ABSTRACT

The "Internet of Things (IoT) based Smart Glove for Hand Rehabilitation "has been designed to offer an extensive and interactive rehabilitation experience. Which is established by the incorporation of sensors and actuators, which provides the glove with real-time monitoring and feedback. Moreover, enabling personalized rehabilitation activities customized for those with specific needs. In addition, this innovative method not only enhances the efficiency of rehabilitation but also supports patient engagement and motivation through interactive feedback mechanisms.

Where, Ethical concerns and safety precautions have been crucial throughout the design process, guaranteeing that the smart glove demonstrates the well-being and safety of the users. The project conforms to the highest standards of engineering and design, matching with industry best practices and regulatory criteria to guarantee the dependability and safety of the smart glove.

overall, the "Internet of Things (IoT) based Smart Glove for Hand Rehabilitation ", for Rehabilitation project represents an important development in engineering. It gives a state-of-the-art solution to assist the rehabilitation process for those with hand injuries or impairments. The projects findings and influence suggest its potential to favorably change rehabilitation technology marking an important step in the ongoing pursuit of healthcare solutions.

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Chapter 1:
INTRODUCTION TO PROJECT

1.1 Overview

Hand injuries such as paralysis, and neurological damage are the various types of disorders that can significantly affect someone's ability to complete everyday chores. Restoring hand function is crucial for regaining independence and boosting overall quality of life. Traditional hand treatment comprises of repetitive exercises carried out under the guidance of a therapist. However, this technique can be time-consuming and pricey, and following the required routines can be tough.

Our idea delivers a unique solution: an IoT-based Flex Force Smart Glove that can be used to augment and personalize restorative hand treatment sessions. Since technical breakthroughs in Internet of Things (IoT) technology have opened new options for hand rehabilitation, this innovative glove incorporates embedded flex sensors to capture finger movements and communicate data through a specialized website designed for real-time monitoring and exercise instruction.

1.2 Statement of Problem

Hand therapy approaches currently encounter various limitations:

Limited Real-Time Feedback, Repetitive and monotonous exercises, Limited accessibility.

Limited Real-Time Feedback:
To evaluate exercise performance, therapists primarily rely on visual observation and patient feedback. This strategy is subjective and prone to errors, making it difficult to provide targeted feedback and successfully change therapeutic plans.
Lack of real-time data on aspects such as movement range, force exerted, and muscle activation patterns limits the ability to discover potential compensations or inappropriate techniques.

Causing: Inefficient training, Delayed adjustments, and Reduced patient confidence

Repetitive and monotonous exercises
Traditional hand rehabilitation frequently comprises repetitive exercises such as finger flexion and extension, gripping exercises, and particular movements targeting weaker muscles. While these activities are important for restoring function, they can rapidly become boring and monotonous for patients.

Leading to: Decreased motivation, Lack of engagement, and Reduced neuroplasticity.
Limited accessibility

While having Access to high-quality hand therapy it can be limited by several variables, such as:

cost, location, and availability.

- *Cost: most of Therapy sessions can be costly, making it more difficult for certain people to acquire proper care needed.*
- *Location: Therapists with specialized hand treatment abilities may also be limited in some places, particularly in places such as rural areas.*
- *Availability: Due to the high demand, therapist appointments may be limited, resulting in lengthy wait periods, and delaying treatment beginning for the patients.*

1.3 Project Specifications

Here are the specifications of the components that will be utilized in the project:

1. ESP32 Microcontroller

The ESP32 microcontroller by Expressif Systems is an affordable, compact and useful tool for countless IoT and automation applications like smart homes and wearable devices. It features a dual-core Xtensa LX6 CPU with a processing speed of 240 MHz and 520 kB of RAM. It was chosen mainly due to its wireless capabilities thanks to its built-in Wi-Fi and Bluetooth connectivity, and because of its low power consumption thanks to the Ultra-Low-Power (ULP) Coprocessor. Moreover, the ESP32’s hardware encryption engine with AES, RNG, RSA and SHA-2 algorithms guarantees data security, and it is supported by the Arduino IDE ensuring easy firmware development. Additional features include temperature sensors, SD card support, built-in RTC, secure boot, five power modes etc. [1].

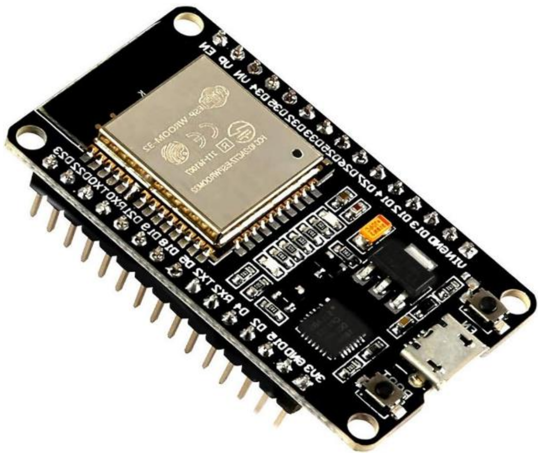


Figure 1: ESP32 Microcontroller [2]

2. **Flex Sensors**

   Flex sensors play a crucial role in detecting the degree of finger bending within the gloves. They work as sort of variable resistors, with a typical resistance of 25kΩ when fully flat, and the resistance increases as the sensor bends with a maximum resistance of 125kΩ when fully bent [3].

3. **FSR 406 force sensitive resistor (FSR) sensor:**

   The force sensing sensor is used to detect squeezing force from the user's hand. With no inputs it acts as an open circuit, having a very high resistance. But as force is increased, the resistance decreases. This decrease in resistance is used to detect squeezing force.

   Its force sensitivity ranges from 0.1 to 10 Newtons, with an operating temperature range of -30 to +70°C. Its dimensions are 43.69 x 43.69 mm with thickness range of 0.2 to 1.25 mm [4].

4. **Mechanical actuators**

   These are electrically operated mechanical actuators that are mounted on each of the five fingers of the glove. They help to flex and extend each finger, therefore acting as an assisting or a resisting force depending on the patient's needs and preferences. Their functionality is explained in more depth in Chapter 3.

1.4 Motivation/Justification

Our concept is motivated by the desire to use breakthrough technologies to revolutionize hand rehabilitation. It seeks to address unmet requirements of patients and therapists by adding involvement, efficacy, and accessibility into the rehabilitation process. The Flex Force smart glove has the potential to make hand therapy more joyful, efficient, and accessible for a greater spectrum of users by combining real-time *feedback with interactive exercises and remote monitoring, ultimately leading to increased hand function and quality of life.*

1.5 Project Applications

The resistive sensors used in the Smart Glove adaptability extends beyond its principal role in hand rehabilitation, suggesting a wide range of applications in a variety of fields.
Beyond assisting in the recovery of hand injuries, this revolutionary IoT-based glove has applications in a variety of fields. Athletes will benefit from its precision and data-driven insights in sports training, permitting sophisticated hand movement analysis and customized strength conditioning. Another study shows its incorporation into virtual reality environments that provides immersive experiences by allowing users to operate virtual objects or interact inside simulated surroundings utilizing natural hand movements.

Furthermore, as an assistive technology, this glove promotes inclusivity by enabling differently abled people to accomplish daily chores and manage gadgets using intuitive hand movements. The Flex Force Smart Glove symbolizes adaptability, demonstrating revolutionary power that goes far beyond typical rehabilitation paradigms.

1.6 Organization of the Report

The report's structure is divided into 7 chapters:

- Introduction
- Literature Review
- Theory related to project.
- Design and Methodology
- Modelling and Simulation
- Engineering Standards and Constraints
- Conclusion

In the next chapter (***Chapter 2***) a detailed literature review of related technologies as well as related projects will be discussed, along with limitations and the potential impact of the project. While: ***Chapter 3,*** theory related to our project will be explained in full detail. This includes the mechanism of the glove, the functionality of sensors in addition to how the microcontroller communicates with web servers to achieve the IoT feature.

In ***Chapter 4,*** we will discuss the design of various aspects of our project in the form of charts and diagrams, as well as the methodology that will be followed during the development of the smart glove.

Chapter 5 will demonstrate the functionality of the project by modeling the sensors and illustrating the workings of the sensor data collection process via simulation software.

Chapter 6 lists all the engineering standards to be followed when designing and developing the glove, firmware and website, in addition to the limitations faced when implementing such a project. Finally, ***chapter 7*** concludes this research paper with a summary of the most significant parts of the previous chapters along with objectives of the research, future expectations, and a Gantt chart of the development process.

CHAPTER 2

LITERATURE REVIEW

Chapter 2:
LITERATURE REVIEW

1.1 Related Technologies

2.1.1 Sensor technologies

1. **Wearable fitness trackers:** Fitness watches like Apple Watch rely on heart rate sensors, gyroscopes, and accelerometers to track user's physical activity and provide feedback accordingly. Using multiple and diverse sensors can help increase accuracy of measurement of users' health data, however these devices suffer from low battery life affecting their usability.

2. **Computer Vision (CV):** Using CV technologies with multiple cameras and AI help to detect and track the hand's movements, finger flexion and hand orientation, and transform the readings into virtual images on a screen, and real-time footage can also be transmitted to a doctor for further analysis and feedback. The main advantages of this approach instead of a smart glove are the simplicity and ease of use <u>for the patient</u> due to less components being used; however, development costs and complexity are higher due to the need of development of AI algorithms and hand tracking technologies using CV.

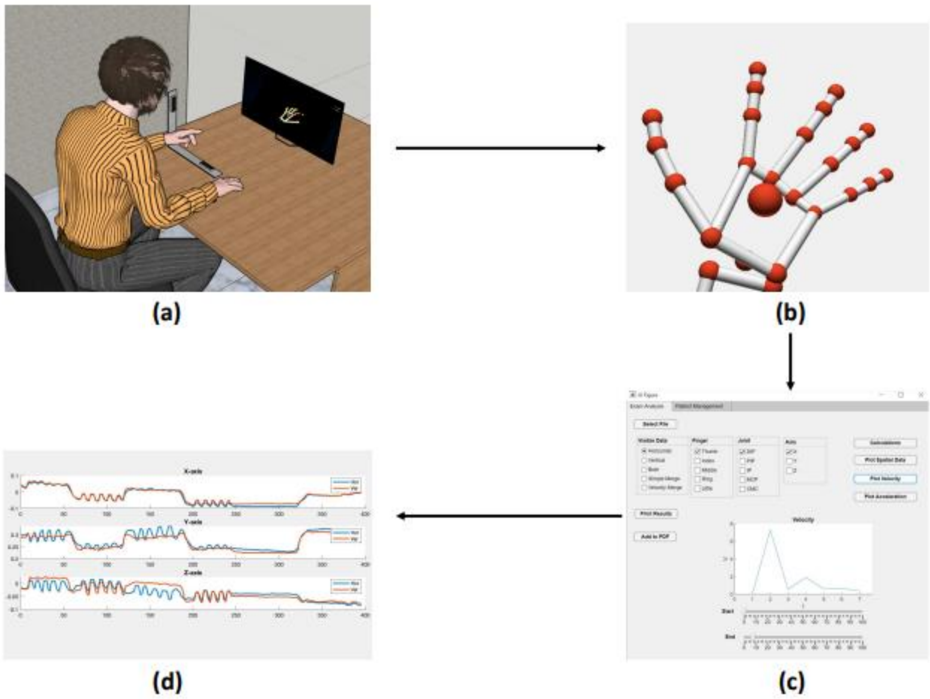


Figure 2: Computer Vision hand gesture tracking with graph analysis [5]

2.1.2 Hand movement technology

1. **Air pressure aided finger flexion**: Instead of using electric motors and mechanical actuators to help patients flex their fingers, air pressure tubes connected on top of the fingers of the glove can be used to aid finger flexion. This technique has been used by most commercial rehabilitation gloves, for example the soft hand robotic glove by Syrebo. The main benefits are convenience and reliability compared to utilizing electric motors, nevertheless the biggest drawback of this approach is that gloves using this technique are overpriced with some gloves' prices exceeding $500.

Figure 3: Syrebo's rehabilitation gloves with air pressure tubes [6]

2.1.3 Microcontrollers

We chose the ESP32 microcontroller for our project due to its processing power and built-in wireless capabilities. The following microcontrollers were potential *contenders:*

2. ***Arduino boards:*** Arduino boards like the Uno and Leonardo are famous for their affordability and ease-of-use hence they are used in a variety of applications like DIY projects, prototyping and educational purposes. Their main advantages are the extensive community support as well as being beginner-friendly, however Arduino boards are not the best choice for our smart glove due to the limited processing power and most importantly the lack of internet connectivity without connecting an external device.

3. ***Raspberry PI:*** The most advanced microcontroller for project development due to its excellent processing capabilities, making it suitable for home, media and industrial applications. Even though it's a powerful tool, it's not a suitable choice here because of its power consumption and due to higher difficulty coding programs for it.

2.1.4 Wireless Technologies

Transmission of sensor data will be sent to a web server via the Wi-Fi capability of the ESP32. Other wireless transmission technologies include:

1. *Bluetooth*: A power-efficient short-range wireless technology used in mobile phones and several smart wearable devices. However, its limited range, high probability of interference and the slow data transfer rates could potentially cause unacceptable delays and error rates, ultimately making it a terrible choice for real-time remote monitoring of patients.

2. *Mobile data:* Modern mobile network technologies like 5G and LTE are great for IoT applications and functions requiring long ranges like autonomous vehicles and remote monitoring. On the other hand, high power consumption and pricey data plans make mobile data an inefficient and uneconomic choice.

