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Emirates International University

College of Engineering

Design a wrist and forearm rehabilitation device for stroke survivors

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Summary

This project focuses on the design of a low-cost wrist and forearm rehabilitation device specifically aimed at aiding stroke survivors in regaining motor function and improving their range of motion. The device integrates advanced features, including three degrees of freedom for simulating natural arm movements, adjustable modes tailored to individual patient needs, and an intuitive control system powered by Raspberry Pi. It also includes a robust safety mechanism with sensors to ensure the patient's well-being throughout the rehabilitation process. By providing a locally available and cost-effective solution, this device addresses the high cost and limited accessibility of existing rehabilitation technologies, ultimately enhancing the quality of care and promoting greater independence among patients.

Authorization

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Student Name	Signature	Date

Dedication

I dedicate this work to my parents, whose endless love, support, and encouragement have been the foundation of my success. Their belief in me has given me the strength to persevere through every challenge.

To my family, friends, and mentors, who have offered invaluable guidance and motivation throughout this journey, thank you for your unwavering support.

This research is also dedicated to all those who face adversity with courage, especially stroke survivors. It is my hope that this project will contribute to their recovery and improve their quality of life.

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Acknowledgment

We would like to express our deep gratitude and thanks to Allah who gave us the ability and guidance to successfully complete our graduation project. Our achievement in this project would not have been possible without the help and guidance of Allah, the source of knowledge and wisdom, who gave us the strength and determination to dedicate ourselves to our work and academic endeavors. We would also like to express our sincere appreciation and thanks to all the faculty members at the university; especially the Head of the Department of Biomedical Engineering, ***Dr. Mohammed Al-Alafi,*** our project supervisor, ***Dr. Mushtaq Al-Azizi,*** and every doctor who taught us during this stage; May Allah bless you all in your future professional and academic endeavors, and we look forward to opportunities to learn and grow continuously under your guidance;

Supervisor Certification

I certify that the preparation of this project entitled

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prepared by ………………………………………………………………………

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was mad under my supervision at ……………. department in partial fulfillment of the requirements of bachelor degree in ………………

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Department Head

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List of Abbreviations

Acronym	Definition
GPIO	General Purpose Input / Output
ROI	Raspberry pi
Tkinter	Toolkit interface (Python's standard GUI toolkit)
PWM	Pulse Width Modulation
SPI	Serial Peripheral Interface
GUI	Graphical User Interface
DOF	Degrees of freedom
RPM	Revolutions Per Minute

Chapter 1

Introduction

1 Chapter 1: Introduction

1.1 Overview

In recent years, there has been significant progress in the field of stroke rehabilitation, particularly in the development of devices aimed at restoring motor function in the affected limbs. This research project focuses on the design of a wrist and forearm rehabilitation device specifically designed to aid in the recovery of wrist and elbow movements following a stroke. The aim of this project is to enhance the existing device by incorporating three degrees of freedom, allowing for a wider range of motion and more versatile rehabilitation exercises.

Stroke is a leading cause of long-term disability worldwide, often resulting in impaired motor function and limited mobility. The wrist and forearm are commonly affected areas, making it crucial to develop effective rehabilitation methods to restore their functionality. Traditional rehabilitation techniques, such as physiotherapy, have been successful to some extent, but they often require intensive manual assistance and may not provide the necessary precision and targeted exercises needed for optimal recovery.

The proposed wrist and forearm rehabilitation device will address these limitations by providing a controlled and adjustable platform for patients to perform specific exercises that target the affected muscles and joints. The device will consist of a supportive structure that securely holds the wrist and forearm, enabling controlled movements in three planes ; These three degrees of freedom will allow for a comprehensive range of exercises that mimic natural wrist and forearm movements.

The device will be equipped with sensors and actuators to monitor and assist the patient's movements. It will provide real-time feedback on the range of motion, force exerted, and progress made, allowing both the patient and the healthcare professional to track the recovery process accurately. Additionally, the device will be programmable to adapt to the patient's specific needs, gradually increasing the intensity and complexity of the exercises as the recovery progresses.

The design of this wrist and forearm rehabilitation device has the potential to significantly enhance stroke rehabilitation outcomes. By offering three degrees of freedom and targeted exercises, it will provide a tailored approach to restoring wrist and forearm movements. The inclusion of real-time feedback and customizable programs

will allow for personalized rehabilitation protocols, improving the effectiveness and efficiency of the recovery process.

In conclusion, this research project aims to design an advanced wrist and forearm rehabilitation device with three degrees of freedom for stroke survivors. The device's versatility, precision, and adaptability hold great promise in enhancing the recovery process and improving the quality of life for stroke survivors. The successful design of this device can contribute to the advancement of stroke rehabilitation techniques and serve as an innovative tool for healthcare professionals in their efforts to aid stroke survivors in regaining motor function in their wrists and forearms

1.2 Project problems :

- High incidence of stroke leading to the need for rehabilitation: The high prevalence of stroke cases necessitates an effective rehabilitation solution to help patients recover their wrist and elbow functions .
- Lack of efficient devices within the country: There is a shortage of advanced rehabilitation devices available locally, which hinders the progress of rehabilitation programs and limits the accessibility to effective treatment options.
- Insufficient healthcare personnel: The shortage of qualified healthcare professionals, specifically nurses, who can dedicate their time to treating individual patients, poses a challenge in providing comprehensive and timely rehabilitation services.
- Lengthy natural recovery process: The natural recovery process for wrist and elbow rehabilitation can be time-consuming, extending over several months. This results in the loss of valuable nursing time that could be utilized for treating other patients.
- Costly existing devices: Previously available rehabilitation devices tend to be expensive, making them less accessible for many healthcare facilities. Developing a cost-effective device with high efficiency and affordable components would address this issue.

- These research problems highlight the need for an innovative, affordable, and efficient rehabilitation device that can cater to the growing demand for post-stroke wrist and elbow rehabilitation, considering the limited resources and personnel available in the healthcare system.

1.3 Project Objectives

General Objective:

To design a rehabilitation device for wrist and forearm recovery for stroke survivors: The primary goal is to design and a device specifically tailored for the rehabilitation of the wrist and forearm in stroke patients, assisting them in restoring motor function and improving their range of motion.

Specific Objectives:

1- A user-friendly device controlled by Raspberry Pi:

Create an easy-to-use device that can be easily controlled using Raspberry Pi, featuring intuitive controls and precise movements to provide targeted exercises for the forearm and wrist

2- A cost-effective and efficient device:

Design a cost-effective and efficient device compared to other existing devices, addressing the high costs associated with traditional therapies.

3- Adjustable modes to suit different patients: Design the device with adjustable modes to suit different patients based on the severity of their condition, allowing the modification of settings according to the complexity and intensity of the therapeutic exercises.

4- Integrated safety system:

Equip the device with a robust safety system that ensures the patient's safety throughout the rehabilitation process, including sensors for motor calibration and reset point determination.

1.4 Project Scope and Limitations

Limited Range of Motion: The device may have limitations in providing a complete range of motion for the wrist and elbow. Depending on the design and mechanical constraints, it may not be able to replicate the full natural range of movement, which could impact the effectiveness of the rehabilitation exercises.

Individual Variability: Each stroke survivor may have unique physical characteristics, abilities, and limitations. Designing a device that accommodates all variations in patient size, age, and specific rehabilitation needs can be challenging. The device may not be suitable for individuals with extreme physical limitations or unconventional anatomical structures.

Lack of Personalized Treatment Plans: The device may not incorporate personalized treatment plans tailored to each patient's specific condition and progress. While it may offer adjustable modes, manual configuration by healthcare professionals may not capture the full complexity of individual patient needs, potentially limiting the device's effectiveness.

Limited Clinical Validation: The research project may have limitations in terms of conducting extensive clinical trials and validating the device's effectiveness on a large scale. Limited resources, time constraints, and access to a diverse patient population may restrict the ability to gather robust empirical evidence supporting the device's efficacy.

Technical Constraints: The use of Raspberry Pi and motors may introduce technical limitations. The computational capabilities of Raspberry Pi may have constraints when it comes to real-time processing and data analysis, potentially affecting the device's responsiveness and ability to provide immediate feedback. The motors used may have limitations regarding precision and range of motion.

Lack of Long-Term Monitoring: The research project may not include long-term monitoring of patients' progress and outcomes. This limitation restricts the ability to assess the sustained impact of the device over extended periods and evaluate its efficacy in promoting long-term rehabilitation outcomes.

User Acceptance and Compliance: The device's success depends on stroke survivors' acceptance and consistent use. Factors such as patient motivation, adherence to the rehabilitation regimen, and user comfort can influence the device's effectiveness. The project may not extensively address these factors, potentially impacting overall patient compliance and results.

The effect of therapy delivered by robotic devices has also been examined. Numerous robotic devices have been studied [1],[2],[3],[4],[5].

These devices offer potential advantages, such as consistent and long-lasting output, programmability, utility for virtual reality applications, safety, high precision, the potential for an improved therapist : patient ratio, and great potential for telerehabilitation and therefore ability to reach underserved regions[6] . However, concerns exist with some aspects of robot-based intervention, for example, the need to understand the mechanism of action, the response of the therapist community to a robotic device, the response of patients to reduced interaction with a human therapist, the effect of such devices on task ecology and object affordance, the limited repertoire that fixed devices have, and the nature of the measurements that a robot is programmed to report.

In one of the largest studies of robot therapy after stroke, Lo et al. [7] enrolled 127 patients in the chronic phase of stroke and found that robot-assisted therapy did not significantly improve motor function after 12 weeks, as compared with usual care or intensive therapy; in secondary analyses, robot-assisted therapy improved outcomes over 36 weeks as compared with usual care but not with intensive therapy. This study may be complicated by the fact that enrollees had relatively severe motor deficits.

Robotic devices have great promise but further research is needed. One recent review noted that (1) effects on motor control are small and specific to the joints targeted by the robotic intervention; (2) limited data support generalization of robot-derived gains to broader functions; and (3) little data exist among patients in the initial weeks following stroke onset [8] . Factors that might represent avenues for improving the impact of robotic therapy include more fully defining the relationship between robotic therapy and traditional physiotherapy, and matching the right patients with the right robotic devices and protocols.

1.5 Project methodology

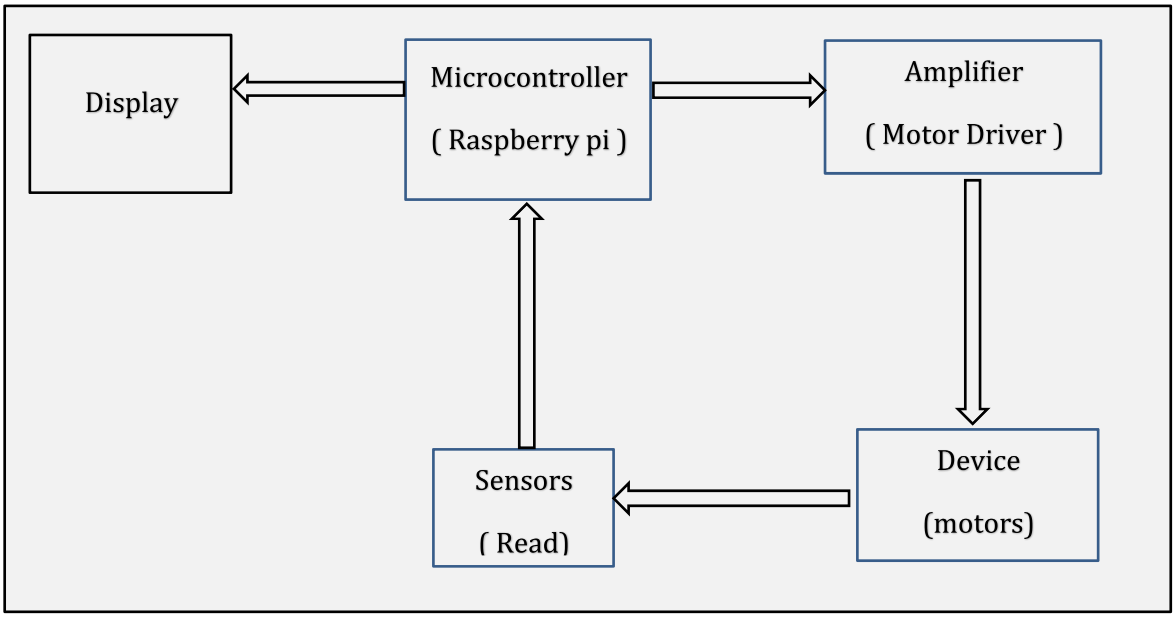

Figure 1-1 Diagram of project

1.6 Report Organization :

Chapter 1: Introduction

This chapter provides an overview of the project, outlining the problems the project aims to solve, the objectives set to address these issues, the scope and limitations, and the methodology followed throughout the project. It also includes the report organization and a section on the mathematical notation used in the project.

Chapter 2: Background and Literature Review

This chapter introduces the effects of stroke on the wrist and forearm, highlighting the challenges and the importance of early rehabilitation. It reviews the relevant literature, comparing existing technologies, and discussing the methodologies applied in this project, including design, control system development, sensor integration, and performance evaluation.

Chapter 3: Requirements Analysis and Modeling

This chapter covers the general structure of the project, the system life cycle, and the various components used, such as the Raspberry Pi, Arduino Uno, and other hardware. It also includes diagrams and models that illustrate the system's architecture.

Chapter 4: Project Design and Implementation

This chapter details the mechanical and electronic design of the device, the materials used, and the safety mechanisms implemented. It explains the software design, the steps taken during the implementation phase, including component assembly, programming, testing, and the challenges encountered along the way.

Chapter 5: Results and Discussion

The final chapter presents the results obtained from the project, discusses these findings in relation to the project's objectives, and offers recommendations for future improvements and applications of the rehabilitation device.

Chapter 2 Background and Literature Review

2 Chapter 2: Background and Literature Review

2.1 Introduction

In recent years, the field of stroke rehabilitation has witnessed significant advancements, particularly in the development of devices aimed at restoring the function of affected limbs. Stroke is a medical condition that occurs when blood flow to a part of the brain is interrupted, either due to a blood clot or bleeding, leading to the death or damage of brain cells. This often results in motor function impairment, especially in the upper extremities such as the forearm and wrist, where many stroke survivors face difficulties in regaining their functions.

This research project focuses on the design of a specialized device for wrist and forearm rehabilitation, designed to assist in the recovery of movement following a stroke. The proposed device aims to enhance the current rehabilitation methods by integrating three degrees of freedom, allowing for a wider range of motion and greater diversity in exercises. This device provides a controlled and adjustable system that targets the affected muscles and joints, addressing the limitations of traditional rehabilitation techniques, which often require intensive manual assistance and may lack the necessary precision for optimal recovery.

The device consists of a supportive structure that securely stabilizes the wrist and forearm, enabling controlled movements across three different levels of freedom. These degrees of freedom facilitate a comprehensive range of exercises that simulate natural wrist and forearm movements. The device is equipped with a set of sensors and motors that monitor and assist the patient's movements, providing real-time feedback on the range of motion, exerted force, and progress. This precise monitoring allows healthcare professionals and patients to accurately track the recovery process.

The device's programmability is a key feature, allowing it to be customized to suit the individual needs of each patient. As the recovery progresses, the device can gradually increase the complexity and intensity of exercises, providing progressive challenges to stimulate continued improvement in therapy. This adaptability ensures that the rehabilitation process remains aligned with the patient's capabilities and goals.

By using this device, patients can enhance their recovery of wrist and forearm function, leading to improved performance of daily activities and a higher quality of life. The device also reduces the need for continuous manual assistance and professional intervention, thus lowering treatment costs and granting patients greater independence and freedom in their daily lives.

In operation, the patient secures their forearm and wrist within the device, which is then programmed and adjusted to meet their specific needs. The patient performs a series of exercises that target the affected muscles and joints, with their movements continuously monitored by the sensors. This real-time data provides immediate feedback, helping patients and healthcare providers make necessary adjustments to optimize recovery.

Overall, the rehabilitation device is an innovative technology with the potential to significantly improve recovery outcomes and enhance the quality of life for stroke survivors. However, it is essential that patients consult with specialized physicians before using any device or starting a rehabilitation program to ensure the treatment is tailored to their individual condition

2.1.1 Some possible effects of a stroke on the wrist and forearm include :

- Partial paralysis or weakness in the muscles controlling the wrist and forearm, making it difficult to control movements.
- Difficulty in performing simple tasks such as feeding or using the hand in everyday activities.
- Problems with sensation, such as difficulty feeling touch or controlling the required force for movements.
- Sensory impairment, where the stroke's impact may lead to abnormal sensations such as increased pain, itching, or altered sensory perception.

It is important to note that the effects of a stroke on the wrist and forearm can vary from person to person and depend on factors such as the location and severity of the stroke, age, and overall health. There is also an opportunity for improvement and recovery from movement and sensory problems associated with stroke through rehabilitation therapy and appropriate exercises that aim to enhance movement and improve motor abilities.

2.1.2 Challenges in rehabilitating the wrist and forearm after a stroke

1. Injury assessment and program determination: Assessing the extent of the injury and determining the appropriate rehabilitation program for the hand is crucial. It can be challenging to determine the range of motion and potential functions of the affected hand and anticipate the expected level of improvement. This requires specialized evaluation and collaboration between the therapy team and the patient.

2. Lack of stimulation and resources: Accessing advanced external devices or intensive therapy programs may be difficult. There may be financial or geographical constraints, or limited availability of specialized rehabilitation facilities.

3. Difficulty maintaining motivation and adherence: Patients may face challenges in maintaining motivation and adhering to a rehabilitation program over an extended period. It can be challenging to stay consistent with the required exercises and training, and patients may feel discouraged if the desired improvement is not achieved quickly. The therapy team and the patient's support network must provide continuous support and encouragement.

4. Psychological and emotional challenges: Patients may experience psychological and emotional challenges during the hand rehabilitation process. They may feel anxiety or depression due to the loss of the ability to use the hand normally and struggle to adjust emotionally and psychologically to the injury. Psychological and emotional support should be provided to the patient, whether through confidence-building sessions or psychological counseling.

5. Functional and social challenges: Hand injury can impact an individual's functional and social abilities. Patients may have difficulty performing basic daily tasks such as cleaning objects, writing, and maintaining independence in daily life. They may struggle to return to work or engage in social activities. Hand training should be integrated within a functional and social context to ensure maximum independence and participation in daily life.

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2.1.3 The importance of early rehabilitation

Early rehabilitation is the process of initiating treatment and rehabilitation as soon as possible after an injury or health problem occurs. Early rehabilitation is very important for several reasons:

1. Enhancing recovery: Early rehabilitation helps enhance the recovery and healing process. Starting treatment and training early can stimulate the body to regain lost or

impaired functions more quickly. It also contributes to reducing the risks of complications and negative effects resulting from the injury.

2. Minimizing muscle atrophy: Early rehabilitation helps minimize muscle wasting and loss of strength and movement. When muscles are not used for extended periods due to injury or health issues, they gradually lose their strength and ability to function normally.

3. Restoring daily functions: Early rehabilitation aims to restore the ability to perform basic daily tasks such as movement, independence in self-care, and feeding. By initiating early treatment, individuals have a better chance of regaining their functional abilities.

4. Alleviating pain: Early rehabilitation may be necessary to alleviate pain and improve comfort. Some injuries and health conditions can cause chronic pain or restrict hand movement. By applying appropriate rehabilitation techniques such as physical therapy and targeted exercises, blood circulation can be improved, inflammation reduced, and pain alleviated.

5. Reducing permanent disability: Early intervention and effective rehabilitation can help reduce the chances of permanent disability. Starting treatment early increases the chances of regaining natural hand functions, movement, and control, thus reducing permanent disability and contributing to achieving better long-term outcomes.

In general, early rehabilitation is considered an important part of comprehensive treatment to restore hand movement and normal functions. It helps stimulate the body's recovery, reduces complications, improves muscle strength, restores movement, and enhances daily functions. Therefore, early initiation of the rehabilitation process is crucial in achieving the best results and enhancing the quality of life for affected individuals.

2.1.4 The expected benefits of the rehabilitation device

Several benefits can be expected from using an innovative rehabilitation device, including:

1. Movement improvement: The device works to improve muscle strength and enhance motor control.

2. Restoration of motor functions: The device can assist in restoring lost or impaired motor functions due to injury. It can enhance the recovery process and help regain natural movement and motor functions.

3. Pain reduction and alleviation of discomfort: The device can help reduce pain and improve comfort. By stimulating the muscles and improving blood circulation, the device can reduce inflammation and alleviate pain associated with the injury.

4. Promotion of independence and quality of life: By restoring movement and improving motor abilities, the device can contribute to promoting independence and enhancing the quality of life. Users of the device can experience increased independence in performing daily activities and achieving personal goals.

5. Tissue healing and recovery stimulation: The device can promote tissue healing and overall body recovery. By stimulating the muscles and improving blood circulation, it can accelerate the wound healing process and tissue regeneration.

6. Reduce the risk of secondary disability: The device can reduce the risk of secondary disability after injury or surgery. By enhancing movement and improving motor functions, the device can contribute to preventing the development of secondary problems and reducing the negative consequences of injury

The use of an innovative rehabilitation device can contribute to achieving positive and tangible results in the rehabilitation process.

