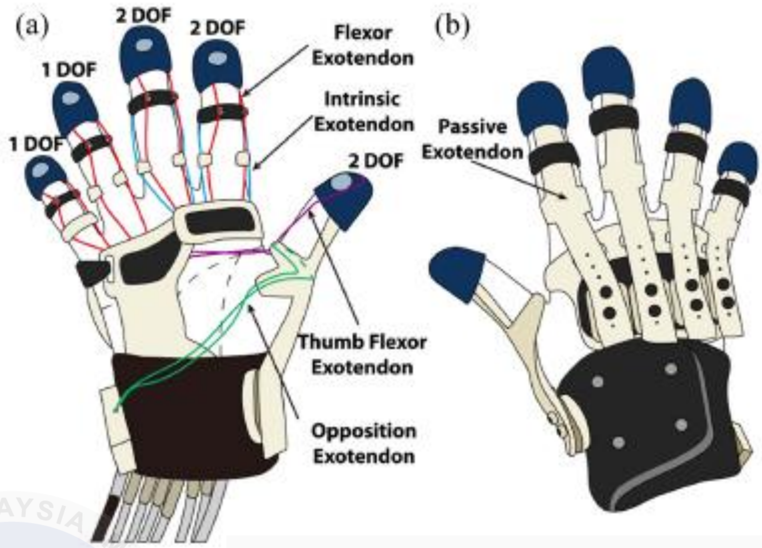


Figure 2. 9: 8-DOF soft-robotic glove. (a) Palmer view of the soft-robotic glove. The colored line indicates the routing of the active exotendons. (b) Dorsal view of the soft-robotic glove. Passive exotendons extend the user's fingers. [22]

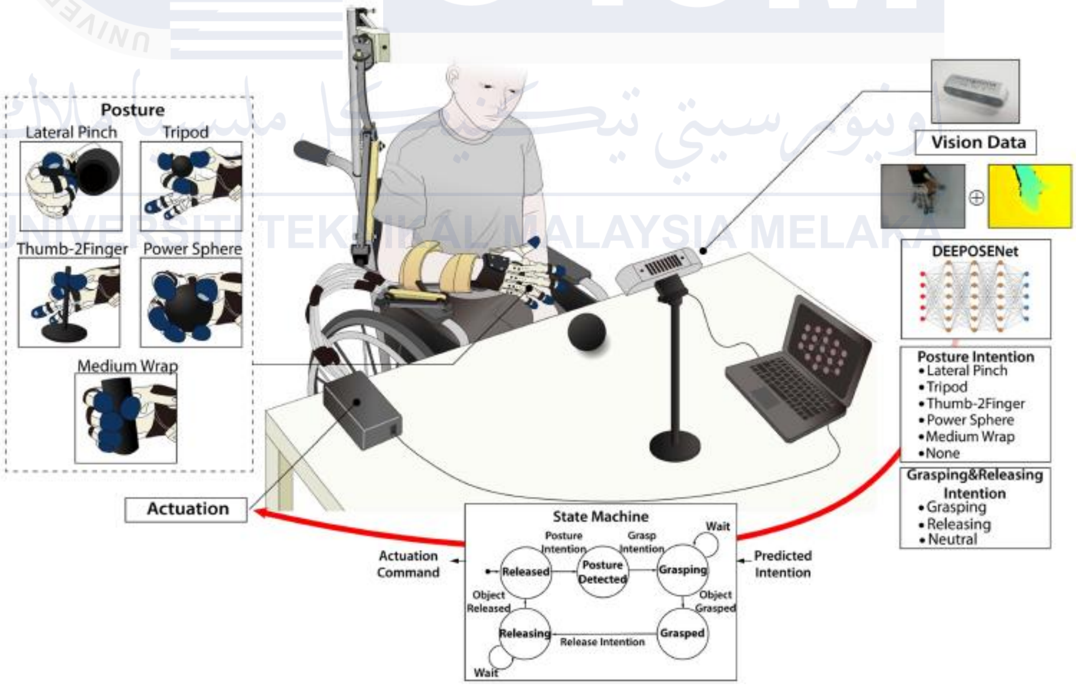


Figure 2. 10: System overview [22]. The framework recognizes the intention of the user to grasp an object and desired hand posture through DEEPOSENet and realizes the posture with an 8-DOF soft-robotic glove. An RGB-D camera is mounted in front of the user observing the user's hand and the object. The cable-driven mechanism is used to actuate the robotic glove.

2.5.7 Probabilistic Model-Based Learning Control of a Soft Pneumatic Glove for Hand Rehabilitation

As mentioned by Tang et al. 2022, the purpose of this study is to address the challenges faced by stroke survivors in performing activities of daily living (ADL) independently due to the loss of hand functions. Soft pneumatic gloves [see Figure 2.11] are being explored as a potential assistance approach for stroke survivors to regain independence in ADL tasks. However, the development of effective control strategies for the integration of the human-soft robot system is hindered by the complexities of soft robots and uncertainties surrounding human intentions. This study seeks to overcome these challenges by developing control approaches to enhance hand functions in stroke survivors within this system.

To achieve this, the study initially utilized a soft pneumatic glove to assist individuals with impaired hand function following a stroke. A novel probabilistic model-based learning control approach was then introduced to tackle the complexity of this system. Additionally, a task-oriented intention-driven training modality was designed to tailor the rehabilitation process to the individual needs of the participants. The control performance was evaluated on both able-bodied subjects and stroke survivors, who participated in a 20 session rehabilitation program.

The findings of the study demonstrate that the proposed approach enabled the soft pneumatic glove to provide personalized and adaptive assistance for all participants, allowing them to accomplish a variety of tasks. The training sessions resulted in a noticeable decrease in tracking error and muscle co-contraction index, while the hand gesture index showed a consistent improvement. Furthermore, all stroke survivors showed enhanced hand functions and improved muscle coordination after the training sessions.

In conclusion, this study successfully developed a learning-based soft robotic glove training system [see Figure 2.12] and demonstrated its potential in post-stroke hand rehabilitation. The significance of this work lies in its contribution to advancing the application of soft robotic training systems in stroke rehabilitation, thus potentially improving the quality of life for stroke survivors. [23]

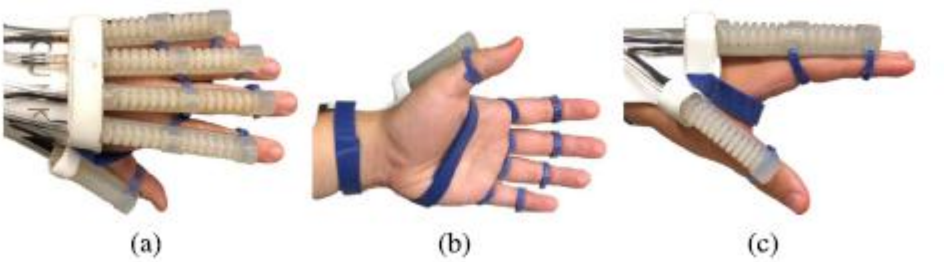


Figure 2. 11: Demonstration of a soft pneumatic glove that consists of a hand base, five soft actuators, and flex sensors. Figures (a), (b), and (c) show the top, bottom, and lateral view of the glove, respectively [23]

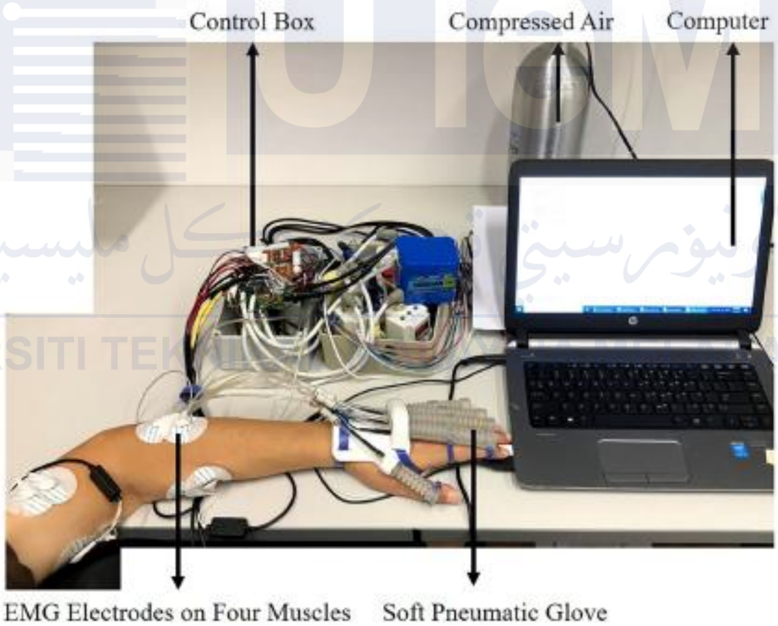


Figure 2. 12: Experimental setup [23]. The control box contains five proportional solenoid valves which regulate air pressure for each finger, and three data acquisition devices which receive and send signals. The compressed air supplies pressure for the soft pneumatic glove. The computer implements the control algorithm. Four pairs of EMG electrodes are attached on the skin surface of FD, ED, BI and TRI muscles.

2.5.8 Review: Hand Exoskeleton Systems, Clinical Rehabilitation Practices, and Future Prospects

As indicated by Tran et al. 2021, spinal cord injury (SCI) and stroke can often lead to the loss or reduction of hand functionality, significantly impacting everyday tasks. As a result, clinical rehabilitation for individuals with SCI or stroke places a strong emphasis on the recovery and improvement of hand function. In recent years, there has been a notable increase in research on hand exoskeletons due to the potential of these devices to automate and enhance clinical rehabilitation. However, there is a noticeable gap between the current clinical practice and exoskeleton research, resulting in limited testing of hand exoskeletons on individuals with SCI and/or stroke. This review article seeks to comprehensively analyze and assess hand exoskeleton studies based on clinical rehabilitation practices. The key findings of this review are as follows:

1. Although current hand exoskeletons can facilitate simple activities of daily living (ADL) tasks, they lack the precision required for fine motor control.

2. Most hand exoskeletons have a lower number of degrees of freedom compared to the human hand, potentially restricting their movement capabilities.

3. A majority of hand exoskeletons are deficient in sensing capabilities, limiting viable control methods [see Figure 2.14] and user interfaces.

4. Inconsistent evaluation methods across studies hinder accurate performance assessment of different exoskeletons.

These findings reveal existing disparities between clinical hand rehabilitation practices and the current state of hand exoskeleton technology [see Figure 2.13 (a), (b), (c), (d), (e), (f), (g)]. It is hoped that by shedding light on these shortcomings, this review will help guide future advancements in the field of assistive and rehabilitative hand exoskeletons, ultimately bridging the gap between research and practical application. [15]

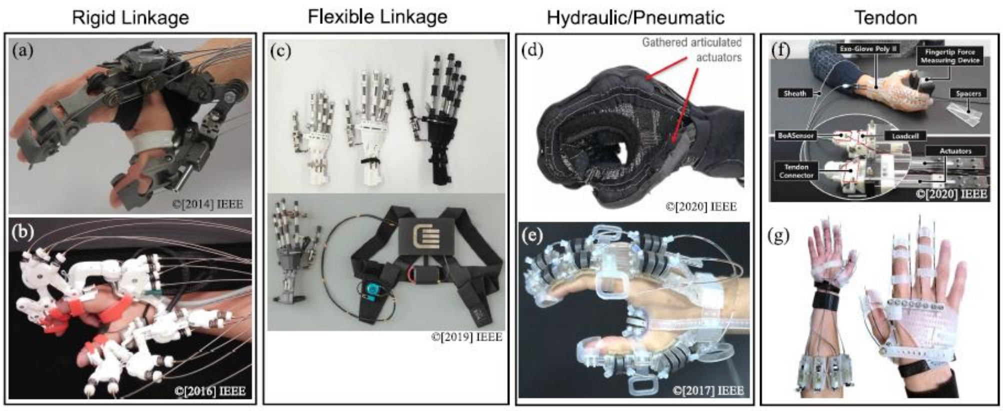


Figure 2. 13: Hand exoskeleton systems in the last decade, (a) HX (b) Maestro, (c) RELab tenoexo (d) Harvard Soft Pneumatic Glove (e) Exo-Glove PM (f) Exo-Glove Poly II (g) FLEXotendon Glove-II [15]

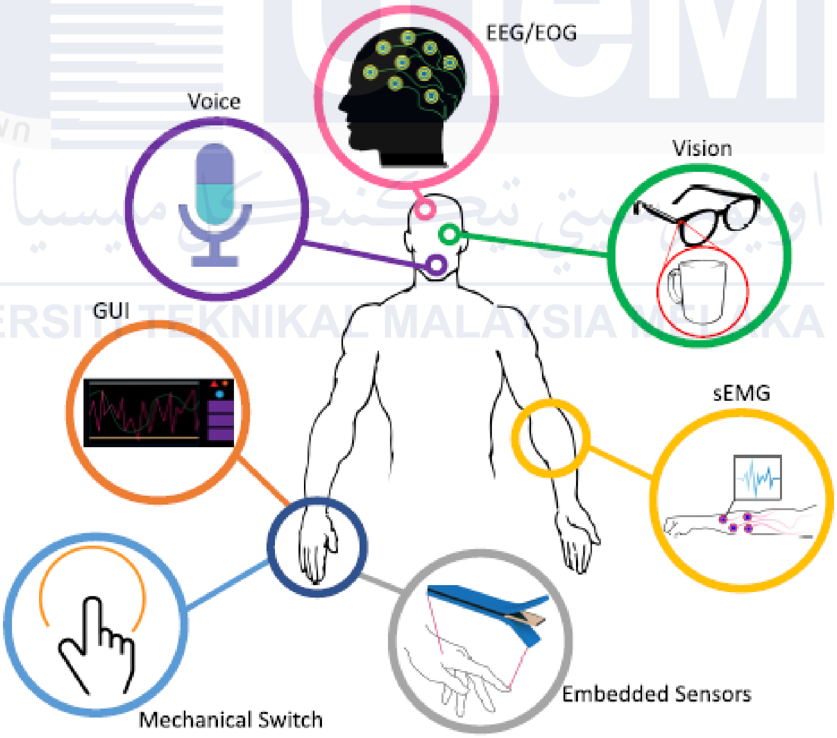


Figure 2. 14: A variety of user interfaces have been used for hand exoskeleton control to accommodate the user's needs and correctly interpret user intention [15]. The most common methods are sEMG , mechanical switch , GUI , EEG/EOG , voice , embedded sensors , and vision.

2.5.9 SSVEP-Based Brain Computer Interface Controlled Soft Robotic Glove for Post-Stroke Hand Function Rehabilitation

From the point of view of Guo et al. 2022, a soft robotic glove controlled by brain-computer interfaces (BCI) [see Figure 2.15] has been utilized to assist in rehabilitating hand function following a stroke. Research has shown that BCI combined with motor imagery (MI) and robotic-aided devices can be an effective tool for improving hand function after a stroke. However, individuals using BCI typically require extensive training and may initially experience unsatisfactory results.

To explore an alternative to MI-BCI, a non-invasive BCI paradigm based on steady-state visually evoked potentials (SSVEP) was proposed as a means of detecting user intention to trigger the soft robotic glove [see Figure 2.16] for post-stroke hand function rehabilitation. In a randomized controlled trial (RCT), thirty post-stroke patients with impaired hand function were divided into three groups: conventional therapy, robotic therapy, and BCI-robotic therapy. Clinical assessments were carried out at pre-training, post-training, and a three-month follow-up.

