

# Dual Glove Stroke Therapy System

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*Hand impairment is a common long-term consequence of stroke, affecting over half of survivors and limiting functional independence.<sup>2</sup> While proprioceptive training has shown promise for sensorimotor recovery, few rehabilitation tools specifically target hand proprioception.<sup>3</sup> We present REX0, a dual-glove rehabilitation system designed for motion replication and proprioceptive retraining in post-stroke patients. The system pairs a Control Glove, which measures finger joint motion using flex sensors, with a Response Glove that mechanically reproduces these movements via micro-servo-driven wire actuation and spring-based retraction. Low-latency communication between gloves is achieved using ESP-NOW, enabling real-time mirroring of hand postures. A supporting web interface provides a training mode and a real-time glove visualization. Prototyping demonstrates reliable finger motion replication and acceptable latency for wireless communication between the gloves and the primary device. REX0 combines wearable mechatronics with proprioceptive training principles to support repeatable hand rehabilitation.*

## I. INTRODUCTION

### A. Project Background

Stroke is one of the leading causes of long-term disability with between 55%-75% of survivors experiencing upper limb impairment<sup>1</sup>, making the restoration of fine motor control a primary challenge in post-stroke rehabilitation. Although partial recovery is common, motor improvements typically plateau within the first six months, underscoring the critical need for accessible and engaging rehabilitation technologies that support continuous, high-repetition therapy.

To address this need, we aim to provide a rehab solution through proprioceptive training, which in recent years has become more popular for research regarding post-stroke motor function rehabilitation. Proprioception is defined as the body's innate sense of limb position and movement, allowing for movements such as touching your hands together with your eyes closed or matching your hand movements with your eyes closed.<sup>1</sup> Given its role in basic movement and motor function, proprioception is undoubtedly affected as the result of strokes, especially in the context of hand motor function.<sup>5</sup>

In a recent pilot study, it was found that proprioceptive training did provide notable improvement in the proprioception and motor function in the upper extremities of post-stroke patients<sup>3</sup>, and we aim to branch off this study by developing a wearable rehabilitation device specifically targeting hand impairments in stroke patients.

We propose REX0, a dual-glove, sensor-driven rehabilitation system that integrates wearable mechatronics, wireless communication, and an accompanying web/mobile application to facilitate motor retraining. The system consists of a Control Glove, worn on the user's unimpaired hand, and a Response Glove, worn on the impaired hand. Together, they enable a training modality we call Motion Mimicry, in which hand postures performed by the healthy hand are reproduced on the impaired hand through a combination of sensing and actuation.<sup>6</sup> With this design, we hope to provide rehabilitation support through motion replication as well as the previously mentioned proprioceptive training.

To detail the gloves more, the Control Glove utilizes flex sensors on each finger to measure the degree of joint bending via resistance readings (Fig. 1), and that information is transmitted wirelessly to the Response Glove, which mirrors the movement by actuating its own fingers until its flex sensors readings match those of the Control Glove.

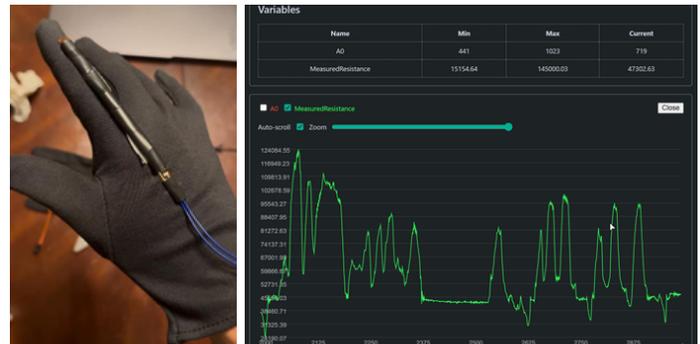


Figure 1 – Flex sensor on glove + resistance reading testing

To actuate the fingers, we used a wire-anchor mechanism that guides the bending trajectory with a micro servo that applies the pulling force and an extension spring system applying a retracting force to achieve neutral position post-movement, allowing for a controlled, repeatable curling motion. (Fig. 2)

