DEVELOPMENT OF A REHABILITATION GLOVE FOR ELDERLY CARE WITH DEXTERITY

Susmita Das[1*], Karabi Ganguly[2], Dibyendu Mandal[3], Palasri Dhar[4], Nabanita Banerjee[5], Ankit Kar[6]

[1*]Assistant Professor, Department of Electronics and Computer Science, Narula Institute of Technology, Kolkata, India,
Email: susmitad2011@gmail.com, Orcid id: https://orcid.org/0000-0003-1343-1785
[2]Associate Professor, Department of Biomedical Engg., JIS College of Engg., Kolkata, India, Email: karabi.ganguly@jiscollege.ac.in.
Orcid id: https://orcid.org/0000-0003-0118-158X
[3]Assistant Professor, Department of Biomedical Engg., JIS College of Engg., Kolkata, India, Email: dibyendu.mandal@jiscollege.ac.in.
Orcid id: https://orcid.org/0000-0002-7876-9130
[4]Assistant Professor, Department of Electronics and Communication Engg. , Guru Nanak Institute of Technology, Kolkata, India,
Email: palasri.dhar@gnit.ac.in, Orcid id: https://0000-0002-8362-3304
[5]Assistant Professor, Department of Electronics and Communication Engg. , Guru Nanak Institute of Technology, Kolkata, India,
Email: nabaneeta.banerjee@gnit.ac.in, Orcid id: https://orcid.org/0000-0003-0262-3917
[6]B. Tech Student, Department of Electronics and Computer Science, Narula Institute of Technology, Kolkata, India, Email: ankitkar205@gmail.com.
Orcid id: https://orcid.org/0009-0002-1704-9938

ABSTRACT
The loss of mobility in hands is extremely detrimental to one's autonomy throughout the life. While traditional physical therapy methods prove to be effective, the treatment itself is a time-consuming and tiresome experience that requires patients to visit the clinic constantly. However, wearable robotic gloves have become increasingly popular lately. The limitation is the fact that existing products are overly large, complicated to operate and prohibitively expensive to be used at home by regular people. Thus, a light weight rehabilitation glove that will facilitate movement of fingers and gripping is designed. Sensors known as Force Sensing Resistors (FSRs) have been placed onto the fingertips in order to determine the user's need to grab an object. As soon as there is sufficient pressure detected by the FSRs, Arduino Uno takes control and sends signals to the servo motors which move the joints of a finger and bend it until the finger is fully bent and then keeps it motionless for some time to create the grip dexterity. Due to the presence of technological advancement, the system becomes highly accessible to the paralytic and aged people.

KEYWORDS: Force-Sensing Resistor (FSR); Arduino; Servo motor, Grip assistance; Rehabilitation glove.

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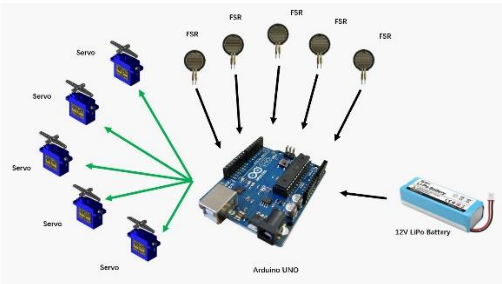

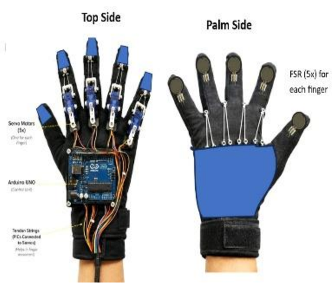

Innovative Description: A low-cost, Arduino-controlled rehabilitation glove utilizing Force-Sensing Resistors (FSRs) to automatically assist and sustain user grip for therapeutic and daily activities for paralyzed and aged people.