The group receiving BCI-robotic therapy demonstrated significant improvement in Fugl-Meyer Motor Assessment of Upper Limb (FMA-UL) scores, FMA shoulder/elbow, FMA wrist/hand, and Wolf Motor Function Test (WMFT) scores compared to the other groups. Furthermore, the improvement in FMA was found to be significantly correlated with BCI accuracy. The study suggested that the use of a SSVEP-BCI controlled soft robotic glove yielded better results in hand function rehabilitation compared to solely robotic glove rehabilitation, and it showed similar efficacy to previously reported MI-BCI robotic hand rehabilitation. This indicates the feasibility of utilizing SSVEP-BCI controlled soft robotic gloves in post-stroke hand function rehabilitation. [24]

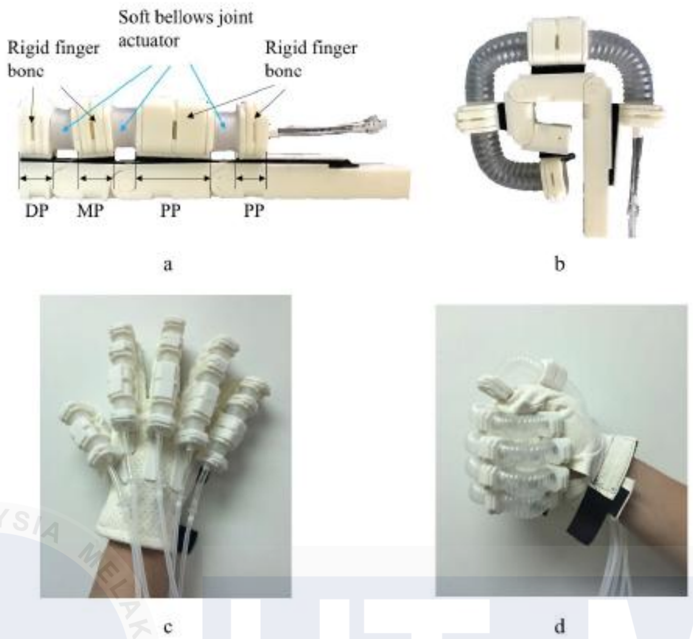


Figure 2. 15: Soft robotic finger extension and flexion. a. extension; b. flexion; c. hand open; d. hand close. [24]

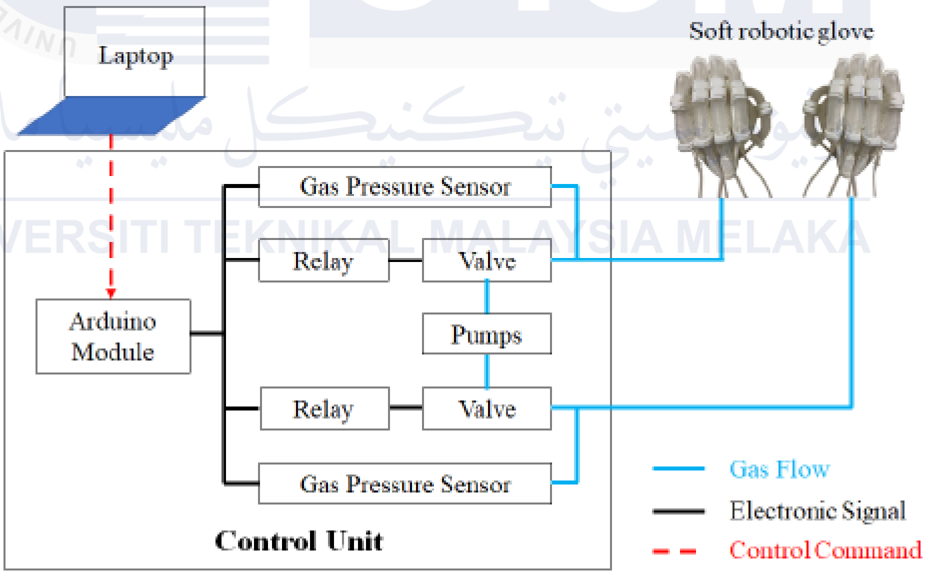


Figure 2. 16: Diagram and working mechanism of the control unit. [24]

2.5.10 Toward Restoration of Normal Mechanics of Functional Hand Tasks Post-Stroke: Subject-Specific Approach to Reinforce Impaired Muscle Function

In this research, Vermillion et al. 2019, explored the use of robotic therapy for stroke survivors to practice intricate hand movements on a larger scale. However, the current devices in use often require patients to mimic specific movement patterns using rigid actuators, without taking into account the unique characteristics of each individual's impairment. This rigidity reduces the overall effectiveness of the therapy.

To address this issue, we tested a novel, theory-based biomimetic method designed [see Figure 2.18] to restore the mechanics of complex hand tasks with personalized assistance patterns. We conducted this study with twelve chronic stroke survivors, who performed two simulated functional tasks: hand opening and a simulated pinch task (pressing with the distal pad of the hand). Our approach involved providing assistance using non-restrictive actuators (extensors) that countered each individual's specific impairments, identified during unassisted task performance [see Figure 2.17]. Importantly, there were no restrictions on movement to predefined patterns.

The assistance patterns required to complete the tasks varied significantly across subjects, reflecting the wide range of impairments and individual needs. For the hand opening task, severely impaired patients experienced significant improvements in range of motion and coordination between joints, while those with less impairment demonstrated enhanced movement quality (reduction in jerk). During the simulated pinch task, subject-specific assistance helped the patients to restore normal mechanics, enabling them to direct fingertip force toward the surface as they would before the injury. The angular deviation reduced from an average of 16.8 degrees to 3.7 degrees. Electromyography data confirmed that the subjects exerted a similar effort level under assistance as they did during unassisted conditions.

Overall, this pioneering approach has the potential to establish a new paradigm for hand rehabilitation, by restoring complex task mechanics with personalized assistance that reflects individual impairment characteristics, while also promoting the active participation of the subjects in their recovery. [25]

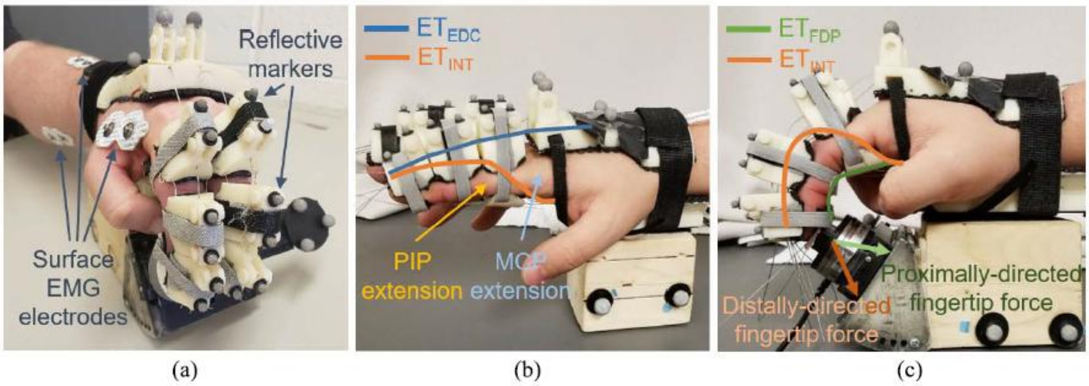


Figure 2. 17: Experimental setup: (a) experimental setup showing electrodes and markers (b,c) Simulated functional tasks: subject performing (b) hand open task;(c)palmar press task with assistance from BiomHED [25]

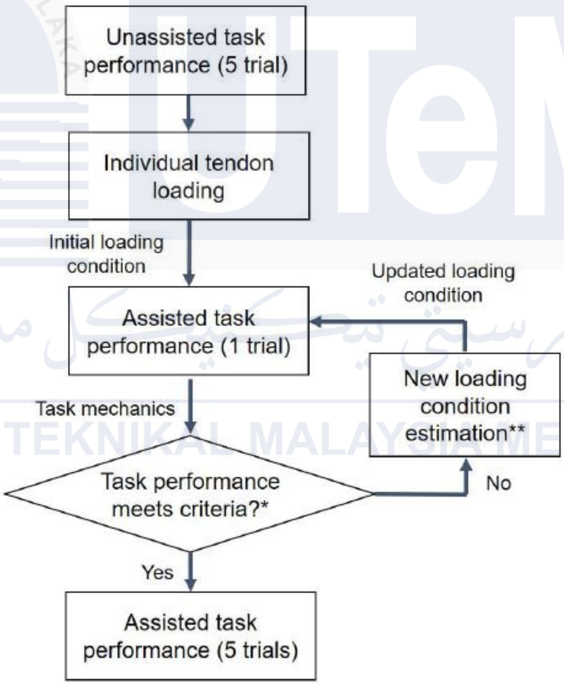


Figure 2. 18: Flowchart of the iterative scheme that determined an assistance pattern for individual patient based on the observed task mechanics. [25]

2.5.11 User-Driven Functional Movement Training With a Wearable Hand Robot After Stroke

Pursuant to Park et al. 2020, conducted a comprehensive study to assess the effectiveness of a cutting-edge robotic orthosis designed to aid individuals with hand impairment following a stroke. This innovative wearable device [Figure 2.19] is completely user-controlled and serves a dual purpose: as a therapeutic tool for facilitating hand exercises to regain neuromuscular function, and as an assistive device for daily activities to enhance hand functionality. In a pilot study involving 11 chronic stroke patients with moderate muscle tone, we implemented a month-long training regimen using the device. The participants were evaluated using standardized measures both with and without the assistance of the device. The results revealed significant improvements in the distal joints of the affected tendon [Figure 2.20] when utilizing the device, indicating its potential as an effective rehabilitative device for the hand. Furthermore, scores on the Action Research Arm Test post-intervention illustrated the device's potential to assist with grasping tasks. These findings underscore the promising potential of wearable, user-driven robotic hand orthoses in expanding the utilization and rehabilitation of the affected upper limb post-stroke. [26]

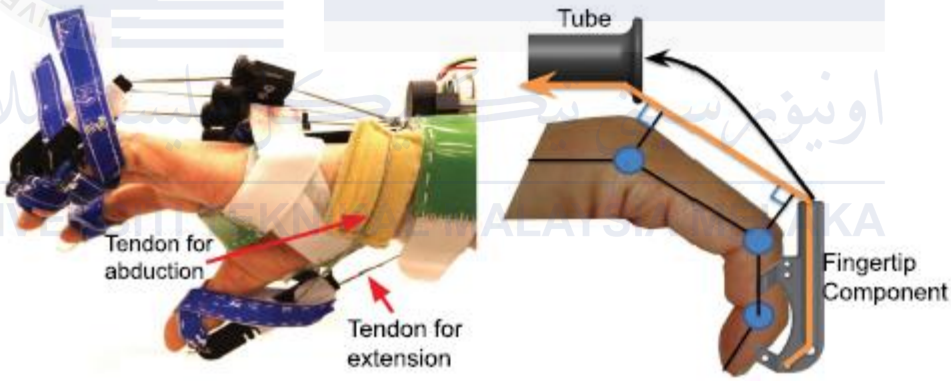


Figure 2. 19: Tendon routes for the thumb (left) and fingertip components (right). [26]

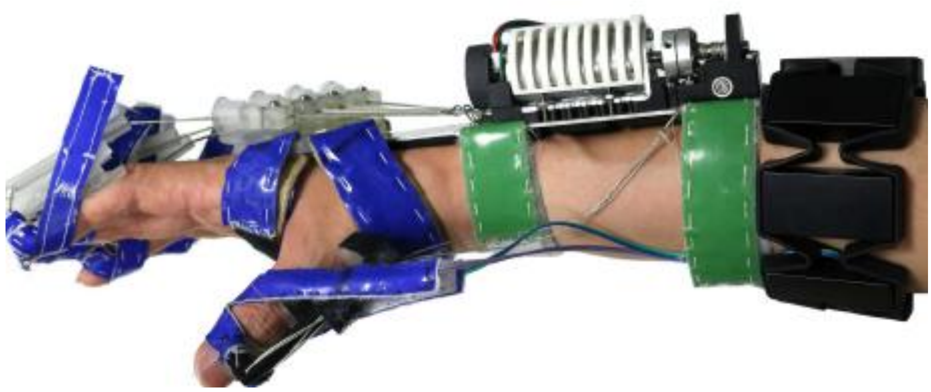


Figure 2. 20: Exotendon device and EMG armband [26]

2.5.12 Design and Control of a Wearable Hand Rehabilitation Robot

As demonstrated by Cheng et al. 2018, this research paper introduces an innovative wearable hand rehabilitation robot designed to assist patients with rehabilitation exercises involving the flexion and extension of their fingers. The robot prototype [Figure 2.21] is characterized by a modularized structure featuring nine degrees of freedom, enabling independent control of the patient's fingers. To mitigate the impact on the patient's hand and arm, the entire control system is ingeniously housed in the patient's backpack, while a cable-driven approach is employed for long-distance power transmission.

Recognizing the repetitive nature of the training and the potential for external disturbances, the paper proposes a sophisticated controller that combines iterative learning control (ILC) and active disturbance rejection control (ADRC) to effectively manage the movements of the fingers. Notably, the contributions of this paper extend to both the design of the robot's modularized structure and the development of the ILC + ADRC controller. Through extensive experimental validation, the research successfully confirms the functionality of the proposed robot and demonstrates the excellent control performance achieved by the proposed controller. [27]

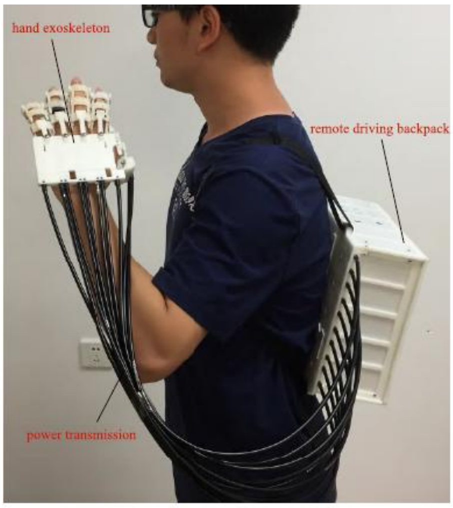


Figure 2. 21: Proposed hand rehabilitation robot including the remote driving backpack, the power transmission and the hand exoskeleton. [27]

2.6 Summary

The field of hand rehabilitation is advancing rapidly with the development of various robotic systems. These range from hybrid arm-hand rehabilitation robots[20] to wearable hand rehabilitation systems with soft gloves[13], all designed to assist patients with tasks such as reach-and-grasp, mirror therapy, and task-oriented therapy [13]. They incorporate advanced technologies such as EMG-based admittance controllers [13], vision-based intention detection frameworks [22], and probabilistic model-based learning control approaches [23]. These systems are improving hand functions needed for daily activities and helping stroke patients with dire hand impairment to grasp and also stabilize everyday objects. The integration of brain-computer interfaces (BCIs) [24] is further enhancing these systems, facilitating finger movements based on the user's intentions. However, there is a need for effective control strategies for the integration of 'human-soft robot' systems, as highlighted in the review of hand exoskeleton systems [15]. Although there is a lack of specific information on user-driven functional movement training with a wearable hand robot, and the design and control of a wearable hand rehabilitation robot, these systems generally involve the use of soft materials and advanced control algorithms to provide safe and effective rehabilitation exercises. These advancements hold promise for the future of hand rehabilitation, particularly for stroke survivors, offering potential solutions for improving hand function, enabling patients to perform daily tasks more independently and broadening the horizon of hand rehabilitation gloves device. The previous technique, advantages, disadvantages and reference of the past hand rehabilitation devices are shown in Table 3.