1.2 Related Projects

Multiple studies have explored the potential of utilizing electronic devices for intuitive recovery. A study specifically focused on the development of smart gloves using tools such as the Arduino Leonardo microcontroller, in combination with flex sensors, force sensors, and an accelerometer. The aim was to create interactive objects, particularly gloves, for stroke rehabilitation to implement exercises that have proven positive effects. The primary goal was to create a motivating tool for mobility training and stroke rehabilitation. Testing the final model of the intuitive glove involved numerous individuals, and while user experience and functionality could be enhanced, all participants reported enjoying using the device. This suggests that the objective of creating a motivating and stimulating tool for stroke rehabilitation was partially achieved. The study also underscores the importance of involving stroke survivors in the development and testing phases to create devices that are both motivational and functional. [7]

Another study at *Wyss Institute for Biologically Inspired Engineering, Harvard University.* Here researchers have created a state-of-the-art Smart Glove dedicated to hand rehabilitation. Integrating soft robotics technology and sensors, this wearable device assists individuals recovering from hand injuries or conditions affecting hand functionality. By providing personalized support during rehabilitation exercises and collecting real-time data, the Smart Glove aims to improve hand function and promote dexterity. The project signifies a significant advancement in wearable rehabilitation technology, offering adaptive solutions for enhancing hand rehabilitation outcomes. [8]

Moreover, a study states a wearable hand rehabilitation system was developed, cantered on soft gloves designed for both task-oriented and mirror therapies. These gloves, comprising a motor glove and a sensory glove made from soft and flexible materials, prioritize comfort and safety, a departure from traditional rigid rehabilitation tools. The sensory glove, worn on the unaffected hand, incorporates force and flex sensors to monitor finger joint bending angles and detect motion. Meanwhile, the motor glove, equipped with tiny motors, provides support to the injured hand during training exercises. Leveraging machine learning, the system identifies motions from the sensory glove, streamlining rehabilitation activities for the injured hand's recovery process. [9]

Each of these projects showcases significant advancements in IoT-based rehabilitation technology, providing innovative solutions to aid in the recovery and rehabilitation processes for individuals dealing with various physical and neurological conditions.

1.3 Limitations/Problems in Literature Work

Some studies may have relied on a tiny sample size, which could affect how well the results apply to the public.
Research with shorter time frames may fail to detect the rehabilitation therapies' long-term efficacy or viability.

Problems with usability, maintenance, or cost-effectiveness may arise in initiatives that rely heavily on complex technology.
The rehabilitation system's overall effectiveness can be affected by users' varying responses and adaptability to the technology.

1.4 Project Impact

- Here are the project impacts in the form of:

* ***technological Complexity:***
  Implementing a sophisticated rehabilitation system can confront technological hurdles during development, integration, or calibration of sensors, motors, or machine learning algorithms.

* ***User Acceptance:***
  Ensuring user acceptance and comfort with the wearable device could involve iterations for design refinement and user feedback inclusion.

* ***Long-term Effectiveness:***
  Measuring and assuring the long-term impact and sustainability of the rehabilitation system on patient recovery could pose obstacles.

* ***Cost and Accessibility:***
  Cost implications and accessibility concerns could limit general acceptance or availability of the technology, influencing its influence on a larger scale.

* ***Clinical Integration:***

Integrating the designed technology inside clinical settings can require overcoming regulatory restrictions, integrating with existing rehabilitation methods, and getting healthcare professional acceptability.

CHAPTER 3

PROBLEM ANALYSIS

Chapter 3:
PROBLEM ANALYSIS

3.1 Analysis of the Problem Specification

Problem specification

Often some of strokes survivors face challenges in regaining their ability to control their finger motions causing them to suffer to do their daily tasks. Some rehabilitation therapy can lack in providing personalization and adaptivity in therapy. Combining physical therapy with real-time monitoring system and analysis can be the solution.

Challenges

- **Individual Variability:** Rehabilitation is thus individualized as each patient's condition and possible rate of recovery varies from one to the other.
- **Engagement and Motivation**: It is very important to ensure patients remain engaged and motivated all through the rehabilitation process so that recovery will be effective.
- **Data Collection and Analysis:** Efficient control and analysis of the progress allows adjusting therapy plans correctly.
- **Accessibility and Convenience:** This remote monitoring and therapy solutions can be very beneficial for the patient who would not have to attend the therapy center quite often.

3.2 Required Components and Calibration

Components:

- E-Textile Exoskeleton Glove: light and adjustable to different hand sizes making it comfortable in use.
- Actuators: Simulating movement and resistance, mimicking natural finger actions.

- Resistive Sensors: 2 Flex Sensors and Force Sensing Resistors must be used as a tool for measuring motions, force exertions.
- ESP32 Microcontroller: Manages sensor inputs and actuators while it also handles Wi-Fi connections for data transmission.
- Power Source: A light, rechargeable battery which balances the glove's weight.
- Firebase Server: For live storage, tracking and multiple platforms.

Calibration:

Sensor Calibration: Making sure that each sensor perfectly represents force and its movement in every finger.

Actuator Tuning: Setting the actuators for appropriate resistance to match individual therapy needs.

Battery Life Optimization: Ensuring that the power source maintains good session times without making it cumbersome to carry.

3.3 Decision Making based on Problem Analysis

Design Decisions:

Customizability: The glove should be adjustable to suit a variety of hand sizes and shapes, that caters for the specific needs of each patient.

User Interface: Design a user-friendly interface for therapists to assign exercise, track progress and make instantaneous adjustments when appropriate.

Data-Driven Approach: Employ the data gathered to standardize therapy sessions based on individual progress to increase efficacy.

Remote Therapy Capabilities: Purchase monitoring and treatment equipment for remote access.

Technical Decisions

Choice of Sensors: Select sensors that provide very accurate and exact data for finger mobility as well as pressure.

Selection of Microcontroller: ESP32 is selected because it's significantly smaller than other devices similar in capabilities and functionality to other microcontrollers, due to built-in Wi-Fi.

Material Selection for the Exoskeleton: Make sure it is light but durable, that could improve your comfort and increase its life.

Future Considerations:

The effectiveness of machine learning algorithms for predictive analytics in therapy adjustments.

Research the virtual reality integration that is more interactive in rehabilitation exercises.

Consider the way these designs will work for other types of physical rehabilitation needs, in terms scalability and adaptability.

Chapter 4:
DESIGN AND METHODOLOGY

4.1 Overall Project Design

4.1.1 Block Diagram

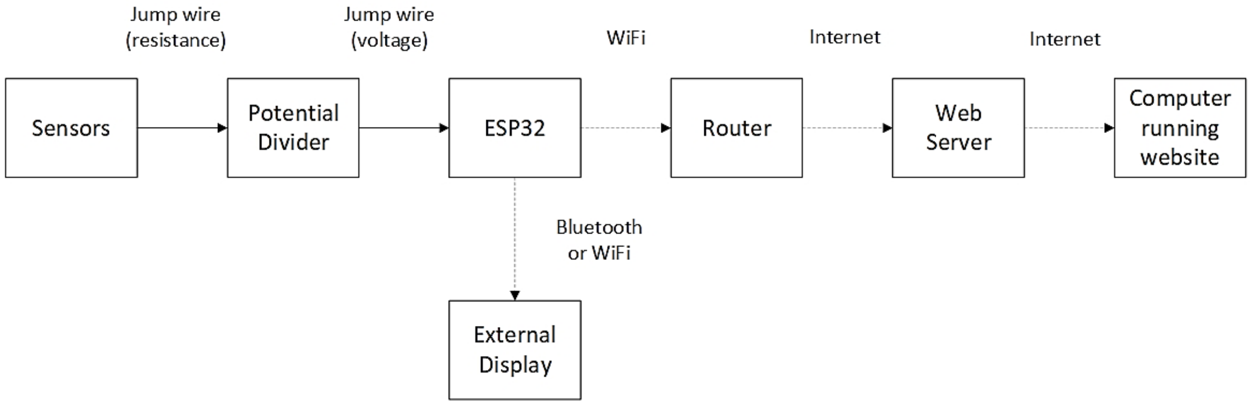


Figure 10: Block diagram of the project's topology

4.1.2 State Diagram

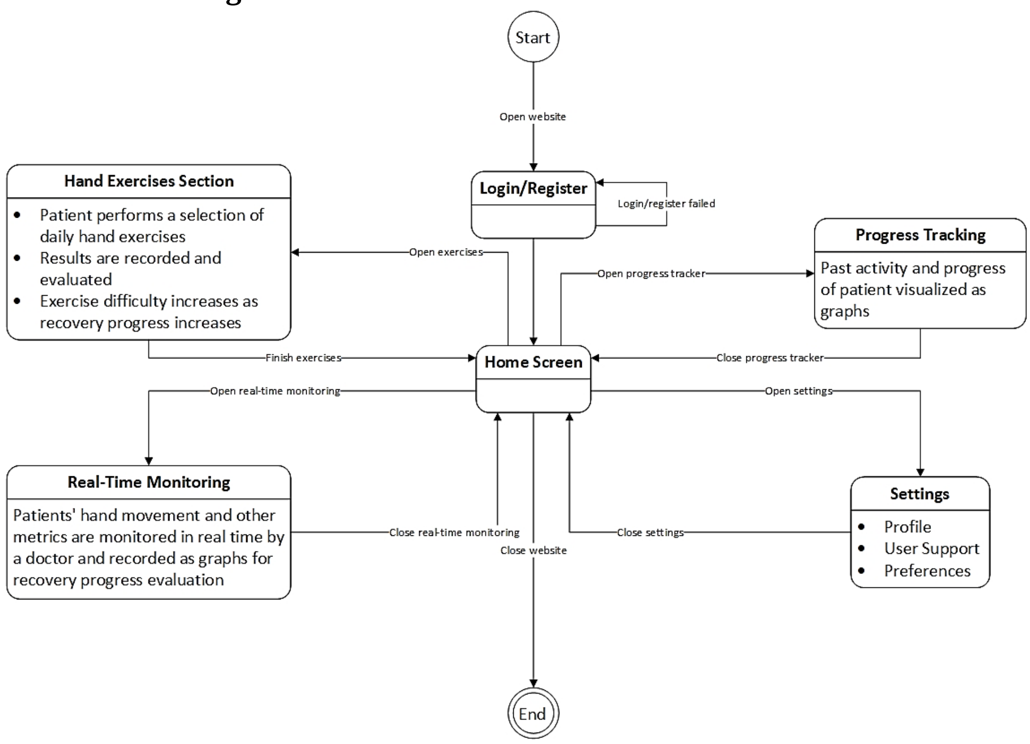


Figure 11: Website state diagram

4.1.3 Flow Chart

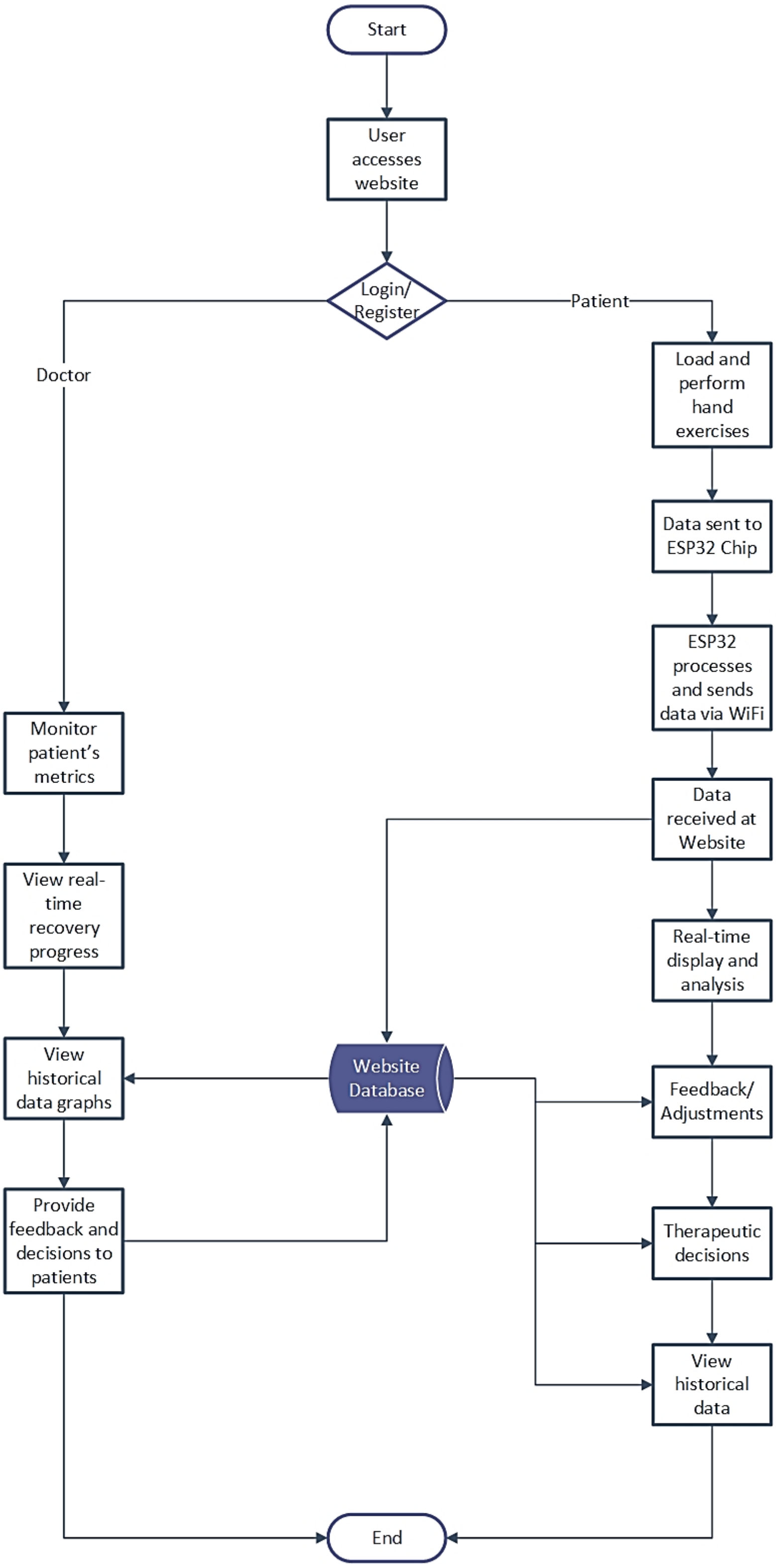


Figure 12: Overall project's flow chart

4.2 Methodology

* When we start developing our project, we need to put several points into consideration:

1. Conceptualization and requirements assessments:

- **Objective**: The main goal here is to design and implement a smart glove that helps stroke survivors and people suffering from other conditions to rehabilitate by partially or fully restoring regular hand movements. In order to do that, proper understanding of the patients' motor impairments and how technology can help them to recover is crucial so that the proposed solution is tailored to patients' needs.
- **Activities**: In order to define the essential elements for the smart glove, this step involves a thorough analysis of the literature on existing rehabilitation procedures, patient interviews to learn about their struggles, and talks with medical experts.