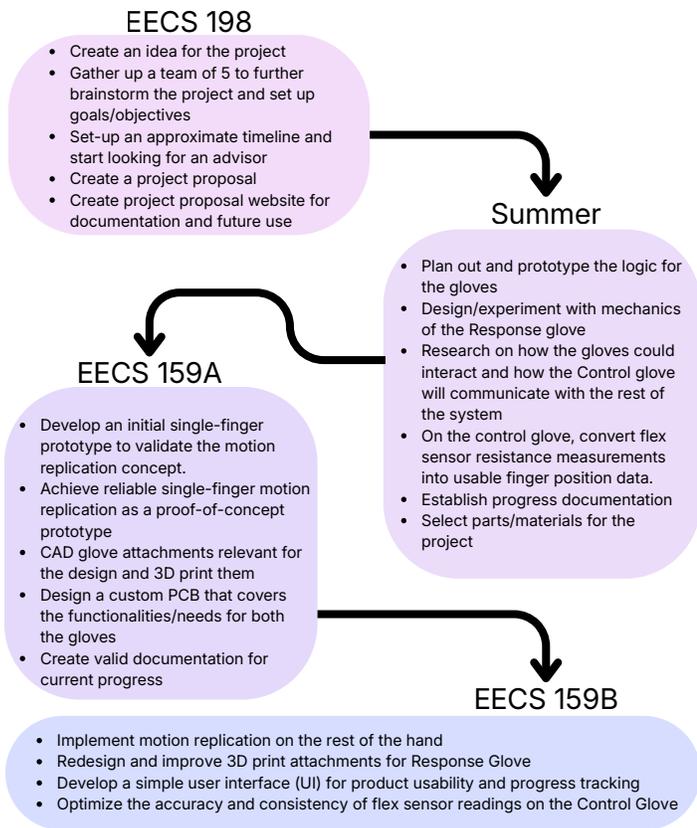


Figure 2 – Response Glove Single Finger Mechanical System

To complement the hardware system, a lightweight web-based application provides real-time visualization and monitoring of device operation. The interface displays finger positions for both gloves, system connection status, and assistive control behavior through numerical indicators and animated 3D hand models. It also includes a training mode that presents target hand configurations and evaluates performance by computing an accuracy score based on how closely the user's measured hand posture matches the displayed pose. Implemented as a full-stack JavaScript application using Three.js for 3D visualization and a Node.js backend for serial communication and WebSocket data streaming, the software translates incoming sensor measurements into intuitive visual feedback. This allows clinicians and users to observe device behavior, guide therapy exercises, and quantitatively evaluate training performance during rehabilitation sessions.

### B. Project Timeline

This project began in Spring Quarter 2025 in Senior Design's intro class, EECS 198, and continued through Winter 2026. Below is an approximated timeline of our project with some summarized project goals that we followed where possible to follow, but had to make adjustments throughout the quarter.



## II. Objectives

### A. Initial/Final Objectives

Our objectives for the project were the following:

- Design and develop a Control Glove sensing system capable of measuring finger joint motion on the functional (non-paralyzed) hand using flex sensors embedded along each finger, and convert resistance measurements into calibrated finger position data.
- Implement a low-latency wireless communication framework to transmit finger motion data from the Control Glove to the Response Glove for real-time motion replication.
- Design and construct the Response Glove actuation system, incorporating micro-servo motors, a wire-driven tendon mechanism, and a spring-based retraction system to mechanically reproduce finger movements.
- Develop motion-mapping algorithms that translate flex sensor readings from the Control Glove into corresponding servo actuation angles for the Response Glove.
- Build and validate an initial single-finger prototype, integrating sensing, communication, and actuation components to demonstrate reliable motion replication. (Fall Quarter Milestone)
- Improve sensing accuracy and control stability through sensor calibration, signal filtering, and optimization of resistance-to-angle conversion methods.
- Extend the validated single-finger implementation to a full five-finger system, enabling complete hand motion replication between the Control and Response gloves.
- Develop a simple and accessible user interface (UI) to visualize finger movement data, support system monitoring, and improve usability for rehabilitation training.