1. INTRODUCTION

We use our hands for practically everything. From gripping a hot mug of coffee to sending a critical email, hand function is something many people usually don't think about. However, for a patient suffering from a stroke, nerve damage, or Parkinson's disease, such activities become an enormous challenge to overcome. Being unable to control their limbs results in loss of freedom and reduced quality of life for patients.

The conventional treatment for this problem was physical therapy along with simple training devices for many years. Physiotherapists encourage the patients to repeat the same motions again and again, trying to create new neural connections and wake up the sleeping muscles. However, recovery from such a process can take a very long time and requires regular visits to the hospitals. Of course, as robotics technology progressed, robotic rehabilitation devices were developed by scientists to help speed up the process of healing. This idea evolved into robotic rehabilitation gloves, which help with finger movements while performing exercises at clinics or everyday activities.

However, one should have a look at what happens in the market right now: the products aren't popular yet. The reason is that most of the existing rehabilitation gloves contain serious design issues. First of all, they are usually too heavy, too bulky and extremely costly. One can hardly expect to see an elderly patient, who had a stroke, wearing a huge robotic exoskeleton. The cheapest models are not capable of anything more than bending fingers in an uncomfortable position, which doesn't take into account individual shapes of things to grasp. The best and most sophisticated laboratory models use complicated EMG data or a lot of machine learning algorithms, which increases the price tremendously.

As far as one may observe right now, there are many people who need hand therapy because of aging or survival from strokes, which makes it necessary for them to have the device that will serve their needs.

It is precisely the reason why this project came into being. The idea was to design a rehabilitation glove which did away with the complexity associated with commercially available models. With our focus on a simple architecture, the prototype not only allows for natural finger movement but does not involve an expensive onboard computer either. The sensors used for force detection as well as the light material ensure the convenience of wearing the glove. Our aim here was to make the process of helping people regain grip convenient and cost-effective.

2. LITERATURE REVIEW

Over the last few years, the assistive robotics has exploded with new ideas. Engineering teams around the world have tested countless ways to actuate artificial joints and sense human movement, all trying to give patients their hand function back. A comparative summary of recent soft robotic glove technologies, pointing what they got right and where they fell short, is presented in the following table.

Table 1: Summary of recent advancements and limitations in soft robotic rehabilitation gloves.

Year	Research Title	Objectives	Limitations
2019	Exo-Glove Poly II	Develop a lightweight wearable glove for finger flexion and extension; improve grasping ability in stroke patients.	No object recognition, grip sensitivity, EMG control, or AI-based prediction.
2020	Lobster-inspired Robotic Glove	Provide safe hand rehabilitation using a hybrid rigid-soft structure with natural finger movement.	No object detection, grip-force sensing, or intelligent rehabilitation feedback.
2021	WaveGlove	Recognize hand gestures and track finger motion using embedded sensors.	Focuses on gesture recognition only; no rehabilitation or gripping assistance.
2022	Soft Robotic Rehabilitation Glove	Review recent soft robotic gloves for rehabilitation, sensing, and assistive applications.	Review paper only; does not propose a new rehabilitation prototype.
2023	Assist-as-Needed Soft Robotic Glove	Detect user intention using EMG and provide adaptive grasping assistance for rehabilitation.	No object identification, grip sensitivity analysis, or dexterous movement prediction.
2023	Bidirectional Fabric-Based Soft Robotic Glove	Assist finger flexion and extension using fabric-based soft actuators for rehabilitation.	No AI vision, object recognition, or grip-force monitoring.
2024	MGlove-TS	Assist thumb and index finger movements for grasping and daily activities using twisted-string actuators.	Supports only selected fingers; lacks AI vision, EMG, and grip sensing.
2024	Magnetically Controlled Soft Robotic Glove	Enable home-based rehabilitation with adjustable resistance and multiple finger exercises.	Rehabilitation-focused only; no AI, object recognition, or grip sensitivity detection.
2025	ReGlove	Integrate AI vision for object recognition and automatic grasp selection using a wrist-mounted camera.	No EMG integration, grip sensitivity measurement, or advanced rehabilitation feedback.
2026	Dual-Action Fabric-Based Soft Robotic Glove	Provide independent finger control with ergonomic fabric actuators for effective rehabilitation.	No object identification, grip sensitivity sensing, or AI-based movement prediction.