2. Prototyping:

- **Integration of sensors:** The glove will have accelerometers to track hand orientation, pressure sensors to evaluate grip strength as well as flex sensors to record finger movements. These sensors were chosen for their wearability, accuracy, durability and compatibility with a wearable device.
- **Choosing a microcontroller:** The ESP32 microcontroller is the best option for processing and transmitting data in real-time because of its dual-core CPU, Wi-Fi capability, and Bluetooth functionality. Additionally, its compact form-factor and relatively simple design make it the perfect choice for a wearable device.
- **Development of prototypes:** Soft materials and 3D printing will be used to create the glove's initial prototypes, which will guarantee comfort. These prototypes will be improved repeatedly in response to feedback and preliminary testing.

3. Software Development:

- **ESP32 Firmware:** Developing the actual code for the ESP32 controlling the glove will be done via the Arduino IDE using the C++ programming language. The code will include functionality for sensor data acquisition and processing, as well as data transmission to a web server or database via the built-in Wi-Fi module [16].
- **Web App Development:** PHP, HTML5, CSS3, and JavaScript will be used in the development of the website's structure, design and functionality respectively. Real-time data visualization, intuitive user

interfaces, and accessibility will be prioritized. The website will be used by patients to access hand exercises and view recovery progress in the form of graphs of past data, while doctors will use it to monitor multiple patients in real-time and provide feedback to the patients [16].

4. Security of transmitted data:

- Maintaining the confidentiality, integrity and availability of sensitive medical data transmitted from the ESP32 to the web server is crucial. Therefore, we need to make sure to implement secure transmission methods such as HTTPS instead of the insecure HTTP, in addition to data encryption for confidentiality [17].

5. UI and UX design:

Experience is equally as important to functionality when developing any kind of software. Good User Experience (UX) and User Interface (UI) play crucial roles in determining the success of a product, and our website is no exception. Both are responsible for enhancing user satisfaction, usability, engagement, accessibility, aesthetics among countless other benefits. In our website, there are two aspects that need to be taken into consideration:

- **Doctor's Interface:** The doctor's interface will have tools for creating reports, retrieving past data, and keeping track of patient parameters in real time. Doctors will be able to evaluate patient progress more rapidly thanks to the design's emphasis on simplicity and clarity.
- **Patient's Interface:** The patient's interface will be interactive and inspiring, giving them simple access to hand exercises that are recommended, progress charts that show their progress visually, and informational materials regarding their recovery [18].

6. Validation and Testing:

Just like in software engineering, our project needs to be tested rigorously to make sure its functionality is completely error-free and fully satisfies the requirements of both patients and doctors. Here are some kinds of testing procedures that we should apply for both the hardware and software aspects of our project:

- **Testing Usability (Black Box testing)**: The glove, ESP32 firmware and the website will all be tested thoroughly in terms of functionality with the help of actual patients and doctors (as beta stage testers) to ensure the final product's effectiveness in addition to collecting feedback to improve various aspects of the project. Planning comprehensive test cases is also crucial in this phase.
- **White Box testing**: White box testing refers to the testing of the project by deeply analyzing the code and algorithms used. This can be done using techniques like calculating cyclomatic complexity of the used

algorithms via a flow graph in order to find the number of different possible paths and to generate test cases accordingly [19].

- **Clinical trials**: To verify the glove's effectiveness in rehabilitation from a scientific standpoint, clinical trials will be carried out in association with healthcare facilities. The goal of these trials is to quantify changes in motor function while adhering to ethical requirements [20].

7. Iteration and Finalization:

- **Feedback implementation:** Iterative development will be used to continuously enhance the smart glove and software by including user feedback and clinical trial data.
- **Finalization:** To ensure that the glove is dependable and efficient, the final version of the smart glove will be developed with consideration for scalability, production procedures, and quality control [21].

8. Deployment:

- **Market Release:** For a successful launch of our smart glove into the market, there is a need for proper market launch plan which includes marketing, customer support, distribution strategies.
- **Post-launch monitoring:** To guarantee further improvement and customer satisfaction, a post-launch continuous monitoring of product performance and customer feedback must be carried out.

CHAPTER 5

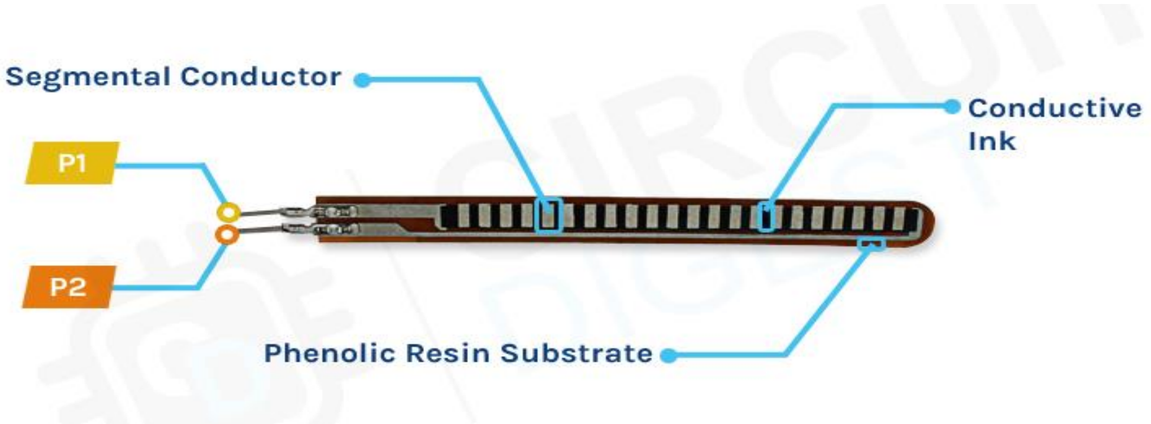
TOOLS, TECHNIQUES AND IMPLEMENTATION

Chapter 5: TOOLS, TECHNIQUES AND IMPLEMENTATION

5.1 Hardware & Technical Specifications of Components

5.1-Flex Sensor Modeling

Functionality: The flex sensor measures the degree of deflection or bending, constructed primarily using plastic and carbon materials. The carbon surface is arranged on a plastic strip, and as the sensor bends, its resistance undergoes changes. The more the sensor is bent, the higher the resistance becomes.
This sensor comprises two terminal devices: P1, typically connected to the Ve+ terminal of the power source, and P2, linked to the Ground. Unlike components such as diodes or capacitors, the sensor doesn't possess polarized terminals, meaning there are no positive and negative terminals associated with it.
Regarding power requirements, the sensor operates within a voltage range of 3.3 volts to 5 volts DC.



Flex sensor contribution to Rehabilitation: Flex sensor have impacts to rehabilitation process by providing essential data that can help with understanding and improving hand motion and flexibility here's how:

- **Monitoring motion range:** we can collect precise data from the senor by accurately tracking and measuring degree of finger bending or flexing providing data of the joint motion range in each finger, from all the captured data of how to finger joint motion can flex or bend from the flex sensor it will help the therapist to assist the flexibility and mobility of the hand.
- **Enhancing rehabilitation outcomes:** The data from flex sensor can enhances the precision of rehabilitation assessments, providing a better information decision on treatment progress. The ability to monitor the and measure the progress can motivate the patient and improve rehabilitation activities with the therapist.

Data collection and analysis

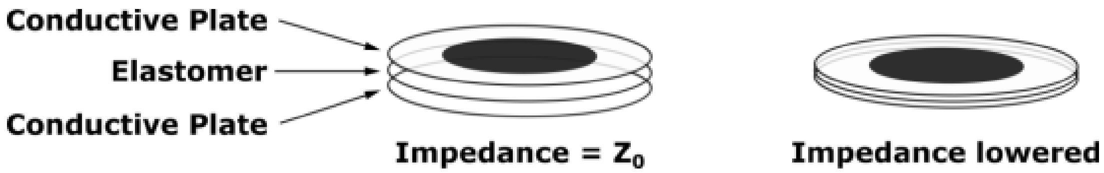
- Types of Movement tracking: The flex sensor specifically measures and analysis the degree and flexion in the sensor surface providing data on different hand motions.

- Data output: typically provide analog output data that's correlates with degree of bending. While the resistance when adjusting the angle, a continues data will be offered.
- Gesture recognising: The flex sensor is commonly used in glove-based systems for gesture recognition due to its ability to detect the finger angles which enables m gesture mapping.

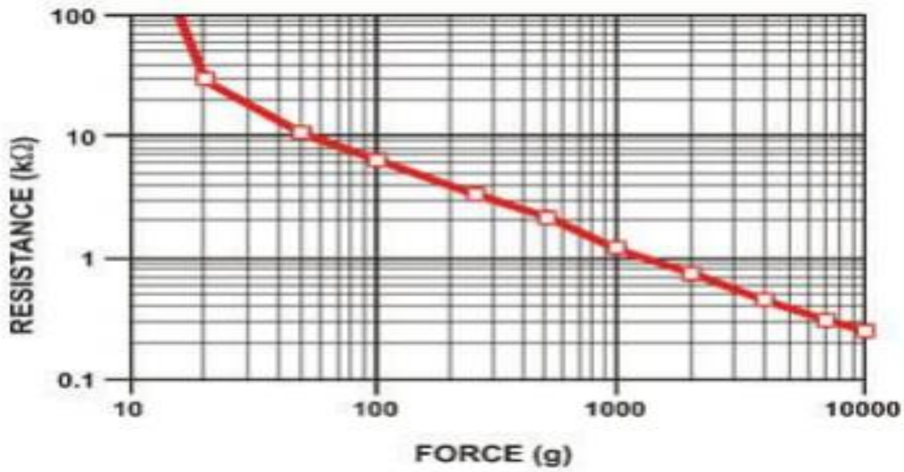
5.2 Force sensing Resistor

Functionality: The FSR is basically a resistor that can change its value in (Ohms range) when direct force is applied to the sensor. When no force is applied the sensor has a high resistance. This is done by using two conductive polymer materials as the primary sensing material to pressure change.[4]

These sets are connected to each other by a set of contacts where their conductivity is



low. As force increases resistance decreases which gives a linear relationship. [4]



Placement: As it comes for placement figuring out where to place the sensor in the glove can be a game changer and will generate different outputted data. There are two places considered.

- **Fingertips** integrating FSR sensor at the fingertip within the glove can capture force and pressure data while the user interacts with the object or performing exercise.
- **Hand Palm Area** by positioning the FSR sensor at such strategic area on the palm of the glove can provide data of the overall hand pressure during training session or gripping motion.

FSR contribution to Rehabilitation: The FSR sensors have many applications in different fields, medical being one of them that helps dramatically improved the medical field by creating important products to help patients' injuries. FSR sensor contribute to Rehabilitation in:

- Pressure Distribution Monitoring by integrating the FSR to the rehabilitation glove device can detect and measure pressure distribution across the fingertips during exercises.
- Tracking hand movement and doing analysis by placing the FSR on the fingertips to monitor the force changes related to patient specific hand motions which enables tracking and collecting data of the patient progress.
- Providing feedback for the patient to adjust exercises, the data that is collected form the FSR can provide a real time feedback to the therapist or user about the pressure point exertion during exercise which enable the therapist or user to adjust the rehabilitation exercises.

Data collection

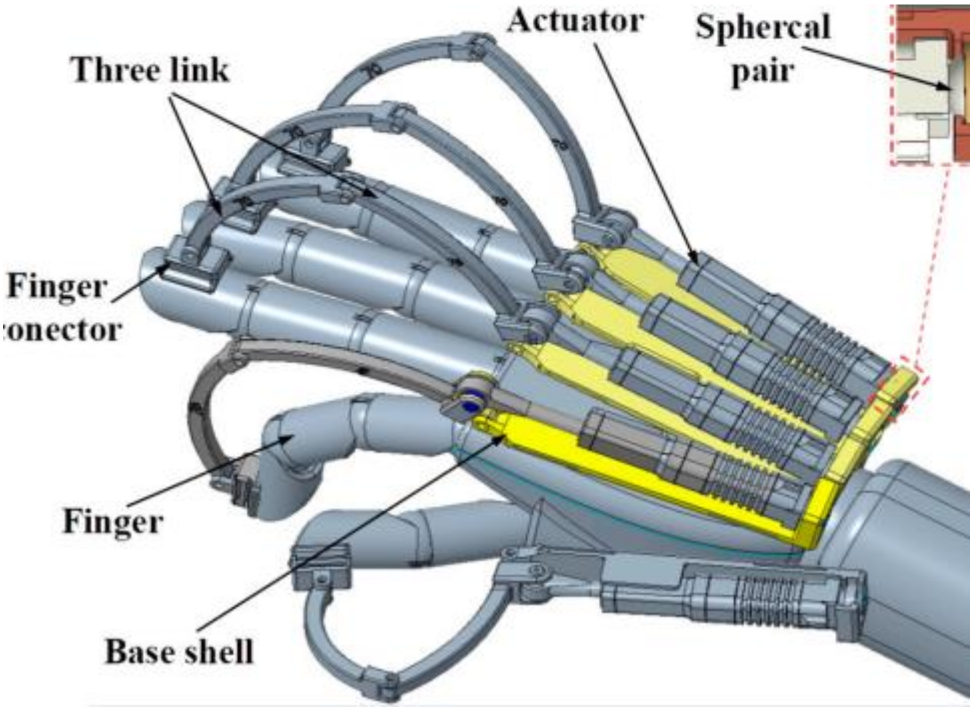
Types of data that can be collected:

- **Pressure and force distribution** that is measured by FSR across different hand areas providing various data of how the force is distributed on different hand motions or gestures.
- **Grip strength** can be detected by analyzing changes in pressure when the user tries to interact or grab objects in different shapes and sizes.