2.1.5 Some reasons why forearm and wrist movement is important

1. Prevention of stiffness and contractures: After a stroke, stiffness and contractures can occur in the muscles and tissues surrounding the elbow and wrist. Regularly moving the elbow and wrist helps maintain tissue flexibility and prevents excessive stiffness and contractures.

2. Improvement of range of motion: Stroke can lead to limitations in the range of motion of the elbow and wrist. Regularly moving them helps improve the range of motion and enables individuals to perform daily movements better and with more independence.

3. Enhancement of muscle strength: Moving the elbow and wrist helps strengthen the surrounding muscles. Improving muscle strength contributes to better mobility and performance of daily tasks.

4. Improvement of motor coordination and precision: Moving the elbow and wrist contributes to improving motor coordination and precision. This can enhance the ability to perform precise movements such as tool manipulation or writing, thereby improving independence and daily life.

5. Enhancement of blood circulation and vascularity: Moving the elbow and wrist promotes blood circulation and improves vascularity in this area. This helps provide the necessary oxygen and nutrients to the affected tissues, promoting healing and recovery.

2.2 Literature Review

Rehabilitation robots are commonly categorized as either end-effector based robots or exoskeletons (refer to Figure 1.1). An end-effector rehabilitation robot is designed in such a way that only the robot's most distal link, known as the end-effector, interacts with the user. Some notable upper-extremity end-effector rehabilitation robot designs with historical significance include the 2-degree-of-freedom (DOF) MIT-MANUS [9],[10],[11] (commercially known as the In Motion ARM/WRIST), the Mirror Image Movement Enabler (MIME) [12] (which is a modification of the industrial 6- DOF PUMA robot), and the 3- DOF ARM Guide [13].

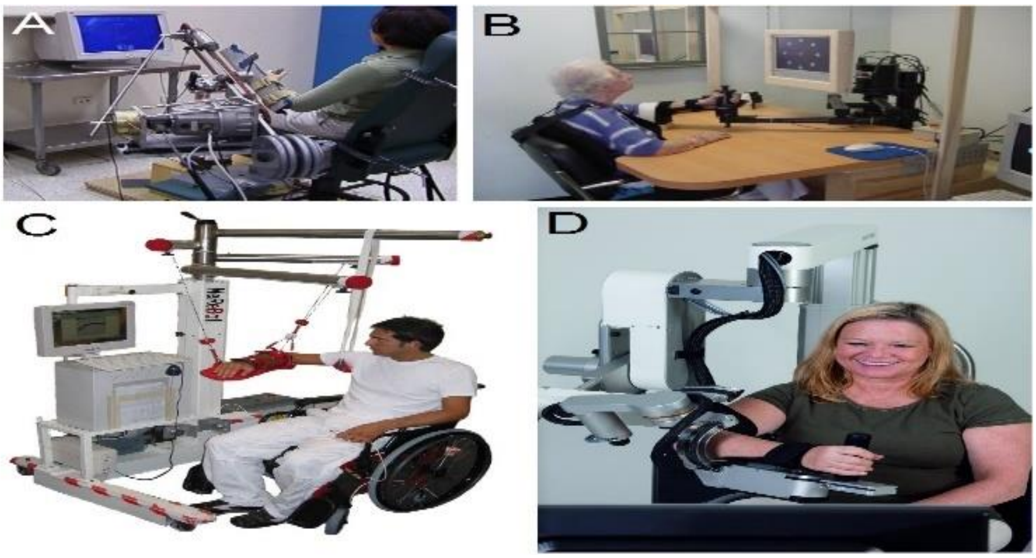

Figure 2-1 upper-extremity end-effector rehabilitation robot designs

End-effector rehabilitation robots generally offer a wide range of functional workspaces, but they do not replicate the human anatomy and, therefore, cannot directly apply torques to human joints.the 6-DOF ARMin III [14] .

ARMin is a robot for arm therapy applicable to the arm training in Clinics, It has an exoskeleton structure and is equipped with position and force sensors. Our latest version ARMin II has six degrees of freedom. The mechanical structure, the actuators, and the sensors of the robot are optimized for patient cooperative control strategies based on impedance and admittance architectures.

The device can work in three therapy modes: passive mobilization, game therapy, and task-oriented training.

The device offers three therapy modes: passive mobilization, game therapy, and task-oriented training. However, it is noteworthy that the device did not provide the desired torque due to its heavy weight. This implies that the device faced challenges in delivering the required force or resistance during therapy sessions.

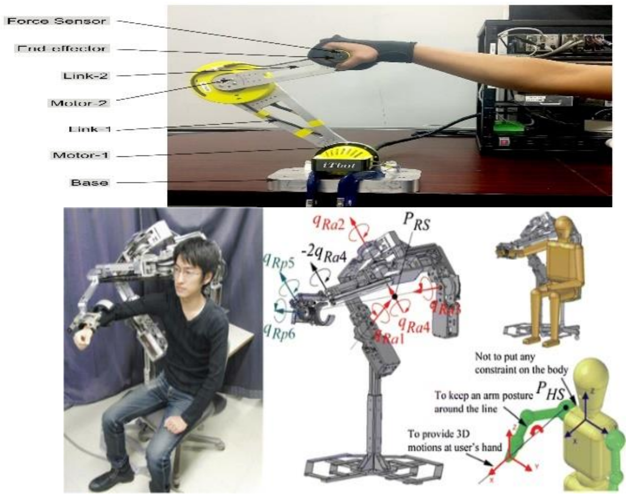

Figure 2-2 ARMin robot 6-DOF

LINarm 2014 [15];

LINarm is a device designed for upper-limb rehabilitation, incorporating force-feedback and variable-stiffness assistance. Its variable-stiffness architecture offers several distinct advantages, including adjustable compliance, improved safety, suitability for human-robot interaction, affordability, lightweight design, and compactness. The initial prototype of this device is currently being assembled.

Furthermore, it should be noted that the device operates with a singular degree of freedom for rehabilitating the elbow and shoulder after a stroke. It also serves the purpose of testing the effectiveness of training. However, the device has not fulfilled its intended purpose due to the lack of necessary movements required for arm motion. This necessitates the development of a device with three degrees of freedom to address this limitation.

An affordable, adaptable, and hybrid assistive device 2016 [16] ;

The device in question is a multisensory and multimodal system designed for neuromuscular rehabilitation of the upper limb. It aims to enhance rehabilitation treatments in both clinical and home settings. Building upon an existing low-cost, variable-stiffness rehabilitation device, this system incorporates additional modules to expand its functionalities and improve its application scenarios and clinical techniques.

The newly developed system integrates several components, including a wearable neuromuscular electrical stimulation system, a virtual rehabilitation scenario, a low-cost unobtrusive sensory system, and a patient model for adapting training task parameters. It also includes the monitoring of user behavior during each session and their progress throughout the entire training period.

One notable characteristic of this device is that it operates with a single degree of freedom. However, there are potential drawbacks that can be addressed.

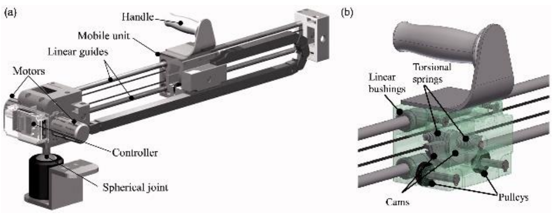

Figure 2-3 LINarm device . for upper-limb rehabilitation

Design of the Open Wrist Exoskeleton 2017 [17] ;
a new hand-wrist exoskeleton device has been developed. This device aims to provide targeted and coordinated therapy for the hand and wrist. The focus of this thesis is on the design of the wrist module and the considerations made to optimize its potential as a coordinated hand-wrist device. The wrist mechanism has been specifically engineered to facilitate easy wearing and removal for individuals with impaired mobility. Additionally, it has been designed to ensure compatibility with the hand module for tasks involving virtual and assisted grasping.

It is worth noting that this effective device operates with three degrees of freedom and is used for patient testing. However, it has been relatively expensive to produce, and its design has not fully met the required torque specifications.

Overall, this device represents an important advancement in rehabilitation robotics, particularly for hand and wrist therapy. Further improvements in cost-effectiveness and torque output are areas that can be addressed in future iterations.

Figure 2-4 Design of the Open Wrist Exoskeleton 2017

MIT-MANUS proved an excellent fit for shoulder and elbow rehabilitation in stroke patients, showing in clinical trials a reduction of impairment in these joints.
The greater reduction in impairment was observed in the group of muscles exercised.
This suggests a need for additional robots to rehabilitate other target areas of the body.
The focus here is a robot for wrist rehabilitation designed to provide three rotational degrees of freedom.
A previous paper at ICORR2003 and its companion book described the basic system design and characterization [18] [19].

2.3 Methodologies

This section describes the methodologies employed in the design of the rehabilitation device for the forearm and wrist, featuring three degrees of freedom.

The device is controlled using a Raspberry Pi, and motion is captured through variable resistors. The device operates using three motors. The aim of the project is to provide the device locally, with low cost and high efficiency.

2.3.1 Design and Prototyping

The rehabilitation device will be designed and prototyped using Computer-Aided Design (CAD) software. The design process will involve creating 3D models of the device components, including the frame, joints, and motor mountings. Rapid prototyping techniques such as 3D printing or CNC machining will be used to fabricate physical prototypes. The prototypes will undergo thorough testing to ensure proper functionality and ergonomic design.

2.3.2 Control System Development

The control system for the rehabilitation device will be developed using a Raspberry Pi microcontroller. The control algorithm will be designed to interpret input signals from the variable resistors and translate them into corresponding motor movements. The programming language Python will be utilized for coding the control system. The control system will undergo iterative testing and calibration to achieve accurate and responsive motion control.

2.3.3 Sensor Integration

To capture the motion of the forearm and wrist, variable resistors will be used as sensors. These resistors will be strategically placed to measure the joint angles and range of motion during rehabilitation exercises. Analog-to-digital conversion will be performed to convert the analog output from the resistors into digital signals that can be processed by the Raspberry Pi. Signal conditioning techniques will be employed to ensure accurate and reliable measurements.

2.3.4 Motor Control

The rehabilitation device will feature three motors responsible for generating the desired movements of the forearm and wrist. Motor control circuits will be designed and implemented to facilitate precise control of the motors. The control signals from the Raspberry Pi will be amplified and converted into appropriate voltage and current levels to drive the motors. The motor control system will be optimized to provide smooth and coordinated movements.

2.3.5 Performance Evaluation

The effectiveness of the developed rehabilitation device will be evaluated through performance assessments. A group of participants requiring forearm and wrist rehabilitation will perform specific exercises using the device. Quantitative measurements, such as range of motion and muscular strength, will be recorded. Additionally, subjective feedback will be collected through questionnaires and surveys to assess the participants' perceived improvements. Statistical analysis will be conducted to analyze the data and evaluate the device's performance.

2.3.6 Cost Analysis

A comprehensive cost analysis will be conducted to determine the affordability and feasibility of local production of the rehabilitation device. The costs associated with materials, components, fabrication, and assembly will be considered. Alternative sourcing options and cost-saving measures will be explored to ensure the device can be produced at a low cost without compromising quality and performance.

This section outlines the methodologies employed in the design of the forearm and wrist rehabilitation device. The design and prototyping phase, control system development, sensor integration, motor control, performance evaluation, and cost analysis are the key methods used to achieve the project objectives

2.4 Method of Data Recording

In order to capture and analyze the relevant data during the operation of the rehabilitation device, the following method of data recording will be employed:

2.4.1 Data Acquisition System

A data acquisition system will be implemented to record and store the necessary data during the rehabilitation sessions. This system will consist of sensors, data acquisition hardware, and software. The variable resistors used for motion capture will serve as the primary sensors.

2.5 Programming Tools :

The design and implementation of the forearm and wrist rehabilitation device in this project involve the use of the following programming tools:

2.5.1 Raspberry Pi Programming:

- Python: Python will be used as the primary programming language for the Raspberry Pi. Python offers a wide range of libraries and modules that facilitate hardware control, data processing, and communication. It is well-suited for prototyping and rapid development.

2.5.2 Motor Control:

- RPi. GPIO: The RPi. GPIO Python library will be used to control the General Purpose Input /Output (GPIO) pins on the Raspberry Pi. This library will enable control over the device’s motors, including setting motor speed, direction, and other parameters.

2.5.3 Sensor Data Reading:

- RPi.GPIO and time: The RPi.GPIO library will be used in conjunction with the time library to read analog sensor values through the use of variable resistors and analog-to-digital conversion. This setup will allow for precise real-time processing of sensor data.

2.5.4 Communication and User Interface:

- Tkinter and math: The Tkinter library will be utilized to develop the interactive graphical user interface (GUI), facilitating device control and displaying relevant information. Additionally, the math library will be used to perform necessary calculations within the interface.

2.5.6. Documentation and Version Control:

2.5.6.1 - Git:

Git is a widely used version (**Figure 2-5**)control system that allows for efficient code management, collaboration, and tracking of project changes. It enables you to maintain a history of your code and easily revert to previous versions if needed.

These programming tools provide a comprehensive set of resources for design and implementing the forearm and wrist rehabilitation device. They offer flexibility, ease of use, and a supportive community, enabling you to achieve the project's objectives of local manufacturing, cost-effectiveness, and high efficiency.

Figure 2-5 system interface of Raspberry pi

2.6 Historical Development of Rehabilitation Devices

The field of rehabilitation technology has undergone significant advancements over the past few decades. Early rehabilitation devices were primarily mechanical, focusing on passive movement and basic support. However, the advent of microcontrollers, sensors, and advanced actuators has revolutionized this domain, leading to the development of sophisticated robotic systems capable of providing active assistance and real-time feedback. These innovations have paved the way for modern rehabilitation devices that not only support but also enhance the therapeutic process. This historical perspective underscores the relevance and importance of the current project, which aims to further refine and improve upon existing technologies to better serve patients recovering from stroke and other motor impairments.

2.7 Comparison of Existing Technologies

In the realm of rehabilitation robotics, various devices have been developed, each with its own strengths and limitations. For instance, end-effector based systems like the MIT-MANUS have proven effective for shoulder and elbow rehabilitation, but they lack the anatomical specificity required for precise wrist and forearm movements. Exoskeletons, such as the ARM in series, offer better joint control but often suffer from issues related to weight and torque output. The LIN arm device, while innovative in its use of variable stiffness, operates with only a single degree of freedom, limiting its applicability. In contrast, the current project aims to combine the best features of these technologies by providing a lightweight, cost-effective device with three degrees of freedom, specifically designed to enhance wrist and forearm rehabilitation.

2.8 Challenges in Rehabilitation Robotics

The design of rehabilitation robotics presents several challenges, including ensuring accuracy in movement control, maintaining affordability, and achieving a user-friendly design that can be easily adopted by both patients and therapists. One of the most significant hurdles is the integration of precise motion control with real-time feedback mechanisms, which is crucial for effective therapy. Additionally, creating a device that is both robust and affordable remains a key challenge, particularly in making these technologies accessible to a broader population. This project addresses these challenges by leveraging modern microcontrollers and sensors, as well as focusing on a modular and scalable design that can be adapted to different levels of patient needs.

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Chapter 3

Requirements Analysis and Modeling

3 Chapter 3: Requirements Analysis and Modeling

3.1 Introduction

Requirements Analysis and Modeling," will focus on identifying and analyzing the specific needs and requirements essential for design a forearm and wrist rehabilitation device. This chapter will outline the functional and non-functional requirements that must be met to ensure the device's effectiveness in aiding stroke patients.

The modeling section will then translate these requirements into structured and detailed design models, providing a comprehensive framework for the device's development and implementation. The analysis will help in understanding the necessary hardware, software, and user interface components, ensuring that all aspects of the device are well-aligned with the project's goals.

3.2 General structure of project

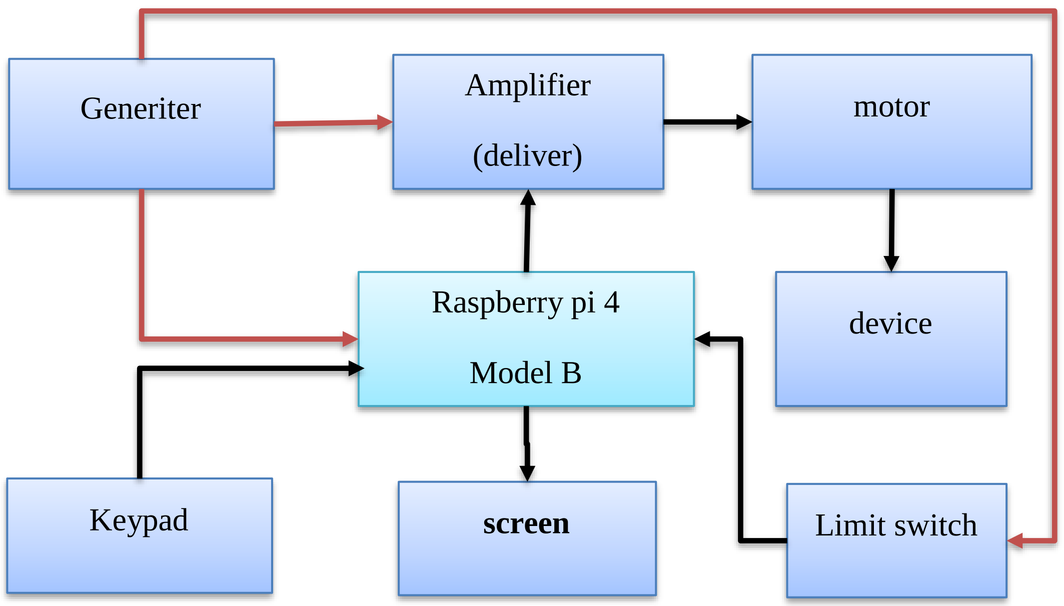

Figure 3-1General structure of project

The general structure of the project, as depicted in the diagram, involves various components working together to ensure the proper functioning of the forearm and wrist rehabilitation device.

At the core of the system is the generator, responsible for generating the appropriate power supply for each component of the project. It distributes the required voltage and current to ensure optimal performance.

The control unit, represented by the Raspberry Pi and Arduino uno, plays a crucial role in issuing commands to effectively control the device. It manages the movement of motors and displays relevant information on the screen.

Additionally, the device incorporates keyboard inputs from the nurse or operator. These inputs allow for user interaction, enabling the customization of settings and ensuring appropriate control. The control unit utilizes the collected sensor data and keyboard inputs to guarantee optimal performance and control.

To control the motor movements, the control unit amplifies the output signal using an amplifier or driver, such as an amplifier . This amplification ensures that the motor receives the necessary signal strength to perform the desired movements accurately.

The screen serves as a visual interface, displaying various modes, options, patient status, and other relevant information. It provides real-time feedback and visual cues to both the operator and the patient, facilitating effective communication and interaction.

In summary, the general structure of the project involves a generator for power supply, a control unit (Raspberry Pi & arduino uno) for issuing commands based on sensor readings and keyboard inputs, an analog-to-digital conversion circuit, motor control through an amplifier or driver, and a screen for displaying modes and patient-related information. This integrated system aims to ensure optimal performance, control, and user experience for the forearm and wrist rehabilitation device.

3.3 live cycle system

The project incorporates several features to ensure smooth operation, minimize friction, and protect both the patient and the device.

To enhance the durability and longevity of the device, bearings have been implemented. These bearings are designed to reduce friction and ensure smooth movement within the device. By minimizing friction, the bearings contribute to the overall performance and extend the lifespan of the device

Additionally, a protection system has been integrated to prevent any potential harm to the patient or damage to the device. This protection system operates in two ways.

Firstly, it includes a timer mechanism that sets an upper limit on the motor's operating time. This ensures that the motors do not exceed the recommended usage duration. Secondly, a safety switch is incorporated to disconnect the motor circuit if it operates beyond the specified range. This feature acts as an additional safety measure to prevent any adverse effects on the patient or the device.

The device undergoes rigorous testing to validate its functionality and safety. This includes examining the sensors and mechanical components that are prone to friction, ensuring their proper operation. Additionally, the integrity of the electrical connections is checked, as continuous movement can potentially lead to wire breakage or disconnection.

In summary, the project incorporates bearings to enhance smoothness and minimize friction, while a protection system safeguards the patient and the device by monitoring motor operating times and implementing a safety switch. The device is thoroughly tested to ensure the proper functioning of sensors, mechanical components, and electrical connections. These measures collectively contribute to the device's performance, safety, and reliability throughout its lifecycle.