Throughout the project, our goals and objectives remained essentially the same with one minor adjustment and addition. Our logic for performing the motion mimicry shifted from corresponding servo actuation angles to adding flex sensors onto the Response glove and having the microsensors keep on spinning/winding the wire until the flex sensors on the Response glove match the readings of the flex

sensors on the Control glove. As for the addition, our final major objective was making the gloves completely wireless and battery powered.

### B. Successful Objectives

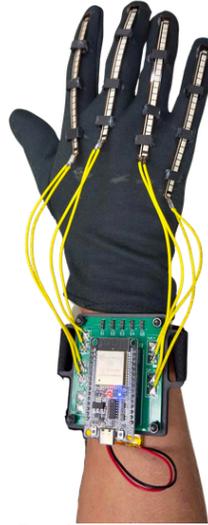


Figure 3 - Improved Control Glove



Figure 4 - Improved Response Glove (Single Finger Prototype)

We were able to successfully meet the following objectives:

- Design and develop a Control Glove [Figure 3] sensing system capable of measuring finger joint motion on the functional (non-paralyzed) hand using flex sensors embedded along each finger, and convert resistance measurements into calibrated finger position data.
- Implement a low-latency wireless communication framework to transmit finger motion data from the Control Glove to the Response Glove for real-time motion replication.
- Design and construct the Response Glove actuation system, incorporating micro-servo motors, a wire-driven tendon mechanism, and a spring-based retraction system to mechanically reproduce finger movements [Figure 2]
- Build and validate an initial single-finger prototype [Figure 4], integrating sensing, communication, and actuation components to demonstrate reliable motion replication. (Fall Quarter Milestone)
- Develop a simple and accessible user interface (UI) to visualize finger movement data [Figure 5], support system monitoring, and improve usability for rehabilitation training [Figure 6].



Figure 5 - Dual Glove Visualization



Figure 6 - Training Mode

### C. Failed Objectives

- Extend the validated single-finger implementation to a full five-finger system, enabling complete hand motion replication between the Control and Response gloves.
- Improve sensing accuracy and control stability through sensor calibration, signal filtering, and optimization of resistance-to-angle conversion methods.

For the first failed objective, we couldn't effectively replicate the ideal motion on a thumb, so we weren't able to do a full five-finger system. The thumb added an additional layer of complexity by having another degree of freedom, which could have been subverted with our current Response Glove, however our current Control Glove was unable to have a proper, reasonable thumb brace to omit that degree of freedom. It was simply out of scope to successfully incorporate that degree of freedom into the project.

For the second failed objective, since we switched out the resistance to angle conversion for that alternative method we explained in section A, we couldn't exactly achieve the accuracy and control stability we envisioned. There are still mild amounts of noise, and we did create a filter to calibrate the flex sensors to adjust to this noise. But, it still doesn't create perfect, smooth finger motion.