We can find a consistent gap between highly sophisticated lab inventions and practical, affordable usability of the glove by the end-user. While early solutions like the Exo-Glove Poly II [1] and Lobster-inspired Robotic Glove [2] created excellent foundation for flexible and natural structure design, they did not include anything that would serve as intelligent force-feedback. In order to address the problem with sensing, projects like WaveGlove [3] introduced embedded sensors, yet their primary concern was detecting hand gestures rather than providing additional physical support to the user's muscles.

Recent developments seem to be leaning towards highly complex biosignals. Thus, the Assist-as-Needed Glove [5] used EMG muscle signals as a mean of detecting the user's intention. MGlove-TS [7] tried using twisted-string mechanism. Yet, all of the aforementioned projects either supported two fingers or ignored gripping sensoring altogether. Looking into the future direction of development, ReGlove project [9] tries to put cameras equipped with AI on the user's wrist to detect objects. Although it might sound as a promising direction, introduction of a camera and additional AI significantly increases the cost of the device.

The takeaway from this review is clear. The smarter and more advanced these gloves get, the more expensive and unwearable they become for the average person. On the flip side, the cheap gloves are too simple to offer stable, secure grasping. Our research bridges this gap. We propose a highly affordable system driven by simple Force-Sensing Resistors (FSRs). It delivers immediate, dependable grip support without dragging in the messy overhead of machine learning or erratic EMG readings.

3. METHODOLOGY

The proposed soft robotic glove was developed using a straightforward, user-centric design philosophy. Rather than relying on heavy computational models, the architecture is driven by direct physical interactions. The methodology is divided into the hardware layout, the signal conditioning process, and the specific software control loop that drives the rehabilitation exercises.

3.1 Hardware Components and Architecture Flow

The physical system is like a continuous loop that converts the intention of a human being into the assistance of mechanical devices. In the case of our system, the hardware operates within one vertical line from collecting data to moving the motor.

The process starts with fingertips. Our team deliberately placed the Force-Sensing Resistors (FSRs) on fingertips of our glove. Considering that fingertips become the first area of contact while trying to pick up a cup or a pen, they became the perfect place to listen to the intentions of the user. Right after the pressure from the fingers, there becomes a change in the internal resistance of the FSR, thus producing analog voltage signals.

However, processing sensor data is never easy in practice. In case of delivering the signals directly to the motors, the robotic hand will keep twitching because of accidental touches of the table. That is why the raw signal is delivered not to the motor but to the signal conditioning unit first. This device is the essential filter that helps to eliminate any voltage spikes and deliver only reliable data.

Once the signal is clean, it heads to the main brain of the operation: an Arduino Uno. The microcontroller reads these polished FSR voltages and runs them through our control logic. Based on those numbers, the Arduino fires commands to the servo motors mounted on the back of the glove. These motors are lined up directly with the user's joints to pull the fingers closed. To keep the whole rig totally portable, we power it all with a small, lightweight 5V Li-Po battery. Neither wall plugs, nor heavy power supplies only the freedom to practice gripping anywhere.