3.4 Diagrams

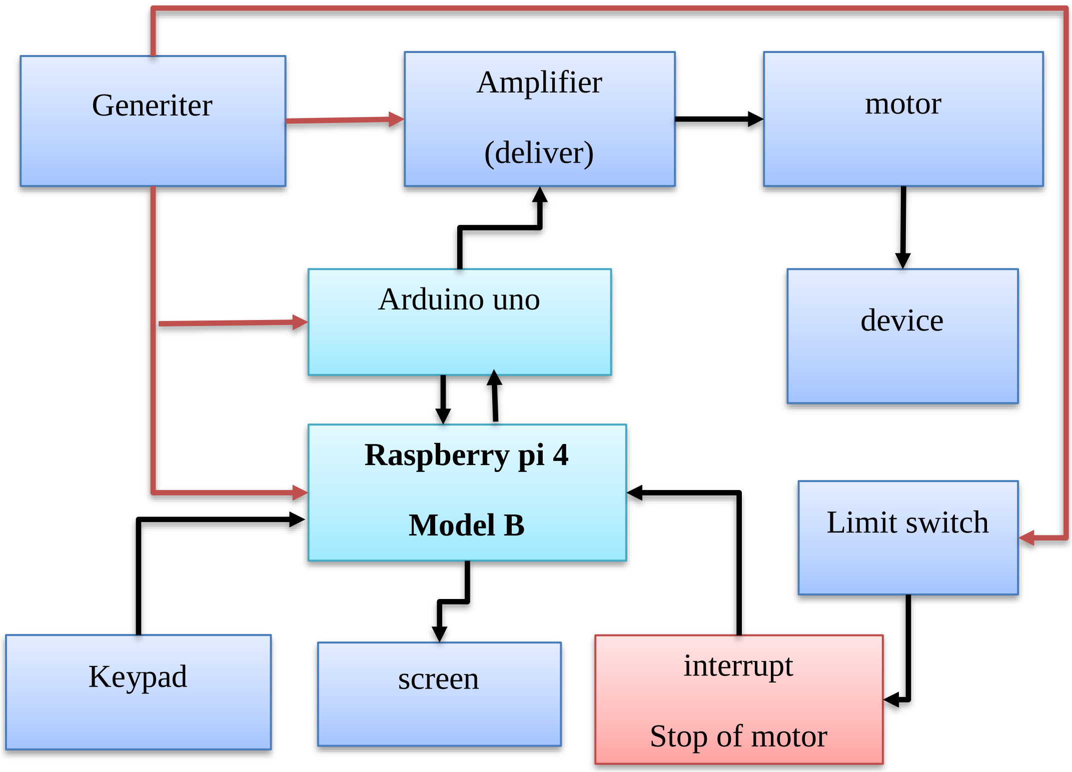

Figure 3-2 Diagrams of Device Operation

3.5 components

3.5.1 Raspberry Pi 4 2GB:

1. Processor: The Raspberry Pi 4 (**Figure 3-4**) contains a 64-bit Broadcom BCM2711 processor, which is a quad-core ARM Cortex- A72 processor with a frequency of 1.5 GHz.

2. Random Access Memory (RAM): The Raspberry Pi 4 features a 2GB RAM capacity. This large memory allows multiple applications and multitasking to run smoothly.

3. Graphics: The Raspberry Pi 4 provides a VideoCore VI GPU that supports OpenGL ES 3x , OpenGL 3.2, H.265 (High Definition Video), MPEG-4 / AVC and other video decoders.

4. Network Connections: The Raspberry Pi 4 features a Gigabit Ethernet port for high-speed local network connectivity. It also features support for Wi-Fi 802.11ac and Bluetooth 5.0 for wireless connectivity.

5. I/O Ports: The Raspberry Pi 4 includes two USB 2.0 ports and two USB 3.0 ports for connecting external devices such as keyboard, mouse, and external storage devices. It also has an HDMI 2.0 port and a 3.5mm audio port for connecting to displays and external speakers.

6. microSD card slot: The microSD card slot is used to expand storage capacity and run the operating system.

7. Operating System: A variety of operating systems can run on the Raspberry Pi 4, including Raspbian, Ubuntu Mate, Open ELEC , LibreELEC , and others. Support for Windows 10 IoT Core is also available.

8. Uses: The Raspberry Pi 4 can be used in many projects and applications, such as creating a multimedia center, playing video games, building robots, setting up a small network server, and learning programming and electronics.

This is some basic information about the Raspberry Pi 4 2GB. If you need more details or specific information, the Raspberry Pi 4 2GB is a model of the Raspberry Pi series, a small Linux-based computer with powerful capabilities and wide compatibility with a variety of applications and projects.

3.5.1.1 Technical Specifications:

- Processor: Broadcom BCM2711 quad-core ARM Cortex-A72, clocked at 1.5 GHz.

- Random Memory (RAM): 2 GB of LPDDR4-3200 memory.

- Graphics: VideoCore VI GPU with OpenGL ES 3.x support.

- Storage: microSD card slot to expand storage capacity.

- Network: Gigabit Ethernet port, support for Wi-Fi 802.11ac and Bluetooth 5.0.

- Input/output ports: two USB 2.0 ports, two USB 3.0 ports, an HDMI 2.0 port, and a 3.5 mm audio port.

- Power: Powered by an external 5V, 3A power adapter.

3.5.1.2 Operating systems:

Raspbian: A Linux-based operating system designed specifically for the Raspberry Pi.

- Ubuntu Mate: A modified version of the Ubuntu system for compatibility with the Raspberry Pi.

- Windows 10 IoT Core: A special edition of Windows 10 designed for Internet of Things (IoT) applications.

3.5.1.3 Uses of Raspberry Pi 4 2GB :

- Multimedia Center: The Raspberry Pi 4 can be used as a center for storing and playing multimedia such as movies and music.

- Robot projects: It can be used to build robots and develop projects related to artificial intelligence and robotics.

- Micro Servers: The Raspberry Pi 4 can be used to set up small servers for files, the web, or games.

- Learn programming: The Raspberry Pi provides an open source development environment that helps users learn programming languages such as Python, Scratch, and others.

- Home Automation Projects: It can be used in building a smart home automation system to control lighting, appliances, and appliances Raspberry

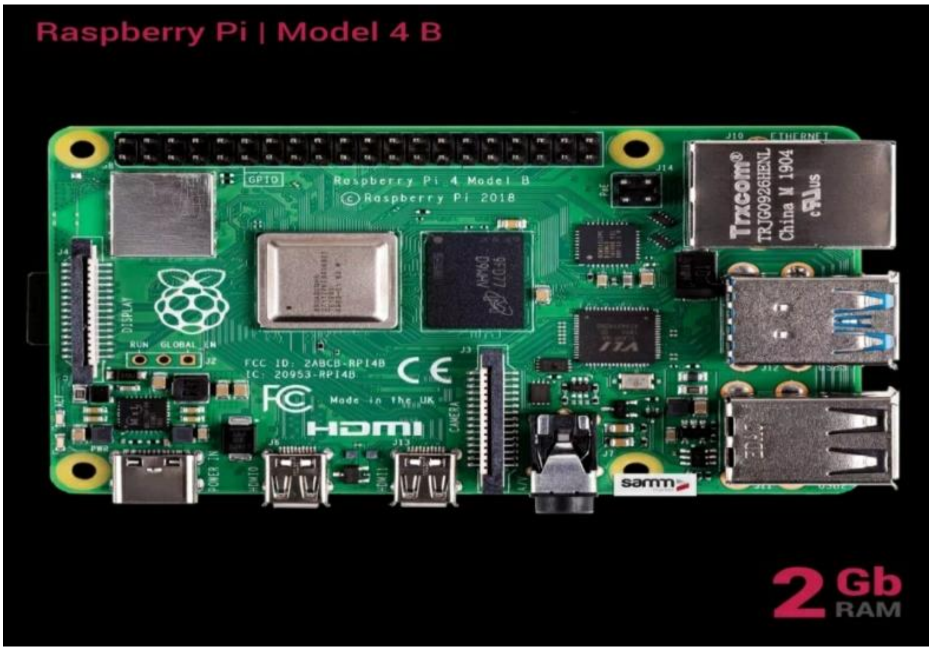

Figure 3-4 Raspberry Pi 4 2GB:

3.5.2 Arduino uno

Arduino Uno (**Figure 3-5**)The Arduino Uno is a popular microcontroller board widely used in electronics projects and prototyping. It’s favored for its simplicity, versatility, and ease of use, making it an excellent choice for beginners and professionals alike.

3.5.2.1 Key Features:

1- Microcontroller :The Arduino Uno is powered by the ATmega328P microcontroller, which provides 32 KB of flash memory, 2 KB of SRAM, and 1 KB of EEPROM. This microcontroller is responsible for executing the code that controls the connected components.

2- Input /Output Pins :The board comes with 14 digital input/output pins, 6 of which can be used as PWM (Pulse Width Modulation) outputs, and 6 analog input pins. These pins allow the Arduino Uno to interact with sensors, LEDs, motors, and other electronic components.

3- Operating Voltage :The Arduino Uno operates at 5V, with a recommended input voltage range of 7 –12 V . It can be powered via the USB connection or an external power supply.

4- Programming :The board is programmed using the Arduino IDE, a user-friendly software that supports C/C++ programming languages. The IDE provides a wide range of libraries that simplify complex tasks such as controlling motors, reading sensor data, and communicating with other devices.

5- Connectivity :The Arduino Uno has a USB-B port for connecting to a computer for programming and power supply. It also features a serial communication interface (UART) for communication with other devices.

6- Onboard LED :The board includes an onboard LED connected to digital pin 13, which is often used for testing and debugging.

3.5.2.2 Applications:

-The Arduino Uno is widely used in various projects and applications, including:
-Robotics: Controlling motors, servos, and sensors in robotic systems.
-Home Automation: Automating lights, fans, and other appliances.
-Wearable Technology: Developing smart clothing and accessories.
-Education: Teaching electronics, programming, and prototyping in classrooms and workshops.
-DIY Projects: Creating custom gadgets, games, and interactive art installations.

The Arduino Uno's open-source nature, combined with a vast community of users and resources, makes it an ideal platform for developing a wide range of creative and innovative projects.

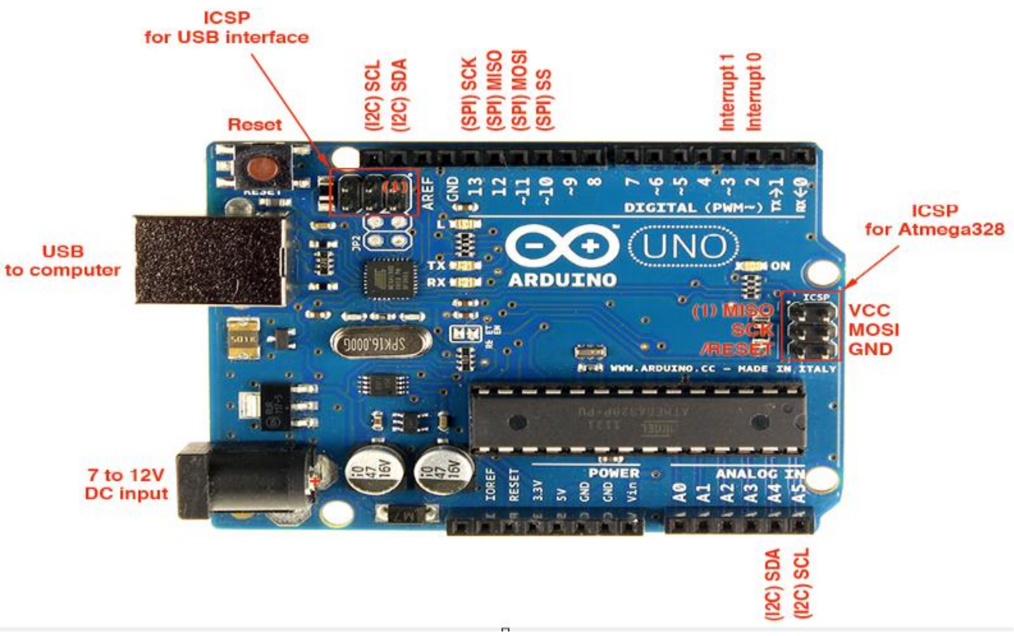

Figure 3-5 Arduino uno

3.5.3 **A4988 Driver :**

The A4988 Stepper Motor Driver (**Figure 3-6**) is an essential component designed for precise control of stepper motors, commonly used in various automation, robotics, and electronic projects. This driver is widely recognized for its efficiency, ease of integration, and versatility in managing stepper motor operations.

3.5.3.1 Key Features:

1- Input: The A4988 driver operates with a wide input voltage range, typically between 8V and 35V, making it compatible with various power sources commonly used in electronic projects .It features control inputs that allow users to manage the step size and direction of the stepper motor, facilitating precise movements and positioning.

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2- Output: The A4988 driver can handle up to 2A per coil with adequate cooling, allowing for the control of a wide range of stepper motors, including those with higher torque requirements .The driver supports micro stepping , enabling finer control over motor movements by allowing steps as small as 1/16 of a full step, which significantly enhances the smoothness and accuracy of the motor's motion.

3- Direction Control: The A4988 provides robust direction control, enabling the stepper motor to rotate clockwise or counterclockwise with ease. This functionality is crucial for applications that require precise directional control, such as 3D printing, CNC machines, and robotic arms .By adjusting the direction input, users can easily reverse the motor's rotation, enabling flexible design and operation in a variety of mechanical systems.

4- Step Control: The A4988 supports multiple step modes, including full-step, half-step, quarter-step, eighth-step, and sixteenth-step, offering a high degree of flexibility in controlling the speed and resolution of the motor's movement .The step control is managed through the STEP and DIR pins, allowing for fine-tuned control over the motor’s rotation and making it suitable for applications that require precise and smooth motion.

5- Protection Features: The A4988 includes several built-in protection features, such as over-temperature shutdown, over-current shutdown, and under-voltage lockout, ensuring the safety and longevity of both the driver and the motor .These protection mechanisms safeguard the system against potential damage caused by excessive heat, current spikes, or inadequate power supply, making the A4988 a reliable choice for various projects.

6- Connectivity: The A4988 is equipped with easy-to-use connection pins, which are designed to interface with microcontrollers, such as the Raspberry Pi, Arduino, or other control systems .The compact size and straightforward pin layout make the A4988 driver easy to integrate into existing circuits, facilitating quick setup and minimizing the space required on project boards.

3.5.3.2 Applications:

The A4988 Stepper Motor Driver is widely utilized in a variety of applications, including but not limited to:

1- 3D Printing: It is a core component in 3D printers, providing precise control over the movement of the print head and build platform to ensure accurate and detailed printing.

2- CNC Machines: The driver is essential in CNC systems, where it controls the precise movements of cutting tools along multiple axes, enabling the production of intricate designs and parts.

3- Robotics: In robotics, the A4988 is used to control the movements of robotic arms, wheels, and other components, allowing for precise positioning and smooth operation.

4. Automation: The driver plays a key role in various automation projects, where it controls stepper motors in conveyor belts, automated inspection systems, and other machinery requiring accurate motion control.

5. Prototyping and DIY Projects: The A4988 is popular in the DIY community for its ease of use and versatility, making it a go-to choice for hobbyists working on motorized projects, such as automated doors, camera sliders, and small-scale robotics.

The A4988 Stepper Motor Driver provides a reliable and precise solution for controlling stepper motors, making it an invaluable tool for projects requiring detailed movement control and high accuracy. Its wide range of features and protection mechanisms ensure smooth operation and long-lasting performance across a diverse array of applications

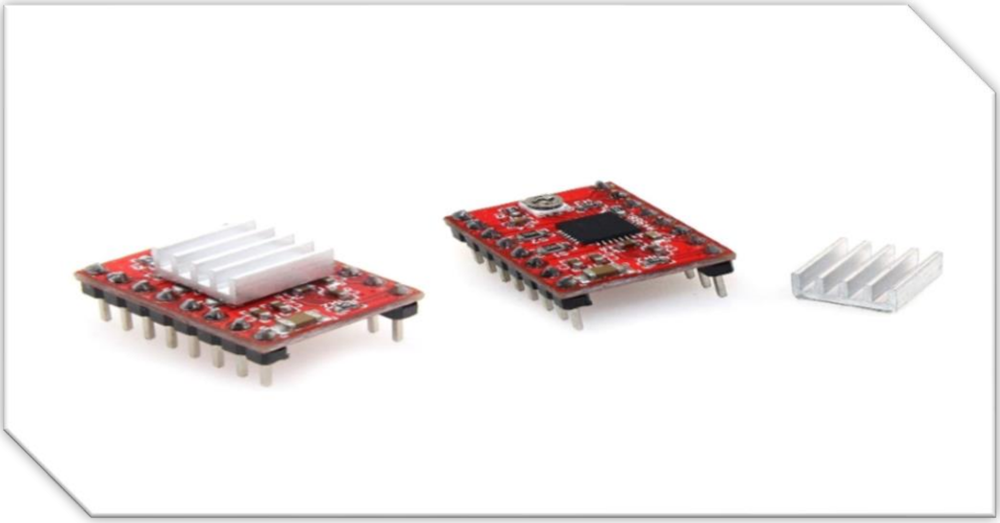

Figure 3-6 A4988 Driver

3.5.4 **The stepper motors**

The JK42HS34 -1334 Stepper Motor (**Figure 3-7**) is a device designed to convert electrical pulses into precise mechanical movements. This motor operates using stepper technology, which allows for accurate control over the position and speed of the motor's shaft. The JK42HS34 -1334 is widely used in applications that require controlled and repeatable movement.

The motor operates at a specific voltage, typically around 12V to 24V DC, depending on the application requirements. This voltage needs to be supplied through the appropriate terminals to activate the motor and produce the desired motion. It is crucial to ensure that the voltage is correctly applied to avoid any potential damage to the motor.

The stepper motor achieves its movement through a series of discrete steps, with each step representing a fixed angle of rotation. For the JK42HS34-1334, each step corresponds to 1.8 degrees of rotation, meaning it takes 200 steps to complete a full 360-degree rotation. This step resolution makes the motor ideal for applications that require precise control over rotational position.

The motor’s ability to hold its position at any given step is one of its key advantages. Unlike other types of motors that may drift when power is removed, the stepper motor maintains its position until it receives further instructions, making it particularly useful in applications like 3D printing, CNC machinery, and robotics.

In addition to the precise control offered by stepper motors, the JK42HS34-1334 is also designed to operate with high reliability and durability. It can be integrated into various systems where accurate and repeatable motion is required. This motor is often used in conjunction with stepper motor drivers, such as the A4988, which provide the necessary electrical pulses to control the motor's movement.

The JK42HS34-1334 Stepper Motor is suitable for a wide range of industrial and hobbyist applications, including CNC machines, 3D printers, robotic arms, and other devices that require precise positioning and speed control. To achieve optimal performance, it may be necessary to use additional control interfaces or circuits to adjust parameters such as speed and direction, or to implement microstepping for smoother motion. Always refer to the manufacturer's specifications and guidelines to ensure proper usage and integration of the motor into your projects.

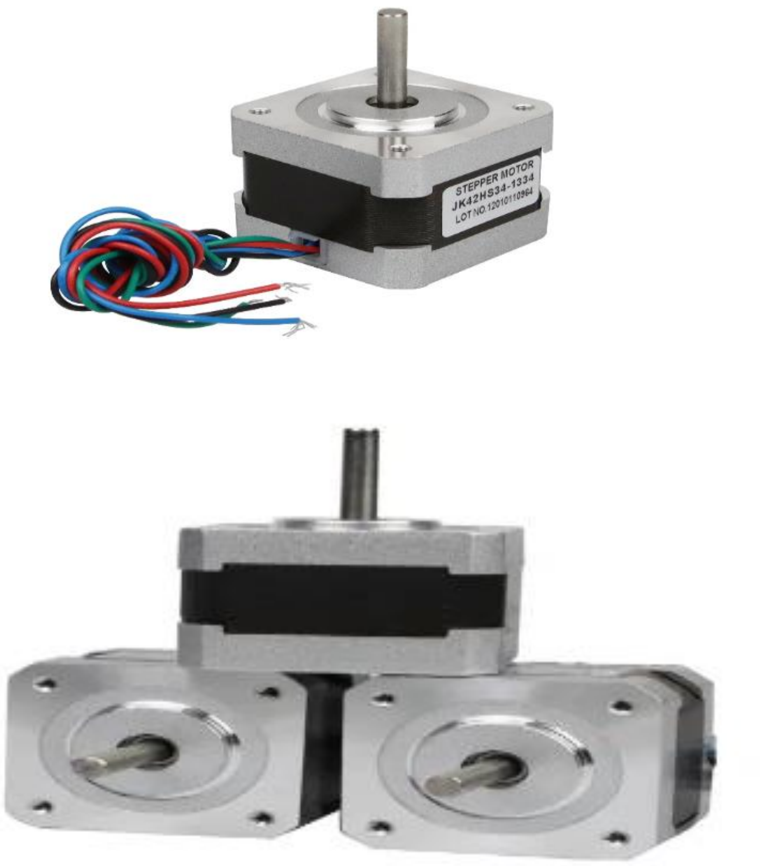

Figure 3-7 The stepper motors

3.5.5 The power supply

The Laptop Universal Adapter 100W (**Figure 3-8**)is a versatile power supply unit designed to provide a stable and adjustable power source for a wide range of electronic devices, including laptops and other equipment requiring consistent power. This adapter is particularly useful in scenarios where a reliable and flexible power source is needed, such as powering a variety of electronic projects, including your rehabilitation device.