## III. Setup Details

### A. Materials/Tools

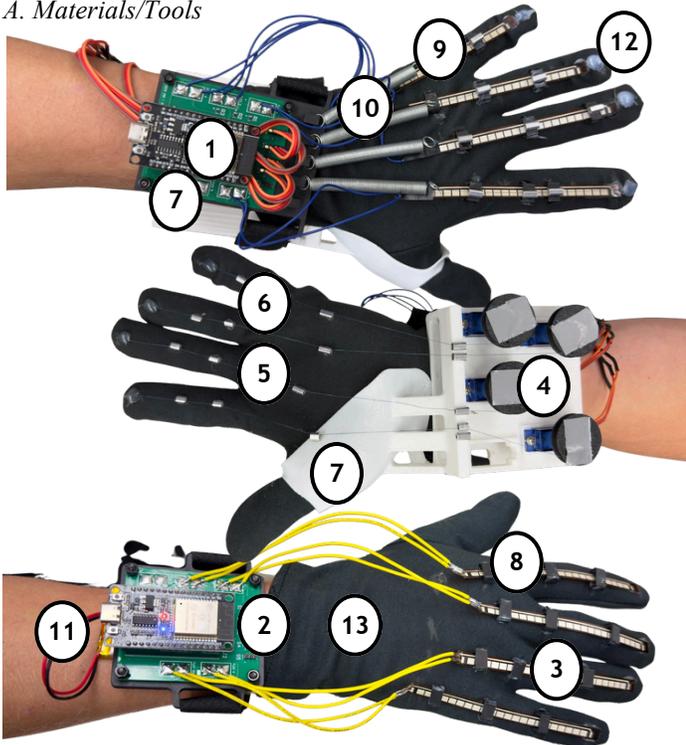


Figure 7 - Glove Materials/Parts (Refer to list below for corresponding part numbers)

1. ESP32 WROOM Dev Board (x2)
2. Custom PCB
3. Long Flex Sensor (x10)
4. Continuous Rotation Micro Servo - FS90R (x5) → with 3D Printed Spool attachment
5. Fishing wire
6. Metal Crimps
7. 3D Printed Glove Attachment (w/ Velcro)
8. 3D Printed Bridge
9. 3D Printed Bridge w/ Crimp
10. Extension springs
11. 3.7V LiPo Battery
12. Hot Glue
13. Fabric Gloves

### Softwares Used:

- Arduino IDE 2.2.1 (libraries involved are pre-installed with this version of Arduino)
- Solidworks 2025
- GitHub
- VSCode
- Website uses JavaScript (EXCMA Script 2026), HTML5, CSS, C++
- PCB made in Altium 24.9

### B. Protocols/Standards

Because REX0 is intended as a rehabilitation device, we plan to adopt ISO 13485, the quality management standard specific to medical devices emphasizing risk management, design traceability, and heavy documentation. Initially, ISO 9001 was considered since it was the general quality management standard for engineering products, but ISO 13485 was more specific and related.

For communication protocol between the Control Glove and Response Glove, we chose to use ESP-NOW, a low-latency, connectionless wireless protocol developed for the ESP32. It enables fast transmission of small data packets without Wi-Fi overhead, making it well suited for real-time finger-position mirroring. Prior to selecting ESP-NOW, we were heavily considering BLE as well since it offered device discovery and broad compatibility, but ESP-NOW was better for simple glove-to-glove communication, so we ended up selecting that.

## IV. Security Considerations

Because the REX0 system relies on wireless communication and wearable hardware interacting directly with a patient, several security considerations must be addressed. The Control Glove transmits finger motion data to the Response Glove using a low-latency peer-to-peer wireless protocol, which introduces potential risks such as unauthorized device pairing, packet interception, or signal spoofing. To mitigate these risks, secure device pairing and MAC address filtering can be implemented to restrict communication to trusted devices only. Additionally, lightweight encryption methods supported by the wireless protocol may be used to protect transmitted motion data from interception or manipulation. From a system safety perspective, safeguards must also be incorporated into the actuation control logic to prevent unintended or unsafe finger movements caused by corrupted data or malicious commands. This may include bounds checking on servo commands, fail-safe neutral positioning, and watchdog timers to halt actuation if communication is lost. Furthermore, because the system may interface with a laptop or web-based user interface that could store patient interaction data, appropriate privacy considerations should be applied to ensure that sensitive rehabilitation data is handled securely and accessed only by authorized users. Together, these measures help ensure that the REX0 rehabilitation system maintains both operational safety and protection against potential cybersecurity threats.

## V. Updated Prototypes

### A. Single Finger Prototype



Figure 8 - Single Finger Response Glove (Same as Figure 2)



Figure 9 - Single Finger Control Glove (Same as Figure 1)

In the Fall, we created a single-finger prototype to test our finger actuation method and control glove accuracy. Figure 9 shows the control glove for this prototype. The flex sensor was wrapped in electrical tape to allow it to slide as the finger bent and follow the shape of the finger. The flex sensor was then connected to a breadboard with a voltage divider, allowing an ESP32 to read the angle. Figure 8 shows the response glove for this prototype. The response glove consists of a servo, driven by an STM32, which spins a spool that controls the length of a string. The string is routed to the tip of the finger, where it is anchored to the glove.