Author, Year	Proposed Technique	Advantages	Disadvantages	Reference
Xie et al. 2021	A Hybrid Arm-Hand Rehabilitation Robot With EMG-Based Admittance Controller (reach and grasp technique)	• Cable driven module for three dimensional arm motion • Exoskeleton gloves	• Use EMG- based admittance controller • Training time is around 20 minutes	[20]
Chen et al. 2021	A Wearable Hand Rehabilitation System with Soft Gloves (mirror therapy and task oriented therapy)	• Support mirror therapy and task oriented therapy • Use flex and force sensor	• Complex training system	[13]
Kim et al. 2023	Cooperative Hand Therapy via a Soft, Wearable, and Unilateral Telerobotic System (grasp and	• Use unilateral tele-robotic system that enables lot of grasping tasks	• Need a stable internet connection for interaction between patient and therapist	[14]

	collab interaction between patient and therapist)	• Cooperative interaction between patient and therapist	• The system is not mobile, need a fixed place	
Alonso-Linaje et al. 2024	Design and Analysis of the M3Rob: A Robotic Platform for Wrist and Hand Rehabilitation (wrist and hand therapy)	• Highly functional devices • The device covers the required motion and force essential for hand rehabilitation	• Complex hand rehab glove • Expansive component that required to construct the project	[21]
Yurkewich et al. 2019	Hand Extension Robot Orthosis (HERO) Glove: Development and Testing with Stroke Survivors with Severe Hand Impairment (grasp and stabilize object technique)	• Hand design is simple • The device is mobile	• Weight of glove is heavy • Discomfort during usage	[8]
Rho et al. 2024	Multiple Hand Posture Rehabilitation System Using Vision-Based Intention	• Use intention expressed system such as EMG and EEG • Use wired actuator	• Need a fixed place to run the system	[25]

	Detection and Soft-Robotic Glove (practice various hand posture)		•Need a lot of feedback component such as vision data camera	
Tang et al. 2022	Probabilistic Model-Based Learning Control of a Soft Pneumatic Glove for Hand Rehabilitation (probabilistic model learning technique)	• Use probabilistic model learning control • Use of soft actuator	• Need of used for EMG electrode that need to be attach every time • Fixed place for hand rehabilitation setup	[23]
Tran et al. 2021	Review: Hand Exoskeleton Systems, Clinical Rehabilitation Practices, and Future Prospects (automated rehabilitation technique)	• The degree of freedom can be custom • The system has motor learning support	• The grasping posture is limited • Evaluation method is not fixed	[15]

Guo et al. 2022	SSVEP-Based Brain Computer Interface Controlled Soft Robotic Glove for Post-Stroke Hand Function Rehabilitation (detect user intention)	• Use brain computer interface • The SSVEP brain computer interface is better than motor imagery brain computer interface	• Place for rehabilitation is fixed • The device is not mobile	[7]
Vermillion et al. 2019	Toward Restoration of Normal Mechanics of Functional Hand Tasks Post-Stroke: Subject-Specific Approach to Reinforce Impaired Muscle Function (biomimetic method)	• Use theory based biomimetic approach • Use of simple exoskeleton design	• Thumb movement is not assisted • The system is not controlled study	[25]
Park et al. 2020	User-Driven Functional Movement Training with a Wearable Hand Robot After Stroke (grasp task)	• The device is mobile • The device has intent detection	• Weight of device is solely in the arm of patient • The design of the device is complex	[26]

Cheng et al. 2018	Design and Control of a Wearable Hand Rehabilitation Robot (flexion and extension technique)	• Glove design is unique • Glove have 9 degrees of freedom	• Overall system design is heavy • The circuit of remote driving backpack is complex	[5]

Table 2. 2: Proposed technique, advantages and disadvantages of past hand rehabilitation devices

CHAPTER 3

METHODOLOGY

In this chapter, the methods and procedure that are used are discuss and elaborate in detail.

3.1 Introduction

For chapter 3, it focused on the outlines of the methodology that are employed in development of Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand) and assessing the smooth progress of the project in this specific area that is crucial for its success. This section offers a concise and comprehensive explanation of the necessary steps to be taken and provides a detailed breakdown of the primary components involved.

3.2 Methodological Approach to Sustainable Development

The top priority for Pneumatic Rehabilitation Gloves Based on McKibben Actuator involves applying sustainable development principles to the design, development, and testing the gloves and also the control device. The primary goal is to develop an effective rehabilitation glove that attach to sustainability principles that particularly focusing on reducing the weight of the rehabilitation glove. This includes using the suitable materials that is cost effective during the design and development phases. The control device and the glove are tested to ensure it functionality at best. The ultimate aim is to contribute to the field of hand rehabilitation by developing sustainable solutions that consider patients' immediate needs as well as the financial consideration.

3.3 Planning for Development of Pneumatic Rehabilitation Glove Based on McKibben Actuator

Planning is the most important phase in any kind of project to ensure the foundation for success is grasp. This can be done by establishing a clear roadmap such as using a Gantt Chart as stated in Table 4 and also in Table 5 below. Through planning, we can anticipate the difficulties, set suitable timelines and ensure the efficient use of our time and resources. Therefore, careful planning enhances the project success by using the comprehensive framework that guide decision making and the execution.

	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Study the previous design and system for hand rehabilitation glove														
Define background, objective, problem statement, and scope of project (Chapter1)														
Literature review (Chapter 2)														
Define methodology and design steps (Chapter 3)														
First draft submission (Completed Chapter 1, 2 and 3)														
Second draft submission (Completed Chapter 4 and 5)														
Final correction of report														
Submit report via e-psm														
BDP Presentation (27th and 28th June)														

Table 3. 1: Gantt Chart for PSM 1

In Table 3.1, the project begins with a comprehensive study of previous designs and systems for hand rehabilitation gloves, spanning Weeks 1 to 6. This phase focuses on researching existing technologies and identifying potential areas for improvement. Concurrently, during Weeks 1 to 4, the background, objectives, problem statement, and project scope are defined and documented in Chapter 1 to establish a solid framework for the project. From Weeks 3 to 6, a literature review (Chapter 2) is conducted to analyze related studies and technologies, providing a theoretical foundation for the project. During Weeks 5 to 9, the methodology and design steps (Chapter 3) are developed, detailing the approach, techniques, and steps to design and build the rehabilitation glove. By Week 8, the first draft of the report, comprising Chapters 1, 2, and 3, is submitted for review. Following this, the second draft submission, which includes Chapters 4 and 5, covering design, testing, and results is due between Weeks 10 and 11. The final phase involves refining the report based on feedback during Weeks 11 and 12, ensuring all corrections are made. The final report is submitted via the e-PSM platform by Week 12. Lastly, the project culminates in the BDP presentation, scheduled for the 27th and 28th of June (Week 14), where the findings, designs, and outcomes of the project will be showcased. This structured timeline ensures a logical progression of tasks and the timely delivery of all milestones.

	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hardware purchase (i.e., remaining required hardware)	■	■												
Development of hardware (Control device)		■	■	■	■	■	■							
Development of hardware (Glove)				■	■	■	■	■						
Development of hardware (Mckibben Actuator)				■	■	■	■	■						
Programming of the device (Arduino IDE)		■	■	■	■	■	■	■	■					
Functionality verification of the complete system										■	■	■		
Correction of (Abstract, Chapter 1, 2 and 3)	■	■	■	■	■	■	■	■						
Report writing (Chapter 4 and 5)							■	■	■	■	■	■		
Demonstration of the complete device										■		■		
Draft submission												■	■	
Submit report via e-psm													■	
BDP presentation (March)														■

Table 3. 2: Gantt Chart for PSM 2

In the Table 3.2, the project begins with the hardware purchase phase, spanning Weeks 1 to 2, where the required components and materials are acquired to proceed with development. From Weeks 2 to 7, the project focuses on the development of hardware, which includes the control device (such as microcontrollers, air pumps, and valves), the glove (designing and fabricating the structural and material components), and the McKibben actuators (designing and integrating the actuators into the system). Simultaneously, programming of the device using Arduino IDE is carried out from Weeks 4 to 8 to ensure proper operation of the pneumatic actuators and control system. In Weeks 8 to 9, the fully integrated system undergoes functionality verification to test and confirm that all components work seamlessly. During this time, corrections and refinements are made to the abstract and Chapters 1, 2, and 3 of the report. From Weeks 9 to 12, focus shifts to report writing, where Chapters 4 and 5 document the design, development, testing, and results. In Week 12, the complete device is demonstrated to showcase its functionality, and the draft report is submitted for review.

The final report submission takes place in Week 13 via the e-PSM platform, ensuring all project documentation is finalized. The project concludes in Week 14 with the BDP presentation, where the developed device and its outcomes are presented, marking the culmination of the project efforts. This timeline ensures a structured progression of tasks, enabling effective development and timely completion.

3.4 Flowchart and Diagram of Project

3.4.1 Flowchart to Powering Up device

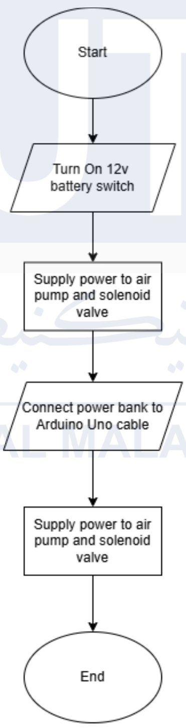


Figure 3. 1: Flowchart to Power Up device

The Figure 3.1 describes the functioning of a system that uses an Arduino Uno, a 12V battery, power bank, an air pump, and a solenoid valve. The process is visually outlined in the flowchart, which serves as a guide for powering and operating the components. The sequence begins by switching on the 12V battery, which provides power to the air pump and the solenoid valve. The battery acts as the primary power source for these components, enabling them to function. After powering the pump and valve, the Arduino Uno is powered separately by connecting it to a power bank using a cable. This ensures that the Arduino receives a stable power supply to execute the programmed instructions. The Arduino Uno acts as the control unit for the system. Once powered, it can manage the activation and operation of the air pump and the solenoid valve based on the programmed logic and external inputs (like button presses). This setup is commonly used in Arduino-based projects that require automated control of devices like air pumps and valves.

3.4.2 Flowchart of Helping Hand device

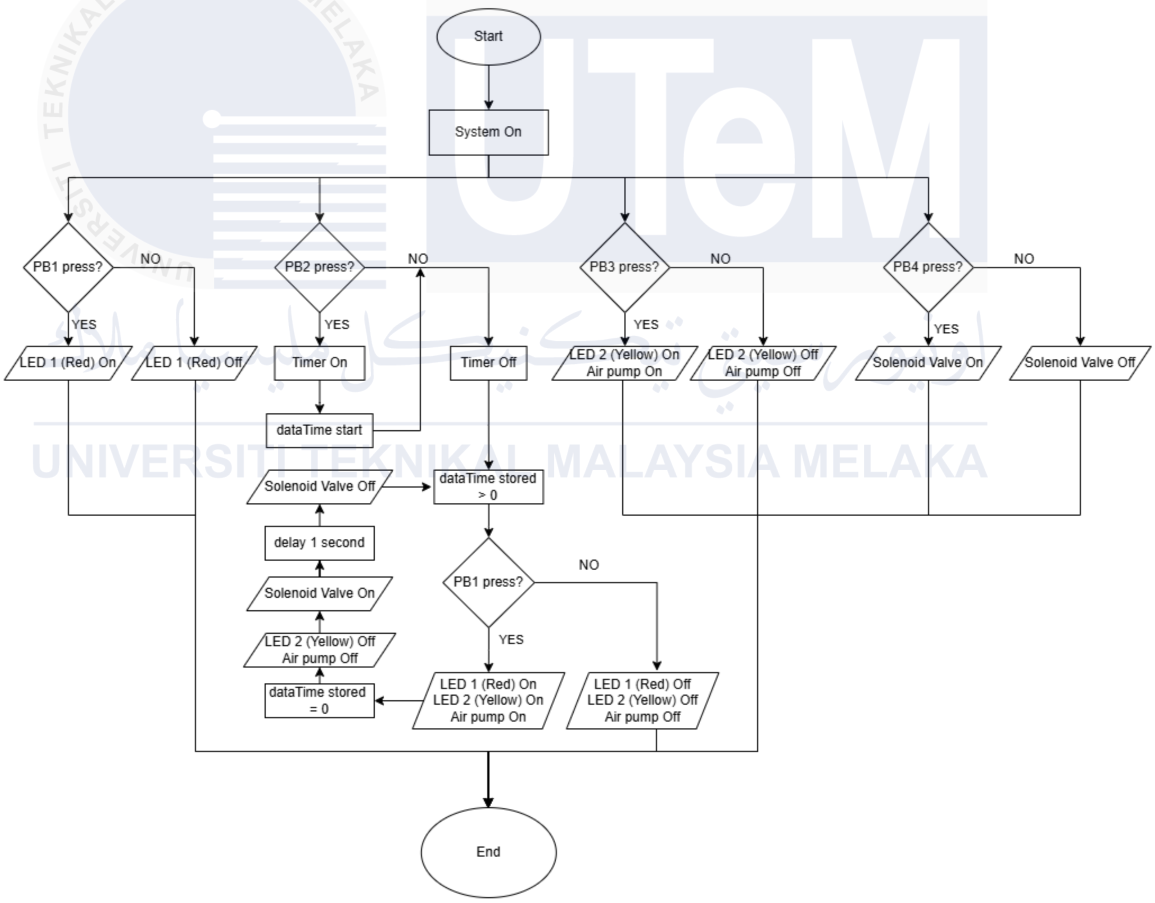


Figure 3. 2: Flowchart of Helping Hand

This Figure 3.2 show the operation of a Helping Hand System involving buttons (PB1, PB2, PB3, PB4), LEDs, a timer, air pump, and a solenoid valve. The system begins with an initialization phase labeled as System On. From here, the system monitors button presses and executes corresponding actions.

When PB1 (Button 1) is pressed, LED 1 (Red) is turned ON. If PB1 is not pressed, LED 1 remains OFF. Similarly, PB2 (Button 2) controls the timer. If PB2 is pressed, the timer starts, and the system initializes the `dataTime` variable, turning the solenoid valve OFF, introducing a delay of one second, and then turning the solenoid valve ON. At this point, LED 2 (Yellow) and the air pump are turned OFF, and the `dataTime` is reset to 0. If PB2 is not pressed, the timer is turned OFF, and the system checks if `dataTime` is greater than 0. If it is, and PB1 is pressed, LED 1 (Red), LED 2 (Yellow), and the air pump are turned ON. Otherwise, all these components are turned OFF.

PB3 (Button 3) is responsible for controlling LED 2 (Yellow) and the air pump. When PB3 is pressed, both are turned ON. If PB3 is not pressed, LED 2 and the air pump are turned OFF. Finally, PB4 (Button 4) controls the solenoid valve. When PB4 is pressed, the solenoid valve is turned ON, and when it is not pressed, the solenoid valve is turned OFF.

The flowchart concludes with an End block, signifying the completion of the system's operation. The flowchart clearly depicts how the system's components interact based on button inputs, enabling precise control over LEDs, the timer, the air pump, and the solenoid valve.

3.4.3 Block Diagram of Pneumatic Rehabilitation Gloves Based on McKibben Actuator (Helping Hand)

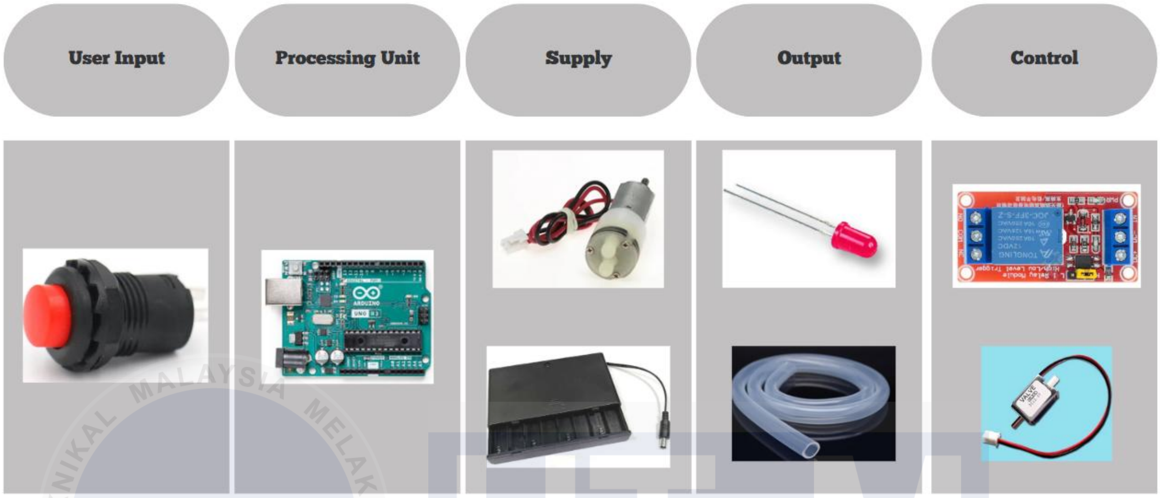


Figure 3. 3: Top – level block diagram of Helping Hand

A block diagram showing the Helping Hand system is shown in Figure 3.3 which is categorizes into various electronic components into five distinct groups that is User input, Processing unit, Supply, Output, and Control. The User input category includes a push button, which allows the user to provide input or trigger specific actions within the electronic system that Arduino Uno. The Processing unit is represented by an Arduino board, that is Arduino Uno which serves as the central hub, managing and controlling the operations of all connected components. The Supply category is divided into two category that is air supply which is 12V DC air pump, which is used to supply air to hose, and power supply that is 12V battery holder that provides power to air pump and solenoid valve.