3.5.5.1 Key Features:

1-Input Voltage Range :

The adapter is designed to operate with a wide input voltage range, typically from 100V to 240V AC. This makes it compatible with electrical outlets worldwide, allowing it to be used in different regions without the need for a voltage converter.

2-Adjustable Output Voltage:

The Laptop Universal Adapter 100W typically offers multiple output voltage settings, ranging from 12V to 24V DC. This adjustability makes it suitable for powering devices with different voltage requirements. You can select the appropriate output voltage that matches the input needs of your device.

3- Power Output :

With a maximum power output of 100 watts, this adapter is capable of providing sufficient power to a wide variety of devices, including laptops, monitors, and other peripherals. This power capacity ensures that the adapter can handle devices that draw significant current without overheating or failing

4-Multiple Connector Tips:

The adapter usually comes with a set of interchangeable connector tips, allowing it to be used with different devices that have varying power input jack sizes. This feature adds to the adapter’s versatility, making it a universal solution for multiple devices

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5- Protection Features:

The Laptop Universal Adapter 100W is typically equipped with built-in protection mechanisms, such as over-voltage protection, over-current protection, and short-circuit protection. These features help to safeguard both the adapter and the connected devices from electrical damage, ensuring safe and reliable operation.

6- Compact and Portable Design:

The adapter is designed to be compact and lightweight, making it easy to carry and store. Its portability is especially beneficial for users who need to power their devices on the go or in different locations

Figure 3-8 The power supply

3.5.6 **Screen**

The 7-inch Raspberry Pi Touchscreen Display (**Figure 3-9**)is a versatile and high-resolution screen designed to integrate seamlessly with Raspberry Pi single-board computers. This touchscreen display provides an interactive interface that enhances the functionality of Raspberry Pi projects, making it ideal for applications requiring direct user interaction, such as in embedded systems, IoT projects, and custom user interfaces.

3.5.6.1 Key Features:

1- Display Size and Resolution :The screen features a 7-inch diagonal display with a resolution of 800x480 pixels. This resolution is sufficient for displaying clear and crisp visuals, whether you are using it for text, graphics, or video playback.

2- Touchscreen Functionality :The display supports 10-point multi-touch input, allowing for a responsive and intuitive user experience. Users can interact with the Raspberry Pi system using simple touch gestures, such as tapping, swiping, and pinching, which is particularly useful for applications like kiosks, home automation systems, or custom controllers.

3- Compatibility :The 7-inch Raspberry Pi Touchscreen Display is fully compatible with most Raspberry Pi models, including Raspberry Pi 2, 3, and 4. It connects directly to the Raspberry Pi via the DSI (Display Serial Interface) port, making setup straightforward and eliminating the need for external power supplies or HDMI cables.

4- Integrated Design :The display is designed to integrate neatly with the Raspberry Pi, with mounting points that allow the Raspberry Pi to be attached directly to the back of the screen. This compact and all-in-one design is ideal for creating portable or space-constrained projects.

5- Power Supply :The screen is powered directly from the Raspberry Pi using the GPIO pins, which simplifies the setup and reduces the number of cables needed. This makes the display an efficient solution that keeps the overall project design clean and organized.

6- Versatility :The display is suitable for a wide range of applications, from simple graphical user interfaces to more complex interactive systems. It can be used to display real-time data, control interfaces, or multimedia content, making it a versatile addition to Raspberry Pi projects.

7- Durable Build :The touchscreen display is built to be durable, with a solid and robust construction that can withstand regular use. This durability makes it well-suited for both personal projects and more demanding industrial or commercial applications.

3.5.6.2 Applications:

- Graphical User Interfaces (GUIs): The touchscreen display can be used to develop and interact with custom GUIs, making it ideal for projects where the user needs to control or monitor the Raspberry Pi directly.

- Portable Projects: Its compact size and integration with the Raspberry Pi make it perfect for portable projects, such as handheld devices or mobile information systems.

- Education and Learning: The display is a popular choice for educational projects, where students can interact directly with their Raspberry Pi setups, gaining hands-on experience with programming and electronics.

- Embedded Systems: The touchscreen can be used in embedded systems where a small, responsive display is required for real-time control and feedback.

- IoT Devices: For Internet of Things (IoT) projects, the screen provides an interface to monitor and control connected devices, making it easier to manage IoT systems in real-time.

Usage Considerations :When setting up the 7-inch Raspberry Pi Touchscreen Display, it's important to ensure that the Raspberry Pi is securely attached to the back of the screen to prevent damage during use. Additionally, proper calibration of the touchscreen may be necessary for accurate touch inputs. Depending on your project, you might also need to adjust the Raspberry Pi's software settings to optimize display performance and power consumption .The 7-inch Raspberry Pi Touchscreen Display is a powerful tool that enhances the functionality of Raspberry Pi by providing an interactive and visually appealing interface. It opens up a wide range of possibilities for creating innovative and user-friendly Raspberry Pi projects.

Figure 3-9 Screen

Chapter 4 :Project Design and Implementation

4 Chapter 4 : Project Design and Implementation

4.1 Introduction

This chapter covers the details related to the design and implementation of the innovative wrist and forearm rehabilitation device we have designed to assist patients after a stroke. A comprehensive overview of the various aspects of the design and execution of this device will be presented.

First, the mechanical and electronic design of the device will be reviewed, including the actuation mechanism, ease of use, safety and security, as well as the fixation tools used. The balance between functional efficiency and user comfort will be outlined.

Subsequently, the software design and signal processing for the device will be highlighted. The algorithms utilized, sensor data processing, user interface development, as well as the main and subsidiary circuits of the system will be

Finally, the manufacturing and assembly process will be discussed, including 3D printing and the tools employed. The chapter will conclude with a discussion of the testing and integration procedures to ensure the overall system performance meets the specified requirements.

4.2 Project Design

4.2.1 Mechanical Design :

The mechanical design of the wrist and forearm rehabilitation device focuses on assisting recovery after a stroke. The device is made of aluminum and PLA material to ensure durability and lightness. It features a wooden base with anti-slip feet, a plastic hand grip, and an arm rest made from PLA. Stepper motors are used to achieve the precise movements required. The design relies on robust and reliable mechanical components to ensure maximum effectiveness in the rehabilitation process.

4.2.1.1 The Main Structure

4.2.1.1.1 The Base

The device features a sturdy wooden board (**Figure 4-1**) base designed to fully support its structure. This base is crucial for maintaining stability and preventing movement during operation. It includes anti-slip synthetic rubber feet that enhance stability further. To secure all mechanical components firmly, strong metal screws and fasteners are utilized. This ensures that the base remains stable and all parts are securely fixed in place, contributing to the overall stability and functionality of the device.

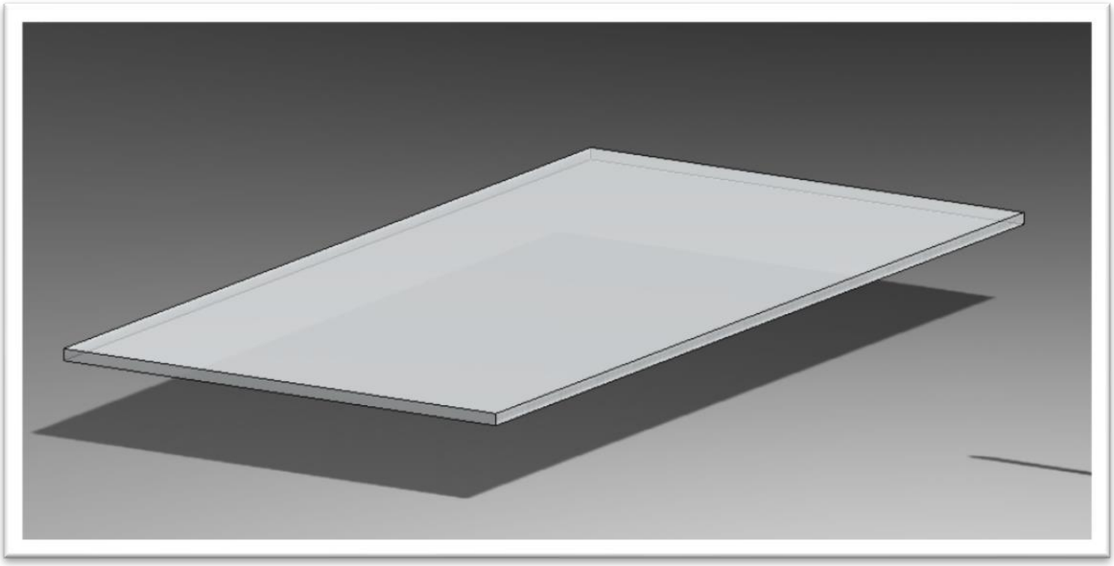


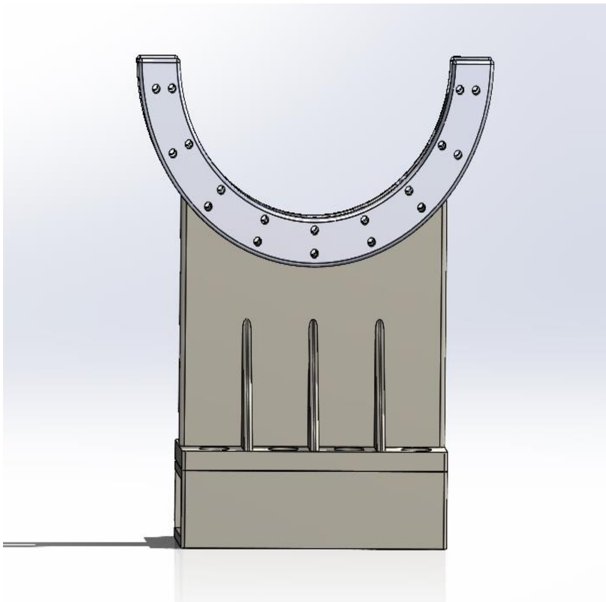
Figure 4-1wooden board

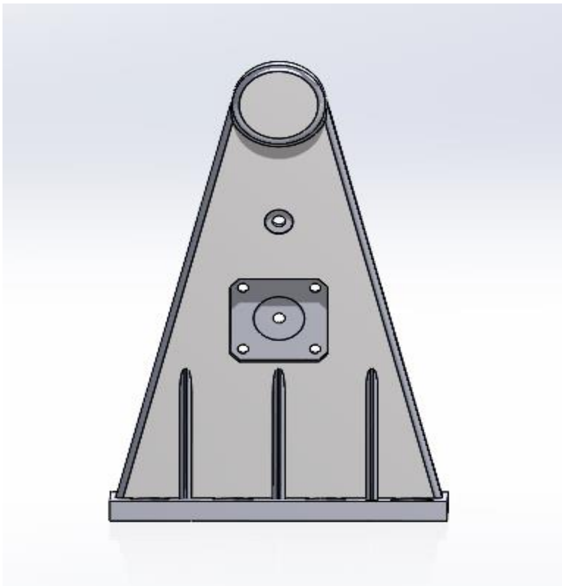
4.2.1.1.2 Holders:

The front and back holders (Figure 4-2) are meticulously designed to provide effective mechanical support for the device's moving parts. These holders form an assistive frame that maintains the stability and smooth movement of these components.

The primary function of the front (a) and back (b) holders is to support and secure the moving parts in their correct positions, allowing them to move accurately and seamlessly. These holders play a crucial role in bearing the weight of the device's moving parts, thereby reducing the stress and pressure exerted on them.

In addition to providing support, the holders ensure that the parts are firmly fixed in their proper locations and guide their movement in a controlled and directed manner. Thanks to the smooth operation of the holders, they enable natural and precise movement of the device's components, enhancing the overall efficiency and reliability





(a) **(b)**

Figure 4-2 (a) front ,(b)back holder

4.2.1.1.3 Stand

The stand was designed with wood to provide stable and comfortable support for the forearm during the use of the rehabilitation device. This component aims to secure the forearm in a fixed position, allowing the device's motors and sensors to deliver effective treatment. The design incorporates adjustability, enabling the stand to move up and down to accommodate various patient sizes, ensuring both comfort and precision in treatment. The choice of wood as the material was made to ensure durability and strength, while also facilitating easy cleaning and maintenance.

Figure 4-3 stand

4.2.1.2 Motion and Control Mechanism

4.2.1.2.1 wheels :

- The device features sophisticated wheel (Figure 4-4) that enable natural and smooth motion. The lower wheel (a) allows for bending and extending the leg with a wide range of motion up to 130 degrees, facilitating free movement of the torso and body. The lateral wheel **(b)** permits moving the leg closer or farther away by an angle up to 75 degrees, which is crucial for sideways movement and maneuvering around obstacles. The posterior wheel **(c)** provides the ability to rotate up to 150 degrees, allowing for smooth backward movement and turning

Each wheel is equipped with an advanced electric motor that precisely controls its movement. These motors respond quickly and with high precision to control commands, ensuring accurate and controlled movements. The electronic and software control system is designed in a sophisticated manner to achieve rapid and smooth responsiveness of the movements.

The wheel and motor system work in seamless integration to provide natural and fluid motion for the device. The coordination between the different wheel movements enables efficient execution of navigation and interaction tasks. Advanced software and algorithms synchronize and harmonize the wheel movements, resulting in a natural and intuitive motion of the device, closely resembling human movement.

Combining the front and rear holders with the sophisticated wheel system, the device achieves exceptional mechanical support and movement precision. The holders provide a stable frame that maintains the stability and alignment of the moving parts, while the wheels and motors enable a wide range of controlled, natural motions. This integrated design ensures the device operates smoothly and efficiently, closely mimicking the nuances of human movement.

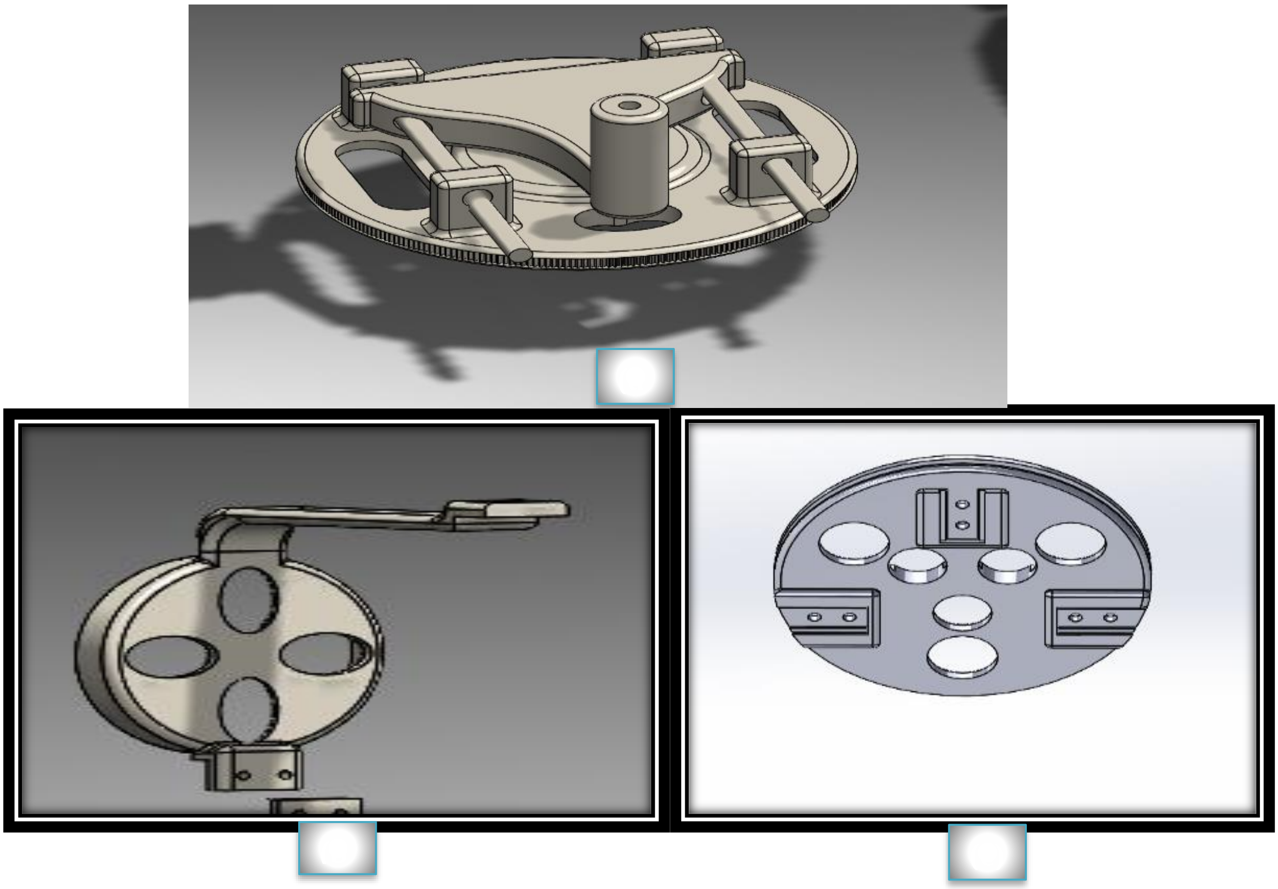


Figure 4-4 (a) lower , (b) lateral,(c)posterior wheels

4.2.1.2.2 front wheel

- The front wheel (Figure 4-5)has an opening leading to the handgrip area where the user interacts with the device. This wheel is fixed to the front frame using bearings, which helps reduce friction during operation.

-The front wheel is connected to the rear joint and side joints through aluminum links. These connections help support the various moving parts of the device and provide overall stability.

Strong metal screws are used to ensure the secure attachment of the front wheel to the rest of the frame.

- Bearings(*Figure 4-6*) are strategically placed beneath the front wheel to reduce friction and enable smooth, unobstructed motion. These bearings are essential to allow the wheel to rotate freely with minimal resistance.

-There are front and rear supports(*Figure 4-7*) to reinforce and stabilize the front wheel. These supports help maintain the proper alignment of the wheel and prevent any unwanted movement or vibrations.

-The front wheel is a critical component that plays a central role in the overall function and performance of the device:

- The opening leading to the handgrip area, where the user interacts with the device, is integrated into the design of the front wheel. This arrangement allows for natural, intuitive control.

- The aluminum links connecting the front wheel to the rear joint and side joints help distribute the forces and loads experienced by the moving parts. This aids in enhancing the stability and responsiveness of the device's motion.

- The use of strong metal fasteners ensures the secure and reliable attachment of the front wheel, preventing any looseness or accidental separation during operation.

- The bearings beneath the front wheel are necessary to enable smooth, low-friction rotation. This allows for easy maneuverability and navigation.

- The front and rear support structures anchor the front wheel, maintaining its proper alignment and preventing any unwanted vibrations or instability that could affect the device's performance.

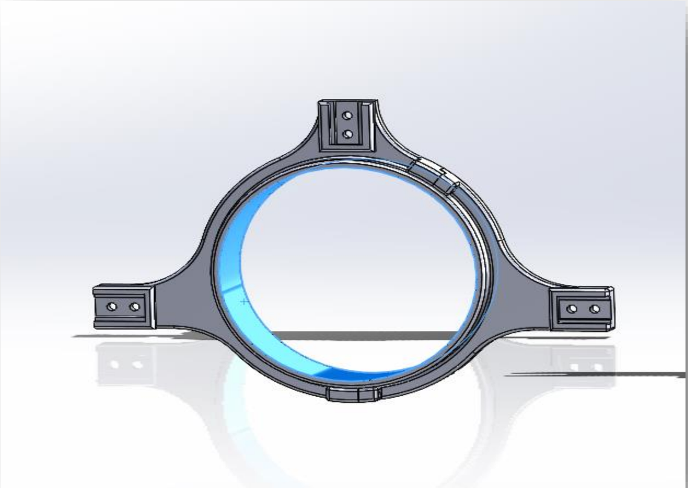


Figure 4-5 4.front wheel

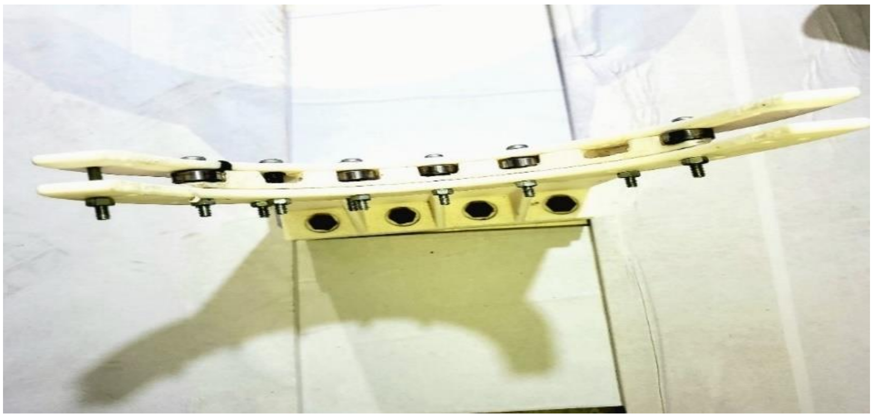


Figure 4-6 Bearings

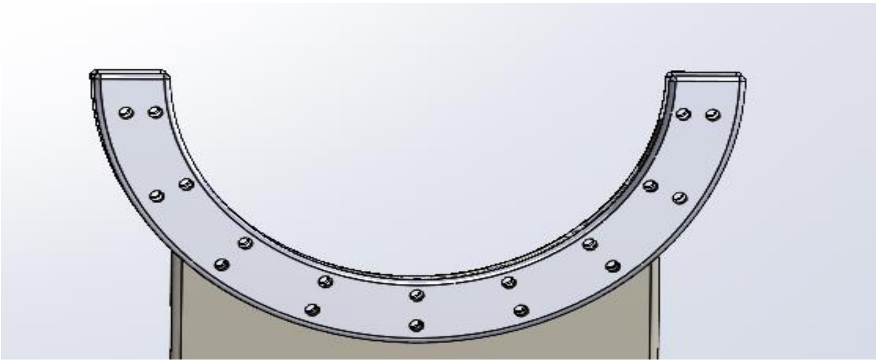


Figure 4-7 front and rear supports

4.2.1.2.3 Control Unit:

Raspberry Pi (Figure 4-8)is a small yet powerful computer that provides the flexibility and capability needed for precise control of the motors and other devices.