On the back side, there is a spring, which is similarly anchored to the tip of the finger. This creates tension, which pulls the finger back when the servo releases string. Figure 10 illustrates the updated version of the single finger prototype, where both gloves are powered via laptop USB, the servo is driven by the intended ESP32, and the response glove has an anchored spring setup with an underlying flex sensor. The Final breadboarding and setup for this version of the Single Finger Prototype was designed with the intent to follow our newer approach to the glove, being matching flex sensor values from both gloves.



Figure 10 - Revised Single Finger Prototype



Figure 11 - CAD models for response glove

Parts of the response glove were modeled on Solidworks and 3D printed. These are the spool, spring holder, and the brace. The spool is placed on the servo and simply rolls up the extra string. The spring holder is the platform on the back of the wrist, which provides an anchor for the spring. Seen in Figure 11, the brace's functionality is twofold: mount the servo, and hold the thumb in place. The thought was that holding the base of the thumb in place would allow only 1 degree of freedom in the thumb, allowing us to read its position with a flex sensor.

This prototype provided many lessons. First, we verified that the finger actuation method using spools, string, and springs would work. We also learned that we would need to add flex sensors to the response glove, as the continuous motion servos were not accurate enough to determine position by integrating rotational velocity. The prototype also provided an opportunity to design and test the software for the ESP32's, including sensing finger positions, sending packets via ESP-NOW, and controlling the servo based on this data.

### B. 4-Finger Prototype

In the Winter quarter, we created a 4 finger prototype (Figure 12) using the lessons we learned from the first prototype. We designed a custom PCB to minimize the space of the electronics, added flex sensors to the response glove, improved flex sensor attachment to the gloves, and created a web app to assist rehabilitation. Additionally, in order to accommodate the PCB, we had to CAD new attachments that would allow for the PCB to rest on the wrist within reasonable distance so that the spring anchors and connections for flex sensors/servos can be properly managed. Figure 13 shows the new attachments.



Figure 12 - Full 4 Finger Prototype

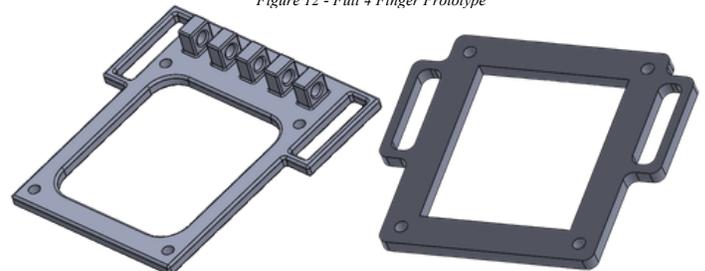


Figure 13 - CAD for new attachments to accommodate PCB

We used Altium 24.9.1 to create a custom PCB that was designed to work for both the response glove and the control glove. It connects the ESP32 to both the servo motors and the flex sensors. The PCB also has a power circuit to input a 3.7V Lipo battery and output 5V to power all components. The PCB layout is shown in figure 15. The ESP32 is placed on the PCB via the two large female headers in the center of the board.