In the Output category, there is a LED, which acts as an indicator or visual output, and a McKibben actuator that will inflate or deflate that is intended for pneumatic applications. Lastly, the Control category features a relay module, which is used to switch circuits on and off within the system, and a solenoid valve which is used to control air outlet of the McKibben actuator. This detailed categorization helps in understanding the roles of each component in the electronic and robotic projects, providing a clear and organized view of their functions within the system.

3.4.4 System Diagram of Pneumatic Rehabilitation Glove Based on McKibben Actuator

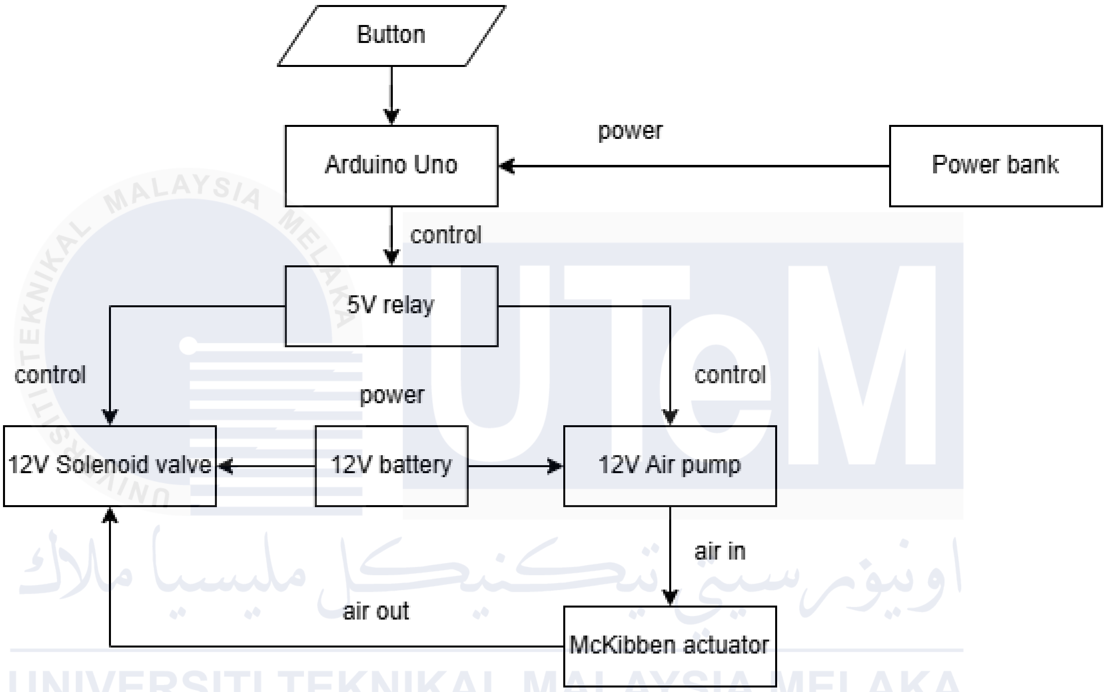


Figure 3. 4: System diagram of Pneumatic Rehabilitation Glove Based on McKibben Actuator

The Figure 3.4 provided is a system diagram of Pneumatic Rehabilitation Glove Based on McKibben Actuator involving various electronic components, including an Arduino Uno, a 5V relay, a 12V solenoid valve, a 12V air pump, a McKibben actuator, a power bank, and a 12V battery. The system is designed to control and power the components in a sequential manner. It starts with a user input through a button, which sends a signal to the Arduino Uno. The Arduino Uno, powered by a power bank, acts as the central processing unit and controls the 5V relay. The 5V relay, in turn, manages the power supply to both the 12V solenoid valve and the 12V air pump. The 12V air pump, powered by the 12V battery, supplies air to the McKibben actuator, then air out is controlled by the solenoid valve that is also power by the 12V battery to regulate airflow. This setup demonstrates a practical application of microcontroller-based control systems in managing pneumatic actuators such as McKibben actuator.

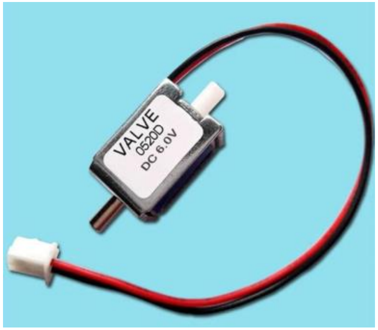
3.5 Hardware Component Specification for Control Device of Pneumatic Rehabilitation Glove Based on McKibben Actuator

a) Arduino Uno

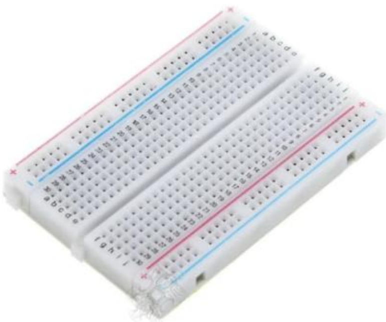
b) 12V power supply

c) 5V Electric relay

d) 12V Air pump



e) 12V Solenoid valve



f) Breadboard

g) Male to female wire

h) Male to male wire

i) Resistor

j) Arduino cable

k) Push button

l) LED

Table 3. 3: Component need to create Control device in development of Pneumatic Rehabilitation Glove Based On McKibben Actuator (Helping Hand)

The Table 3.3 displays the essential electronic components frequently utilized in making of the Control Device of the Helping Hand. At the heart of the system is the Arduino Uno, a microcontroller board based on the ATmega328P, featuring numerous digital and analog I/O pins, crucial for building interactive devices. Complementing this is the 12V power supply, typically housed in a battery holder designed to accommodate eight 1.5V AA batteries in series, providing a stable power source for components that require a 12V input. The 5V electric relay plays a pivotal role, acting as a switch to control high voltage devices using a low voltage signal from the Arduino. This setup often includes a 12V air pump, which is a small device used to move or compress air, making it suitable for applications like inflatables or small pneumatic systems. Similarly, the 12V solenoid valve is integral in regulating the flow of liquids or gases; it opens or closes the valve when energized. The breadboard offers a versatile platform for prototyping circuits without soldering, allowing components and wires to be inserted into its grid to create temporary connections.

Plus, jumper wires, such as male-to-female and male-to-male wires, which are essential for connecting different parts of a circuit. A resistor is shown, which is used to limit the current flow and adjust signal levels within the circuit. An Arduino cable, typically used to connect the Arduino board to a computer for programming and power supply, is also present. Additionally, a push button is included, allowing users to manually control the flow of electricity in the circuit. Finally, an LED (Light Emitting Diode) is shown, which emits light when current flows through it and is often used as an indicator in electronic projects.

3.5.1 Hardware Component Specification for Glove of Pneumatic Rehabilitation Glove Based on McKibben Actuator

a) Air Hose

b) Long air ballon

c) Breaded wire sleeve

d) Glove

e) Cable tie

f) 5 way air flow splitter

Table 3. 4: Component needed to create Gloves of Pneumatic Rehabilitation Glove Based on McKibben Actuator

The Table 3.4 showcases the components that are used in project. The component includes an air hose, which is a coiled transparent hose commonly utilized for transferring air or gases in pneumatic systems due to its flexibility and durability. Also included are long air balloons, typically used for experimental setups requiring inflatable components. The breaded wire sleeve is an expandable black sleeve designed for organizing and protecting wires, preventing tangling, and providing abrasion resistance and in this project is used as outer layer of the McKibben actuator. The pair of black gloves likely serves as protective gear during tasks such as handling delicate components or performing mechanical work. Additionally, there are cable ties, versatile tools used to secure cables or other items together. Finally, the 5-way air flow splitter is a blue device with five outlets, essential for distributing airflow to multiple outputs in a pneumatic system, for each outlet are connected to each finger.

3.6 Tool for Software Design – Arduino IDE

The Arduino Integrated Development Environment (IDE) serves as a crucial software in the creation of hand rehabilitation gloves. Its primary function is to provide a platform for writing and uploading code to the Arduino microcontroller, which plays an essential role in controlling the functionality of the glove.

In the development of hand rehabilitation gloves, the Arduino IDE is instrumental in programming the Arduino to interpret input data, manage actuators, and establish communication with other devices. For instance, push button is used as input data, and the Arduino processes this data to control the electric relay to active the other component such as solenoid valve and air pump that activate the hose actuator in facilitating finger movement.

Furthermore, the Arduino IDE offers robust support for a diverse array of libraries, streamlining the development process significantly. These libraries encompass sensor data processing, motor control, and wireless communication, allowing for the swift implementation of these capabilities within the glove.

As conclusion, the Arduino IDE stands as a key equipment in the development of Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand), enhance a programming platform for the Arduino microcontroller that regulate the glove's functionality.

3.7 Parameters

There are a lot of parameters that can be set for the development of Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand). The first parameter is the design of the pneumatic rehabilitation glove places a strong emphasis on user comfort and ergonomics. One of the primary considerations is the weight of the glove, ensuring it remains lightweight to avoid causing fatigue during prolonged use. Additionally, the materials chosen are breathable and flexible, promoting a comfortable wearing experience that does not disturb the user's hand movements.

Plus, At the core of the rehabilitation glove's functionality are the McKibben actuators, which are strategically positioned to mimic natural muscle contractions and provide smooth, precise hand movements. The performance parameters include generating sufficient force to assist with hand movements without causing discomfort and having a quick response time to accurately replicate natural hand motions.

Next, the rehabilitation glove's control system is powered by an Arduino Uno microcontroller, which manages the actuators and processes user inputs. The system features a user-friendly interface that allows patients to easily adjust therapy settings, ensuring the device can be tailored to individual rehabilitation needs.

In addition, safety is paramount in the design of the rehabilitation glove. Mechanisms are in place to prevent overextension of fingers, reducing the risk of injury. The glove and its components are designed to withstand regular use, ensuring durability and longevity. Additionally, temperature control measures are implemented to prevent the actuators and control unit from overheating during operation, which is critical for maintaining consistent performance and user safety. These safety and reliability measures are essential for gaining user trust and ensuring the device's long-term viability.

Finally, the affordability is a key consideration in the development of the rehabilitation glove. By selecting cost-effective materials and components that do not compromise on quality, the project aims to make the device accessible to a broader range of users. This focus on cost-effectiveness ensures that more people can benefit from the rehabilitation technology without financial barriers.

Ultimately, the primary goal of the rehabilitation glove is to facilitate effective hand therapy through repetitive movements essential for recovery. The device is designed to support a full range of motion for the fingers and thumb, enabling comprehensive rehabilitation exercises. Additionally, the glove is capable of collecting and analyzing data on usage and effectiveness, providing valuable insights for further improvements and personalized therapy plans. This emphasis on therapeutic efficacy ensures that the glove delivers meaningful benefits to users, aiding in their recovery and improving their quality of life.

3.8 Limitation of Proposed Methodology

The development of Pneumatic Rehabilitation Glove based on McKibben Actuator had a various process that call for a mere understanding of human anatomy, pneumatic, and Arduino. It is essential for these gloves to work on a fine balance between comfort, durability, and usability, which often require numerous design iterations and considerable testing.

Firstly, selecting the appropriate gloves for hand rehabilitation can prove to be a challenging attempt due to the multiple arrangement of options available in the market, each component have its unique features and advantages. Identifying the most suitable glove that aligns with the system specific requirements.

Next, the design of the casing housing for the electronic components of the system is critical. This casing must show a strength to shield the internal components from damage, while also being lightweight and compact. Striking the ideal balance between durability, weight, and size poses a significant challenge in designing the casing.

Plus, the incorporation of a precise and reliable valve within the system for regulating fluid or air flow is compulsory. However, sourcing a suitable valve that meets these criteria can be a challenging feat.

Furthermore, the selection of suitable components for the McKibben actuator needs careful consideration. Each component must undergo careful selection to ensure its effective and reliable performance under operating conditions. This process involves a lot of research, testing, and validation of each component, thus consuming considerable time and resources.

Lastly, the creation of a durable and flexible hose for the actuator is importance. This requirement must have a depth understanding of material properties and specification to ensure that the hose can withstand the pressures generated by the actuator.

These potential limitations underscore the intricate nature of designing and developing hand rehabilitation gloves. Despite these challenges, with meticulous planning, comprehensive research, and precise execution, the development of an effective and user-friendly hand rehabilitation glove is attainable. It is important to note that these limitations are general in nature, and specific limitations may vary depending on the individual design and implementation of the hand rehabilitation glove. It is always advisable to conduct a thorough practicality study before running the development process to identify potential challenges and come up with strategies to counter them.

3.9 Summary

Chapter 3 explains the process of creating the Pneumatic Rehabilitation Glove using McKibben Actuators (Helping Hand) and evaluating its progress. The design focuses on affordability, lightweight materials, and ease of use while ensuring functionality through structured planning and testing. The system includes components like an Arduino Uno, air pump, solenoid valve, and McKibben actuators, with software developed using Arduino IDE for control and precision. The glove is designed to be comfortable, safe, and effective for hand therapy, with considerations for durability and cost. While challenges like finding suitable materials, designing a durable casing, and perfecting the actuators exist, the project aims to provide an affordable and practical solution for rehabilitation needs.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, the result and the discussion are shown in form of figure and data. The figure and data gained are discussed and recorded.

4.1 Introduction

For chapter 4, it focused to show on the expected result obtain from the execution of the Pneumatic Rehabilitation Glove Based on McKibben Actuator (Helping Hand). The chapter will focus on showing the anticipated outcomes according to the methodology and design that are discussed on the previous chapters.

4.2 Component Testing

Component testing is an essential process in developing, manufacturing, and maintaining electronic devices. It involves evaluating individual components like push button, resistors, relay, air pump and etcetera to ensure they work correctly and meet performance standards. This testing helps identify and fix defects early, ensuring quality control and reliability. Various tests, such as electrical continuity testing and functional testing, are performed using tools like multimeters and suitable power supply.

4.2.1.1 Arduino Testing

Testing an Arduino Uno is straightforward and ensures that the board is functioning correctly. First, connect the Arduino Uno to your computer using a USB cable. Open the

Arduino IDE software and select the correct board and port under the Tools menu. Next, open the Blink example sketch from the File menu under Examples -> 01. Basics -> Blink. This sketch is a simple program that will blink the onboard LED on pin 13. Click the upload button (an arrow icon) in the Arduino IDE to upload the sketch to the board. If the upload is successful, the onboard LED should start blinking on and off every second. This simple test confirms that the Arduino Uno can communicate with your computer, be programmed, and has working digital I/O pins.

4.2.2 Push Button Testing

To test a push button, you'll need a multimeter set to continuity mode, often indicated by a sound wave symbol. First, place the multimeter probes on the push button terminals. When you press the button, the multimeter should emit a beep, indicating continuity and confirming that the button is making an electrical connection. Upon releasing the button, the beeping should stop, which signifies that the connection is broken. This simple procedure helps verify that the push button functions correctly by making and breaking the electrical circuit as intended.

4.2.3 LED Testing

Tes ting an LED (Light Emitting Diode) involves using a multimeter to ensure it works properly. First, set the multimeter to the diode test mode. Place the black probe on the LED's cathode (shorter leg) and the red probe on the anode (longer leg). The LED should light up if it's working correctly. If it doesn't light up, reverse the probes and try again. If the LED still doesn't light up, it might be faulty. This simple test helps verify that the LED can emit light and is functioning as expected.