- The Raspberry Pi unit will execute the algorithms and programs required to control the movements of the arm and wrist through the motors.
- The developed software will use user inputs and motion analysis to generate the appropriate control signals for the motors.

- Raspberry Pi will provide sufficient computational capabilities to process data and control the devices quickly and efficiently.

- Raspberry Pi will be connected to the rest of the electronic components like motors and sensors through the input/output interfaces.

In addition to the Raspberry Pi, an Arduino Uno is also integrated into the system to assist in specific control tasks.

Arduino Uno is a microcontroller that is well-suited for handling real-time, low-level control tasks.

- The Raspberry Pi will send high-level commands to the Arduino Uno, which will then manage precise motor control, sensor data acquisition, and other tasks requiring rapid, real-time response.

- The Arduino Uno will act as an intermediary, receiving instructions from the Raspberry Pi and then directing the motor drivers and other hardware components accordingly.

- This division of labor between the Raspberry Pi and Arduino Uno will allow for more efficient system performance, ensuring that complex calculations and real-time control tasks are handled effectively.

4.2.1.2.4 Motors:

- High-precision Stepper Motors (*Figure* **4-9**)are used in this design.

- One motor (a) is mounted on the rear holder and controls the rotation of the arm.

- Another motor(b) is mounted on the lower arm link and controls the flexion movement of the wrist.

- A third motor(c) is mounted on the side arm link and controls the adduction movement of the wrist.

- These precise motors provide the required control for the fine movements of the prosthetic limbs.

- The motion from the motors is transferred to the moving parts through appropriate gears and transmission systems.

- The motors are firmly mounted on the frame using specialized screws and fasteners.

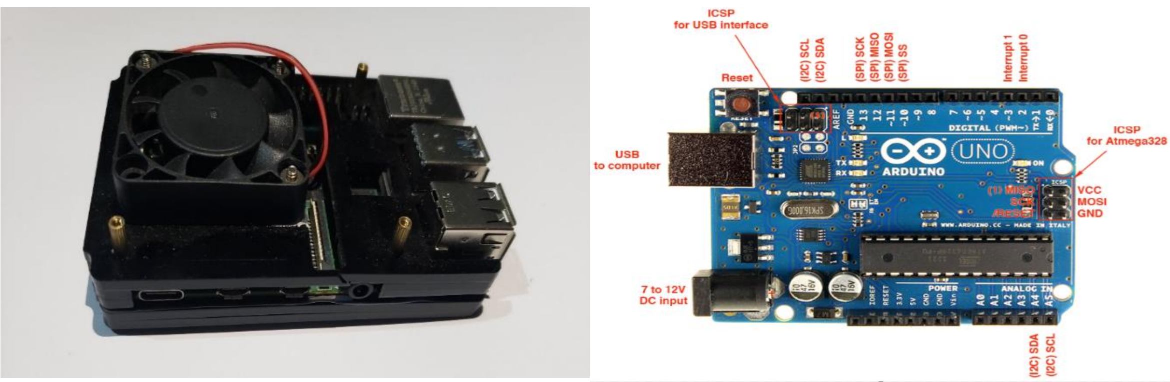


Figure 4-8 Control Unit

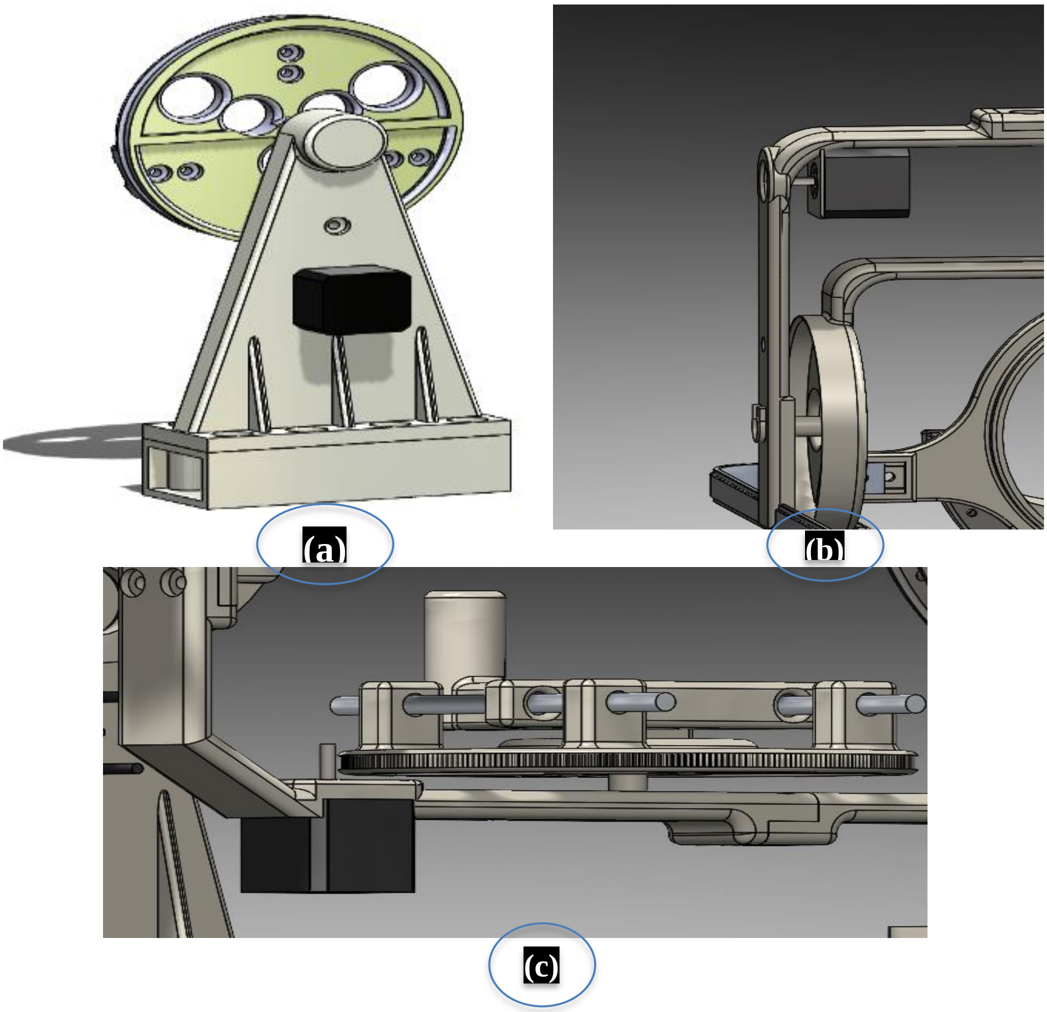


Figure 4-9 three Motors

4.2.1.2.5 Links

Aluminum and PLA links are used in the device to achieve the required mechanical integration to facilitate movement and connect the separate parts with each other. Aluminum links(*Figure 4-11*), known for their strength and lightweight, connect the rear joint to
the side joint all the way to the front wheel,
ensuring smooth and efficient movement of the different parts of the device. Thanks to these links, the device can move smoothly and efficiently, as aluminum provides the necessary strength to support repeated movements and mechanical stress.

On the other hand, PLA links(*Figure 4-10),* which are a biodegradable plastic material used in 3D printing, are used to connect some of the other parts in the device. These links connect the side joint to the lower joint and allow the mounting of two electric motors on them. This arrangement helps in the distribution of weight and improves the overall balance of the device. PLA links provide design flexibility, allowing for easy and quick modifications in case the design needs to be adjusted or improved.

To mount the motors on the PLA links, the electric motors are attached in a way that ensures their stability and efficient performance. Part of these links is connected to the aluminum links to ensure the strength and durability of the entire device. This integration between PLA and aluminum links contributes to providing a strong and integrated structure, helping to distribute loads evenly and improve the overall performance of the device.

By using these diverse links, a strong and effective mechanical design for the device has been achieved, ensuring its ability to perform the required movements for rehabilitation efficiently and effectively.

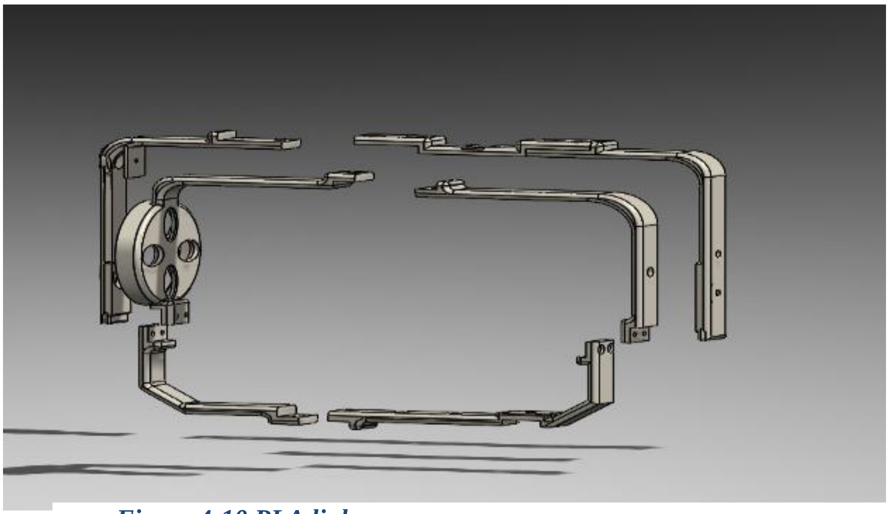


Figure 4-10 PLA links

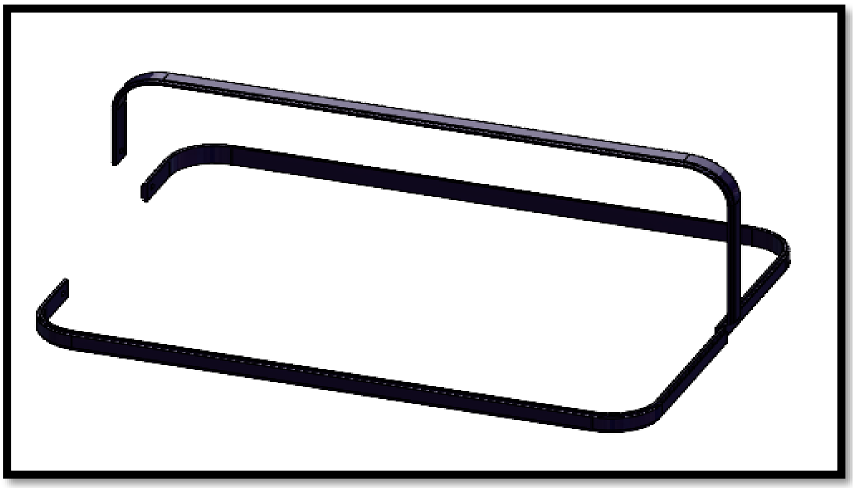


Figure 4-11 Aluminum links

4.2.2 The material used

The design features a base made from a sturdy wooden board, chosen for its affordability and strong weight-bearing capabilities. This provides a stable foundation for the entire structure.

Holders and wheels are crafted from Polyactic Acid (PLA), a biodegradable thermoplastic known for its ease of use in 3D printing, good mechanical properties, and environmental benefits. PLA ensures lightweight, durable components capable of withstanding operational stresses.

Links connecting the wheels are made from two materials: some from lightweight and corrosion-resistant Aluminum, providing necessary rigidity and secure connections, and others from PLA, maintaining consistency with the holders and wheels.

The materials chosen—PLA for lightweight durability and ease of manufacturing, and Aluminum for strength and stability—combine effectively to ensure a balanced design that meets both structural and functional requirements.

4.2.3 Safety and Security Mechanisms:

To prioritize the safety and security(Figure 4-12) of patients using the device, a comprehensive set of safety features was implemented. A key aspect of this is the integration of 6 limit switches strategically placed along the device's range of motion.
The limit switches are positioned at both the beginning and end of the device's allowed range of motion for the motor. This ensures that the motor's movement is confined within the predetermined safe boundaries. If the motor attempts to exceed these limits, the corresponding limit switch will be triggered, immediately sending a signal to stop the motor's operation.
The placement of these 6 limit switches creates a fail-safe system that prevents the device from moving beyond its safe operating range. This provides an extra layer of protection against unintended or excessive motion that could potentially harm the patient during the rehabilitation process.

When the motor reaches the edge of its allowed range and triggers a limit switch, the device will instantly halt the motion, ensuring the patient's wrist and forearm are not subjected to unsafe levels of movement or force. This rapid response time is crucial in maintaining the patient's safety and well-being throughout the rehabilitation session.

By incorporating these 6 limit switches, the device's safety and security protocols are greatly enhanced. The ability to automatically stop the motor's movement when the predetermined limits are reached significantly reduces the risk of injury to the patient, giving them peace of mind and allowing them to focus on their recovery.

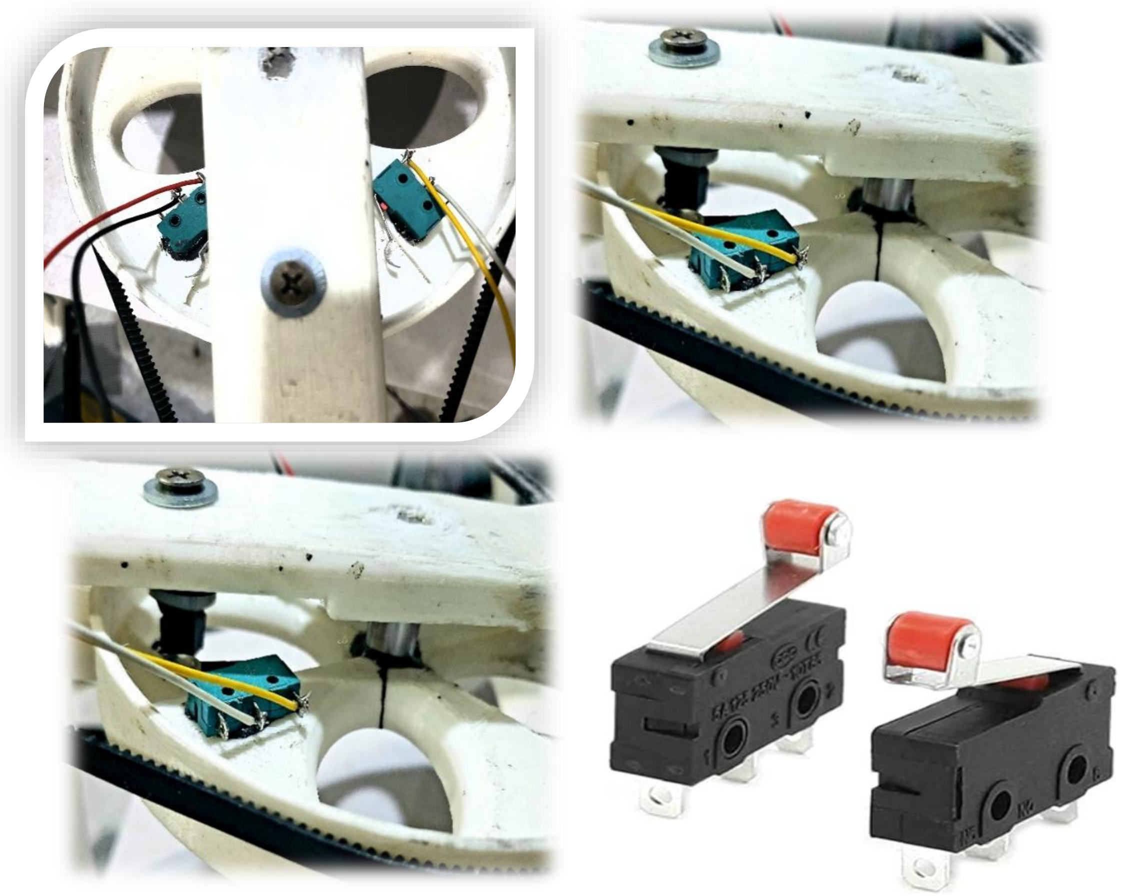


Figure 4-12 Safety and Security Mechanisms

4.2.4 The Electronic Design

4.2.4.1 Introduction

This section covers the electronic design of the device used for forearm and wrist rehabilitation post-stroke. The design relies on a Raspberry Pi controller and uses Stepper Motors along with other components such as sensors and transistors to achieve the required movements and measure the level of recovery.

4.2.4.2 Main Components

1. Raspberry Pi Controller:

- The Raspberry Pi is used to control all components of the device. It provides the capability to program complex operations and analyze data from the sensors.

2. Stepper Motors:

- Stepper motors are used to achieve the precise movements needed for rehabilitation. These motors are controlled using the A4988 motor driver connected to the Raspberry Pi. The stepper motors offer high precision in movement control, allowing the motion to be divided into very small steps, thus enabling smooth and accurate control.

.4. Electronic Circuits:

- The electronic circuits include basic components such as resistors, capacitors transistors, and microcontrollers. These circuits enable the control of motor operation and the reception of measurement signals.

4.2.4.3 Electronic Circuit Design

1. Motor & Sensor & A4988 Motor Driver & Limit Switch & Arduino uno Connection Diagram to Raspberry Pi:

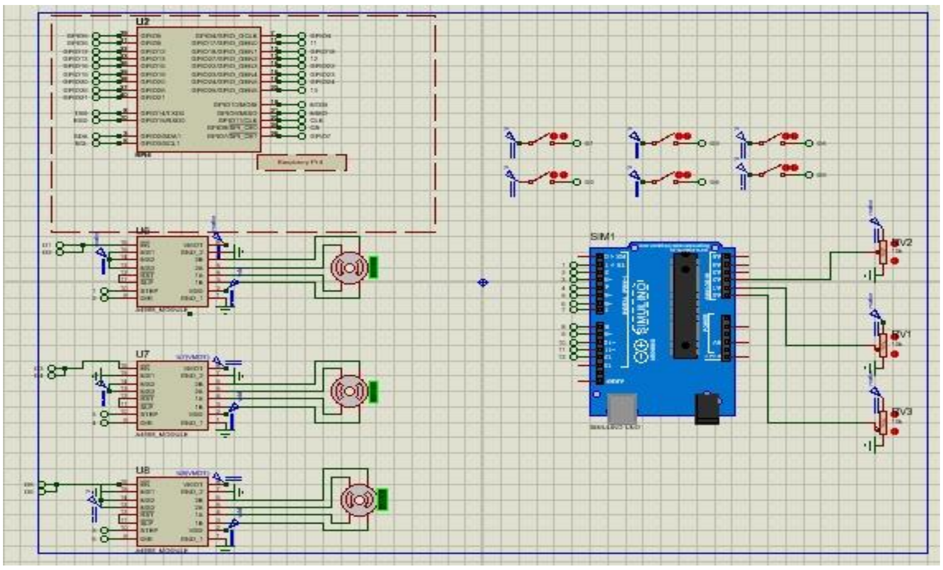


Figure 4-13 Genaral electronics circute

- Basic Connections:

- Connect the stepper motors to the A4988 motor driver.

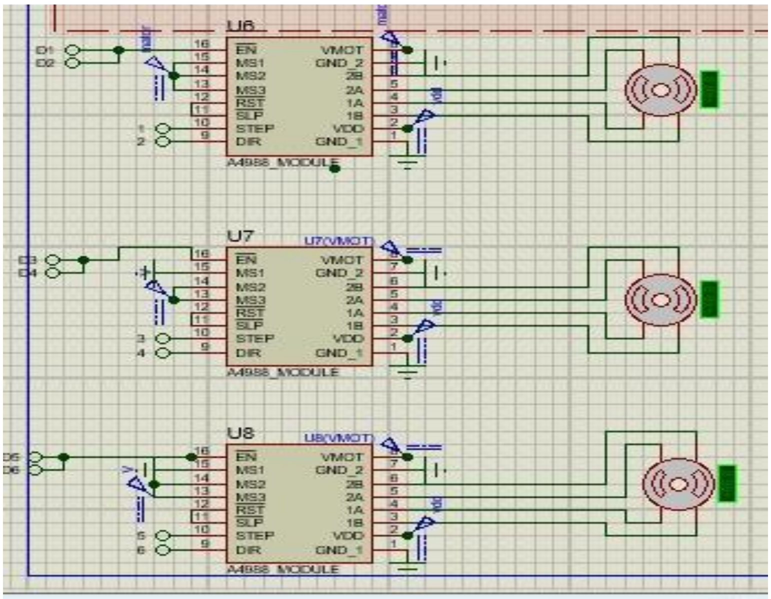


Figure 4-14 motors connect to A4988

- Connect the sensors to the input ports on the Arduino uno.