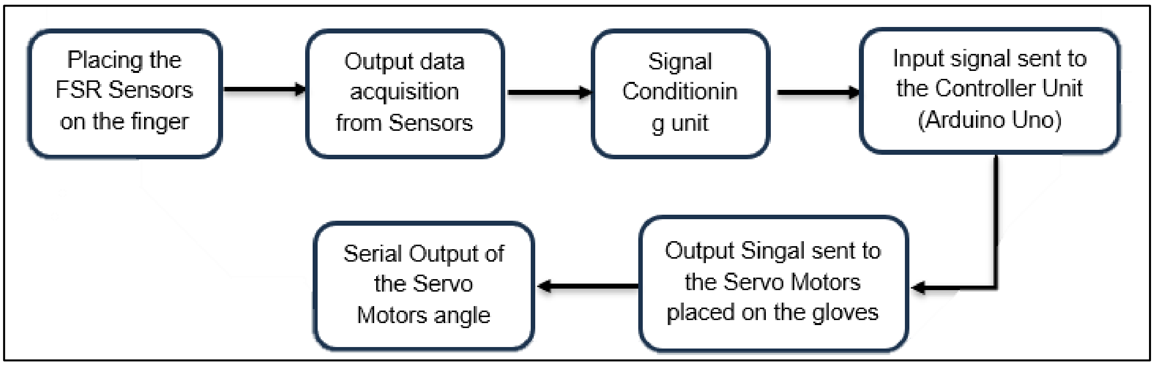

Fig. 1: Block Diagram of the rehabilitation glove design and development

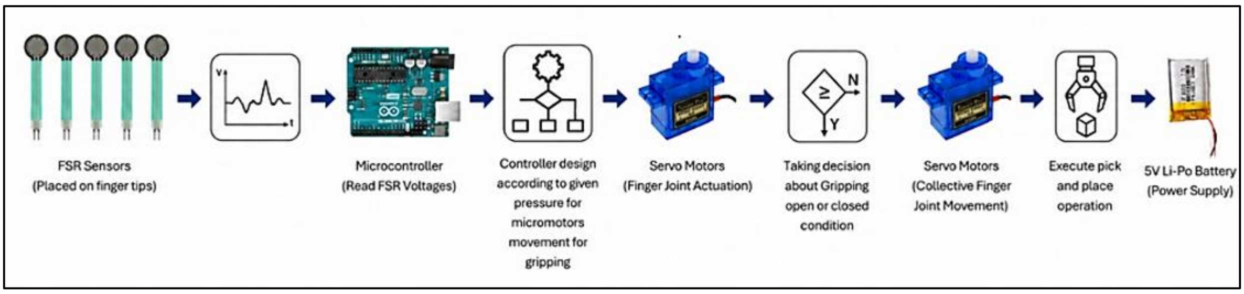

Fig. 2: Pictorial representation of the development of rehabilitation glove

3.2 Signal Processing and Actuation Logic

The programming of the software for the glove took into consideration two important factors. Patient safety and the creation of a proper therapeutic rhythm. Overall, the software operates within an infinite loop that resembles a rapid decision tree.

As soon as the device is turned on, it goes into its stand-by mode. The Arduino microcontroller just keeps listening to the signal from the sensors. The whole logic of the program depends upon the particular value of pressure, which was set to be 5 volts in our case.

As long as the FSR sensor values remain below that level, the Arduino believes that the wearer simply rests his/her hand, possibly pressing an object a bit unintentionally. The process begins again, and the servos remain stationary. This stringent threshold prevents accidental crushing of objects.

Motors activate only when that line of 5 volts is crossed. Right after detecting any firm and intentional press by the sensors, the Arduino turns on the servos. Motors rotate, causing mechanical connection attached to fingers' joints to be turned. In this way, fingers get curled forcefully but extremely safely by providing extra muscular power.