4.2.4 12V Air Pump Testing

To test a 12V air pump, start by connecting it to a 12V power source, such as a car battery. Turn on the power and listen for the motor to start running. Check for any unusual noises that might indicate a problem. Next, attach a pressure gauge to the pump's outlet and turn on the pump. The gauge should show an increase in pressure, indicating that the pump is working correctly. If the pump doesn't start or the pressure doesn't increase, check the power connections, fuse, and for any leaks in the hoses. This simple test helps ensure that your 12V air pump is functioning properly.

4.2.5 12V Solenoid Valve Testing

To test a 12V solenoid valve, start by setting your multimeter to the ohms setting (Ω). Disconnect the solenoid valve from any power source and measure the resistance across its terminals. A typical 12V solenoid valve should show a resistance between 20 to 150 ohms. If the reading is significantly outside this range, the solenoid may be faulty. Next, reconnect the solenoid to a 12V power source and activate it. You should hear a clicking sound as the valve operates. If there's no sound or the valve doesn't move, the solenoid might not be working correctly. This simple test helps ensure that your 12V solenoid valve is functioning properly.

4.2.6 5V Relay Testing

Testing a 5V relay is simple. First, you'll need a multimeter and a 5V power source. Set your multimeter to the ohms setting and measure the resistance across the relay coil terminals; it should read between 50 to 200 ohms. If the reading is significantly different, the coil might be faulty. Next, connect the relay coil terminals to the 5V power source; you should hear a clicking sound indicating the relay is activating. While the relay is activated, use the multimeter to check continuity across the normally open (NO) and common (COM) terminals. The multimeter should show continuity, indicating a closed circuit. When you disconnect the power, the relay should click again, and there should be no continuity between NO and COM. This process verifies that both the coil and contact operations are functioning correctly.

4.2.7 Braided Wire Sleeve Diameter Testing

Testing the diameter of a PET braided wire sleeve is simple. First, take a piece of the sleeve and flatten it to get an accurate measurement. Then, use a ruler or a caliper to measure the width of the flattened sleeve. Multiply this width by two to get the diameter of the sleeve when it is round. This straightforward test ensures that the sleeve has the correct diameter to fit around your rubber ballon.

4.3 Hardware Implementation for Control Device of Pneumatic Rehabilitation Glove Based on McKibben Actuator

4.3.1 Schematic and Pinout/Connection of the Control Device

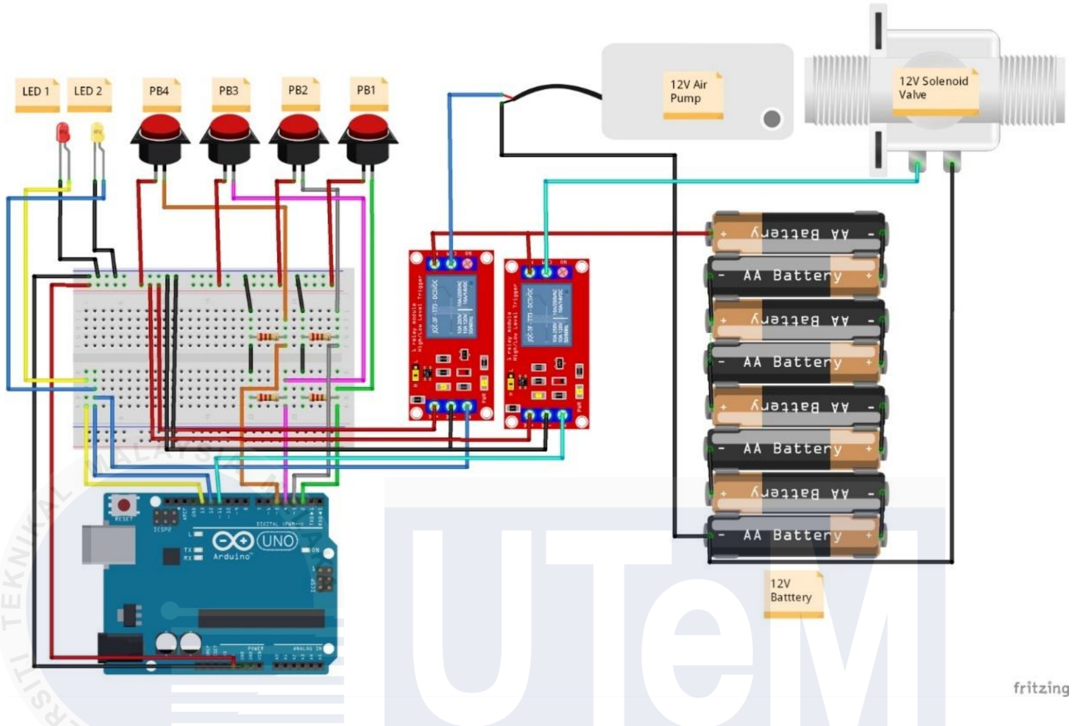


Figure 4. 1: Schematic diagram of Pneumatic Rehabilitation Glove Based on McKibben Actuator

Component	Pinout/ Connection
LED 1 (Red)	LED 1(+) – Arduino (13)
	LED 1(-) – Arduino (Gnd)
LED 2 (Yellow)	LED 2(+) – Arduino (12)
	LED 2(-) – Arduino (Gnd)
Push Button 1	Leg 1 – Arduino (+)
	Leg 2 – Arduino (2)
Push Button 2	Leg 1 – Arduino (+)
	Leg 2 – Arduino (3)
Push Button 3	Leg 1 – Arduino (+)
	Leg 2 – Arduino (4)

Push Button 4	Leg 1 – Arduino (+)
	Leg 2 – Arduino (5)
Relay 1 (Air pump)	DC (+) – Arduino (+)
	DC (-) – Arduino (-)
	Signal pin – Arduino (12)
	Normally open – Battery 12V (+)
	Common – Air pump (+)
	Air pump (-) – Battery 12V (-)
Relay 2 (Solenoid valve)	DC (+) – Arduino (+)
	DC (-) – Arduino (-)
	Signal pin – Arduino (11)
	Normally open – Battery 12V (+)
	Common – Solenoid valve (+)
	Solenoid valve (-) – Battery 12V (-)

Table 4. 1: Pinout/ Connection of components

The Figure 4.1 show the schematic diagram of the Pneumatic Rehabilitation Glove Based on McKibben Actuator that is Arduino-based control system. The system is centered around an Arduino Uno, which serves as the microcontroller responsible for processing user inputs and controlling the outputs. The Table 4.1 show the connection for each of the components. The project includes four push buttons (PB 1, PB 2, PB 3, and PB 4) which are used as an input that is connected to pin 2, pin 3, pin 4, pin 5 of the Arduino. The output LED 1 is connected to the pin 13, the LED 2 and the signal pin of the 12V air pump is connected to the pin 12, and the signal pin of the solenoid valve is connected to pin 11 of the Arduino. Additionally, two LED indicators (LED 1 and LED 2) provide visual feedback to indicate the operational status of the system which is the LED 1 refer to the system is turn On. The circuit also incorporates two relay modules, which act as electronic switches to control high-power components by isolating them from the low-power control circuit. The Relay 1 is active High, that is when the signal is High the relay is activated and the Relay 2 is active Low, that is when the signal is Low the relay is activated. By using these relays, it allows the Arduino to manage the 12V air pump and the 12V solenoid valve, ensuring safe operation without exposing the microcontroller to high voltage.

The power supply for the system consists of a 12V battery pack, which provides the necessary voltage and current to drive the air pump and solenoid valve, while the Arduino itself operates using either USB power or an external 5V power source. A breadboard is used for prototyping and wiring, allowing easy connections between the Arduino, buttons, LEDs, and relays. In terms of functionality, when a user presses one of the push buttons, the Arduino reads the input and sends a corresponding signal to the appropriate relay module. The relay then toggles the 12V circuit, either allowing or cutting off power to the air pump or solenoid valve. The LEDs provide real-time status updates, indicating whether the pump or valve is active.

This system is particularly useful in applications involving pneumatic control, where precise activation of an air pump or solenoid valve is required. The push buttons could be programmed to perform different operations, such as turning the air pump on for a specific duration or controlling the solenoid valve based on predefined conditions.

4.3.2 Stages of Hardware Implementation for Control Devices

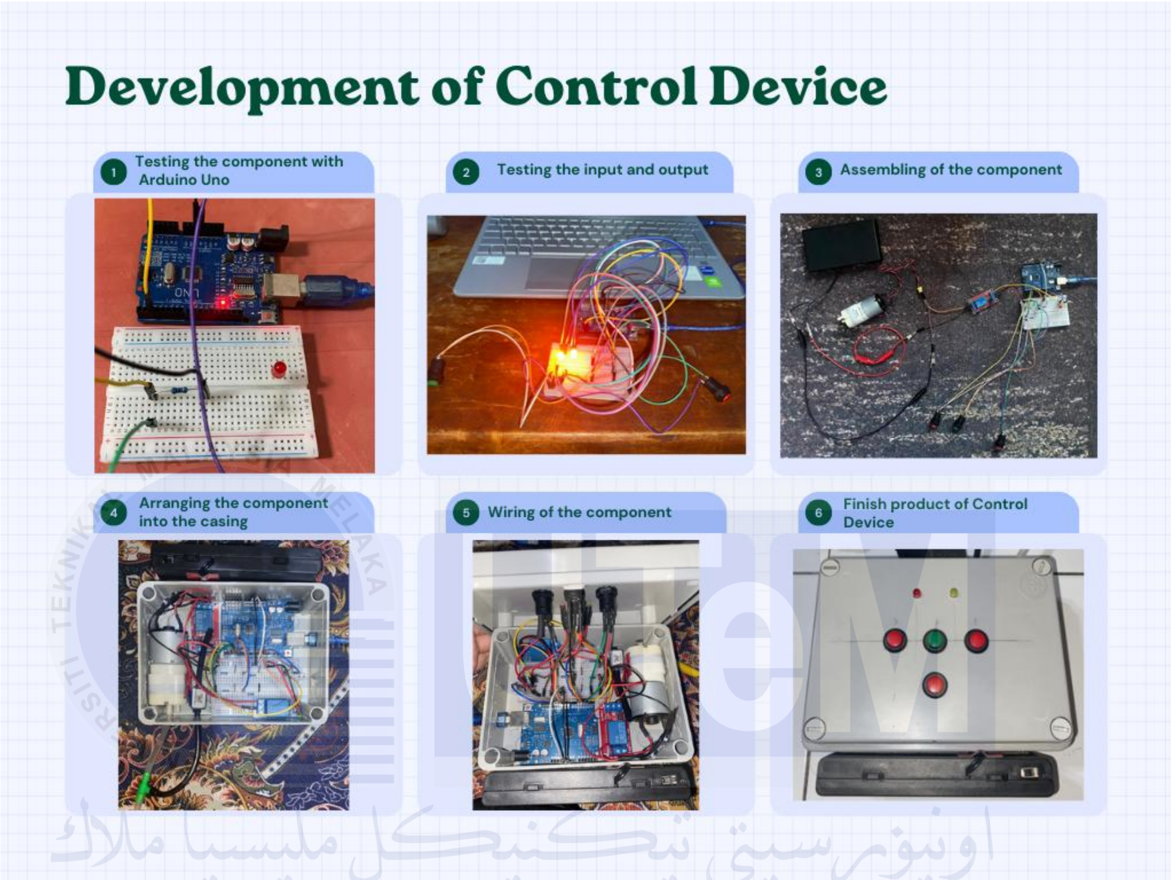


Figure 4. 2: Development of Control Device

The Figure 4.2 illustrates the step-by-step development process of a control device, detailing six key stages from component testing to the final product.

In the first stage, **Testing the component with Arduino Uno**, an Arduino Uno is used to verify the functionality of individual components by connecting them to a breadboard. This ensures that each element operates correctly before integration. The second stage, **Testing the input and output**, involves checking the responsiveness of connected input and output such as PB, LED, relay, air pump and solenoid valve with Arduino. This is done by wiring them to a laptop and observing their interaction, particularly focusing on LED indicators to confirm proper signal transmission.

The third stage, assembling **of the component**, shows the arrangement of different electronic parts, such as power modules, relays, and control circuits, on a work surface. This helps in understanding wiring configurations before placing them into a fixed casing. The fourth stage, **Arranging the component into the casing**, involves securing the tested components into a protective enclosure, ensuring organized placement for durability and ease of access.

Next, the fifth stage, **Wiring of the component**, highlights the structured connection of wires inside the casing, linking switches, power supply, and microcontrollers in a way that ensures reliability and functionality. Proper cable management is essential at this stage to prevent short circuits or malfunctions. Finally, the sixth stage, **finished product of Control Device**, presents the completed control device in its final enclosure, featuring operational buttons and indicators for user interaction.

This structured process ensures that the control device is systematically developed, tested, and assembled to function reliably in its intended application.

4.4 Hardware Implementation for Glove of Pneumatic Rehabilitation Glove Based on McKibben Actuator

4.4.1 Stages of Hardware Implementation for Glove

Figure 4. 3: Development of Glove Based on McKibben Actuator

The Figure 4.3 illustrates the step-by-step development process of a glove integrated with McKibben actuators for assisted hand movement. It follows a structured approach to constructing and assembling the components necessary for the glove's functionality.

In the first stage, **Heating the braided wire sleeve**, a heat gun is applied to a braided wire sleeve, causing it to shrink and form a more compact structure. This process helps the shape of the material to be spring-like structured that is important for the McKibben actuator function. The second stage, **Braided wire after heated**, shows the result of the heating process, where multiple pieces of the sleeve are uniformly contracted and ready for assembly

The third stage, **long balloon and hose combined**, involves combining an elastic balloon with a hose to create the essential structure of the McKibben actuator. These components work together to simulate the contraction and expansion of muscles when air pressure is applied. All the material are hold together using a cable tie. In the fourth stage, **Alteration of the glove**, modifications are made to a standard glove to accommodate the actuators. The glove is cut to a desired design for better breathability and comfort. The glove is reinforced and structured to support the placement of the McKibben actuators using cable tie while ensuring comfort and functionality.

In the fifth stage, **Placement of McKibben onto glove**, the McKibben actuators are strategically attached to the glove, aligning them with the fingers to enable controlled movement by using the O type actuator that is secured by using hot glue. The actuators are securely fastened by the cable tie, allowing them to mimic natural muscle contractions. Finally, in the sixth stage, **finished product for Glove Based on McKibben Actuator**, the completed glove is shown with all actuators integrated and properly connected. This final version is designed to assist hand movement by responding to applied air pressure, making it useful for rehabilitation or assistive technology applications.

This detailed development process ensures the successful construction of a functional glove that utilizes McKibben actuators to provide smooth and natural hand motion.