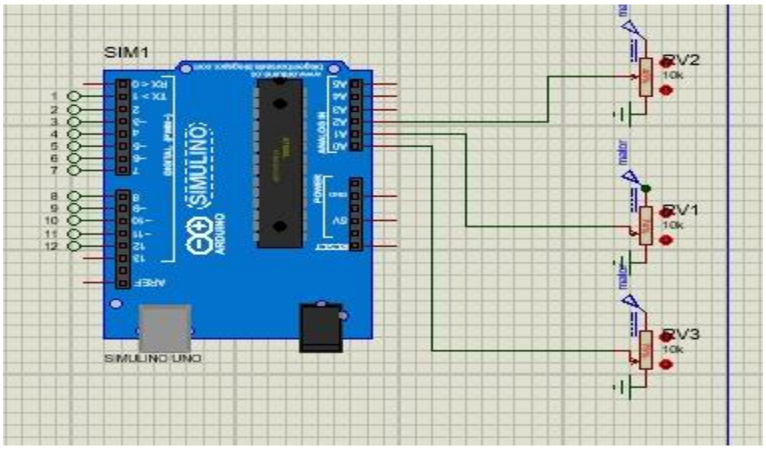


Figure 4-15 connect sensors to Arduino uno

2. Motor Control Circuit:

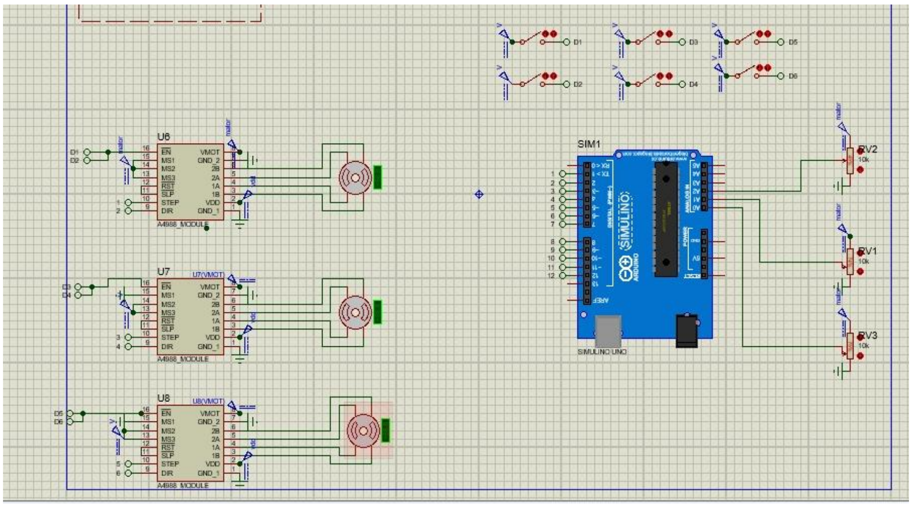


Figure 4-16 Motor Control Circuit

- The A4988 is an integrated digital stepper motor driver that generates the control pulses needed to move the stepper motor accurately. It allows control over the speed and precision of motor movement by amplifying the electric current to the motor coils. The A4988 provides control over
the number of movement steps and the direction of motor rotation, supporting various operating modes such as Full Step, Half Step, and Micro-Stepping.

- In the design, the A4988 is connected to the stepper motors to provide precise control of the movement. Control signals are sent from the Raspberry Pi to the A4988, which converts these signals into pulses that move the stepper motors according to the required settings.

Assembly and Testing of Circuits

- Component Assembly:
  - All electronic components were assembled according to the drawn schematics. The wiring was checked for correctness, and the components were securely fastened.
- Circuit Testing:
  - The circuits were tested individually to ensure the integrity of each component. The motors were run to check their response to control signals, and the sensors were tested for accurate readings during movement.

Conclusion

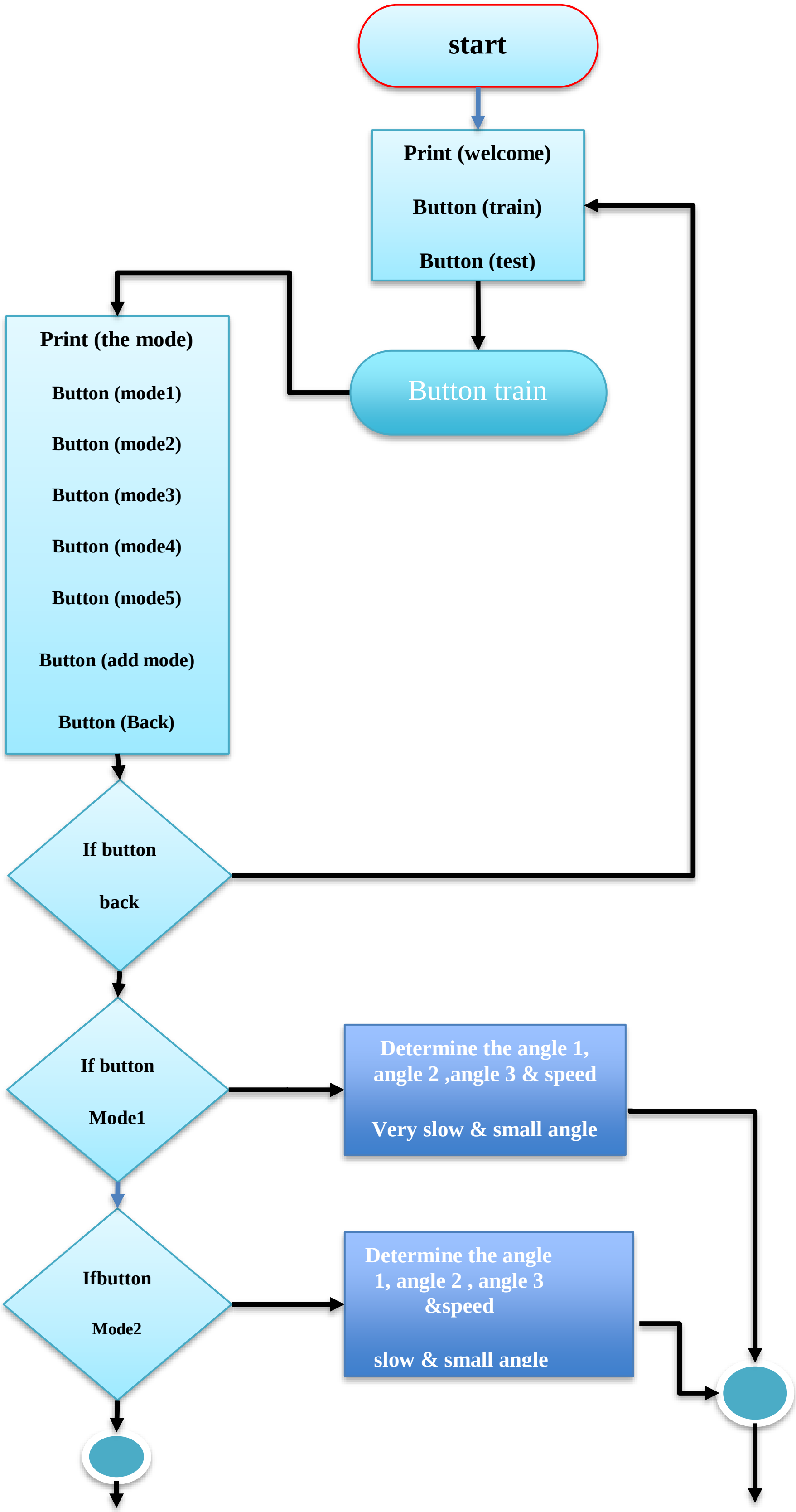
The electronic design of the forearm and wrist rehabilitation device ensures the efficient and precise execution of the required tasks. The Raspberry Pi is used to control all operations, allowing for future expansion and development. Additionally, the electronic circuits were carefully designed to meet technical requirements and ensure the device's sustainable performance.

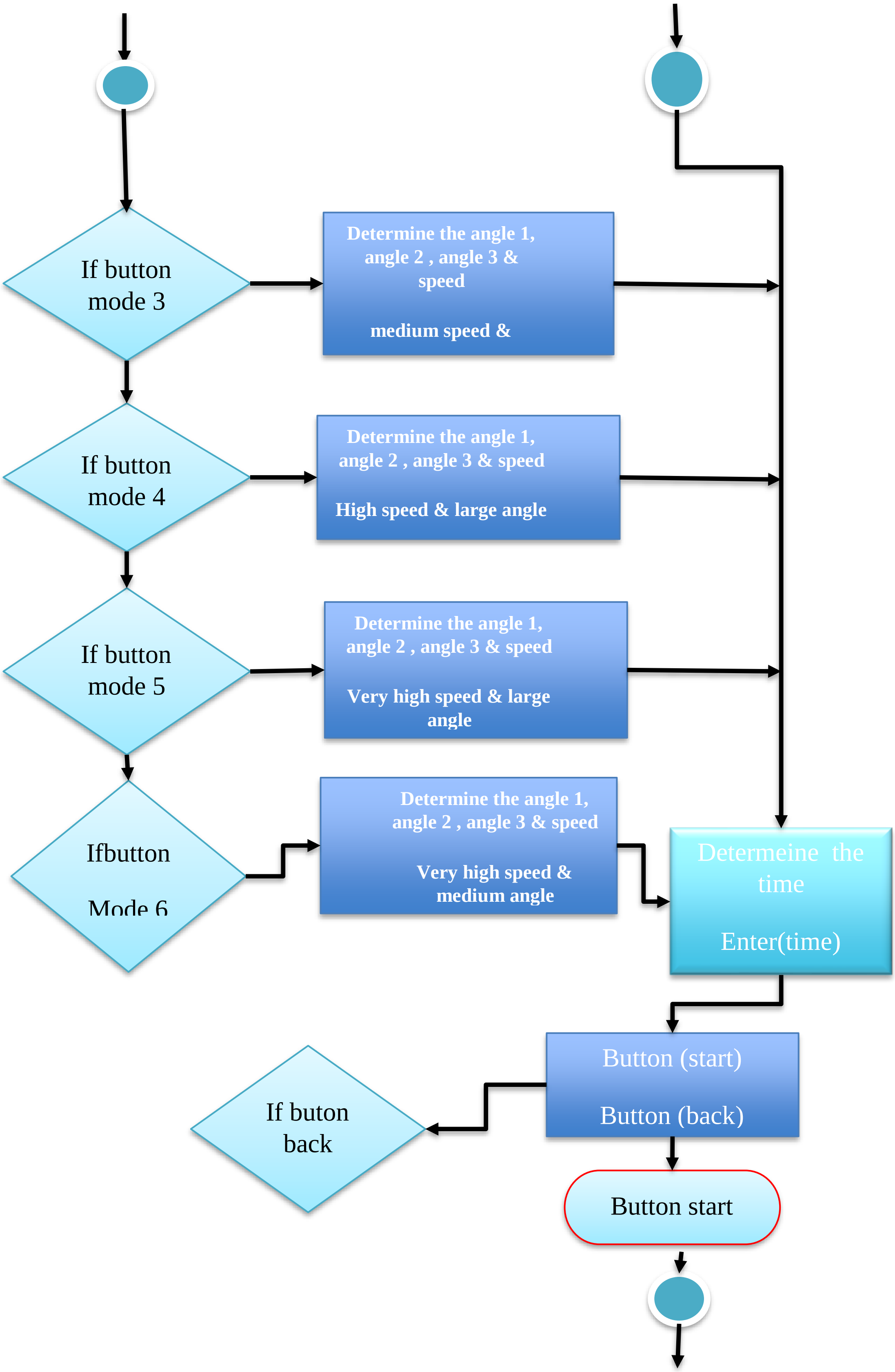
4.2.5 Software Design

4.2.5.1 Introduction

This section provides a detailed explanation of the software design for the forearm and wrist rehabilitation device used after a stroke. Python was chosen as the programming language to code the necessary functions for controlling the device and analyzing data from the sensors. The software design includes a user interface that allows both the patient and the therapist to control the device and effectively track the progress of the therapy.

4.2.5.2 Flow diagrams





If button mode 3
Determine the angle 1, angle 2 , angle 3 & speed
medium speed &
If button mode 4
Determine the angle 1, angle 2 , angle 3 & speed
High speed & large angle
If button mode 5
Determine the angle 1, angle 2 , angle 3 & speed
Very high speed & large angle
Ifbutton Mode 6
Determine the angle 1, angle 2 , angle 3 & speed
Very high speed & medium angle
Determeine the time
Enter(time)
Button (start)
Button (back)
If buton back
Button start

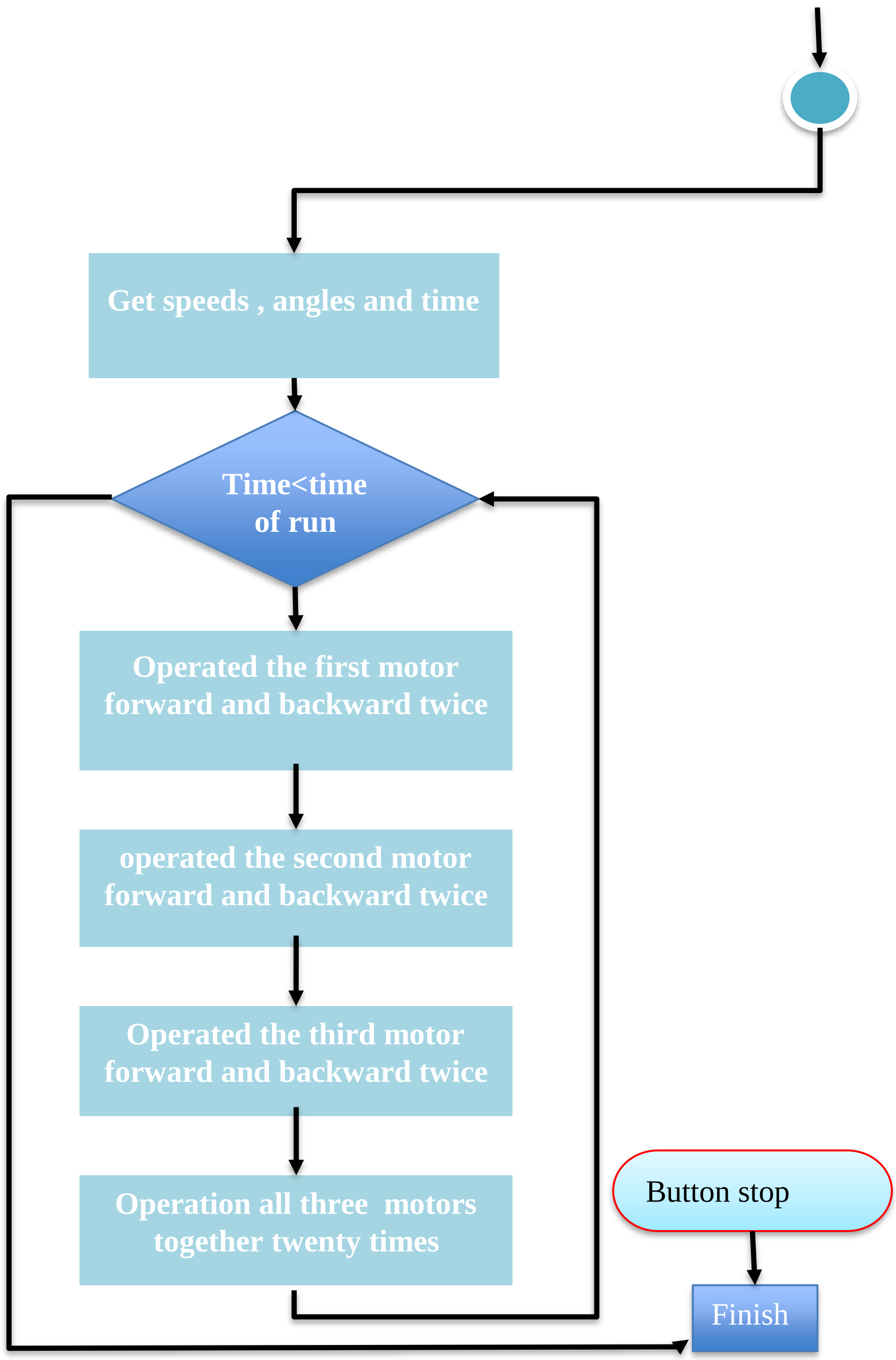


Figure 4-17 Flow diagrams of software Design

4.2.5.3 Main Components of the Software Design

4.2.5.3.1 Raspberry Pi Controller

The Raspberry Pi (**Figure 4-18**) model used is the 2GB , 64-bit version running the Raspberry Pi OS. The software was developed using Python, which offers powerful libraries and tools for efficient hardware control and data processing.

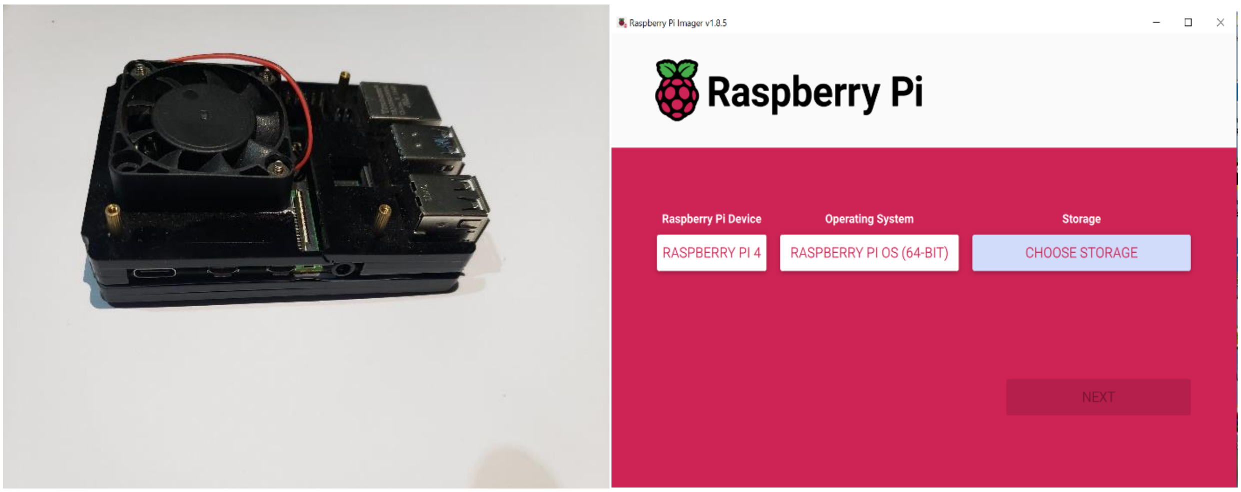


Figure 4-18 Raspberry Pi Controller

Motor Control Algorithms :

The program includes advanced algorithms for controlling stepper motors, managing sensor data, and coordinating movements with high precision. These algorithms calculate the number of steps and direction required for each motor based on input commands and the current position. Additionally, they manage motor acceleration and deceleration to ensure smooth and consistent movement, reducing mechanical stress on the device and enhancing the accuracy of therapeutic exercises.

Libraries and Tools Used:

- RPi GPIO : This library is essential for low-level hardware control, allowing precise signals to be sent to the motors to control their movement.
- Tkinter : Chosen for its ease of use in creating simple and effective user interfaces, providing a straightforward way to interact with the device without needing complex or web-based frameworks.
- Time and Math Two crucial libraries for timing and synchronization. The Time library controls the timing of the pulses that determine motor speed, while the Math library is used to synchronize motor movements with mathematical functions such as sine and cosine, ensuring the motors operate in harmony and accurately, which is vital for the required synchronized movements in therapeutic exercises.

4.2.5.3.2 Motor Control

Motor control is a crucial aspect of the software design for the forearm and wrist rehabilitation device. The movement of stepper motors, responsible for executing precise therapeutic motions, is managed by sending electrical pulses to **A4988** driver modules. Specific **GPIO** pins on the **Raspberry Pi** are assigned to direct these pulses, with pins (17, 27, 22) controlling the

steps of the motors, and pins (15, 18, 25) determining the direction of each motor's rotation. This setup allows precise control of each motor individually.

To adjust the speed of the motors, **the Time library** (***Figure 4-20***) in Python is used to regulate the timing of the pulses. For example, increasing the pulse frequency results in higher motor speeds. Additionally, this library allows setting the duration of therapy sessions, enabling the device to operate for a specified time before stopping automatically.