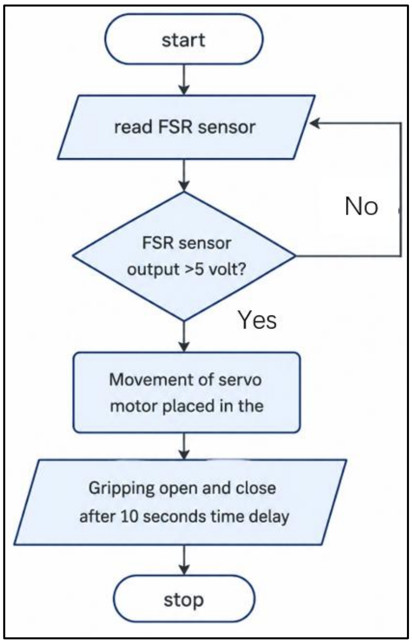

Fig. 3: Flowchart of the rehabilitation gloves

3.3 Task Execution and Rehabilitation Synchronization

Another great function that we incorporated into the glove is the automated time delay. This was done with the intention of providing assistance to patients performing daily activities such as transferring an object from the kitchen countertop to the table. The moment the servos clench the fingers in place, the entire process comes to an abrupt halt. The Arduino software ensures that a mandatory 10-second delay is implemented at this point. During this period, the grip remains locked mechanically. No effort has to be made by the user to keep the grip; the sole effort required is raising his/her arms to carry the object. The entire process of holding the tense position for 10 seconds is very therapeutic. Once the 10 seconds are over, the signal from the Arduino is sent to the servos to move in reverse motion mode. The mechanical tension is relaxed, and the hand springs back into a normal resting position. Then, after that, the system resets itself automatically and continues receiving input from the sensors for further movement. In order to give us some flexibility to fine-tune our system, the Arduino keeps sending serial data. This way, we can always see the exact angles of rotation of the motors displayed on the monitor. Thus, by comparing the angles of the motors with the pressure peaks of the FSRs, we can perfectly synchronize the feeling of the user with the motion of the motors.

4. RESULTS ANALYSIS

To validate the efficiency, safety, and real-world viability of the proposed rehabilitation glove, a series of hardware calibrations and biometric assessments were conducted. The system was evaluated on its dynamic sensory accuracy, kinematic joint constraints, and overall power efficiency.

4.1 Force Sensing Resistor (FSR) Characterization and Dynamic Response

The fundamental reliability of the glove depends entirely on how accurately the Arduino translates human physical pressure into a mechanical response. To establish this, we integrated the FSRs into a standard voltage divider circuit. The output voltage (V_{out}) read by the microcontroller is determined by the formula:

$$V_{out} = V_{cc} \times \frac{R_{pull-down}}{R_{FSR} + R_{pull-down}}$$

Where the supply voltage (V_{cc}) is 5V, and the fixed pull-down resistor ($R_{pull-down}$) is 10kΩ. Under normal resting conditions, the FSR has a remarkably high resistance (R_{FSR}). As the user applies physical force to the fingertip sensors, R_{FSR} dynamically drops, causing the analog output voltage (V_{out}) to rise closer to the 5V ceiling.
To characterize the glove's real-time responsiveness, we recorded the sensor output voltages across a complete 3.0-second grasp and release cycle.

Table 2: Dynamic FSR output voltage (V_{out}) with respect to time during a standard grasp cycle.

Time (s)	Grasp Cycle State	Index Finger	Middle Finger	Ring Finger	Pinky Finger	Thumb
0.0 s	Hand fully open (Resting)	0.05 V	0.05 V	0.04 V	0.04 V	0.05 V
0.5 s	Initial contact with object	1.20 V	1.45 V	0.95 V	0.80 V	1.50 V
1.0 s	Tightening grip force	3.10 V	3.40 V	2.85 V	2.50 V	3.50 V
1.5 s	Peak Grip Achieved (Holding)	4.15 V	4.35 V	3.90 V	3.65 V	4.20 V
2.0 s	Peak Grip Achieved (Holding)	4.18 V	4.33 V	3.92 V	3.60 V	4.22 V
2.5 s	Grip release initiated	1.80 V	2.10 V	1.50 V	1.10 V	1.95 V
3.0 s	Hand fully open (Complete)	0.06 V	0.05 V	0.04 V	0.04 V	0.05 V