4.5 Software Implementation for Pneumatic Rehabilitation Glove Based on McKibben Actuator

4.5.1 Arduino IDE Coding

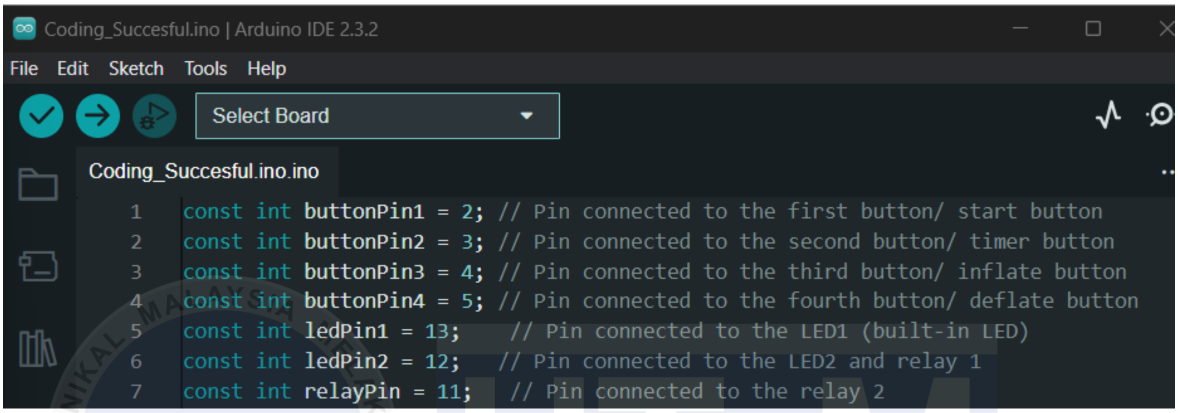


Figure 4. 4: Declaration of pin and variable

The Figure 4.4 show, at the beginning of the code, the pins for four buttons and three output components (two LEDs and one relay) are defined. The **buttonPin1**, **buttonPin2**, **buttonPin3**, and **buttonPin4** are assigned to pins 2, 3, 4, and 5, respectively, representing different control functions: a start button, a timer button, an inflate button, and a deflate button. The output components include **ledPin1** (pin 13), **ledPin2** (pin 12, controlling an LED and Relay 1), and **relayPin** (pin 11, controlling Relay 2).

```
int buttonState1 = 0;     // Variable to store the first button state
int buttonState2 = 0;     // Variable to store the second button state
int buttonState3 = 0;     // Variable to store the third button state
int buttonState4 = 0;     // Variable to store the fourth button state
```

Figure 4. 5: Variable to store the state

In Figure 4.5, the variable is named **buttonState**, the **buttonState** is declare 1 until 4 and the state that is store in the variable is zero or low.

```
unsigned long startTime = 0;  // Variable to track the timer start
unsigned long dataTime = 0;   // Variable to track the remaining time
unsigned long initialDataTime = 0; // Variable to store the initial dataTime value
bool timerRunning = false;    // Flag to check if the timer is running
bool firstTimeHigh = true;    // Flag to check if buttonState1 is HIGH for the first time
```

Figure 4. 6: Declaration of variable

For Figure 4.6, the system uses several variables to manage the timer functionality. The variable **startTime** records the time when the timer begins, while **dataTime** keeps track of the remaining time. **initialDataTime** stores the original set time to facilitate resetting the timer. The **timerRunning** variable indicates whether the timer is currently active. Lastly, **firstTimeHigh** ensures that the relay is activated only on the first press of the button, preventing multiple activations.

```
void setup() {
  pinMode(buttonPin1, INPUT);  // Set Button 1 as input
  pinMode(buttonPin2, INPUT);  // Set Button 2 as input
  pinMode(buttonPin3, INPUT);  // Set Button 3 as input
  pinMode(buttonPin4, INPUT);  // Set Button 4 as input
  pinMode(ledPin1, OUTPUT);    // Set the LED pin as output
  pinMode(ledPin2, OUTPUT);    // Set the LED pin as output
  pinMode(relayPin, OUTPUT);   // Set the Relay pin as output
  Serial.begin(9600);          // Start serial communication
}
```

Figure 4. 7: Setup () function

In Figure 4.7, the setup involves configuring the **buttonPins** as **Input** to detect button presses by using the **pinMode** function such as for the **buttonPin1** until **buttonPin4**. The **ledPin**s and **relayPin** are set as **Output** to control the LEDs and relays also by using **pinMode** function. Additionally, serial communication, **Serial.begin(9600)** is initiated to facilitate debugging, allowing for real-time monitoring and troubleshooting of the system's behaviour.

```
void loop() {
  buttonState1 = digitalRead(buttonPin1); // Read the first button state
  buttonState2 = digitalRead(buttonPin2); // Read the second button state
  buttonState3 = digitalRead(buttonPin3); // Read the third button state
  buttonState4 = digitalRead(buttonPin4); // Read the fourth button state
```

Figure 4. 8: Loop () function

The **loop ()** function in Figure 4.8 runs continuously, monitoring the state of all four buttons to detect any changes. Based on the button states, it updates the control of the LEDs, timer, and relays accordingly. For example, when the **buttonPin1** is pressed the **digitalRead** function capture the state **High** and the data is store into variable **buttonState1**. This ensures that the system responds promptly to user inputs, maintaining accurate control over the air pump and solenoid valve operations.

```
  // Control the first LED based on the first button
  if (buttonState1 == HIGH) {  // Button 1 pressed
    digitalWrite(ledPin1, HIGH); // Turn the LED on
    Serial.println("Button 1: LED1 ON");
  }
  else { // Button 1 released
    digitalWrite(ledPin1, LOW); // Turn the LED off
    Serial.println("Button 1: LED1 OFF");
  }
```

Figure 4. 9: Coding for PB 1

The Figure 4.9 controls an LED 1 using a push button. When the button is pressed, the condition if (**buttonState1** == **HIGH**) evaluates to true, triggering the **digitalWrite** (**ledPin1**, **HIGH**); command, which turns the LED1 on. Additionally, a message Button 1: LED1 ON is printed to the Serial Monitor for debugging purposes. If the button is not pressed (else condition), the LED is turned off using **digitalWrite** (**ledPin1**, **LOW**); and the message Button 1: LED1 OFF is displayed in the Serial Monitor. This ensures real-time feedback on the button's status, allowing the user to verify its operation.

```
// Start or stop the timer based on the second button
if (buttonState2 == HIGH && !timerRunning) { // Button 2 pressed to start the timer
  timerRunning = true;
  startTime = millis(); // Record the current time
  dataTime = initialDataTime; // Initialize dataTime with the initial value
  Serial.println("Timer started!");
}
else if (buttonState2 == LOW && timerRunning) { // Button 2 released to stop the timer
  timerRunning = false;
  unsigned long elapsedTime = (millis() - startTime) / 1000; // Calculate elapsed time in seconds
  dataTime = elapsedTime; // Copy elapsed time to dataTime
  initialDataTime = dataTime; // Store the initial dataTime value
  Serial.print("Timer stopped! Elapsed time: ");
  Serial.print(elapsedTime);
  Serial.println(" seconds");
}
```

Figure 4. 10: Coding for PB2

The Figure 4.10 show the code controls a countdown timer using PB2. When PB2 is pressed (**buttonState2** == **HIGH**) and the timer is not already running (**!timerRunning**), the timer starts by setting **timerRunning** to true, recording the **currentTime** using **millis()**, and initializing **dataTime** with the stored **initialDataTime**. A message Timer started! is printed to the Serial Monitor for feedback. When PB2 is released (**buttonState2** == **LOW**), the timer stops by setting **timerRunning** to false. The elapsed time is calculated by subtracting **startTime** from the **currentTime** (**millis ()**) and converting it into seconds by dividing by 1000. This elapsed time is then stored in **dataTime** and **initialDataTime**, ensuring that the recorded time can be used for future operations. Finally, the **elapsedTime** is printed to the Serial Monitor, providing real-time feedback to the user.

```
// Display timer progress if it's running
if (timerRunning) {
  unsigned long currentTime = (millis() - startTime) / 1000; // Calculate elapsed time in seconds
  Serial.print("Timer running: ");
  Serial.print(currentTime);
  Serial.println(" seconds");
}
```

Figure 4. 11: Coding for Timer display

The Figure 4.11 show the provided code continuously displays the **elapsedTime** while the timer is running. It checks if **timerRunning** is true, indicating that the timer has been started.

If so, it calculates the **elapsedTime** by subtracting **startTime** from the **currentTime** (**millis ()**) and converting it into seconds by dividing by 1000. The calculated **currentTime** is then printed to the Serial Monitor along with the message Timer running:, followed by the **elapsedTime** in seconds. This allows the user to monitor the duration for which the timer has been active in real time.

```
  // When button 1 is on and timer has been set, turn on relay after the first time
  if (buttonState1 == HIGH && dataTime > 0) {
    dataTime--;
    Serial.print("Data time: ");
    Serial.print(dataTime);
    Serial.println(" seconds");
    digitalWrite(ledPin2, HIGH); // Turn on LED2 & Relay 1(Air Pump)
    firstTimeHigh = false; // Mark that buttonState1 was HIGH for the first time
  }
  else if (buttonState1 == HIGH && dataTime == 0) {
    digitalWrite(ledPin2, LOW); // Turn off LED2 & Relay 1(Air Pump)
    if (!firstTimeHigh) {
      dataTime = initialDataTime; // Reset dataTime to the initial value when it reaches 0 and buttonState1 is HIGH
      Serial.print("Data time reset to: ");
      Serial.print(dataTime);
      Serial.println(" seconds");
      digitalWrite(relayPin, LOW); // Turn on Relay
      delay(1000);// Delay after solenoid valve on
      digitalWrite(relayPin, HIGH); // Turn on Relay
      delay(1000);// Delay after solenoid valve on
  }
    }

  else {
    digitalWrite(ledPin2, LOW); // Turn off LED2 & Relay 1(Air Pump)
  }
```


Figure 4. 12: Coding of Relay control for air pump

Figure 4.12 state that when PB1 is pressed and **dataTime** is greater than zero, the system activates the air pump by turning on LED2 and Relay 1. Simultaneously, **dataTime** starts decrementing, representing the countdown of the timer. Once **dataTime** reaches zero, the air pump is turned off, stopping its operation. However, if PB1 is pressed again after **dataTime** has reached zero, the system resets **dataTime** to its initial value, allowing the air pump to operate again for the preset duration. This ensures that the air pump runs only for the specified time and can be restarted by pressing PB1 again.

```
// Check the third button and control LED2
if (buttonState3 == HIGH) {
  digitalWrite(ledPin2, HIGH); // Turn on LED2
  Serial.println("Button 3: LED2 ON");
}
else {
  Serial.println("Button 3: LED2 OFF");
}
```

Figure 4. 13: Coding for PB3

In Figure 4.13, when PB3 is pressed, the system activates the air pump by turning on LED2, which is connected to Relay 1. This indicates that the air pump is powered on and functioning. However, if Button 3 is not pressed, the air pump remains off, ensuring that it only operates when explicitly activated by the user. This simple control mechanism allows manual operation of the air pump, providing straightforward on-demand functionality.

```
// Check the fourth button and control relay
if (buttonState4 == HIGH) {
  digitalWrite(relayPin, LOW); // Turn on Relay
  Serial.println("Button 4: Relay ON");
}
else {
  digitalWrite(relayPin, HIGH); // Turn off Relay
  Serial.println("Button 4: Relay OFF");
}

```

Figure 4. 14: Coding for PB4

In Figure 4.14, when the PB4 is pressed, the solenoid valve is activated by setting the relay to LOW, which turns it ON. This is because the relay is active LOW. This allows the valve to open and function to release air from the McKibben actuator. Once PB4 is released, the relay is set to HIGH, turning the solenoid valve OFF and stopping its operation. This mechanism ensures that the solenoid valve only remains active while the button is being pressed, providing precise and controlled operation based on user input.

```
    delay(1000); // Short delay for stability
}
```

Figure 4. 15: Coding for Delay

The Figure 4.15 show a 1 second delay is introduced in the program to prevent rapid switching of components and to minimize unnecessary serial output. This delay helps stabilize the system by ensuring that button presses and relay activations do not trigger too frequently, which could lead to erratic behaviour or unintended activations.

4.6 Data Analysis

4.6.1 Weight Reduction Analysis

Item	Weight (kg)
Pneumatic Rehabilitation Glove Based on McKibben Actuator	0.15
BUZUD Hand Rehabilitation Training Gloves	0.17
Vendra Medical Vrehab-M1 Portable Rehabilitation Robotic Gloves	0.2
Hand of Hope Rehabilitation Glove	0.45
Neofect Smart Glove	0.2
HandTutor Rehabilitation Glove	0.25

Table 4. 2: Comparison of weight for hand rehabilitation gloves

Figure 4. 16: Helping Hand weight is taken

The Table 4.2 show, the Pneumatic Rehabilitation Glove Based on McKibben actuator (Helping Hand) glove display a large reduction in weight compared to the past hand rehabilitation gloves. The data related to the component and the overall weight of Helping Hand glove is compared to the past hand rehabilitation gloves.

The Pneumatic Rehabilitation Glove Based on McKibben Actuator is the lightest glove, weighing only 0.15 kg as show in Figure 4.16. The weight of the glove is manually taken using luggage scale. This makes it an excellent choice for users who prioritize a lightweight option for ease of use and minimal fatigue during rehabilitation exercises.

Next, the BUZUD Hand Rehabilitation Training Gloves weigh slightly more at 0.17 kg. While still relatively light, they offer a bit more heft, which might provide a different feel during use compared to the McKibben Actuator glove.

The Vendra Medical Vrehab-M1 Portable Rehabilitation Robotic Gloves and the Neofect Smart Glove both weigh 0.2 kg, making them more in terms of weight. This glove is heavier than the Helping Hand glove.

The HandTutor Rehabilitation Glove is a bit heavier at 0.25 kg. This additional weight might offer more resistance or stability during rehabilitation exercises, which could be beneficial for certain types of therapy.

Finally, the Hand of Hope Rehabilitation Glove is the heaviest glove on the list, weighing 0.45 kg. This glove might provide the most substantial feel and resistance, which would be the most disadvantageous for users in the intensive rehabilitation support.

In summary, the weights of these gloves range from 0.15 kg to 0.45 kg, offering a variety of options for users based on their preferences for weight and the specific needs of their rehabilitation therapy. So, the Pneumatic Rehabilitation Glove Based on McKibben Actuator is the most suitable and the light weight gloves compared to the past rehabilitation gloves.

4.6.2 Cost Efficency Analysis

Item	Quantity	Price (RM)	Total Price (RM)
Push Button	3	3	9
LED	3	0.12	0.36
12V Air pump	1	14.09	14.09
12V Solenoid valve	1	9.91	9.91
Arduino Uno	1	12.50	12.50
Resistor	4	0.01	0.04
12V Battery casing	1	5.50	5.50
6 x 4 x 3 box	1	5.40	5.40
5V Relay	2	2.45	4.90
Female to male wire	>1	3.85	3.85

Male to male	>1	3.85	3.85
Breadboard	1	4.95	4.95
Air flow control valve	1	6.12	6.12
12V Battery holder	1	14.09	14.09
Glove	1	9.50	9.50
Long shape ballon	5	1.46	1.46
Cable tie	>1	0.77	0.77
Breaded wire sleeve	1	12.35	12.35
Total Price (RM)			105.34

Table 4. 3: Costing of Pneumatic Rehabilitation Glove Based on McKibben Actuator

The Table 4.3 lists the various items along with their quantities, prices per unit in Ringgit Malaysia (RM), and the total price for each item. It includes components and materials that is used for the Helping Hand project.

As example, it lists 3 push buttons at RM 3 each, totaling RM 9, and 3 LEDs at RM 0.12 each, totaling RM 0.36. Other items include a 12V air pump at RM 14.09, a 12V solenoid valve at RM 9.91, an Arduino Uno at RM 12.50, and various resistors, battery casings, relays, wires, breadboards, air flow control valves, battery holders, gloves, long shape balloons, cable ties, and breaded wire sleeves, each with their respective quantities and total prices. The total price for all items combined is RM 105.34.

Item	Cost (RM)
Pneumatic Rehabilitation Glove Based on McKibben Actuator	105.34
BUZUD Hand Rehabilitation Training Gloves	1260
Vendra Medical Vrehab-M1 Portable Rehabilitation Robotic Gloves	3169
Hand of Hope Rehabilitation Glove	572
Neofect Smart Glove	459
HandTutor Rehabilitation Glove	795

Table 4. 4: Comparison of cost for hand rehabilitation gloves

The Table 4.4 lists various hand rehabilitation gloves along with their respective costs in Malaysian Ringgit (RM). It includes the **Pneumatic Rehabilitation Glove Based on McKibben Actuator** priced at RM 105.34 which is the cheapest, the **BUZUD Hand Rehabilitation Training Gloves** priced at RM 1260, the **Vendra Medical Vrehab-M1 Portable Rehabilitation Robotic Gloves** priced at RM 3169 which is the expansive, the **Hand of Hope Rehabilitation Glove** priced at RM 572, the **Neofect Smart Glove** priced at RM 459, and the **HandTutor Rehabilitation Glove** priced at RM 795. This table provides a clear comparison of the costs associated with different rehabilitation gloves and this make it clear that the Helping Hand glove is the most cost effective glove.