Synchronization between the motors is essential to ensure that all motors work in harmony and perform the required movements accurately. This synchronization is achieved using the **Math** library, applying mathematical functions such as **(Sin and Cos (Figure 4-19))** to the motor movements. This approach ensures smooth and coordinated motor performance, reduces mechanical stress on the device, and enhances the effectiveness of the therapeutic exercises.

```
while angle <= 2 * math.pi:
    x =  int(step1 * math.sin(angle) )
    y = int(step2 * math.sin(angle) )
    z = int(step3 * math.sin(angle) )
    xn = x - xp
    xp = x
    yn = y - yp
    yp = y
    zn = z - zp
    zp = z
    GPIO.output(dir_pins[0], GPIO.HIGH if xn > 0 else GPIO.LOW )
    GPIO.output(dir_pins[1], GPIO.HIGH if yn >= 0 else GPIO.LOW )
    GPIO.output(dir_pins[2], GPIO.HIGH if zn >= 0 else GPIO.LOW )
    print (x ,'    ',xp,'        ' , xn)
    motion_of_ellipse( xn , yn , zn , speed)
    xp = x
    angle += 2 * math.pi / steps_per_revolution
```

Figure 4-19 (Sin and Cos)

```
def det_time(speedd , angle11 , angle22 , angle33 ):
    global tti
    t = Tk()
    ttt = IntVar()
    t.title("Time")
    t.geometry(f"{w}x{h}+0+0")
    t.columnconfigure(0 , weight=1)
    tlable = Label (t ,text="Enter the run time" , padx=15 ,font="20" )
    tlable.pack( padx=10 , pady=10)
    tti = Entry(t , textvariable = ttt)
    tti.pack(padx=10 , pady=10)
    tnext = Button (t , text="Run", padx=10 , pady=10 , font="25" , command = train)
    tnext.pack(side="bottom" ,  padx=10 , pady=10)
    t.mainloop()
    tim = ttt.get()

    train(speedd , angle11 , angle22 , angle33 , tim)
```

Figure 4-20 Cod of time

4.2.5.3.3 Motor Programming:

Individual Motor Control : We started by programming the system to control each motor individually. This was done by calling a specific function for each motor that causes the motor to perform two separate movements. This step was necessary to ensure that each motor operates correctly and independently before coordinating the movements of the motors together.

```python
def move_motor(step_pin, dir_pin, steps, direction , speed):
    GPIO.output(dir_pin, direction)
    for i in range(steps):
        GPIO.output(step_pin, GPIO.HIGH)
        time.sleep(1 /speed)  # Short delay between steps
        GPIO.output(step_pin, GPIO.LOW)
        time.sleep(1 / speed)
```

Figure 4-21 move motor single

```python
for i in range(2):
    move_motor(step_pins[0] , dir_pins[0] , step1 , 1 , speed)
    move_motor(step_pins[0] , dir_pins[0] , step1 , 0 , speed)
    move_motor(step_pins[0] , dir_pins[0] , step1 , 0 , speed )
    move_motor(step_pins[0] , dir_pins[0] , step1 , 1 , speed )
for i in range(2):
    move_motor(step_pins[1] , dir_pins[1] , step2 , 1 , speed)
    move_motor(step_pins[1] , dir_pins[1] , step2 , 0 , speed)
    move_motor(step_pins[1] , dir_pins[1] , step2 , 0 , speed )
    move_motor(step_pins[1] , dir_pins[1] , step2 , 1 , speed )
for i in range(2):
    move_motor(step_pins[2] , dir_pins[2] , step3 , 1 , speed)
    move_motor(step_pins[2] , dir_pins[2] , step3 , 0 , speed)
    move_motor(step_pins[2] , dir_pins[2] , step3 , 0 , speed )
    move_motor(step_pins[2] , dir_pins[2] , step3 , 1 , speed )
```

Figure 4-22 call move motor single

Coordinating Motor Movements: After verifying the performance of each motor individually, we moved on to the next stage, which involved coordinating the movements of all the motors together. We used mathematical functions like Sin and Cos from the Math library to achieve this coordination. These functions were used to calculate the movement of the motors so that they all work in harmony and with precision, ensuring

```python
def motion_of_ellipse( x , y , z , speed ):
    Xx = int(abs( x ))
    Yy = int(abs( y ))
    Zz = int(abs( z ))
    while Xx > 0 or Yy > 0 or Zz > 0 :
        if Xx > 0 :
            GPIO.output(step_pins[0], GPIO.HIGH)
        if Yy > 0 :
            GPIO.output(step_pins[1], GPIO.HIGH)
        if Zz > 0 :
            GPIO.output(step_pins[2], GPIO.HIGH)
        time.sleep( speed )
        GPIO.output(step_pins[0], GPIO.LOW)
        GPIO.output(step_pins[1], GPIO.LOW)
        GPIO.output(step_pins[2], GPIO.LOW)
        time.sleep( speed )
        Xx -= 1
        Yy -= 1
        Zz -= 1
```

Figure 4-23 move all motors

```python
for i in range(20):
    steps_per_revolution = 200  # Number of steps per full revolution
    angle = 0
    x=0
    y=0
    z=0
    while angle <= 2 * math.pi:
        x =  int(step1 * math.sin(angle) )
        y = int(step2 * math.sin(angle) )
        z = int(step3 * math.sin(angle) )
        xn = x - xp
        xp = x
        yn = y - yp
        yp = y
        zn = z - zp
        zp = z
        GPIO.output(dir_pins[0], GPIO.HIGH if xn > 0 else GPIO.LOW )
        GPIO.output(dir_pins[1], GPIO.HIGH if yn >= 0 else GPIO.LOW )
        GPIO.output(dir_pins[2], GPIO.HIGH if zn >= 0 else GPIO.LOW )
        print (x ,'    ',xp,'        ' , xn)
        motion_of_ellipse( xn , yn , zn , speed)
        xp = x
        angle += 2 * math.pi / steps_per_revolution
    if i == 20 :
        xt = 0 - x
        yt = 0 - y
        zt = 0 - z
        GPIO.output(dir_pins[0], GPIO.HIGH if xt > 0 else GPIO.LOW )
        GPIO.output(dir_pins[1], GPIO.HIGH if yt >= 0 else GPIO.LOW )
        GPIO.output(dir_pins[2], GPIO.HIGH if zt >= 0 else GPIO.LOW )
        print (x ,'    ',xp,'        ' , xn)
        motion_of_ellipse( xt , yt , zt , speed)
```

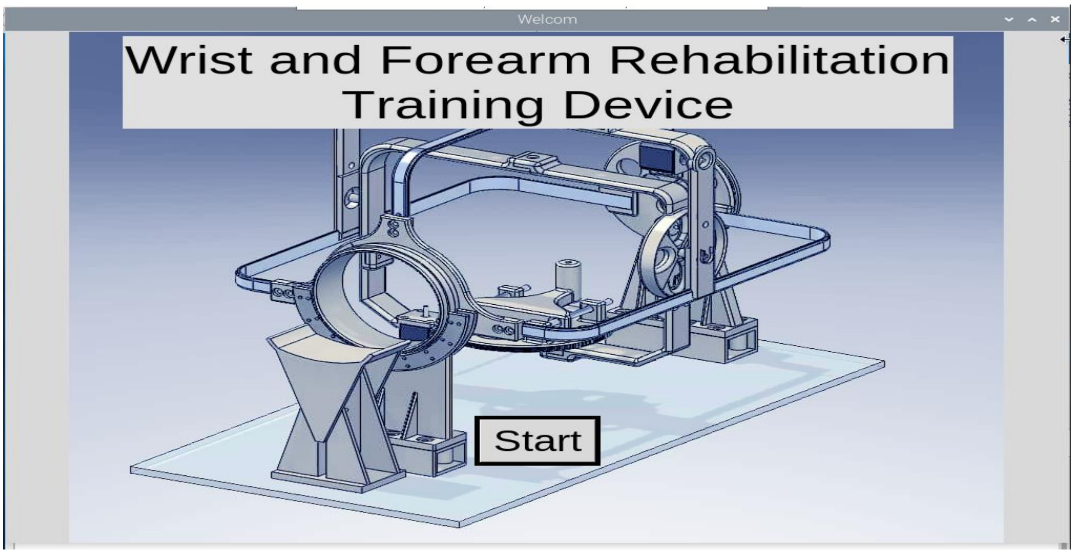
Figure 4-24 call move all motors

4.2.5.3.4 User Interface

The user interface was designed using the Tkinter library in Python, which is used to create graphical user interfaces on the desktop. This interface allows users to interact with the device in an intuitive and user-friendly way.

4.2.5.3.4.1 Main features:

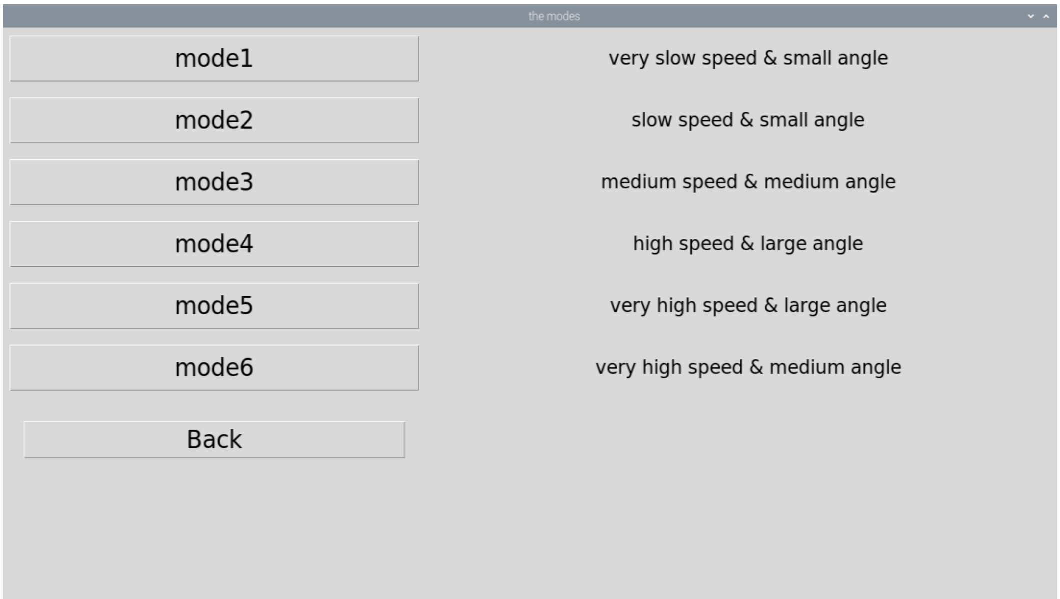
Welcome Screen : Upon starting the program, a welcome screen appears, allowing the user to select the device's usage mode, either for training or testing .This choice determines how the device is set up and its functions, making it easier for the user to access the appropriate mode for their needs .




```
def main_veiw() :
    vwelcom == False
    global h
    global w
    global main
    main = Tk()
    wn = main.winfo_screenwidth()
    hn = main.winfo_screenheight()
    w =int( wn/2)
    h = int(hn/2)
    main.geometry(f"{w}x{h}+0+0")
    main.title("Welcom")
    select_start = Button(main, text="train", command=  you_select.ytrain ,padx=10 ,font="30")
    select_start.pack(pady=30)
    select_startt = Button(main, text="test", command= you_select.ytest ,font="30")
    select_startt.pack()
    main.mainloop()
```

Figure 4-25 Welcome Screen

Settings Control: After selecting the usage mode, multiple interfaces appear with control tools for adjusting the device settings .These settings include choosing the operating mode (such as basic or advanced), specifying exercise duration, and adjusting other parameters like motor speed and angles.




```
def modes() :
    vmodes = False
    global mode
    mode = Tk()
    mode.geometry(f"{w}x{h}+0+0")
    mode.columnconfigure(0 , weight=1)
    mode.columnconfigure(1 , weight=1)
    mode.title("          the modes")

    mode1 = Button(mode , text="mode1", padx=10 , pady=10 , font="25" , command=you_select.ymodel1_time)
    mode1.grid(row=0 , column=0 ,sticky="we", padx=10 , pady=10 )

    mode1_text= Label(mode, text="very slow speed & small angle" , padx=15 ,font="20")
    mode1_text.grid(row=0 , column=1 , padx=10 , pady=10 ,sticky="we")

    mode2 = Button(mode , text="mode2", padx=10 , pady=10 , font="25" , command=you_select.ymodel2_time)
    mode2.grid(row=1 , column=0 , padx=10 , pady=10 ,sticky="we")
    mode2_text= Label(mode, text="slow speed & small angle" , padx=15 ,font="20")
    mode2_text.grid(row=1 , column=1 , padx=10 , pady=10 ,sticky="we")

    mode3 = Button(mode , text="mode3", padx=10 , pady=10 , font="25" , command=you_select.ymodel3_time)
    mode3.grid(row=2 , column=0 , padx=10 , pady=10 ,sticky="we")
    mode3_text= Label(mode, text="medium speed & medium angle" , padx=15 ,font="20")
    mode3_text.grid(row=2 , column=1 , padx=10 , pady=10 ,sticky="we")

    mode4 = Button(mode , text="mode4", padx=10 , pady=10 , font="25" , command=you_select.ymodel4_time)
    mode4.grid(row=3 , column=0, padx=10 , pady=10 ,sticky="we")
    mode4_text= Label(mode, text="high speed & large angle" , padx=15 ,font="20")
    mode4_text.grid(row=3 , column=1 , padx=10 , pady=10 ,sticky="we")

    mode5 = Button(mode , text="mode5", padx=10 , pady=10 , font="25" , command=you_select.ymodel5_time)
    mode5.grid(row=4 , column=0 , padx=10 , pady=10 ,sticky="we")
    mode5_text= Label(mode, text="very high speed & large angle" , padx=15 ,font="20")
    mode5_text.grid(row=4 , column=1 , padx=10 , pady=10 ,sticky="we")

    mode6 = Button(mode , text="Enter mode", padx=10 , pady=10 , font="25" , command=you_select.ymodel6_time)
    mode6.grid(row=5 , column=0 , padx=10 , pady=10 ,sticky="we")
    mode6_text = Label(mode, text="select" , padx=15 ,font="20")
    mode6_text.grid(row=5 , column=1 , padx=10 , pady=10 ,sticky="we")

    back = Button(mode , text="Back" , command=you_select.yback)
    back.grid(row=6 , padx=30 , pady=30 ,sticky="we")

    mode.mainloop()
```

Figure 4-26 Settings Control


```python
def det_time(speedd , angle11 , angle22 , angle33 ):
    global tti
    t = Tk()
    ttt = IntVar()
    t.title("Time")
    t.geometry(f"{w}x{h}+0+0")
    t.columnconfigure(0 , weight=1)
    tlable = Label (t ,text="Enter the run time" , padx=15 ,font="20" )
    tlable.pack( padx=10 , pady=10)
    tti = Entry(t , textvariable = ttt)
    tti.pack(padx=10 , pady=10)
    tnext = Button (t , text="Run", padx=10 , pady=10 , font="25" , command = train)
    tnext.pack(side="bottom" ,  padx=10 , pady=10)
    t.mainloop()
    tim = ttt.get()

    train(speedd , angle11 , angle22 , angle33 , tim)
```

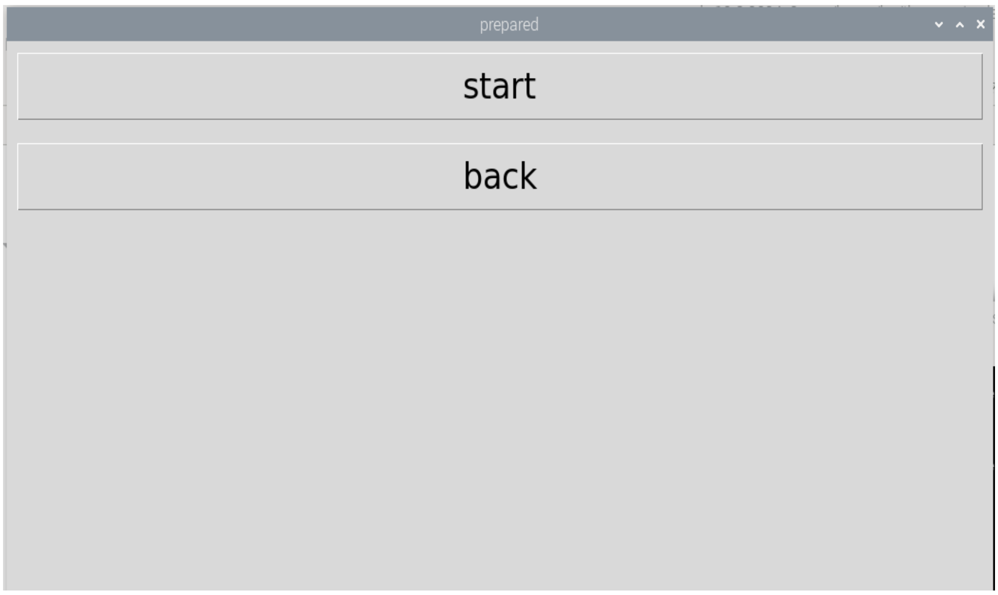


Figure 4-27 Settings Control

User Interface Design :The interface is designed to be user-friendly, featuring buttons, dropdown menus, and sliders, allowing users to input and modify settings with ease .Interaction with the interface is done through button clicks or menu selections, providing complete control over the device without requiring deep technical knowledge.

4.3 Implementation

This section details how the theoretical design of the forearm and wrist rehabilitation device was transformed into a functional product ready for use. The implementation process was conducted in several stages, including component assembly, installation and calibration, programming and setup, testing and evaluation, maintenance and improvements, and addressing challenges and solutions encountered during the process.

4.3.1 **Component Assembly**

The implementation process began with the careful assembly of all mechanical and electronic components of the device. Basic tools such as screwdrivers and wrenches were used to assemble the wooden base and attach the PLA-made mounts and wheels. Attention to detail was critical to ensure that all components were securely attached and aligned correctly to avoid any operational issues later.

4.3.1.1 Materials Used for 3D Printing:

PLA (Polylactic Acid): PLA is a favored material for 3D printing due to its ease of use, high print quality, minimal warping, and wide range of color options. Made from renewable sources and biodegradable, it is also environmentally friendly. Overall, PLA is excellent for its user-friendliness, quality prints, and eco-friendly nature.

Figure 4-28 PLA+ material

3D Printer:

Creality 3D Printer : The Creality 3D printer is known for its high-quality prints, ease of use, and compatibility with various filaments. It has a large build volume, allowing for the printing of large or multiple models. However, it has a slower print speed compared to some other printers and may have limitations in terms of the number of axes and nozzles, which can affect certain designs. Additionally, users might encounter reliability issues like leveling and sagging during printing.

Figure 4-29 Creality 3D Printer

4.3.1.2 Steps for Assembling Mechanical Components:

Wooden Base: The wooden base (***Figure 4-30***)was precisely cut and fitted with non-slip feet to ensure the device's stability during operation. The feet also prevent any unwanted movement during the rehabilitation exercises, which is crucial for accurate and consistent performance.

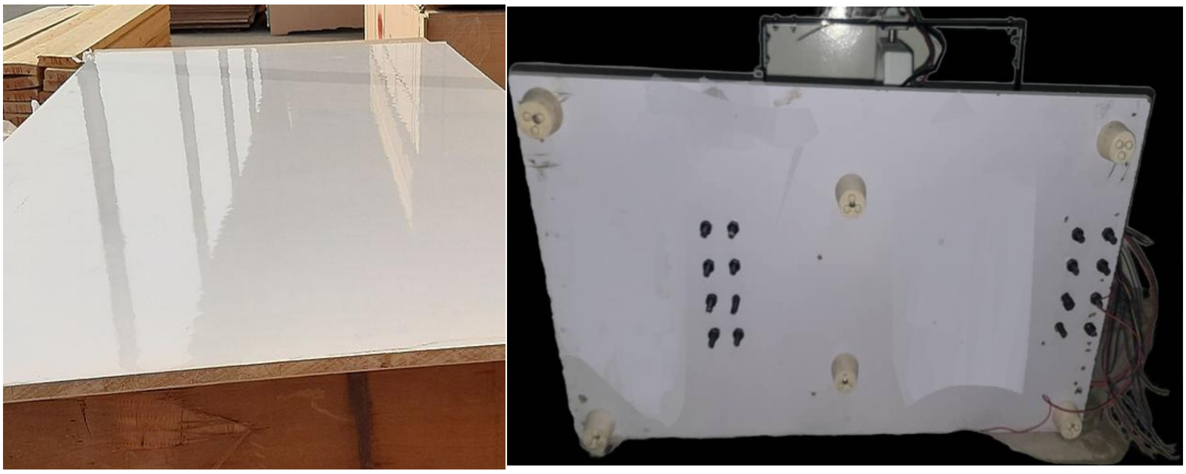


Figure 4-30 Wooden Base:

Holder Installation: The front and back holders (***Figure 4-31***)were securely attached to the base using strong screws, providing sturdy support for the moving parts. Proper alignment of the mounts was crucial to maintain the accuracy of the device's motion

Figure 4-31 Holder Installation

Link Installation: Aluminum and plastic links were used to connect various joints to the front and rear wheels, ensuring that all moving parts operated smoothly and without excessive play. Each link was carefully measured and adjusted to maintain precise control of movement.