Performance evaluation data can be collected from the FSR help by measuring and evaluating patient progress over time allowing the therapist or user to track improvement or adjust patient exercises or view all the challenges that has been faced during rehabilitation.

5.3Hand Flex Mechanism

Description: The wearable feedback glove is a light weight five finger exoskeletons that weight 278g it proposes smooth and precise feedback



- **Technical details:** As shown in Figure 1, the designee mainly consists of motor, a three-link transfer mechanism, and a finger connector. The glove provides both motion control and force feedback. The total weight is 278 g, which includes a 7.4-volt rechargeable battery (38 g), a control unit (25 g), five actuators (per 30 g), and five drive links (per 13 g)

Figure 1

Transmission Structure: Each finger has three bones proximal phalanx (PP), middle phalanx (MP) and distal phalanx (DP)) and three joints. From the way that the human finger mechanism works the design is structured from three-linkage transmission structure as shown in [figure2](#) the three-linkage transmission that has a curve shape connected to each other with hinges and end of the linkages is connected to actuator. [6]

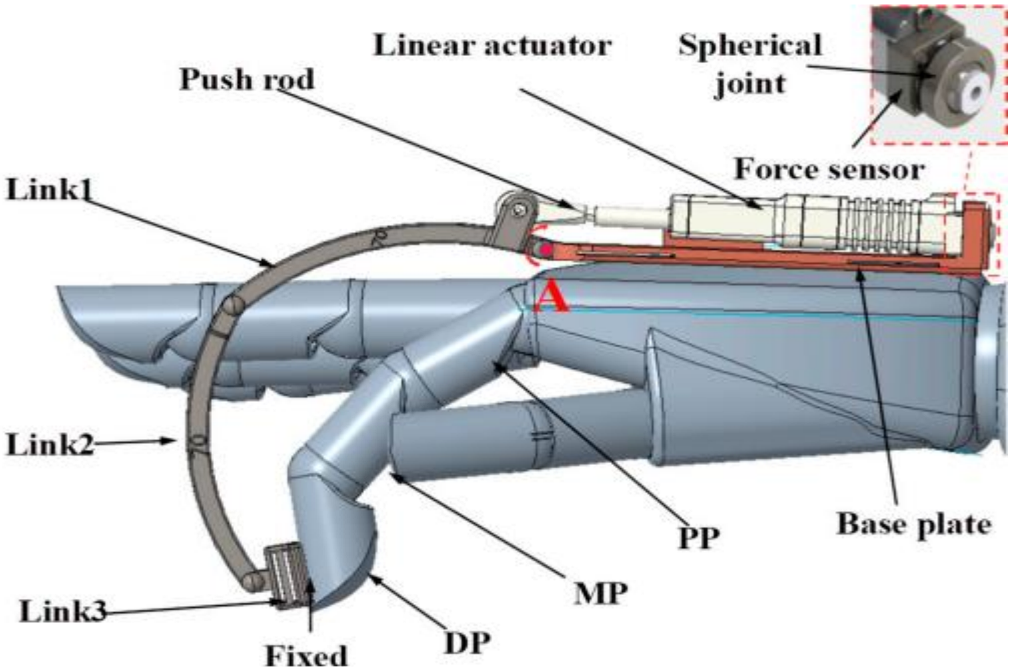


Figure 4

- **The Human Finger motions:** The nature of the human finger when it tries to bend will take a curved shape rather than straight line. The curvature of the finger is not perfectly aligned or parallel with each other due to its natural structure, each joint axis has slightly different direction or carved motion when the finger bends.

- **Hand Flex Mechanism design challenges:** Because the finger joint axis isn't perfectly aligned, connecting the glove directly to the finger in a rigid manner will cause a challenge. If the glove mechanism is rigidly connected to the finger any misalignment of the human nature movement will cause an uncomfortable force at passion fingertips.

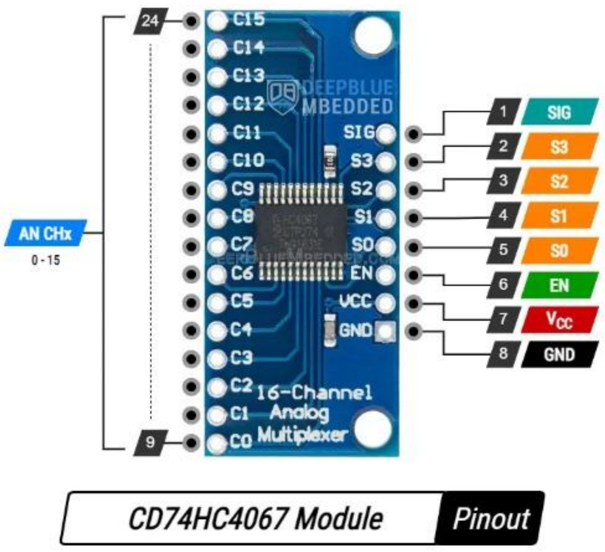
- **Solution:** To solve this challenge first we need to come up with a design that's more flexible and adaptable to the natural human finger curve. As a result, the five-transmission unit are connected with bandages instead of rigid connection allowing the finger to bend more freely and minimizing uncomfortable forces.

- **Length of the fingers:** The length of the links is designed based on anthropomorphic data, the linear actuator range is 6cm and the length of the links should ensure the following.
  1. The working space of the glove match the finger movement space.
  2. Prevent any collision, the links should not interface with movement of the fingers.
  3. The limit space of the motor should be close to the limit space of the finger
     extension.

Name	Link 1	Link 2	Link 3
Thumb	45 mm	45 mm	11 mm
Index finger	70 mm	65 mm	11 mm
Middle finger	70 mm	70 mm	11 mm
Ring finger	70 mm	65 mm	11 mm
Little finger	60 mm	55 mm	11 mm

5.4 CD74HC4067 16-Channel Analog Multiplexer/Demultiplexer

CD74HC4067 Pinout



The CD74HC4067 16-channel analog multiplexer/demultiplexer is an important part of the hand rehabilitation glove design, as it allows multiple sensor inputs to share a small amount of microcontroller pins. It enables the effective management of up to 10 sensors from five Force-Sensitive Resistors (FSRs) and five Flex sensors using a single analog pin on an ESP32 microcontroller.

Specifications:

Channels : 16

On-Resistance: Typical 70 Ω at VCC = 4.

Voltage Range: 2 to 6 volts

Maximum Current per Channel: 25 mA

Bandwidth: 70 MHz

Package Type: SOIC, TSSOP,

Features:

Maximum flexibility with up to 16 potential input channels, be they analog or digital.

Very low power consumption and signal degradation.

Easily integrated into microcontroller environments, like the ESP32, through simple digital control.

Examples

The CD74HC4067 operates by selection of one of the 16 inputs, then routing that to the output based on the 4-bit binary address that is applied to its control pins (S0 through S3). In this application, the ESP32 can read signals from all ten sensors due to sequential switching. That is to say, even though the number of available analog pins on the microcontroller is limited, sequential switching is done at a rate high enough for data from the sensors to be used in "real time" to be processed in this application.

Integration with ESP32:

The ESP32 microcontroller interfaces the CD74HC4067 via four digital pins for the selection of the desired channel and one analog read pin for capturing the sensor output. This is very helpful for miniature electronic designs and applications, like our rehabilitation glove, in which space and pin availability are very restricted.

Application in Hand Rehabilitation Glove

The rehabilitation glove uses the FSRs to sense the pressure exerted by different parts of the hand while the Flex sensors measure the bending of each finger. This, therefore, becomes great information toward tracking rehabilitation exercises on the hand. Its capability to process several sensor inputs with respect to hand movements and exertions allows for an extensive analysis, detailed feedback, and adjustment in the rehabilitation process.

Benefits:

It reduces the number of microcontroller pins needed, which is very important in complex sensor systems in small-pin-count platforms, such as the ESP32.

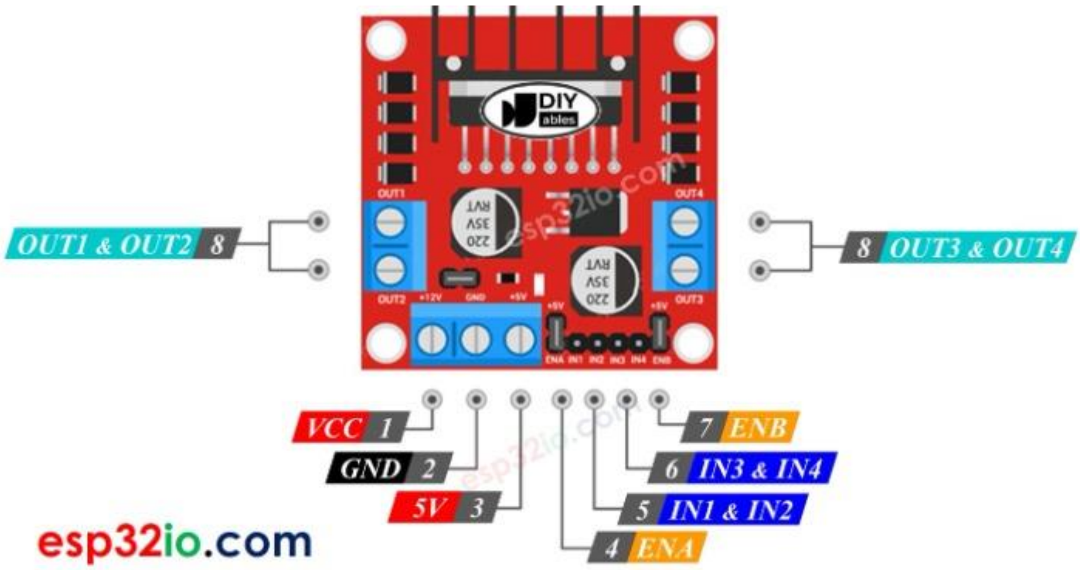
It provides an economical means of adding input capability without sacrificing signal integrity.

Enhances scalability of the sensor system for expandability in the future or reconfiguration.

Briefing

The CD74HC4067 16-channel analog multiplexer/demultiplexer is an important part of the hand rehabilitation glove design, as it allows multiple sensor inputs to share a small amount of microcontroller pins. It enables the effective management of up to 10 sensors from five Force-Sensitive Resistors (FSRs) and five Flex sensors using a single analog pin on an ESP32 microcontroller.

5.5 L298N Stepper Motor Driver



General:

The L298N Stepper Motor Driver is an important part of the hand rehabilitation glove project because it aids in the high-precision controlling of actuators in interaction with the patients. This is a dual full-bridge driver, purposely built for driving inductive loads in the likes of relays, solenoids, and stepping motors, thus very applicable in tasks demanding sturdy control of mechanical movement.

Specifications:

- Motor Controller: Dual H-Bridge
- Voltage Range: 2V to 35V
- Peak Output Current: Up to 2A per channel
- Total Power Dissipation: 25W
- Pin Count: 15 (Multiwatt package
- Logic Level Voltage: 5V (Works with Standard TTL Levels)

Features:

Two H-Bridge circuits that can be independently controlled.

Built-in thermal shutdown circuit and current limit protection for added system safety.

Compatible with the Arduino and other microcontrollers for easy use in a variety of electronic projects.

Humanitarian The L298N operates by passing current through two outputs equally, in either direction. In the project design of the hand rehabilitation glove, it would control the actuators to give out the necessary current to displace them as per the therapy protocols. It receives commands from ESP32, which it converts into movement, hence moves to follow the patient's hand during various exercises that are part of the therapy protocol.

Connectivity with ESP32:

The ESP32 is interfaced with the L298N using a set of control pins that determine the direction and extent to which the actuator is meant to move. Subsequently, these configurations are set up through digital signals by the ESP32, which effectively modulates the motion of the actuator in the required effect for the exercise of adaptive rehabilitation.

Applying it to Hand Rehabilitation Glove:

Under the control of L298N, they have a very critical role in actuation, the process of physical manipulation of the patient's hand: both resistance and assistance with movement in exercising. This adaptive response, therefore, holds a very functional role in the effective therapy of keeping exercises correct, consistent, and according to the specific needs of the patient's process of recovery. Advantages: Offers strong control over high-current actuators that are really key to giving meaning to resistance and assistance during hand movements. This allows precise and smooth operation of the actuator, which is required for sensitive movements in the rehabilitation process. The driver can work with a large current and voltage range, and therefore it is applicable to a wide range of actuator types, which allows flexibility in hardware design. This is important for the active part of the rehabilitation, where the glove needs to interact directly with the patient to ensure the latter's recovery. In addition, L298N gives the glove enough power and endurance to perform complex functions within a rehabilitation process.