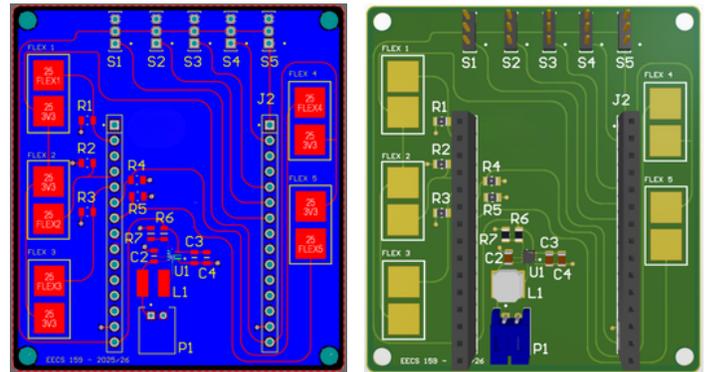


Figure 15 - PCB Layouts

A voltage divider is created for each flex sensor using a resistor. This means that the variable resistance of the flex sensor causes a voltage difference across the resistor, which is measured by an analog to digital converter on the ESP32. The resistors, labeled R1 through R5, are on the left side of the layout. The ADC pins of the ESP32 are connected to the voltage dividers by the female header on the left. The flex sensors are soldered to the pads labeled Flex 1 through Flex 5.

The PCB also connects the ESP32 to the servo motors. Each servo motor is connected using the male headers at the top of the board, labeled S1 through S5. These each have 3 pins: GND, 5V, and signal. The signal pins are routed to the respective signal pins on the ESP32 using the female header on the right.

The last function of the PCB is powering the board using a 3.7 V

lipo battery. The power circuit is shown on the bottom left of the schematic. It uses a boost converter to convert 3.7V to 5V, which is used to power the STM32 and the servo motors. The battery is connected using the JST connector at the bottom of the layout, labeled P1. The PCB can also be powered by plugging the ESP32 into a power source using its on-board USB-C connection.

### C. Web Application



Figure 16 - Dual Glove Visualization (Same as Figure 5)

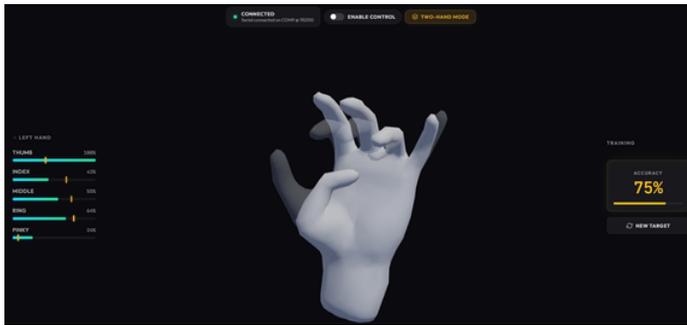


Figure 17 - Training Mode (Same as Figure 6)

The web app serves as the interactive dashboard and visualization layer of the system, providing a real-time interface for monitoring hand motion, system status, and assistive control behavior while the device is operating. Its purpose is to translate incoming sensor data into a form that is immediately understandable to the user, clinician, or developer through both numerical readouts and animated 3D hand models. The interface displays individual finger positions for both hands, reports connection and data-stream status, and allows the assistive control function to be enabled or disabled during operation. In addition to live monitoring, it also includes a training mode that presents target hand configurations and computes an accuracy score based on how closely the measured hand matches the displayed pose. This makes the software valuable not only as an operating dashboard, but also as a tool for guided rehabilitation exercises and system testing.

The application was built as a lightweight full-stack JavaScript system with a clear separation between visualization and hardware communication. The front end uses HTML, CSS, and Three.js to render a polished user interface and animate rigged 3D hand models, while the back end uses Node.js, Express, WebSockets, and serial communication

libraries to bridge incoming microcontroller data to the browser in real time. Finger measurements are parsed from the serial stream, mapped into normalized values for each digit, and broadcast to the interface, where they update both the on-screen indicators and the articulated hand models. A custom hand-rigging module handles bone mapping, calibration, and smooth finger animation so that measured flex-sensor values produce realistic hand motion on screen. Together, these design choices provide a robust and intuitive software layer that supports the overall system by making device behavior visible, interactive, and measurable during use.

## VI. Results/Outcomes and Future Work

### A. Results and Outcomes

The REX0 system successfully achieved the development of a functional dual-glove prototype capable of capturing and replicating

finger motion for rehabilitation purposes. The implemented system includes both the Control Glove and the Response Glove, each supporting motion sensing and actuation for four fingers. The Control Glove utilizes flex sensors embedded along the fingers to measure bending motion through resistance changes, which are converted into calibrated positional data. This data is transmitted wirelessly to the Response Glove using ESP-NOW, which has about 10 millisecond latency at our data rate.<sup>4</sup> On the Response Glove, micro-servo actuators reproduce the detected finger movements using a tendon-based wire actuation mechanism coupled with a spring-assisted retraction system.