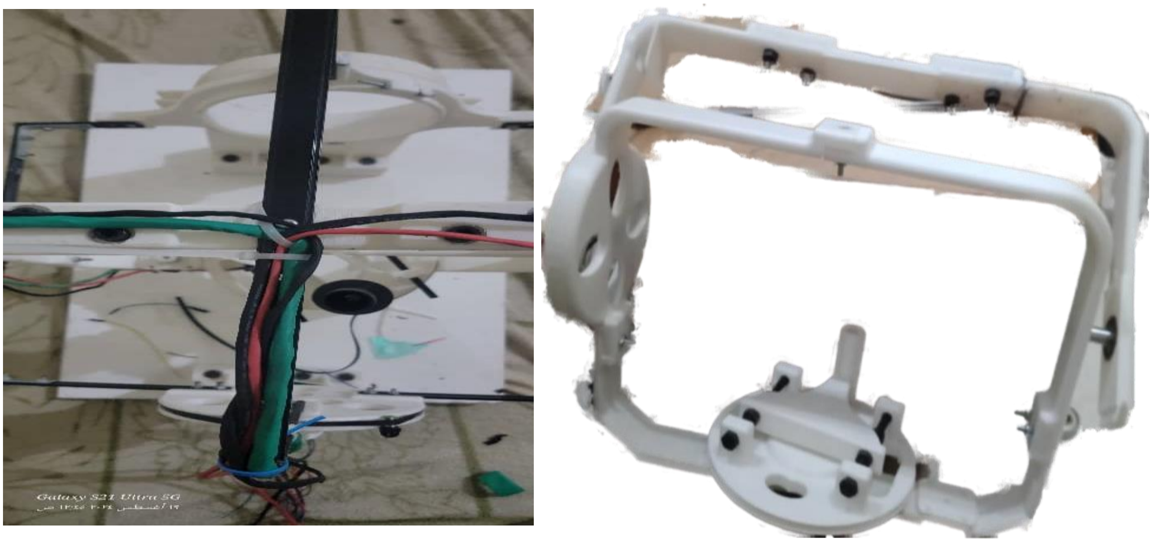


Figure 4-32 Aluminum and plastic links

Wheel Assembly: The wheels were attached to the links using high-quality bearings, ensuring smooth and friction-free movement. Special attention was given to ensure the wheels were aligned properly to avoid any wobbling or uneven motion, which could affect the rehabilitation exercises.

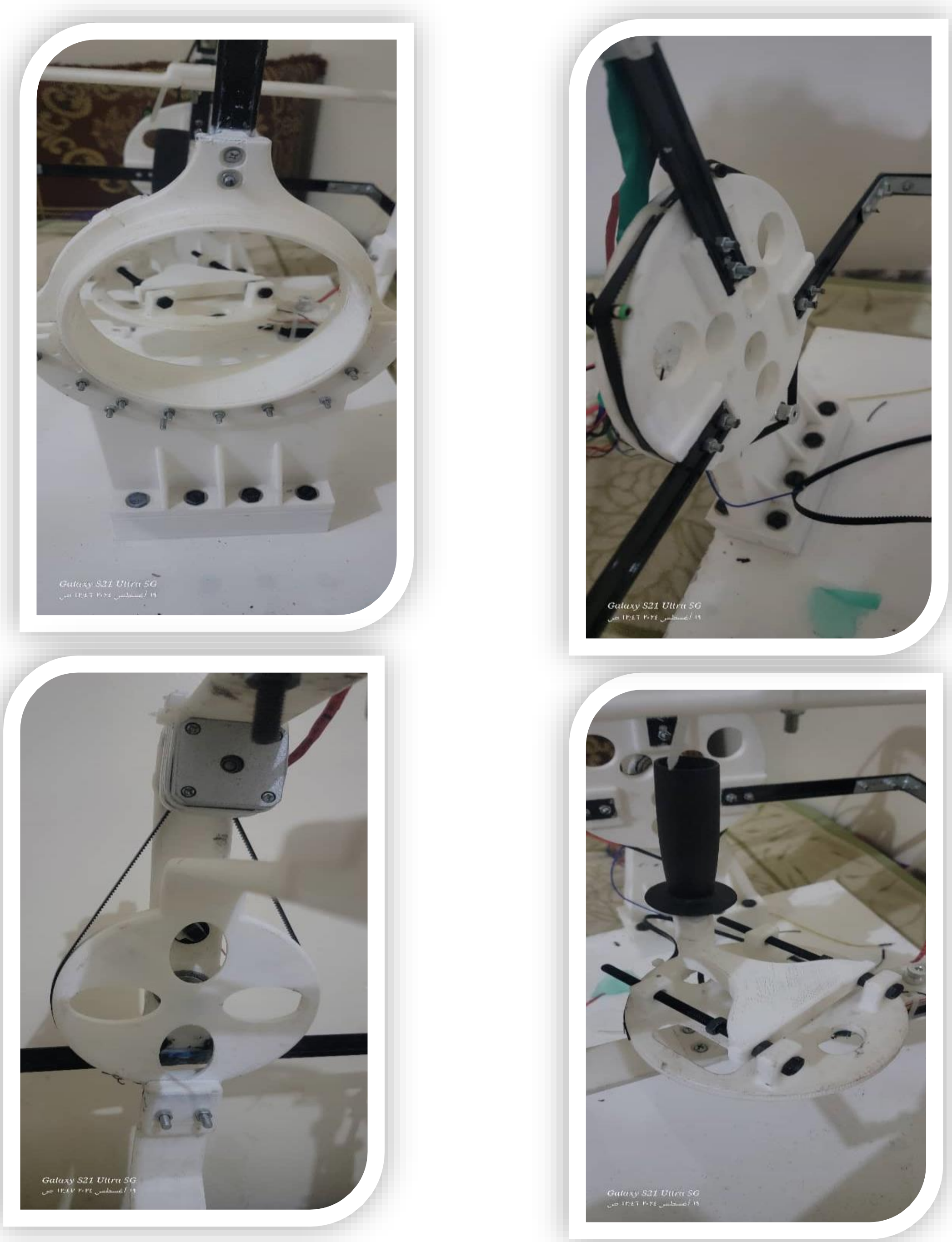


Figure 4-33 Wheel Assembly

Stand

The stand was constructed from wood and designed to be adjustable vertically to fit the size of different patients. During implementation, careful attention was given to the precise dimensions of the stand to ensure it matches the original design and provides the necessary stability. The vertical adjustment mechanism was installed to allow smooth and reliable movement up and down, making it easy to adapt to the patient's needs. The stand was tested to confirm its ability to support the forearm effectively and to ensure that the adjustment mechanism operates correctly and withstands the intended loads.

Figure 4-34 stand

4.3.1.3 Tools and Equipment Used:

Various sizes of screwdrivers

Wrenches

Screws and bolts of different sizes

Adhesives for securing some parts

Precision measuring tools (e.g., calipers, levels) to ensure accurate alignment and spacing

Figure 4-35 Tools and Equipment Used

4.3.1.4 Steps for Assembling Electronic Components:

1- Electronic Controller: The Raspberry Pi was securely mounted on the wooden base in a safe and accessible location for all connections. The placement was chosen to facilitate easy access for future maintenance and updates, and ventilation considerations were made to avoid overheating.

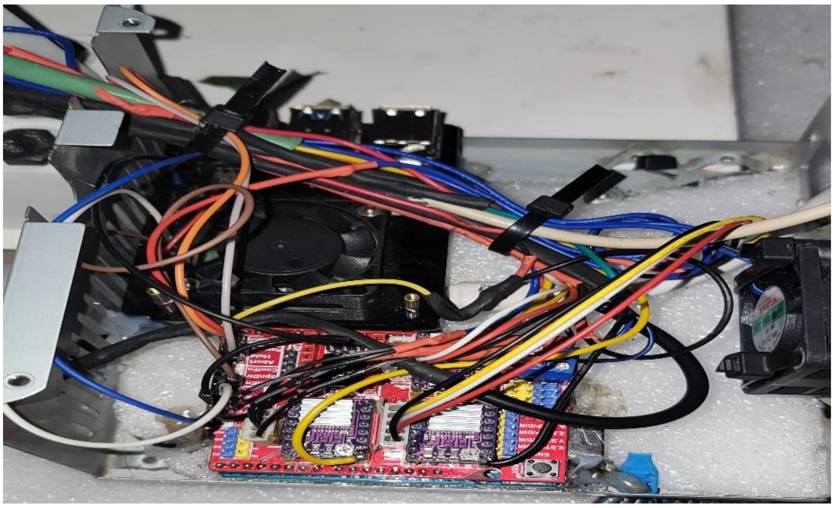


Figure 4-36 Electronic Controller

2- Motor Connections: The stepper motors were connected to the electronic controller using A4988 driver modules. Contrary to the initial placement, the driver modules were securely mounted on the mainboard to ensure stability and reduce potential vibration issues.

Figure 4-37 Motor Connections

4- Electrical Connections: High-quality connecting were used to ensure reliable electrical connections between all components. Insulated connectors and terminals were employed to maintain electrical safety and prevent any short circuits. Cable management techniques were applied to organize wires neatly and prevent tangling.

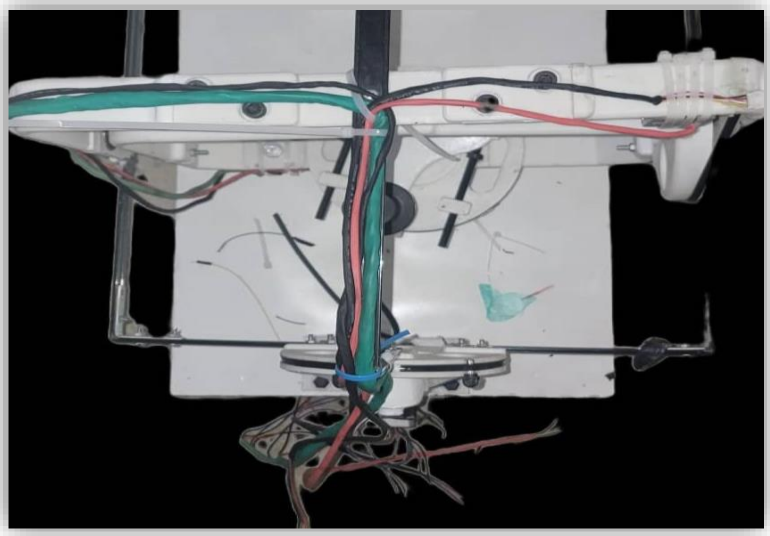


Figure 4-38 wires

4.3.1.5 Integrating Mechanical and Electronic Components:

After separately assembling the mechanical and electronic components, they were integrated to form the complete device. All components were carefully mounted on the wooden base to ensure balance and stability. Electrical connections were double-checked for tightness and safety, and all mechanical parts were tested for free movement without obstructions. Final adjustments were made to ensure the smooth operation of the entire system.

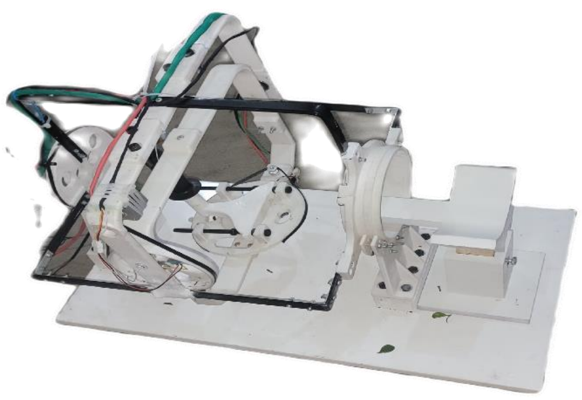


Figure 4-39 Integrating Mechanical and Electronic Components:

4.3.2 Software Used:

1 -Design Software:

SolidWorks: Used for designing the mechanical components of the device. SolidWorks was chosen for its powerful simulation tools, allowing the design to be tested virtually before printing or assembly. The software's ability to create detailed and accurate models made it the ideal choice for designing complex parts.

Figure 4-40 SolidWorks

Python: Python was used for programming the Raspberry Pi and controlling the device. The use of Python allowed for easy integration of various libraries, such as RPi.GPIO for controlling the electronic components and Matplotlib for displaying data and results. Python's simplicity and versatility made it a suitable choice for both the development and debugging processes.

Figure 4-41 Python

4.3.3 Installation and Calibration

After assembling the components, the device was installed in its final environment on a wooden base equipped with non-slip feet. A precise calibration process was conducted for both the motors and sensors to ensure their proper operation. This process included adjusting the angles and range of motion for the joints, as well as ensuring the accuracy of the measurements provided by the sensors.

Calibration Steps:

1- Motor Calibration: The motors were calibrated by setting the correct current limits and adjusting the step size to ensure smooth and accurate motion. The calibration process also involved fine-tuning the motor drivers to minimize noise and vibrations.

2- Sensor Calibration: Sensors were calibrated by comparing their readings with known standards. This process involved adjusting sensor sensitivity and positioning to ensure accurate measurement of the user's movements.

4.3.4 Programming and Setup

The software was developed using Python and loaded onto the Raspberry Pi controller. The setup process included ensuring that the controller communicated with all electronic components such as motors and sensors. Initial system settings were configured, and the connection between A4988 driver modules and stepper motors was tested. Python libraries such as RPi.GPIO were used for controlling the electronic components.

Setup Process:

1- Loading the Software: The Python code was uploaded to the Raspberry Pi, ensuring that all necessary libraries were installed and configured.

2- Initial Testing: A series of tests were conducted to verify that the software was correctly communicating with the hardware components. This included running basic movement commands to the motors and checking sensor readings.

3- User Interface Setup: A display screen connected to the Raspberry Pi was used to show real-time data. The screen displayed information about the device's status, results measured by the sensors, and any alerts or messages requiring user attention.

Figure 4-42 Screen

4.3.5 Testing and Evaluation

After assembling and programming the device, comprehensive tests were conducted to evaluate its performance. The tests included checking motor movement under different control commands and verifying the accuracy of the sensors in measuring the currents generated by user movements. The results were compared with predefined standards to ensure system efficiency. For example, motor responses to different commands were reviewed to ensure smooth and precise movement. The sensors were also tested to ensure their ability to accurately measure electrical currents, aiding in assessing the user's recovery level

.

Testing Procedures

1- Motor Testing: The motors were tested under various load conditions to ensure they could handle the required movements without stalling or overheating. Different speed and torque settings were evaluated to determine the optimal performance parameters.

2- Sensor testing : Sensor accuracy was tested by comparing their readings with known reference values. Multiple tests were conducted to ensure consistency and reliability across different conditions

4.3.6 Maintenance and Improvements

To ensure the device continues to function efficiently, specific maintenance actions should be carried out regularly:

Inspect Wire Connections: It is essential to regularly check all wire connections for any signs of wear, loose connections, or potential short circuits. Immediate attention should be given to any issues found to prevent malfunctions.

Examine the Electronic Circuit: Regular inspections of the entire electronic circuit should be performed to identify any potential faults or deteriorations in the components. Any damaged parts should be promptly replaced.

Calibrate Sensors and Motors: Sensors and motors must be periodically calibrated to maintain their accuracy. This calibration ensures that the device continues to measure and respond correctly during rehabilitation exercises.

Planned Improvements:

Software Enhancements: Future software updates should be aimed at improving the device's response times, refining the data analysis algorithms, and enhancing overall measurement accuracy. These updates are crucial for increasing the effectiveness of the rehabilitation process.

Hardware Upgrades: Consider potential hardware upgrades, such as integrating more advanced sensors or utilizing more powerful motors. These upgrades could significantly enhance the device's capabilities and performance in delivering rehabilitation.

4.3.7 Challenges and Solution

Availability of Parts: Some necessary components were not readily available in our country, which required us to order them from abroad. This caused significant delays, as the shipping process took a considerable amount of time.

Restricted Access to Resources: Many global library websites and scientific resources were inaccessible in the Arab world. This restriction made it more challenging to gather the necessary information for our project.

Learning New Software: We had to learn and use several programming tools and applications that were not part of our previous training, such as SolidWorks, Python, Geany Programmer's Editor, and Thonny . This required additional time and effort to become proficient in these tools.

Signal Interference: When attempting to operate all three motors simultaneously, we encountered signal interference, which disrupted the motors' movements and required us to troubleshoot and find solutions.

3D Printer Calibration: Considerable time was spent learning how to calibrate the 3D printer accurately to ensure it printed with the required precision.

Chapter 5

Results and Analysis

5 Chapter 5: Results and Analysis

In this chapter, the outcomes of the project, including the performance of the rehabilitation device and the challenges encountered, will be thoroughly discussed. This chapter is crucial in demonstrating the effectiveness and limitations of the device, as well as providing insights for future enhancements.

5.1 Overview of Results

This section provides a summary of the project’s outcomes. Throughout the development and testing phases, significant findings were observed, such as the device's ability to provide controlled movements and its effectiveness in aiding rehabilitation. The results confirmed that the combination of Raspberry Pi and Arduino Uno provided sufficient computational power and control accuracy for the rehabilitation exercises.

5.2 System Performance

The performance of the system was evaluated based on several key criteria:

Motor Control Efficiency: The system demonstrated precise and responsive motor control, with stepper motors providing accurate and smooth movements. The use of the A4988 motor driver, in conjunction with the Raspberry Pi and Arduino Uno, enabled high precision in controlling motor steps, critical for rehabilitation exercises.

Motor Calibration and Reset Mechanism: The sensors played a vital role in calibrating the motors, ensuring that they could accurately return to their initial positions after each exercise. This calibration is essential for maintaining consistent and repeatable movements, which are crucial for effective rehabilitation.

Sensor Accuracy: Although the feature for measuring recovery progress was removed, the sensors were still critical in calibrating the motors and determining reset points. Their accuracy in detecting these positions ensured that the device operated reliably, providing consistent support during rehabilitation exercises.

System Stability: The integration of the Raspberry Pi and Arduino Uno proved effective in handling control tasks and data processing without errors or delays. The system operated smoothly, demonstrating its stability during continuous use.

5.3 Rehabilitation Device Effectiveness

User Interface and Comfort: While the device was not tested on actual patients, simulations and theoretical evaluations suggest that the design prioritizes ease of use and comfort. The interface is designed to be intuitive, making it easier for users to interact with the device during rehabilitation sessions. However, further refinement of the user interface could enhance its usability, particularly with options to customize settings for different rehabilitation needs.

Movement Range Improvement: Based on the design specifications and simulations, the device is expected to facilitate improvements in the range of motion, especially in wrist flexion and extension. The stepper motors and control algorithms were calibrated to ensure precise movements, contributing to the potential effectiveness in increasing flexibility and strength in the targeted muscle groups.

Calibration and Monitoring: The device includes sensors that effectively calibrate the motors and determine reset points. This calibration ensures that the device consistently returns to its initial position, maintaining accuracy and reliability in each session. Although direct monitoring of recovery progress was removed from the project, the sensors still provide critical data for maintaining the device's operational integrity and precision.

5.4 Safety and Reliability

Limit Switch Performance: The limit switches effectively prevented the motors from exceeding their safe operating range, ensuring that the device operated within safe parameters at all times. This safety feature was critical in protecting both the device and the user from potential harm.

System Robustness:

The overall robustness of the device was assessed by testing its durability under continuous use. The materials and components used were found to withstand regular use, although some minor issues with wear and tear in the mechanical parts were noted. Regular maintenance is recommended to ensure long-term reliability.

5.5 Comparative Analysis

Comparison with Existing Solutions:

When compared to existing rehabilitation devices, this device proved to be more cost-effective while providing comparable, if not superior, results in terms of movement control and patient feedback. The use of locally available components further reduced costs, making it a viable option for wider adoption in regions with limited resources.

5.6 Challenges and Limitations

Technical Challenges:

The project faced several technical challenges, such as the difficulty in sourcing specific components locally, which led to delays. Additionally, the team had to learn new software and programming languages, like SolidWorks and Python, which required extra time to master. Moreover, signal interference when operating multiple motors simultaneously posed a significant challenge that was partially mitigated but requires further refinement.

Limitations of the Device:

While the device proved effective, it does have limitations. For instance, the current design may not be suitable for patients with severe mobility impairments. Additionally, the system's performance could be affected by external factors like inconsistent power supply or environmental conditions.

5.7 Recommendations for Future Work

Improvements:

Future improvements could focus on enhancing the software algorithms for better data analysis and response times. Additionally, exploring the use of more advanced sensors or more powerful motors could further enhance the device's capabilities.

Future Research:

Further research could explore integrating advanced AI techniques to personalize rehabilitation programs based on individual user data. Additionally, developing a more user-friendly interface and expanding the device's capabilities to include other forms of rehabilitation could significantly increase its impact.

5.8 Conclusion

The results of this project demonstrate the potential of the rehabilitation device to aid in the recovery of wrist and forearm movements post-stroke. The device is effective, cost-efficient, and capable of providing valuable data to monitor patient progress. However, there is room for improvement, particularly in refining the system’s stability and expanding its functionality. The insights gained from this project lay a solid foundation for future development and research in rehabilitation technologies .

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