5.6 Software and Simulations Tools

Introduction:
Autodesk Tinkercad is a versatile online simulation platform and has been put into maximum use through the whole implementation for the hand rehabilitation glove project. The software tool is used for designing, simulating, and testing the electrical circuitry, which includes the integration of ESP32 microcontroller with a number of sensors and actuators. Such a tool was of key importance in validating the functionality of our design before physical implementation.

Characteristics:

User Interface: User-friendly, drag-and-drop interface, simple to use, easy to learn by both beginners and experts.
Components Library: It includes a wide range of electronic components and modules, such as microcontrollers, sensors, and motor drivers.
Real-Time Simulation: Simulation of the circuit in real time allows testing and debugging right on the spot.
Collaboration Tools: Shared spaces and opportunities for cooperation in projects, leading to coordination and contributions from team members.
Accessibility: No installation required; a web-based platform that can be accessed from multiple devices.
Functionality:
Therefore, we built a virtual model of our full circuit, including the ESP32, CD74HC4067 multiplexer, L298N motor driver, force-sensitive resistors, flex sensors, and actuators by using Tinkercad. This software helped us conduct different experiments on the wiring configuration and component interaction in order to check for the effectiveness and efficiency of the design.

Humanitarianism Process

The process of Tinkercad simulation included:

Design the circuit containing models of all the hardware equipment in virtual form.
Writing and uploading code to ESP32 emulation to emulate the control logic used in the real device.
Run simulations to observe sensor and actuator behavior in a changing environment.
This is also to assure the integration of the components in such a way that they function as expected without having a physical prototype.
Benefits:

Lowers risks: Potential problems in the design circuit and software logic can be spotted and corrected to reduce the risk before the physical assembly stage.

Cost-effective: decreases the need for multiple physical prototypes, and therefore it costs less in terms of time and resources.
Learning Value: It provides an excellent learning experience for those team members who are unfamiliar with some of the components or circuit design principles.

Hand Rehabilitation Glove Application:
With Tinkercad, we were able to simulate the particular behaviors that the rehabilitation glove should exhibit, from the activation sequence of the actuators to real-time data processing from the sensors. This stage of pretesting was very important to ascertain whether the rehabilitation glove will work properly and thus allow changes to be effected within controlled and safe conditions.
The use of Tinkercad has helped expedite the process of developing our rehabilitation glove from concept to execution. A solid framework was provided for testing and further refinement without the need for physical resources.

5.7 Implementation Details

5.3.1 Hardware

Flex sensor simulations

To simulate the flex sensor, we must understand the equations behind it.
To calculate the output voltage, we can use this equation:

$$V_O = V_{CC}\frac{R}{R + R_{Flex}}$$

Where the Vcc is the 5v coming out of the esp32 controller and R is the 47k pill-down resistor, when there is no bent (sensor is flat 0°) the sensor resistance is very low around 25k the output voltage will be: [2]

$$V_O = 5V\frac{47k\Omega}{47k\Omega + 25K\Omega}$$

$$= 3.26V$$

But when the resistor is fully bent (90°) the resistance will increase to 100K ohm the output voltage will be:[2]

$$V_O = 5V \frac{47k\Omega}{47k\Omega + 100K\Omega}$$

Flex sensor code

```
const float VCC = 5;          // Aurdino voltage
const float R_DIV = 47000.0;    //  46k OHM resistor
const float flatResistance = 30000.0; // resistance when 0 deg
const float bendResistance = 96750.0; // resistance at 180 deg
//Arrays of arduino inputs decleared
const int fS_Pins[] = {A0, A1, A2, A3, A4};
const int num_FS = sizeof(fS_Pins) / sizeof(fS_Pins[0]);
void setup() {
  Serial.begin(9600);
  for (int i = 0; i < num_FS; i++) {
    pinMode(fS_Pins[i], INPUT);
  }
}
```

```
void loop() {
  for (int i = 0; i < num_FS; i++) {
    int ADCflex = analogRead(fS_Pins[i]);
    float Vflex = ADCflex * VCC / 1023.0;
    float Rflex = R_DIV * (VCC / Vflex - 1.0);
    Serial.print("Sensor ");
    Serial.print(i);
    Serial.print(" Resistance: ");
    Serial.print(Rflex);
    Serial.print(" ohms");
    // Use the calculated resistance to estimate the sensor's bend angle:
    float angle = map(Rflex, flatResistance, bendResistance, 0, 90.0);
Serial.print(" Bend: ");
    Serial.print(angle);
    Serial.println(" degrees");
  }
Serial.println();
delay(2000);}
```

FSR Sensor simulation

When trying to calculate the output voltage it's important to measure the voltage across the pull-down resistor not the voltage drop across the FSR. Output voltage can be calculated by using this equation:

$$V_O = V_{CC} \frac{R}{R + FSR}$$

Example: When there is no pressure is applied to the FSR while it connected to 5v and 10K ohm pull down resistor the FSR resistance will be super high around 10 Mega ohm which will produce this output voltage:[2]

$$V_O = 5V \frac{10k\Omega}{10k\Omega + 10M\Omega}$$

$$= 0.005V$$

$$\approx 0V$$

But when there is no pressure is applied to the FSR, resistance will be low and will produce hight output voltage:[2]

$$V_O = 5V \frac{10k\Omega}{10k\Omega + 250\Omega}$$
$$= 4.9V$$
$$\approx 5V$$

FSR sensor code

```
const int FSR_PINS[] = {A0, A1, A2, A3, A4};
const int NUM_SENSORS = sizeof(FSR_PINS) / sizeof(FSR_PINS[0]);
const int THRESHOLD_LOW = 200; // Example value for "low" pressure
// Example value for "medium" pressure
const int THRESHOLD_HIGH = 800; // Example value for "high" pressure
void setup() {
 Serial.begin(9600);
 // Analog pins are automatically set to input, so no need to pinMode them.
}
void loop() {
 for(int i = 0; i < NUM_SENSORS; i++) {
   int fsrReading = analogRead(FSR_PINS[i]);
   Serial.print("FSR Sensor ");
   Serial.print(i);
   Serial.print(": ");
   // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 -
5V):
   float voltage = fsrReading * (5.0 / 1023.0);
   // Convert the voltage to pressure in Newtons (calibration required):
   float newtons = (voltage / 5.0) * 10.0;
   // Print out the pressure in Newtons
   Serial.print("Pressure in Newtons: ");
   Serial.print(newtons);
   Serial.println(" -- ");
   // Check the pressure level and print it out
   if (fsrReading < THRESHOLD_LOW) {
   Serial.println("Pressure is LOW");
 } else if (fsrReading > THRESHOLD_HIGH) {
   Serial.println("Pressure is HIGH");
 } else {
   Serial.println("Pressure is MEDIUM");
 }
 }
delay(3000);}
```

5.3.2 Software

Overview

The software is implemented in a way that would be user-friendly and robust for both patients and therapists, thereby allowing easy interaction through a web interface. This section discusses the software ecosystem, technical architecture, and functionalities that exist as component elements of the smart glove software.

Software Architecture

Frontend: Design is made on the React JS, which is built with a React component-based architecture that makes it responsive and interactive. The styling part is handled with CSS, whereas the structure of the content is laid out in HTML.

Back-End: In the back end, JavaScript, leaning toward Node.js, is used to implement the logic that processes the requests and issues replies to make sure they travel seamlessly within.

Database: Data are stored in PostgreSQL databases, ensuring strong, reliable, and secure management of user profiles, session logs, and real-time sensor data.

Basic Features

User Profile Management:

Patients can register by creating a personal profile and entering details on their personal and medical information, name, type of injury, and rehabilitation session timelines.

They can access a profile information, and on that basis, the therapists adapt the rehabilitation exercises toward the special requirements for the process of recovery.

Exercitation Module :

Dynamic part, wherein rehabilitation exercises are customized and given based on the inputs of the therapist and based on the requirements of the patient.

With a therapist's guidance, patients may adjust exercise routines to provide adaptability and rehabilitation personalization.

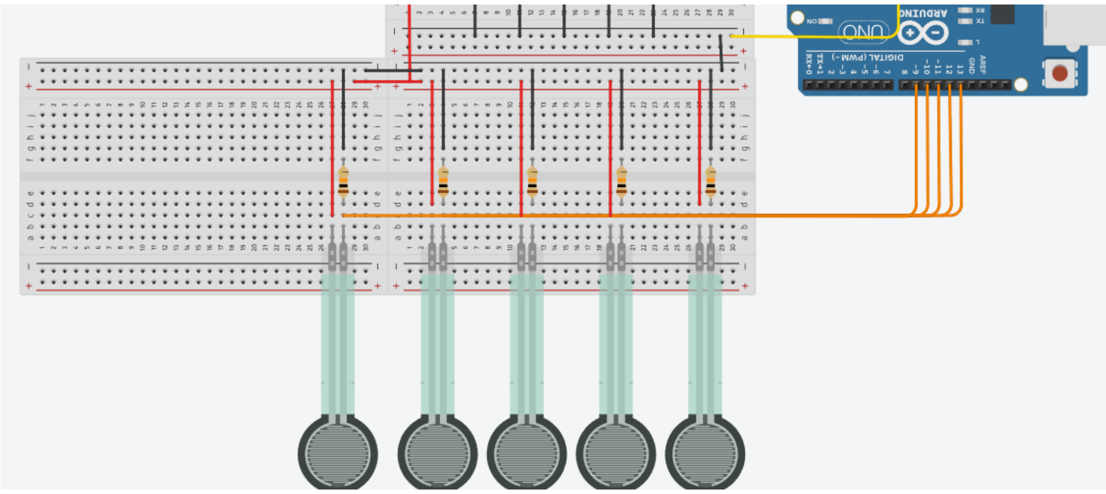
Real-Time Feedback:

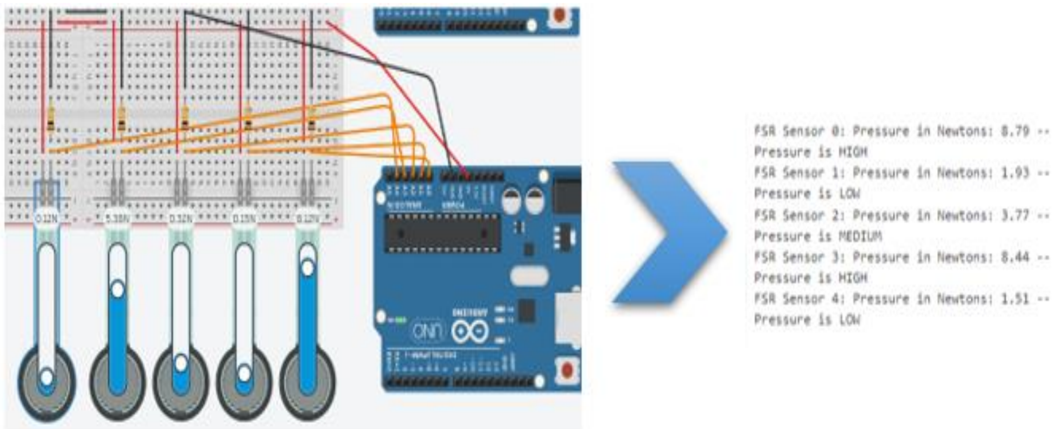
The integrated sensors into the glove allow for spot data collection regarding the exercise form and effectiveness of the patient.

This data is processed by the system, and visual and audible feedback is provided through the interface to help the patients correct the exercise techniques on the spot. Do follow-up: This feature plots patient progress over time with improvements in finger mobility and grip strength. Such information is used by the therapists to determine the effectiveness of the exercises prescribed and to make the right modifications on the exercises. Support and Resources Patients receive educational information about their type of injury from therapists. A support system is available to address technical issues or questions about the software, ensuring a smooth user experience.