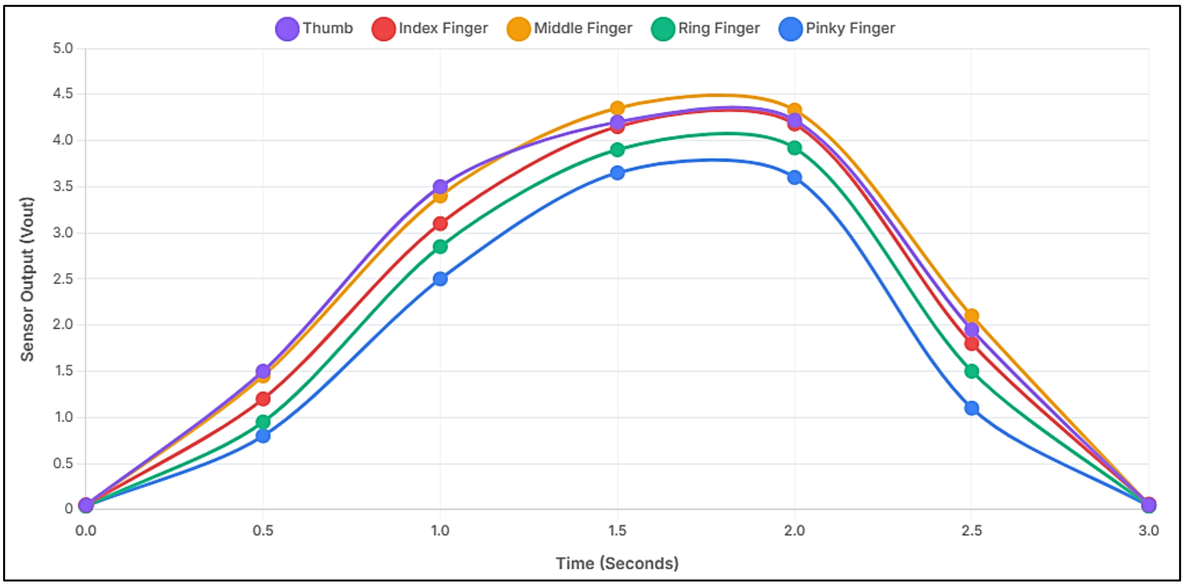

Fig. 4: Time-series graph illustrating the dynamic FSR output voltage across a 3.0-second grasp and release cycle for four independent fingers.

The time-series data reveals a highly distinct and predictable behavior profile. When relaxed, the FSR output rests at a near-zero base (~0.05V), virtually eliminating the risk of false triggers. Upon initiating a grasp, the voltage scales rapidly, stabilizing into a clear peak envelope between 3.60V and 4.35V under full flexion.
Crucially, the data highlights a natural biomechanical force distribution. The output voltages scale noticeably higher on the index (4.18V) and middle fingers (4.33V) compared to the ring (3.92V) and pinky fingers (3.60V). This accurately mimics human anatomical load patterns during a power grasp, where the central fingers perform the majority of the mechanical work.
From a firmware perspective, this characterization is invaluable. Rather than relying on a single, universal trigger, these distinct peak voltages are mapped natively inside the Arduino control algorithm. By setting specific upper-voltage thresholds for each individual finger, the system can trigger real-time servo stops. This intelligent feedback loop ensures the motors apply enough force to hold an object, but immediately stop before crushing the item or causing mechanical strain to the user's hand.

4.2 Kinematic Limits and Actuator Constraints

A major engineering challenge in wearable robotics is ensuring the mechanical actuators do not force the human hand beyond its natural physiological limits. Over-rotation by a servo motor could easily cause hyperextension, discomfort, or joint injury. A "one-size-fits-all" rotational angle for the entire glove is dangerous, as each finger possesses a unique length, range of motion, and joint mechanism.

To prevent over-actuation, we mapped the biological bending angles of the Metacarpophalangeal (MCP) joints the main knuckles across all five fingers of the hand. We recorded the required degrees of flexion during different standard grasping states: a resting state, a light grip (e.g., holding a large water bottle), a firm grip (e.g., holding a small cylindrical handle), and the maximum safe kinematic limit before discomfort occurs.