4.6.3 Data Analysis for Effectiveness of the Pneumatic Rehabilitation Glove Based on McKibben Actuator

A qualitative research method that is an interview is conducted for the effectiveness of the Pneumatic Rehabilitation Glove Based on McKibben Actuator. The structured interview is conducted one-on-one conversations between interviewer and the interviewee where and open-ended question is asked to gather the feedback and detailed answers from the interviewees. The number of interviewee is set to 10 person for this project to allows for a range perspectives while still beig manageable for in depth analysis. The following set of question are asked:

1) How easy was it to put on and take off the glove?

2) Did the glove fit well on your hand, or were there any areas that felt too tight or loose?

3) How effective do you think the glove will help in aiding the rehabilitation exercises?

4) How well does the glove mimic natural hand movements?

5) Overall, how satisfied are you with the Pneumatic Rehabilitation Glove?

6) Are there any additional features you would like to see in future versions?

From the interviews a feedback and valuable insights from the interviewee are collected and are analysed below.

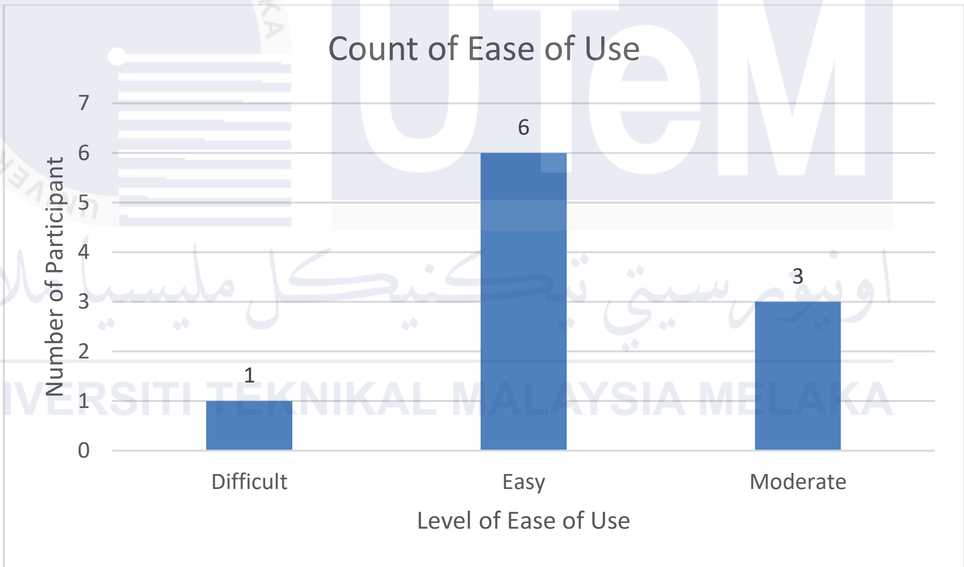


Figure 4. 17: Column Chart for the Count of Ease of Use

The Figure 4.17 show the column chart titled **Count of Ease of Use** represents participants' feedback on the usability of a product, likely a **pneumatic rehabilitation glove**. The x-axis categorizes the levels of ease of use, while the y-axis represents the number of participants who provided each response. The majority of participants (**six out of ten**) rated the glove as **Easy** to use, indicating that its design and functionality are intuitive and user-friendly. Additionally, **three participants** found it to be **Moderate** in ease of use, suggesting that while it is generally accessible, some users may experience minor challenges in operation.

However, **one participant** rated the glove as **Difficult** to use, highlighting the possibility of usability concerns for certain individuals.

Overall, the data suggests that the glove is generally perceived as **easy to use**, with **90% of participants** rating it as either **Easy** or **Moderate.** However, the presence of a **Difficult** rating indicates that some improvements may be necessary to enhance accessibility further. Possible enhancements could include **simplified controls, clearer instructions, or minor design modifications** to accommodate users who may struggle with its operation. Addressing these concerns would ensure that the glove is **accessible and user-friendly** for a broader range of individuals, ultimately improving its effectiveness as a rehabilitation tool.

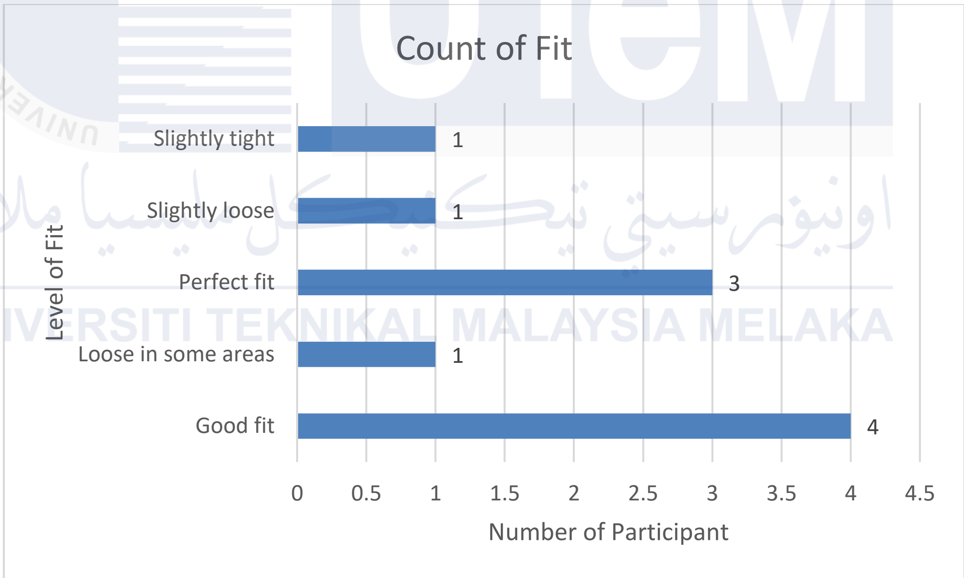


Figure 4. 18: Bar Chart for the Count of Participant by Initial Impression

The Figure 4.18 in the bar chart titled **Count of Fit** represents participants' feedback on the fit of a product, likely a **pneumatic rehabilitation glove**. The x-axis indicates the number of participants, while the y-axis categorizes different levels of fit experienced. The most common response, given by **four participants**, was **Good fit,** suggesting that the glove generally conforms well to users' hands. Additionally, **three participants** described the fit as **Perfect fit,** reinforcing the idea that the design is effective for a majority of users. However, some participants reported minor fit issues, with **one participant each** mentioning **Slightly tight, Slightly loose, and Loose in some areas.**

Overall, the data suggests that the rehabilitation glove has a **generally well-accepted fit**, with the majority of users (7 out of 10) describing it as either a **Good fit** or a **Perfect fit.** However, the presence of **slight tightness, looseness, or uneven fit in some areas** highlights potential areas for improvement in design, such as incorporating **adjustable features** or offering **multiple size options** to enhance user comfort. Addressing these minor fit issues could further optimize the effectiveness of the glove, ensuring that it provides both **comfort and functionality** for a broader range of users.

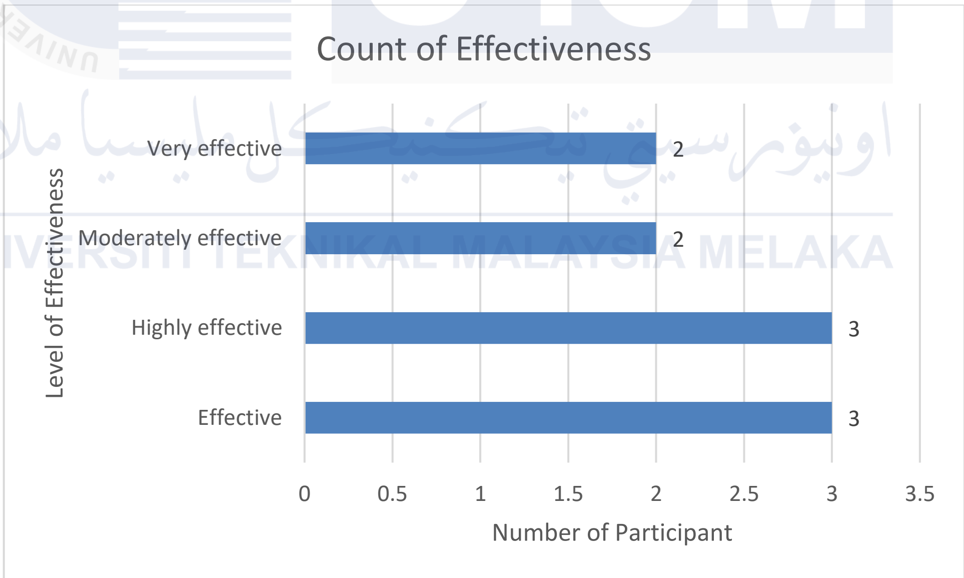


Figure 4. 19: Bar Chart for the Count of Effectiveness

The Figure 4.19 show the bar chart illustrates the count of participants for varying levels of effectiveness in a particular evaluation. It categorizes effectiveness into four levels: Very effective, Moderately effective, Highly effective, and Effective. Each level is associated with the number of participants who deemed it applicable. The data shows that three participants rated the system or intervention as Highly effective and another three as Effective, making these the two most common responses. Meanwhile, two participants each rated the system as Very effective and Moderately effective, indicating slightly lower levels of perceived effectiveness among these groups.

This distribution suggests a generally positive response, as the majority of participants found the system either Highly effective or Effective. However, there is a slightly smaller group that considers the system to be Moderately effective or Very effective, which could indicate areas for improvement or variability in user experiences. Overall, the data reflects that the system is well-received, with a need to address the concerns of those in the lower categories to achieve greater consistency in perceived effectiveness.

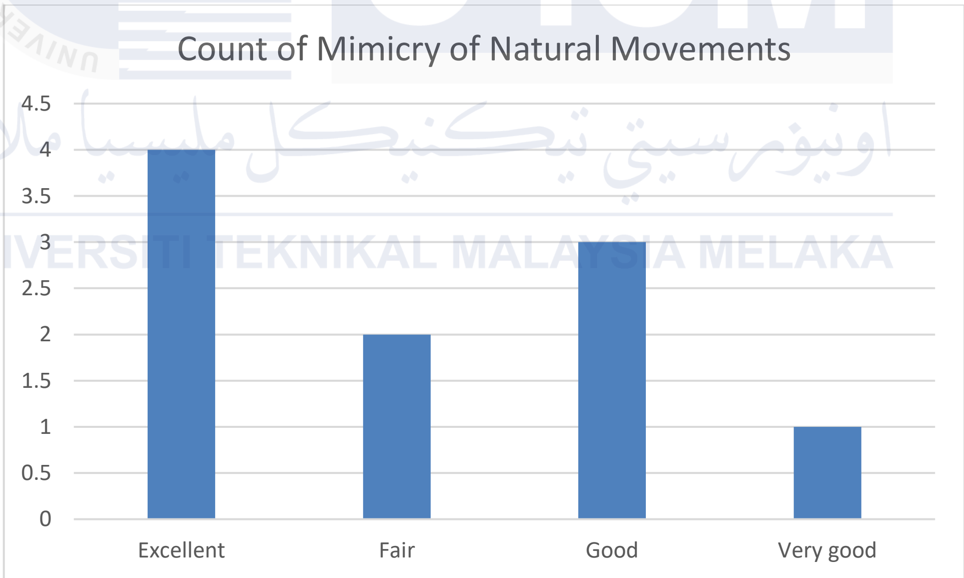


Figure 4. 20: Column Chart for the Count of Mimicry of Natural Movements

The Figure 4.20 show the column chart depicts the count of participants who evaluated the mimicry of natural movements across four levels: Excellent, Very good, Good, and Fair. The data shows that the highest number of participants, four in total, rated the mimicry as Excellent, suggesting that the system or model demonstrated a strong capability in replicating natural movements. Three participants rated it as Good, making it the second most common response, while fewer participants rated it as Fair (two participants) and Very good (one participant).

This distribution highlights a predominantly positive perception, with most participants finding the mimicry to be either Excellent or Good. However, the lower counts in the Fair and Very good categories suggest room for refinement to improve the consistency of the mimicry and elevate overall satisfaction. These results suggest that while the system performs well in general, targeted improvements could ensure a broader consensus of higher ratings.

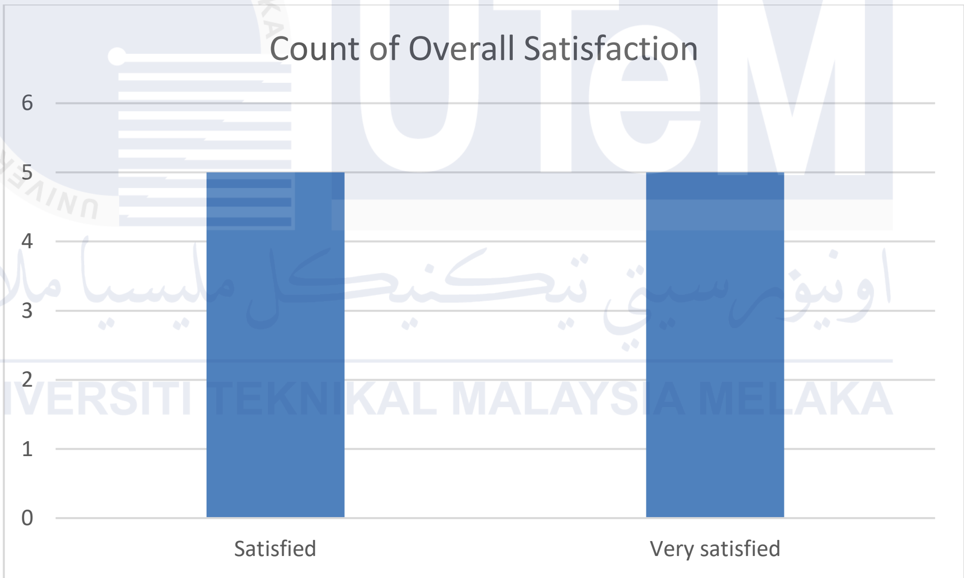


Figure 4. 21: Column Chart for the Count of Overall Satisfaction

The Figure 4.21 show the column chart represents the overall satisfaction levels of participants, categorized into Satisfied and Very satisfied. Both categories have an equal count of five participants, indicating a balanced level of satisfaction across the two groups. This demonstrates that all participants have a positive perception of the evaluated system, with no responses falling below the Satisfied threshold.

The equal distribution of responses between Satisfied and Very satisfied highlights a strong overall acceptance of the system. While the feedback is highly favorable, efforts to enhance specific aspects of the system might encourage a greater number of participants to move from Satisfied to Very satisfied, further boosting the overall satisfaction levels.

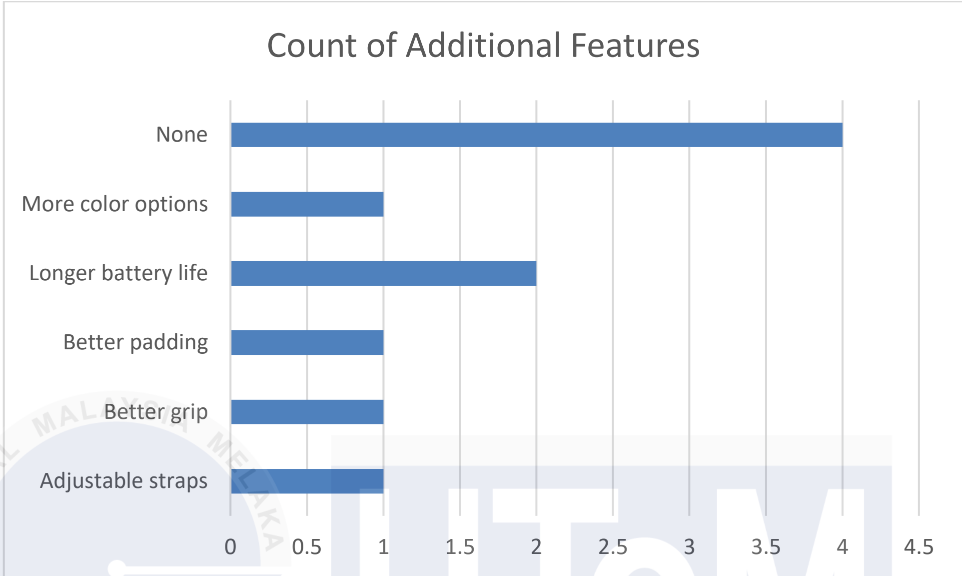


Figure 4. 22: Bar Chart for the Count of Additional Features

The Figure 4.22 show the bar chart displays the distribution of additional features requested by users for a product, based on their frequency of mention. Among the options listed, None was the most selected, with a count of approximately 4.5, indicating that many users were satisfied with the product as it is and did not require additional features. This suggests that the current design or functionality is meeting the expectations of a significant portion of the user base.