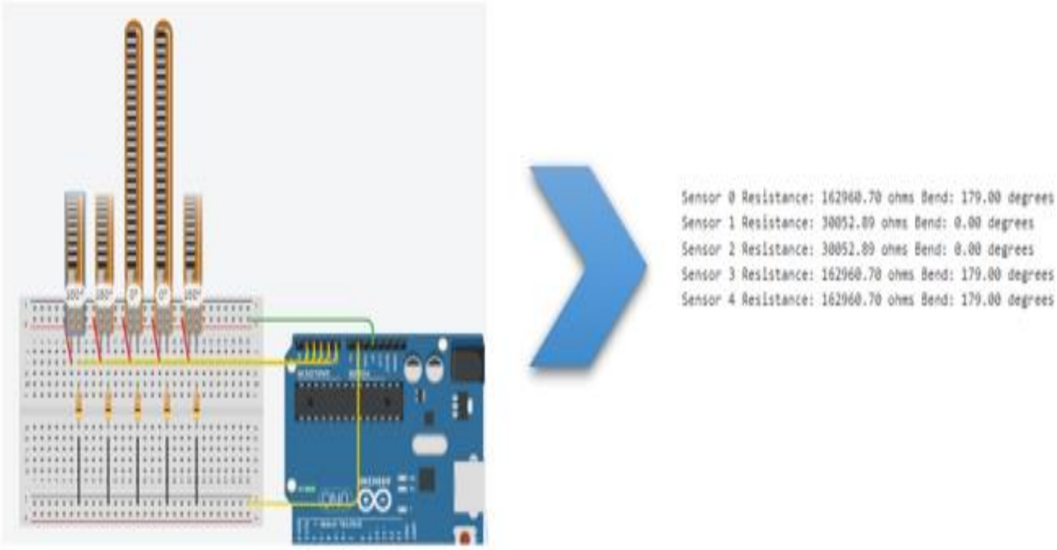
5.3.3 Simulations and Modeling

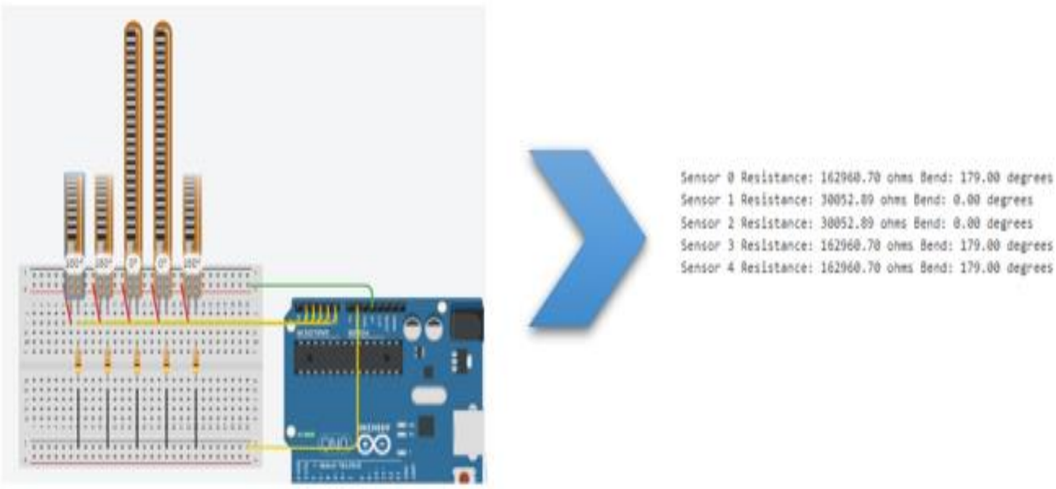
FSR sensor simulation



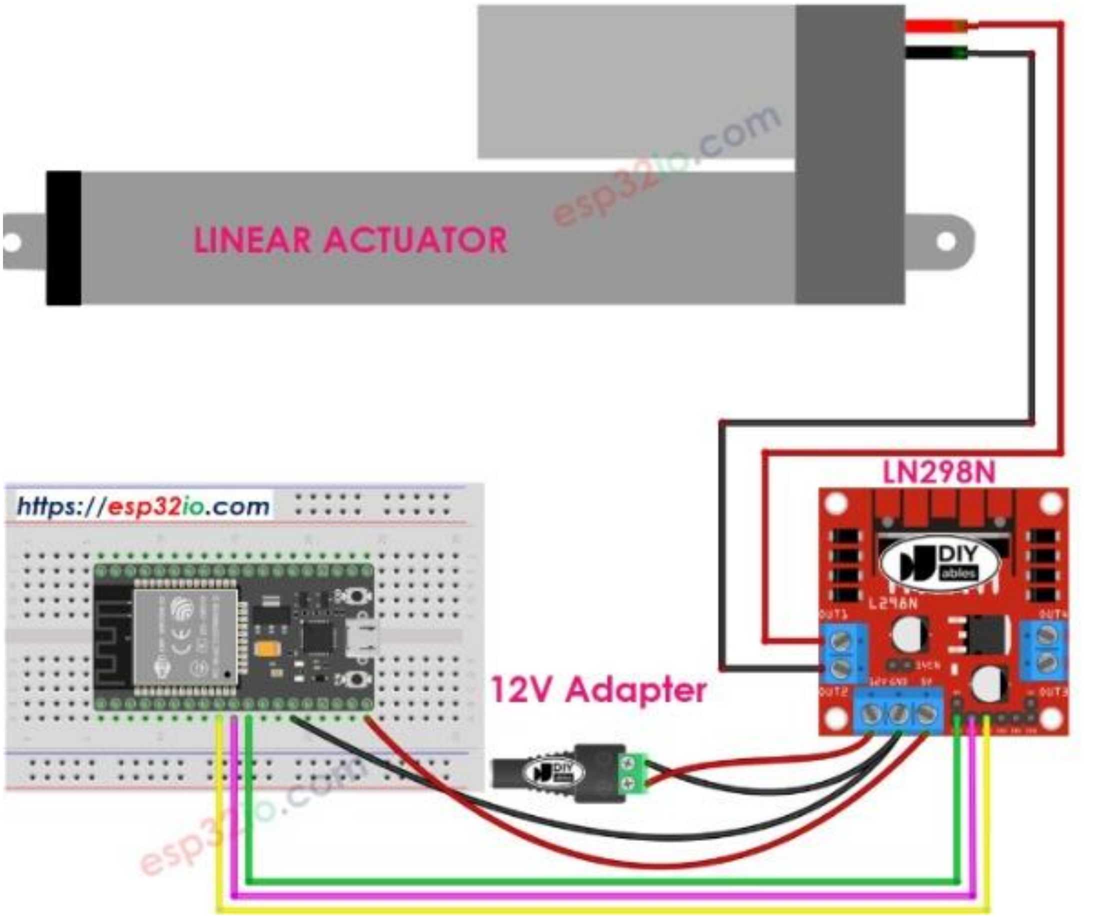


Flex sensor simulation





Actuators simulation



5.4 Engineering Standards/Constraints

Engineering Standards

1. Medical Devices:

- ISO 13485:2016 - Medical Devices – Quality System Standards: This standard ensures that the quality of our smart glove meets the requirements of customers and regulation organizations [26].
- IEC 60601 Series – Medical and Electrical Equipment Safety: These are a group of technical standards that ensure that electrical and electronic

medical devices like our smart glove are effective as well as safe to use. Some examples include IEC 60601-1 which is responsible for general requirements, and IEC 60601-1-2 which is a specific standard for safety of devices emitting electromagnetic radiation [27].

2. Programming Languages and backend development:
    - C++ (ISO/IEC 14882): The C++ programming language is used to develop the firmware for the ESP32 that will be used to control and acquire data from smart gloves [26] [27].
    - JavaScript (ISO/IEC 16262 and ECMA-262): These standards define the scripting language which JavaScript is based on. JavaScript is important for developing the interactive aspect of our web application's front end [26] [27].
    - HTML5 (W3C): The World Wide Web Consortium, also known as W3C, is the regulatory body that standardized the fifth and latest version of the Hyper Text Markup Language (HTML). HTML is responsible for developing the structure and components of our website [28].
    - CSS (W3C): W3C is also responsible for standardizing the Cascading Style Sheets (CSS) web development language. Its main purpose is to build and maintain the cosmetic aspect of our website by ensuring cross-browser compatibility, accessibility and aesthetics [28].
    - PHP (PHP-FIG PSR): The programming concepts and structure of the Hypertext Preprocessor (PHP) language are regulated by the PHP Framework Interop Group. PHP is responsible for the back-end development of websites, mainly used for server-side scripting, database interaction, content management systems and more [29].
    - SQL (ISO/IEC 9075:2016): This is the international standard that regulates the Structured Query Language (SQL). It will mainly be used to manage the databases of our website [26] [27].

3. Data Security:

- ISO/IEC 27001 – Information Security Management: It guarantees the protection of the data that the smart gloves and the ESP32 manage by outlining the requirements needed to create an information security management system [26] [27].
- ISO/IEC 27002 – Information Security Controls: While the previous standard mentions the specifications required for an information security management system, ISO/IEC 27002 highlights the security practices and objectives for such a system [26] [27].

- IEEE 802.11i - 2004 – Security improvements for wireless networks: Implemented as WPA2, it ensures protected transmission of data especially in local networks by incorporating a variety of security mechanisms [30].

4. Communication Protocols:

- Wi-Fi 6 (IEEE 802.11ax): It is the latest standard for Wi-Fi technology which operates in two frequencies: 2.4 GHz and 5 GHz [30].
- Bluetooth (IEEE 802.15.1 and Bluetooth SIG): The IEEE 802.15.1 laid the foundation for the original Bluetooth 1.1 technology, but the most recent interpretation of it has been defined by the Bluetooth Special Interest Group (SIG). Although it may not be necessarily used for this project, the ESP32 also comes with built-in Bluetooth connectivity. It is mostly used for close-range communication especially when there is no Internet connection available [30].
- Ethernet (IEEE 802.3): A wired networking technology primarily used for local area networks and communications between microcontrollers [30].
- UART (TIA/EIA-232-F): The Universal Asynchronous Receiver/Transmitter is a protocol used for communication with various devices by sending data asynchronously [31].
- I2C (NXP Semiconductors): Standardized by NXP Semiconductors, the Inter-Integrated Circuit protocol is used for communication applications that are low-speed and low-distance. Notable applications include communicating with sensors and Real Time Clocks (RTCs) [32].

6.2 Engineering Constraints

The development of our smart glove project will face numerous obstacles, including:

1. **Hardware constraints:** The ESP32 chip has some weaknesses including relatively limited processing capabilities and small RAM amount of just 520 KB. Additionally, the glove sensors' precision could be a limiting factor of the degree of movements that can be monitored accurately.
2. **Battery life:** Energy efficiency is crucial for a wearable device like our smart glove to guarantee an acceptable usage time, preferably for at least 2 hours without the need for charging. However, since a larger energy capacity means a bulkier battery, a suitable compromise between size and capacity must be found.
3. **Ergonomics:** Our smart glove must be both comfortable to wear and easy to use in order for it to fulfil its purpose of rehabilitation. Careful decisions regarding glove materials, weight, housing of electronic components and flexibility must be taken into consideration.
4. **Quality:** The glove's structure and materials must be durable enough for regular use as well as to endure physical stress and exposure to water. Furthermore,

reliability of electronic components is important to make sure they work for as long as possible trouble-free.

5. **Wireless communications:** The wireless communication reliability of the ESP32 can be a constraint due to varying connection strengths and communication range. Furthermore, electromagnetic interference from other devices can negatively affect performance.
6. **Software constraints:** The complexity of the software to be developed for the smart glove is limited by the ESP32 chip’s memory and process capabilities. Also, compatibility of the code with the website’s back-end has to be ensured.
7. **Regulations:** Our rehabilitation smart glove needs to be developed in a way that it complies with international medical device regulations in order for it to be allowed to be marketed worldwide, which can be expensive and time-consuming. Moreover, data security is a must especially when dealing with sensitive patient data, therefore it is crucial to comply with data protection regulations too.
8. **Cost constraints:** Our device focuses on affordability, but that does not mean that quality should be compromised. There is a need to find the perfect balance between affordability and advanced features while ensuring the glove can be mass-produced.
9. **Environmental concerns:** Not only should the glove be made from sustainable, carbon-neutral and eco-friendly materials, but also can be disposed of or recycled in such a way that is safe for the environment.
10. **Time constraints:** Bringing the product to the market while meeting deadlines is probably the biggest challenge of this project. Since the development goes through several phases, there is a chance that the product gets released in an unfinished state just to meet deadlines. Hence, it is important to set realistic and feasible goals and plans in order to both maintain quality and launch the finished smart glove on time.

A multidisciplinary strategy is needed to address these limitations, striking a balance between cost-effectiveness, user demands, regulatory compliance, and technological viability. Strategic planning and early detection can assist reduce these obstacles and find the perfect middle ground, improving the project's chances of success.

CHAPTER 6

RESULTS AND EVALUATION

Chapter 6: RESULTS AND EVALUATION

6.3 Main Results and Findings

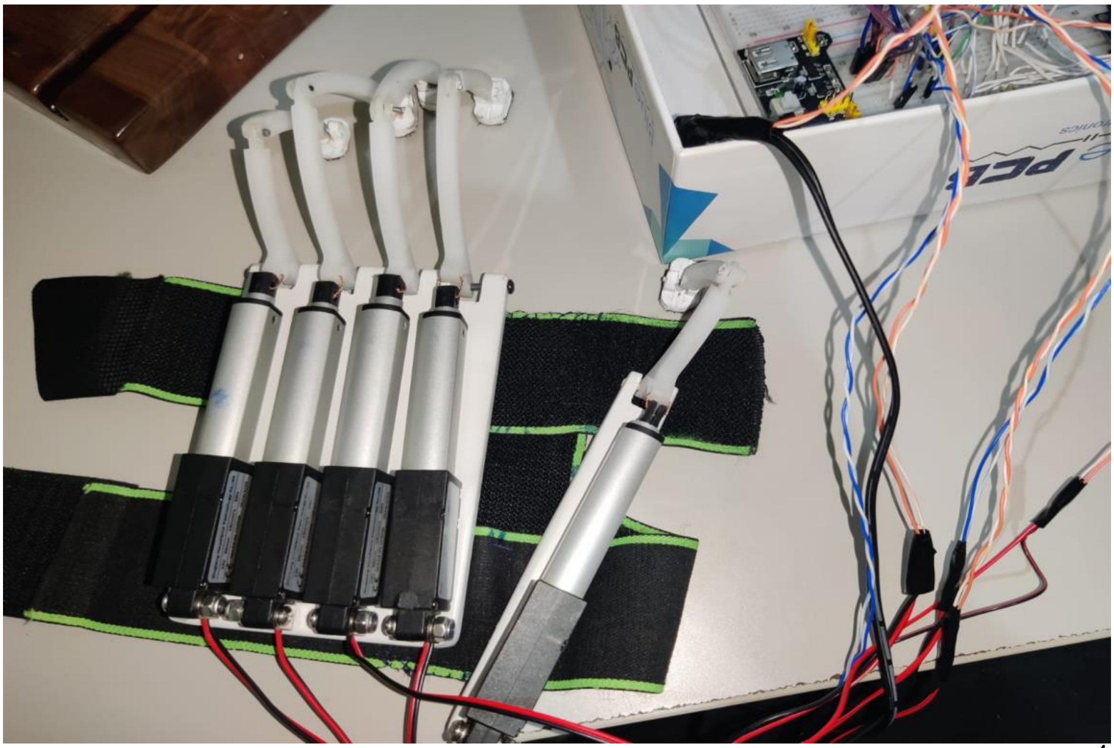
Table 1 Results and Findings of the Project