Experimental testing demonstrated that the system is capable of reliably capturing finger movement from the functional hand and reproducing the motion on the Response Glove in near real time. Figure 18 shows a graph of measured finger positions while moving one finger back and forth and keeping the others still. The measured positions are accurate to about 5% of the actual position. The implemented control algorithm maps flex sensor readings to corresponding servo angles, allowing the Response Glove to approximate the posture and motion of the Control Glove with consistent responsiveness. While the current prototype focuses on four fingers, the design architecture was developed with scalability in mind, enabling future expansion to full five-finger functionality.

In addition to the hardware implementation, a supporting web application was developed to provide system visualization and interaction capabilities. The interface allows users to observe finger position data and monitor system behavior, serving as a foundation for future rehabilitation training tools. Comprehensive project documentation was also developed to support system understanding, reproducibility, and continued development.

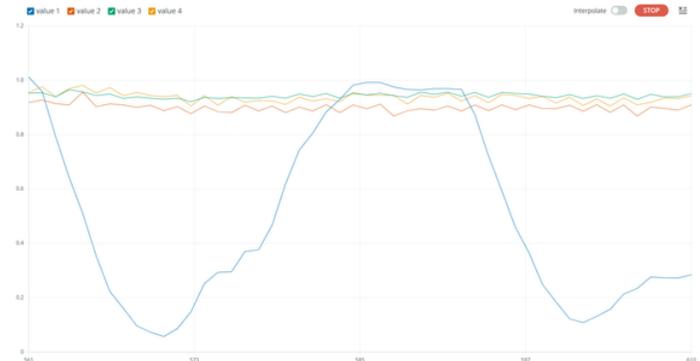


Figure 18 - Single Finger Movement Graph

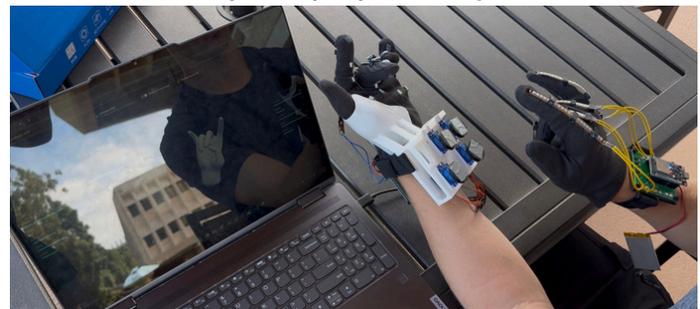


Figure 19 - 4-Finger Set-up Testing (Response Glove Face Up)

### B. Future Work

While the current prototype successfully demonstrates the core functionality of mirrored hand motion replication, several areas remain for future development. One primary limitation is the absence of thumb actuation and sensing within the current design. The thumb introduces additional biomechanical complexity due to its unique range of motion and rotational degrees of freedom, which require more sophisticated sensing and mechanical actuation strategies.

Future work will also focus on improving the accuracy and stability of motion sensing. Flex sensors can exhibit nonlinear behavior, drift, and signal noise during repeated bending cycles. Improvements may include refined calibration procedures, digital filtering techniques, or

the integration of supplemental sensing technologies such as force or pressure sensors to improve motion estimation reliability.

Another direction for future development involves expanding the software capabilities of the system to better support rehabilitation training. Planned improvements include incorporating progress tracking, performance metrics, and guided rehabilitation exercises within the web interface. These features could enable clinicians and patients to monitor recovery progress and adjust therapy routines accordingly.

Finally, further refinement of the glove hardware will be pursued to improve modularity, flexibility, and ergonomic comfort. Enhancing cable routing, actuation packaging, and structural support will help improve durability and wearability of the system while maintaining reliable motion replication performance.

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