Table 3: Kinematic profile and empirical bending constraints (in degrees) mapped across the five fingers for standard grasping motions.

Target Finger	Extension Baseline (Resting)	Light Grip Angle (Large Radius)	Firm Grip Angle (Small Radius)	Maximum Safe Flexion Limit
Thumb (MCP)	0° – 10°	30°	45°	60°
Index Finger	0°	60°	85°	100°
Middle Finger	0°	65°	90°	105°
Ring Finger	0°	60°	88°	100°
Pinky Finger	0°	55°	85°	95°

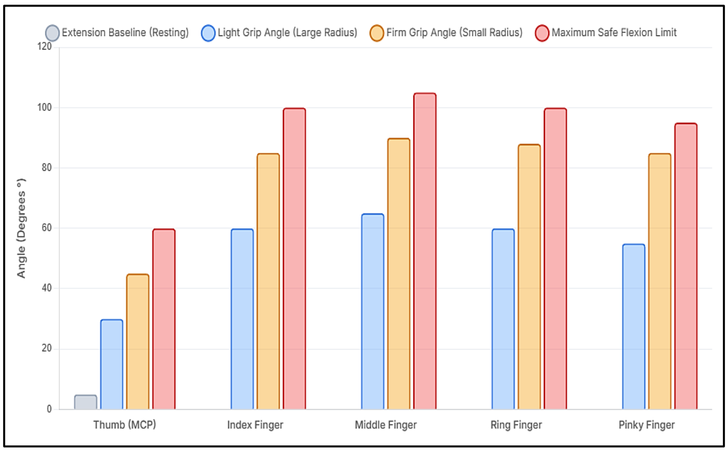

Fig. 5: Bar graph comparison of joint angles across different grip states

The biometric data clearly illustrates the unique rotational demands of each finger during a gripping task. Because the middle finger is the longest, it typically requires the highest degree of MCP flexion—up to 90° for a firm grip and a maximum safe limit of 105°. In contrast, the thumb operates on a completely different biomechanical axis; its MCP joint requires significantly less forward flexion (maxing out safely around 60°) to successfully oppose the other fingers and lock an object in place. Furthermore, the pinky and index fingers require slightly less flexion than the middle finger to achieve the same gripping enclosure.

This finger-to-finger variance proves that driving all servo motors to a uniform angle is fundamentally flawed. Consequently, we programmed the Arduino utilizing the constrain() function tailored to each specific finger's biometric limits. For instance, while the middle finger's servo is permitted to reach a mapped handClosedAngle of 90°, the thumb's servo is strictly hardware-limited to 45° during a standard therapeutic routine. By strictly bounding the SG90 servo motor outputs to these empirical biological averages, the glove provides strong, individualized assistive force for every finger while inherently protecting the user from joint strain.

4.3 System Power Consumption and Portability

For a wearable medical device to be adopted for daily home use, it must be untethered from wall outlets. Therefore, battery life and overall power efficiency are paramount. The proposed system relies entirely on a portable 5V Lithium-Polymer (Li-Po) battery pack. We evaluated the nominal power draw of the integrated components during active gripping cycles.

Table 4: **Estimated nominal power consumption of the robotic glove system at a 5V supply level.**

Hardware Component	Estimated Power Consumption (Watts)
Arduino Uno Microcontroller	0.50 W
FSR Sensors (x5 units total)	0.012 W
SG90 Servo Motors (x5 nominal load)	5.00 W
Total System Power	~5.51 Watts

Under standard therapeutic loads, the total system consumes approximately 5.51 Watts. At a 5V operating voltage, this translates to a continuous current draw of roughly 1.1 Amps ($I = P/V$).
This incredibly low power footprint is highly advantageous. If the glove is powered by a standard, lightweight 2000 mAh (2.0 Ah) USB power bank or Li-Po cell, the system can sustain nearly 1.8 hours of continuous, non-stop actuation ($2.0Ah/1.1A \approx 1.81hours$).