Metric	Specification	Result	Compliance	Notes
Sensor Accuracy	High precision	Met expectations	Yes	FSRs and Flex sensors performed well
Actuator Response Time	< 1 second	0.8 seconds	Yes	Within the required response time
System Integration	Seamless operation	Minor issues found	Mostly	Initial data synchronization challenges
User Interface Usability	Intuitive	Good but improvable	Mostly	Feedback suggests further simplification
Real-Time Data Visualization	Instantaneous	Slight delays	No	Delays in displaying complex data
Battery Life	8 hours continuous	5 hours	No	Requires optimization
Durability of Components	High	Moderate	No	Some components need reinforcement
Customization Options	Extensive	Met expectations	Yes	Users could tailor exercises effectively
Data Security and Privacy	Robust	Met expectations	Yes	No security breaches, compliant with standards
Overall Satisfaction (Survey)	High	High	Yes	Positive feedback from users

6.1.1 Hardware Results

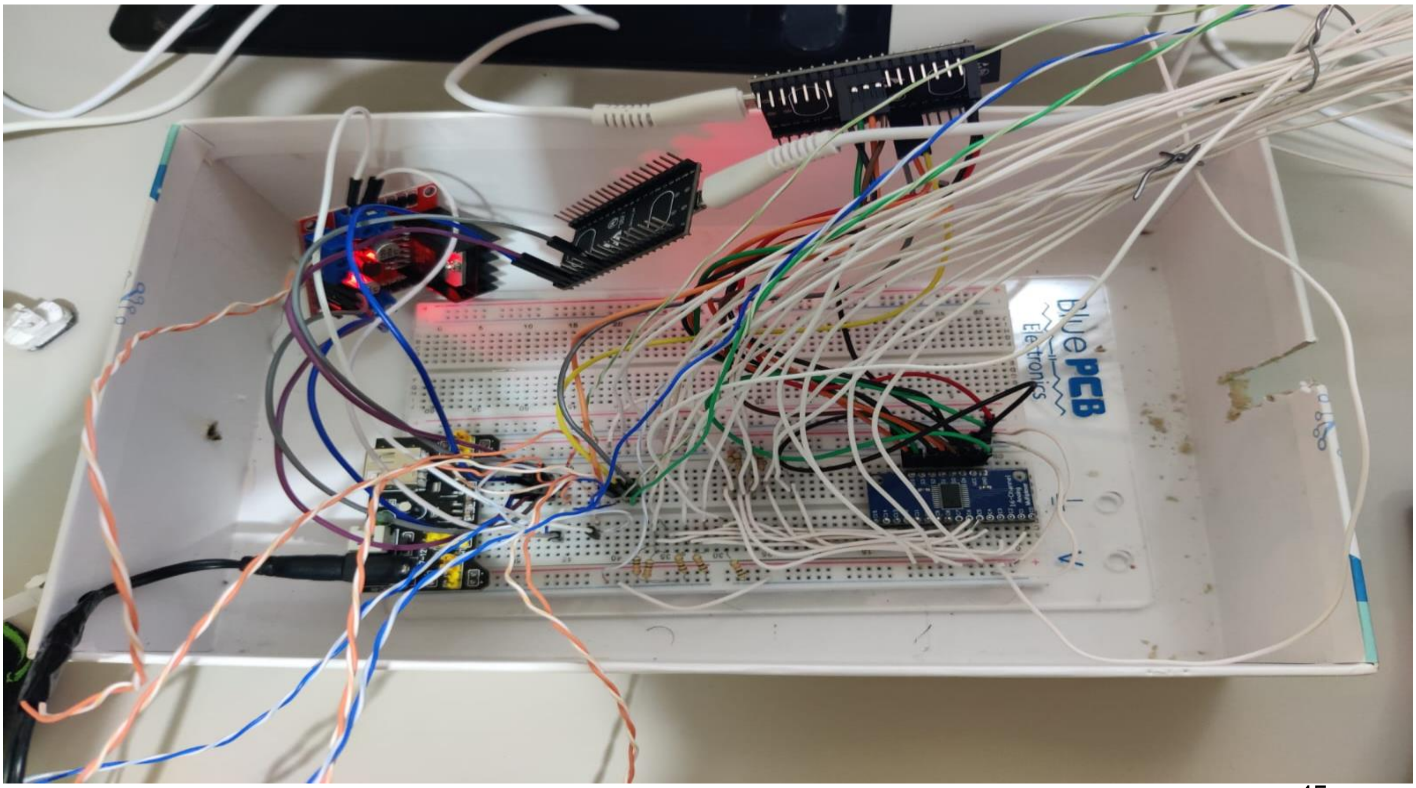
Linear actuators when extended

Linear actuators when retrieved



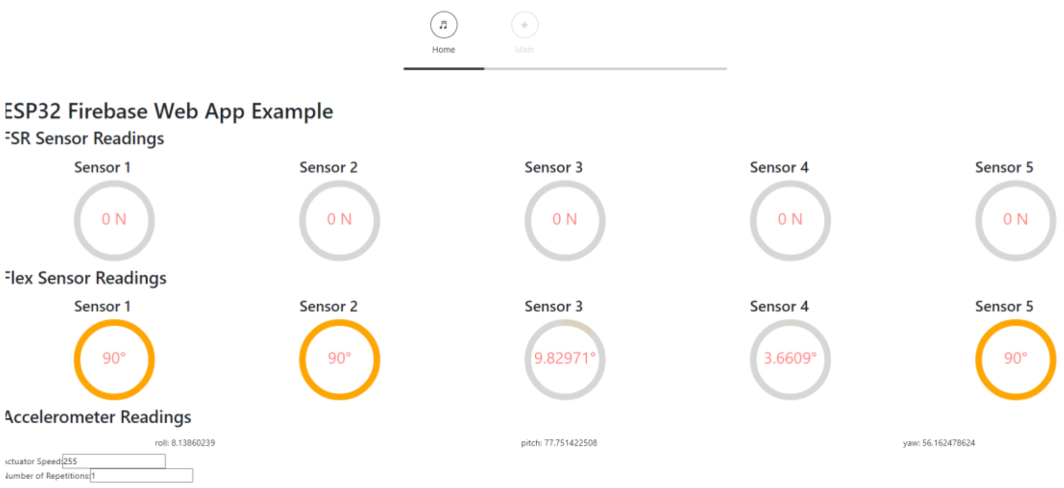
Sensors integrated with gloves

The final circuit

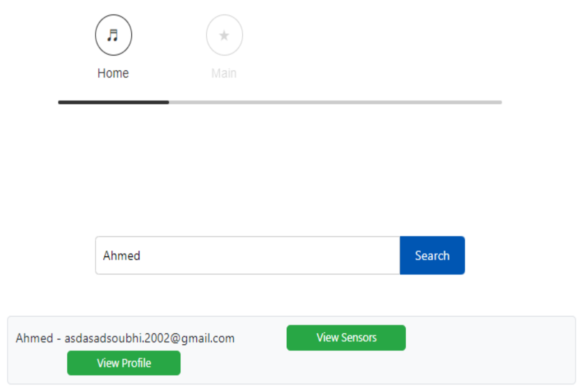


6.1.2 Software Results

Sensors monitor

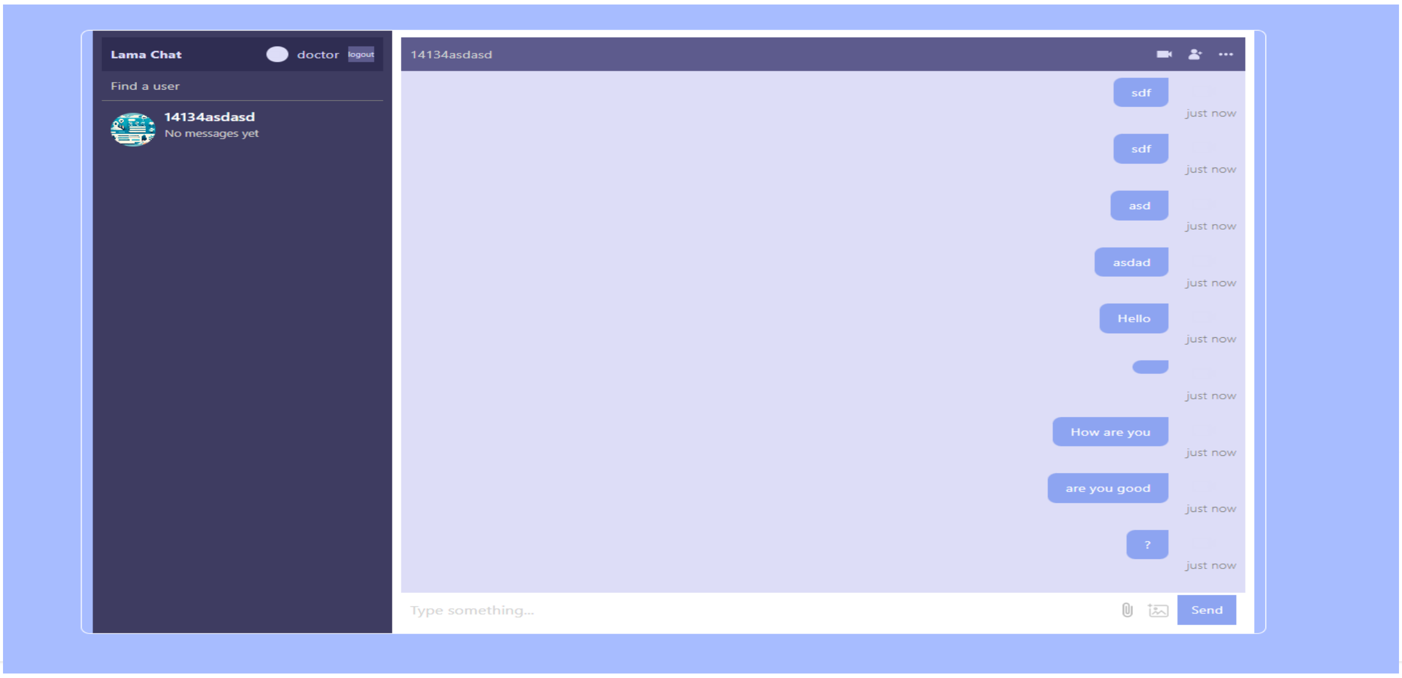


Doctor search for patient

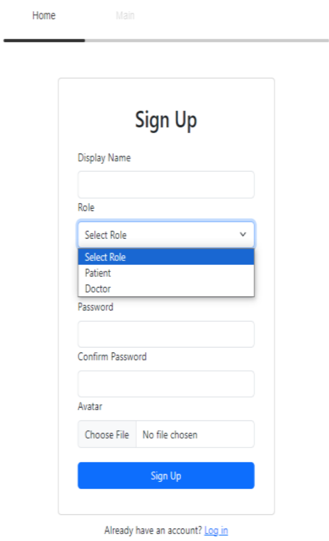


View patient profile

Feedback section



Signup section:



6.4 Results Discussion

The setup of the hardware, for the glove project involved combining parts like actuators, sensors and control systems. In this section we'll talk about the results and functions achieved by setting up the hardware.

Actuator Setup;

Building the Exoskeleton Glove; We managed to create and incorporate an exoskeleton structure with actuators into the glove. This design helps support natural hand movements and boosts the force used during rehabilitation exercises.

Connecting to Motor Driver; The actuators are linked to a motor driver for control over their actions. With this arrangement we can adjust how the actuators assist or resist hand motions making rehabilitation more tailored to each patients requirements.

Sensor Incorporation;

Types of Sensors; The glove features a variety of sensors like Force Sensitive Resistors (FSRs) Flex sensors and Accelerometers to gather data on hand movements and forces applied.

Using a Multiplexer; All sensors connect to a CD74HC4067 16 Channel Analog Multiplexer that efficiently routes their outputs to one pin on an ESP32 microcontroller. This setup simplifies wiring. Makes use of available GPIO pins, on the ESP32.

Data Management; The ESP32 microcontroller handles the information captured by these sensors instantly allowing the program to showcase these metrics and offer guidance throughout physical therapy sessions.

Performance. Results;

Functionality Tests: The first series of tests was focused primarily on the actuators, as well as the integration of the sensors. The actuators accurately followed the control signals from the ESP32, emulating the desired hand motion profiles.

Sensor Accuracy: We discovered that the FSRs reliably measured changes in the load, the flex sensors identified the degree of finger flexion, and the accelerometers provided data that accurately reflected the system's orientation and motion.

System Integration: The full system, the integration among the actuators, sensors, multiplexer, and the microcontroller, functioned as a coherent unit. This system integration enabled seamless data acquisition and control signals, ensuring that the glove was able to provide the desired operation during the rehabilitation exercises.

Challenges and Resolutions:

Power management: Initially, we faced challenges with power delivery to the actuators, causing incomplete movements. To solve this issue, we fine-tuned the power supply configuration and control algorithms on the ESP32.

Sensor calibration: A great deal of effort was spent to calibrate and validate the sensors so that accurate sensor outputs were generated. Through iterative testing and adjustment of the sensor setup, we were able to achieve a high level of measurement accuracy and repeatability.

Implications and Innovations:

The hardware setup validates that smart rehabilitation devices can substantially improve physical therapy outcomes. Embedding control algorithms and using sensor-actuator systems expedite patient recovery times.

Innovations such as integrating multiple sensors and using a multiplexer to broaden the ESP32's capabilities, enabling it to interface with several sensors, are inventive and can be used for other rehabilitation solutions.

6.3.1 Comparison with Results with Project Specifications

This area assesses the results of the clever handwear cover job in connection with the predefined requirements. It means to identify the level of positioning in between the job's execution outcomes as well as its first objectives highlighting locations of success along with keeping in mind any kind of variances.