Other features, such as Longer battery life, were also notable, showing a count of about 2, highlighting a moderate demand for extended usage time. Features like Better padding, Better grip, and Adjustable straps were equally sought after, with each having a count close to 1, reflecting a smaller but consistent interest in improving comfort and usability. More color options, however, had the least demand, slightly below 1, suggesting that aesthetic customization is less of a priority for most users.

4.7 Summary

To conclude all, the design of Helping Hand glove is much more cost effective and much lighter glove than the past hand rehabilitation gloves. The effectiveness of the Helping are also tested and it is proven to be effective.Therefore, the Helping Hand glove are more superior alternative compared to other glove which can provide a much more affordable and have a better weight reduction hand rehabilitation glove.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Chapter 5 focus on the conclusion that have been made according to the previous chapter. The potential for commercialization and future work are also discuss on this chapter.

5.1 Conclusion

In summary, the Helping Hand rehabilitation glove have partially solved the key challenges of stroke rehabilitation therapy by providing a cost effective and weight reduced rehabilitation device. The outcome for development of the glove is recorded and observed to highlight the possible potential of the Helping Hand glove in improving the hand motion of the stroke survivor yet in improving the overall quality of hand stroke survivor life. The development and testing will be also done in the future to enhance the Helping Hand device or glove to make sure it become a valuable factor in the field of rehabilitation. Thus, to make sure the Helping Hand can benefit more and more people in the future.

5.2 Future work

The are a few things that are recognized during the completion of this project and there is a room for improvement for the project in the future. The thing that are concern are the complete design of the Helping Hand gloves, the air flow from the air tube to the wire conduit and the real cost of the glove and system.

REFERENCES

[1] K. S. Tan and N. Venketasubramanian, "Stroke Burden in Malaysia," *Cerebrovasc Dis Extra*, vol. 12, no. 2, pp. 58–62, Mar. 2022, doi: 10.1159/000524271.

[2] A. Kaku, C. Fernandez-Granda, and N. Razavian, "Harnessing Data and Deep Learning for Stroke Rehabilitation," United States -- New York, 2024. [Online]. Available: https://libproxy.utem.edu.my/login?url=https://www.proquest.com/dissertations-theses/harnessing-data-deep-learning-stroke/docview/2932962188/se-2?accountid=34984

[3] "Effects of Stroke | Johns Hopkins Medicine." Accessed: May 23, 2024. [Online]. Available: https://www.hopkinsmedicine.org/health/conditions-and-diseases/stroke/effects-of-stroke

[4] K. M. Nordin, K. Chellappan, and R. Sahathevan, "Upper limb rehabilitation in post stroke patients: Clinical observation," in *2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES)*, IEEE, Dec. 2014, pp. 700–704. doi: 10.1109/IECBES.2014.7047597.

[5] L. Cheng, M. Chen, and Z. Li, "Design and Control of a Wearable Hand Rehabilitation Robot," *IEEE Access*, vol. 6, pp. 74039–74050, 2018, doi: 10.1109/ACCESS.2018.2884451.

[6] D. H. Kim, Y. Lee, and H. S. Park, "Cooperative Hand Therapy via a Soft, Wearable, and Unilateral Telerobotic System," *IEEE Trans Biomed Eng*, vol. 70, no. 1, pp. 366–377, Jan. 2023, doi: 10.1109/TBME.2022.3191690.

[7] N. Guo *et al.*, "SSVEP-Based Brain Computer Interface Controlled Soft Robotic Glove for Post-Stroke Hand Function Rehabilitation," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 30, pp. 1737–1744, 2022, doi: 10.1109/TNSRE.2022.3185262.

[8] A. Yurkewich, D. Hebert, R. H. Wang, and A. Mihailidis, "Hand extension robot orthosis (hero) glove: Development and testing with stroke survivors with severe hand impairment," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 27, no. 5, pp. 916–926, May 2019, doi: 10.1109/TNSRE.2019.2910011.

[9] L. Tomasetti, L. J. Hollesli, K. Engan, K. D. Kurz, M. W. Kurz, and M. Khanmohammadi, "Machine Learning Algorithms Versus Thresholding to Segment Ischemic Regions in Patients with Acute Ischemic Stroke," *IEEE J Biomed Health Inform*, vol. 26, no. 2, pp. 660–672, Feb. 2022, doi: 10.1109/JBHI.2021.3097591.

[10] Indarto, E. Utami, and S. Raharjo, "Mortality Prediction Using Data Mining Classification Techniques in Patients With Hemorrhagic Stroke," in *2020 8th International Conference on Cyber and IT Service Management (CITSM)*, IEEE, Oct. 2020, pp. 1–5. doi: 10.1109/CITSM50537.2020.9268802.

[11] N. Neema, R. J. Prathibha, and N. M. Sonali, "Analysis and Classification of Occurrence of Brain Stroke Types using Machine Learning Approaches," in *MysuruCon 2022 - 2022 IEEE 2nd Mysore Sub Section International Conference*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/MysuruCon55714.2022.9972403.

[12] J. Chaki and M. Wozniak, "Deep Learning and Artificial Intelligence in Action (2019-2023): A Review on Brain Stroke Detection, Diagnosis, and Intelligent Post-

Stroke Rehabilitation Management,” *IEEE Access*, vol. 12, pp. 52161–52181, 2024, doi: 10.1109/ACCESS.2024.3383140.
[13] X. Chen *et al.*, “A Wearable Hand Rehabilitation System with Soft Gloves,” *IEEE Trans Industr Inform*, vol. 17, no. 2, pp. 943–952, Feb. 2021, doi: 10.1109/TII.2020.3010369.
[14] D. H. Kim, Y. Lee, and H. S. Park, “Cooperative Hand Therapy via a Soft, Wearable, and Unilateral Telerobotic System,” *IEEE Trans Biomed Eng*, vol. 70, no. 1, pp. 366–377, Jan. 2023, doi: 10.1109/TBME.2022.3191690.
[15] P. Tran, S. Jeong, K. R. Herrin, and J. P. Desai, “Review: Hand Exoskeleton Systems, Clinical Rehabilitation Practices, and Future Prospects,” Aug. 01, 2021, *Institute of Electrical and Electronics Engineers Inc.* doi: 10.1109/TMRB.2021.3100625.
[16] J. Plantin, *RECOVERY AND PREDICTION OF HAND MOTOR FUNCTION AFTER STROKE-A LONGITUDINAL STUDY USING NOVEL METHODS TO QUANTIFY HAND FUNCTION AND CONNECTIVITY IN BRAIN NETWORKS*.
[17] B. W. Gasser, A. Martinez, E. Sasso-Lance, C. Kandilakis, C. M. Durrough, and M. Goldfarb, “Preliminary Assessment of a Hand and Arm Exoskeleton for Enabling Bimanual Tasks for Individuals with Hemiparesis,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, no. 10, pp. 2214–2223, Oct. 2020, doi: 10.1109/TNSRE.2020.3018649.
[18] R. Li *et al.*, “Automated fine motor evaluation for developmental coordination disorder,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 27, no. 5, pp. 963–973, May 2019, doi: 10.1109/TNSRE.2019.2911303.
[19] M. Comellas, V. Chan, D. K. Zondervan, and D. J. Reinkensmeyer, “A Dynamic Wheelchair Armrest for Promoting Arm Exercise and Mobility After Stroke,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 30, pp. 1829–1839, 2022, doi: 10.1109/TNSRE.2022.3187755.
[20] C. Xie, Q. Yang, Y. Huang, S. Su, T. Xu, and R. Song, “A Hybrid Arm-Hand Rehabilitation Robot with EMG-Based Admittance Controller,” *IEEE Trans Biomed Circuits Syst*, vol. 15, no. 6, pp. 1332–1342, Dec. 2021, doi: 10.1109/TBCAS.2021.3130090.
[21] G. Alonso-Linaje, A. Cisnal, J. C. Fraile, and J. P. Turiel, “Design and Analysis of the M3Rob: A Robotic Platform for Wrist and Hand Rehabilitation,” *IEEE Access*, vol. 12, pp. 30472–30481, 2024, doi: 10.1109/ACCESS.2024.3369908.
[22] E. Rho *et al.*, “Multiple Hand Posture Rehabilitation System Using Vision-Based Intention Detection and Soft-Robotic Glove,” *IEEE Trans Industr Inform*, vol. 20, no. 4, pp. 6499–6509, Apr. 2024, doi: 10.1109/TII.2023.3348826.
[23] Z. Q. Tang, H. L. Heung, X. Q. Shi, R. K. Y. Tong, and Z. Li, “Probabilistic Model-Based Learning Control of a Soft Pneumatic Glove for Hand Rehabilitation,” *IEEE Trans Biomed Eng*, vol. 69, no. 2, pp. 1016–1028, Feb. 2022, doi: 10.1109/TBME.2021.3111891.
[24] N. Guo *et al.*, “SSVEP-Based Brain Computer Interface Controlled Soft Robotic Glove for Post-Stroke Hand Function Rehabilitation,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 30, pp. 1737–1744, 2022, doi: 10.1109/TNSRE.2022.3185262.
[25] B. C. Vermillion, A. W. Dromerick, and S. W. Lee, “Toward Restoration of Normal Mechanics of Functional Hand Tasks Post-Stroke: Subject-Specific Approach to Reinforce Impaired Muscle Function,” *IEEE Trans Neural Syst Rehabil Eng*, vol. 27, no. 8, pp. 1606–1616, Aug. 2019, doi: 10.1109/TNSRE.2019.2924208.

[26] S. Park *et al.*, “User-Driven Functional Movement Training with a Wearable Hand Robot after Stroke,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, no. 10, pp. 2265–2275, Oct. 2020, doi: 10.1109/TNSRE.2020.3021691.
[27] L. Cheng, M. Chen, and Z. Li, “Design and Control of a Wearable Hand Rehabilitation Robot,” *IEEE Access*, vol. 6, pp. 74039–74050, 2018, doi: 10.1109/ACCESS.2018.2884451.

APPENDICES

Appendix 1: Coding for Pneumatic Rehabilitation Glove Based on McKibben Actuator

```
const int buttonPin1 = 2; // Pin connected to the first button/ start button
const int buttonPin2 = 3; // Pin connected to the second button/ timer button
const int buttonPin3 = 4; // Pin connected to the third button/ inflate button
const int buttonPin4 = 5; // Pin connected to the fourth button/ deflate button
const int ledPin1 = 13;    // Pin connected to the LED1 (built-in LED)
const int ledPin2 = 12;   // Pin connected to the LED2 and relay 1 (Air pump)
const int relayPin = 11;   // Pin connected to the relay 2 (Solenoid valve)

int buttonState1 = 0;     // Variable to store the first button state
int buttonState2 = 0;     // Variable to store the second button state
int buttonState3 = 0;     // Variable to store the third button state
int buttonState4 = 0;     // Variable to store the fourth button state

unsigned long startTime = 0;  // Variable to track the timer start
unsigned long dataTime = 0;   // Variable to track the remaining time
unsigned long initialDataTime = 0; // Variable to store the initial dataTime value
bool timerRunning = false;    // Flag to check if the timer is running
bool firstTimeHigh = true;    // Flag to check if buttonState1 is HIGH for the first time

void setup() {
  pinMode(buttonPin1, INPUT);  // Set Button 1 as input
  pinMode(buttonPin2, INPUT);  // Set Button 2 as input
  pinMode(buttonPin3, INPUT);  // Set Button 3 as input
  pinMode(buttonPin4, INPUT);  // Set Button 4 as input
  pinMode(ledPin1, OUTPUT);    // Set the LED pin as output
  pinMode(ledPin2, OUTPUT);    // Set the LED pin as output
  pinMode(relayPin, OUTPUT);   // Set the Relay pin as output
  Serial.begin(9600);          // Start serial communication
}

void loop() {
  buttonState1 = digitalRead(buttonPin1); // Read the first button state
  buttonState2 = digitalRead(buttonPin2); // Read the second button state
  buttonState3 = digitalRead(buttonPin3); // Read the third button state
  buttonState4 = digitalRead(buttonPin4); // Read the fourth button state

  // Control the first LED based on the first button
  if (buttonState1 == HIGH) {  // Button 1 pressed
    digitalWrite(ledPin1, HIGH); // Turn the LED on
    Serial.println("Button 1: LED1 ON");
  }
  else { // Button 1 released
    digitalWrite(ledPin1, LOW); // Turn the LED off
```

```
    Serial.println("Button 1: LED1 OFF");
  }

  // Start or stop the timer based on the second button
  if (buttonState2 == HIGH && !timerRunning) { // Button 2 pressed to start the timer
    timerRunning = true;
    startTime = millis(); // Record the current time
    dataTime = initialDataTime; // Initialize dataTime with the initial value
    Serial.println("Timer started!");
  }
  else if (buttonState2 == LOW && timerRunning) { // Button 2 released to stop the timer
    timerRunning = false;
    unsigned long elapsedTime = (millis() - startTime) / 1000; // Calculate elapsed time in
seconds
    dataTime = elapsedTime; // Copy elapsed time to dataTime
    initialDataTime = dataTime; // Store the initial dataTime value
    Serial.print("Timer stopped! Elapsed time: ");
    Serial.print(elapsedTime);
    Serial.println(" seconds");
  }

  // Display timer progress if it's running
  if (timerRunning) {
    unsigned long currentTime = (millis() - startTime) / 1000; // Calculate elapsed time in
seconds
    Serial.print("Timer running: ");
    Serial.print(currentTime);
    Serial.println(" seconds");
  }

  // When button 1 is on and timer has been set, turn on relay after the first time
  if (buttonState1 == HIGH && dataTime > 0) {
    dataTime--;
    Serial.print("Data time: ");
    Serial.print(dataTime);
    Serial.println(" seconds");
    digitalWrite(ledPin2, HIGH); // Turn on LED2 & Relay 1(Air Pump)
    firstTimeHigh = false; // Mark that buttonState1 was HIGH for the first time
  }
  else if (buttonState1 == HIGH && dataTime == 0) {
    digitalWrite(ledPin2, LOW); // Turn off LED2 & Relay 1(Air Pump)
    if (!firstTimeHigh) {
      dataTime = initialDataTime; // Reset dataTime to the initial value when it reaches 0
and buttonState1 is HIGH
      Serial.print("Data time reset to: ");
      Serial.print(dataTime);
      Serial.println(" seconds");
      digitalWrite(relayPin, LOW); // Turn on Relay
      delay(1000);// Delay after solenoid valve on
      digitalWrite(relayPin, HIGH); // Turn on Relay
```

```
    delay(1000);// Delay after solenoid valve on
  }
   }

  else {
   digitalWrite(ledPin2, LOW); // Turn off LED2 & Relay 1(Air Pump)
  }

  // Check the third button and control LED2
  if (buttonState3 == HIGH) {
   digitalWrite(ledPin2, HIGH); // Turn on LED2
   Serial.println("Button 3: LED2 ON");
  }
  else {
   Serial.println("Button 3: LED2 OFF");
  }

  // Check the fourth button and control relay
  if (buttonState4 == HIGH) {
   digitalWrite(relayPin, LOW); // Turn on Relay
   Serial.println("Button 4: Relay ON");
  }
  else {
   digitalWrite(relayPin, HIGH); // Turn off Relay
   Serial.println("Button 4: Relay OFF");
  }

  delay(1000); // Short delay for stability
}
```