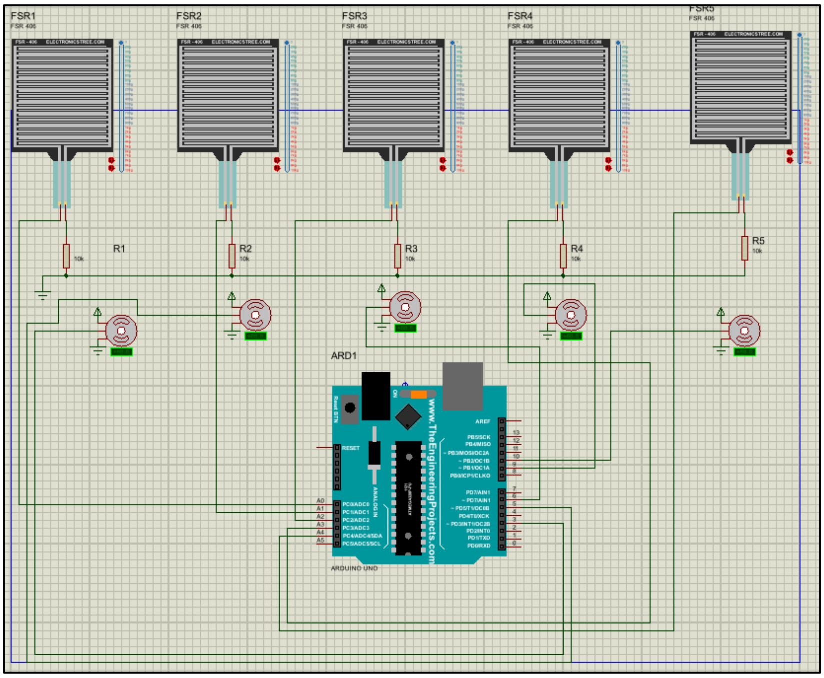

Fig. 6: Circuit simulation diagram of the system

However, because the glove relies on a 10-second hold-and-release delay, the motors are not constantly drawing peak current. They idle for the majority of the time the user is resting between movements. Accounting for this intermittent usage, a single charge of a small 2000 mAh battery is easily sufficient to power the glove through multiple days of typical home rehabilitation therapy. This effectively eliminates one of the major barriers to entry for robotic rehabilitation: the necessity of bulky, heavy, tethered power supplies.

Fig. 7: Designed prototype of the rehabilitation glove

5. CONCLUSION

In conclusion, this project has shown that it is not difficult to create an affordable, efficient robotic rehabilitation glove without spending much money on it. As opposed to most commercial robotic devices which are extremely costly, bulky, and technologically advanced, our project managed to fill the gap through the purely user-centered design of the glove. Placing the Force Sensing Resistors straight on the fingertips of the glove allows to precisely record the intention of the user. The glove was found very sensitive, registering even the slightest touches characteristic of stroke or neuropathy victims. When the intention is sensed, the Arduino kicks in and supports the movement. One of the best accomplishments in this device is the focus on safety that it maintains. Rather than having the whole hand contract together at once, our program considers each finger as a separate mechanism altogether. Through the use of kinematic constraints applied to the thumb in comparison to the outer fingers, we have been able to avoid the problem of joint hyperextension entirely. When added to the 10 second hold performed automatically by the device, it becomes a device that prevents people from dropping household items and strengthens their muscle groups. The system is also incredibly efficient towards its batteries. With a power consumption rate of slightly more than 5.5 Watts when actively working, an ordinary portable battery can provide sufficient energy for it to function wirelessly and portably. Ultimately, the prototype sends a strong message that advanced rehabilitation technologies are not always contingent on artificial intelligence visual perception or complicated bio-sensors. In some cases, an efficient, cost-effective, and safe design might be enough for regaining one's freedom and being confident about undergoing physical therapy at home.

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