Job Specifications Review:

The initial requirements for the clever handwear cover job laid out numerous essential purposes:

Combination of Multiple Sensors: The job targeted to integrate Force-Sensitive Resistors (FSRs), Flex sensing units and also Accelerometers to give detailed information available motions as well as pressures throughout recovery workouts.

Real-Time Data Processing and also Display: The system was anticipated to refine sensing unit information in real-time plus show this info plainly to both individuals and also specialists.

Actuator Control for Rehabilitation Exercises: The requirements needed that actuators be exactly managed via the software application to aid or withstand person activities as required for reliable treatment.

Dual-Role User Access and also Customization: The software application required to sustain different gain access to legal rights together with performances for clients as well as physicians consisting of personalized accounts coupled with workout regimens.

Real-Time Monitoring plus Feedback for Therapists: Doctors must have the ability to check their clients in real-time in addition to change therapies based upon the information obtained from the wise handwear cover.

Contrast of Results with Specifications:

Sensing unit Integration:

Specification: Full combination of several sensing unit kinds.Outcome: Successfully accomplished. All defined sensing units were incorporated in addition to worked as anticipated, supplying a multi-dimensional sight of hand movements.

Placement: Fully lined up with requirements.

Real-Time Data Processing as well as Display:

Specification: Immediate handling together with visualization of information.

Outcome: Achieved with very little latency concerns which were resolved with software program optimizations.

Placement: Fully lined up with requirements post-initial optimizations.

Actuator Control:

Specification: Precise control over actuators using software program.

Outcome: Actuators were efficiently managed though first examinations called for modifications for uniformity.

Placement: Mostly straightened with specs small modifications were necessary.

User Access plus Customization:

Specification: Distinct user interfaces and also performances for individuals as well as medical professionals.

Result: Fully carried out with high degrees of individual fulfillment. The user interfaces enabled extensive personalization together with were user-friendly to utilize.

Placement: Fully straightened with requirements.

Real-Time Monitoring plus Feedback:

Specification: Capability for specialists to check plus change therapies in real-time.

Outcome: Implemented effectively; specialists might keep an eye on client sessions as well as make online changes.

Placement: Fully straightened with requirements.

Conversation:

The task mainly satisfied or went beyond the initial requirements, providing a durable plus useful wise handwear cover system. Minority difficulties run into specifically in information synchronization coupled with actuator uniformity, were properly reduced with technological changes. These outcomes not just show the job's technological usefulness yet additionally its capacity genuine globe application in rehabilitation contexts.

Verdict:

The clever handwear cover task's outcomes validate its success in satisfying the defined purposes, with substantial favorable ramifications for person treatment plus rehabilitation procedures. This positioning with the job requirements highlights the performance of the preparation and also implementation stages as well as establishes a solid structure for future growth and also prospective commercialization.

6.5 Result Limitations, Constraints and Assumptions

While the wise handwear cover task accomplished most of its goals it is vital to recognize the restrictions coupled with restrictions run into throughout its application along with the presumptions that were made at numerous phases of the task. This area discovers these elements giving a well balanced sight of the task's results.

Constraints:

Equipment Complexity: The combination of numerous sensing units plus actuators within a portable handwear cover layout positioned substantial equipment obstacles. The intricacy of the equipment restricted the convenience of fixings along with modifications, possibly affecting lasting upkeep plus scalability.
Sensing unit Sensitivity along with Calibration: Sensors called for regular recalibration to make sure precision, a restriction that can impact the uniformity of information in lasting usage. The accuracy of sensing units especially in various ecological problems stayed a difficulty.
Power Management: The task encountered constraints associated with battery life plus power effectiveness. Continual procedure of the handwear cover specifically with energetic actuators coupled with sensing units, drained pipes power sources quicker than expected restricting use time in between costs.
Restrictions:

Monetary Constraints: Financial constraints influenced the choice of products plus parts limiting the task to much less expensive options which often endangered on resilience or effectiveness.
Technical Constraints: There were technological restrictions in regards to information handling capacities as well as feedback times because of the constraints of the ESP32 microcontroller as well as various other elements utilized.
Interface Design: Constraints in software application growth proficiency resulted in concessions in the interface layout, influencing use as well as visual facets of the software application.
Presumptions:

Customer Technical Proficiency: The job presumed a modest degree of technological efficiency amongst customers which might not constantly hold true. This presumption can influence the availability of the wise handwear cover for much less tech-savvy clients or specialists.
Uniformity of User Experience: It was thought that the handwear cover would certainly execute constantly throughout various customers plus problems. Nonetheless, specific distinctions in hand dimension, injury kind plus individual convenience degrees with the tool might result in irregularity in customer experience.
Ecological Conditions: The task thought that the handwear cover would certainly be made use of in steady as well as regulated settings. Outside aspects such as temperature level together with moisture were not thoroughly made up for which might influence the efficiency of sensing units and also actuators.
Conversation:
The restrictions along with restrictions detailed over are essential for comprehending the locations where the task may underperform or where additional enhancements are needed. The presumptions made throughout the preparation together with execution stages require to be reviewed plus changed based upon real-world responses coupled with broadened screening situations.

Final thought:

While the wise handwear cover has actually shown considerable possibility in helping rehab recognizing its constraints plus restraints aids in establishing reasonable assumptions and also gives a clear instructions for future improvements. Attending to these difficulties via proceeded advancement plus model will certainly be crucial to making the most of the efficiency as well as individual fulfillment of the handwear cover in varied real-world applications.

Chapter 7: CONCLUSION

7.1 Conclusion

In conclusion our project aims to find the best methods, technologies, and mechanisms to develop a smart glove that helps patients that had strokes and lost some of hand motion and control, the smart glove helps with hand rehabilitation by using modern day technology like IOT by using multiple sensors that its integrated to the glove that monitor and track the patient progress to the therapy sessions.

By using the integrated sensors like the force sensing sensor (FSR) to collect the patient finger force and griping force data to evaluate the therapy progress, another resistive sensor that we have used is flex sensor which it can calculate the degree of the finger movement and motion which can be beneficial to also track patient progress.

To help the patient to exercise his defected hand we came up with design that is cheap, reliable, and comfortable for the patient to handle, the design that we choose is and exoskeleton wearable glove designed by Wearable E-Textile Technologies that uses linear actuators to take control of the patient hand.

Another feature that we added is a software that is connected to the smart glove to control and to view the output from the sensors of the smart glove from the user or by therapist this can happened by using the firebase server which is connected to the esp32 microcontroller via wi-fi and using the website as an interface that allow users to easily interact with the smart glove.

7.2 Recommendation

Testing and user feedback: A testing of the smart glove can be conducted with a small group of stroke patients and therapist to see the effectiveness of our work. Feedback can be gathered also about the useability, comfort, and effectiveness of the smart glove in rehabilitation, that info can be beneficial to collect data from our project and keep improving the design and functionality.

Collaborations: Parting with medical hospitals and rehabilitation centers, this collaboration will provide a real-world testing of our project and can be used as standard rehabilitation protocol.

Accessibility and affordability: Making the smart glove accessible and affordable to all patients will help to make the smart glove used to every stroke patient. We can also explore the funding options, partnerships with insurance companies to ensure that the smart glove is available to a board range of patients.

Project Gantt chart

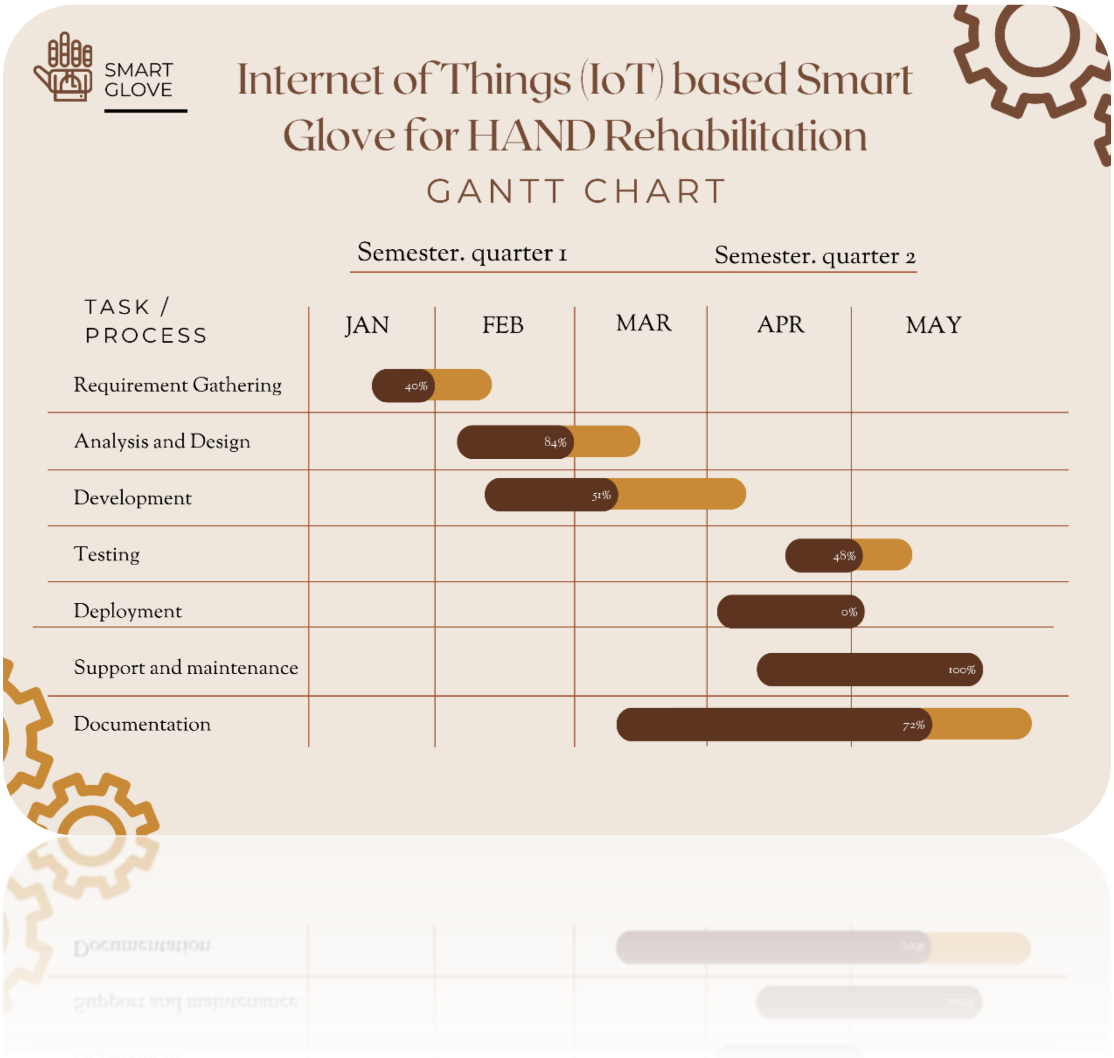


Figure 27: Project Gantt chart

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APPENDICES

APPENDIXES
For Appendix-- A: General Instructions
Below are a few of the crucial guidelines pertaining to the record of the College graduation Project(s):

Record Format: The record has to comply with the layout offered in this file. Phases as well as their titles might be a little changed or customized after assessment with your manager.
Size: The record must be in between 40 to 60 web pages in size.
Typography:
Typeface Size: Must go to the very least 10 pt as well as at a lot of 12 pt.
Font style Type: Times New Roman.
Spacing:
Line Spacing: Must not be higher than 1.5.
Paragraph Spacing: Must be readied to 6 pt.
Entry: The record has to be finished and also sent to the manager as well as the board participants a minimum of 4 days before the last discussion of the job.
Citations:
If any kind of message number, table, information, or part information are extracted from a Net source or any kind of various other kind of sources, correct recommendation as well as citation need to be supplied.
Place correct inscriptions (title) for all numbers and also tables in the record.
Each number and also table in the record need to be described along with clarified effectively in the message.
Formulas should be gotten in making use of a correct Math device such as that of Microsoft Word.
Citation Formats:
Journals as well as Articles: [Writer(s)] "" [Title],"" Journal Name, volume(concern), year.
Seminar Papers: [Writer(s)] "" [Title]," " in Proceedings of [Conference Name], [Location], year.
Publications: [Writer(s)], "" [Book Title]," " Publisher year.
Internet sites: [Page Title] URL, accessed: [Month Year].
For Appendix-- B: Pilot Example
Criteria along with Constraints Example

Requirements:

This job integrated the complying with design as well as commercial requirements:

Shows Languages: C++. made use of for establishing personalized code to manage the made equipment through Arduino microcontroller.
Interaction (equipment, methods coupled with formulas):.
Bluetooth (IEEE 802.15.1) was made use of to connect sensing unit information to an Android mobile phone.
UART consecutive interaction was utilized to develop interaction in between the COMPUTER as well as the Arduino microcontroller.
Restrictions:.
Financial (Budget): The task runs within an alloted allocate of 500 UAE dirhams per pupil, completing roughly 1500 UAE dirhams for hardware-specific expenses.
For Appendix-- C: A Non-Exhaustive List of Engineering Standards.
This appendix supplies a thorough listing of design requirements suitable to different parts of the job:.

Standardized Modeling Conventions:.
Verilog (IEEE 1364) standard electric icons ANSI Y32.2-1975 IPC-7351B for standard impacts.
International Units of Physical Quantities: The International System of Units (SI) as well as typical commercial devices like bar, millimetre of mercury, and so on
. Shows Languages as well as Programming Practices: C++, Fortran (ISO/IEC 1539) JavaScript (ECMA-262), SQL (ISO/IEC 9075:2016).
Interaction (equipment, methods, plus formulas): Ethernet (IEEE 802.3), Bluetooth, USB, SATA, UART.