DESIGN OF ADVANCED GLOVE TECHNIQUE FOR STROKE REHABILITATION USING 3D MODELLING

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I. Introduction:

Recovery of hand function after a stroke is important because this facilitates recovery of independent living in daily activities, though this is achieved slowly and painfully. Simple routine activities including grasping and holding objects, writing, or even the most basic self-care skills can be lost. Thus, physical therapy turns into a cornerstone in the entire rehabilitation process. However, traditional rehabilitation may take much time, and it could further depend on access and facilities and quality of care. Most existing active hand-rehabilitation devices are strengthened with little personalization or adaptability, hence being somewhat limited in their effectiveness for meeting unique needs of each patient's journey.

The project design therefore proposes a customized solution, couched in the form of a 3D-printed rehabilitation glove for stroke patients. The raw material used is Thermoplastic Polyurethane. Here, it reflects flexibility and comfort. The material TPU is elastic, resistant, and skin-friendly, so it's well adapted to rehabilitative devices used every day. The ability of this device to bend allows the glove easily to fit according to the natural curves of the hand and then offer very soft resistance over their shape for hand muscle and function strengthening. Moreover, 3D printing offers the possibility to print a glove which will be uniquely personalized for every single patient, offering support that is uniquely tailored to his needs and the ability to adjust with progress over time for each patient.

The application is interconnected with the glove, and this will provide support in a digital manner to rehabilitation. The app provides guided exercises for hand therapy, tracks progress, and offers motivational positive feedback. One of the properties that make this application stand out is that there is an SOS button in its design; with the help of this feature, users will be able to request help if at any moment during the exercises they generate discomfort or feel something wrong, increasing their feelings of security when doing the exercise independently. The app also allows health professionals to track data on movements of the hand and exercise completion and remotely monitor patient progress while making any adjustments in therapy if needed. This is rehabilitation aided, combined with the support given by an application that enables a comprehensive approach to stroke recovery. Equipped with the elasticity of TPU, precision through 3D printing, and guided by the application, this solution will be tailored to the needs of each patient in development for independence and effective rehabilitation.

2. Literature Survey:

2.1 3D-Printed Assistive Devices for Rehabilitation:

This study highlights the potential of 3D printing for customizable rehabilitation devices. By using materials with adjustable flexibility, assistive devices can be tailored to fit patients' needs precisely, supporting varied motor tasks. The research shows that 3D-printed devices offer cost-effective solutions that adapt well to patients' hands, enhancing comfort and effectiveness. Their modular design makes repairs or modifications easy, which is advantageous for long-term rehabilitation.

2.2 Impact of material properties on rehabilitation equipment:

Exploring various materials used in rehabilitation devices, this paper emphasizes the importance of flexibility, durability, and comfort. Materials like TPU stand out due to their balance of comfort and resilience. The study suggests that choosing appropriate materials is crucial for durability and patient satisfaction. Material properties directly impact the device's effectiveness in promoting motor functions without discomfort, underlining the role of resilient materials in recovery.

2.3 Sensor Integration in Rehabilitation Devices for Real-Time Feedback

This paper reviews wearable devices equipped with sensors that track hand movements and provide real-time feedback. These insights help clinicians monitor patient progress and adjust therapy accordingly. Sensor-equipped devices promote more precise hand movements and allow for customized adjustments, proving beneficial for personalized care. The study concludes that sensors significantly improve rehabilitation outcomes by enabling patients to perform guided exercises.

2.4 Thermoplastic Polyurethane (TPU) in Medical Device Manufacturing

Investigating TPU’s properties, this study highlights its flexibility, tear resistance, and comfort in creating medical devices, particularly wearables. TPU’s adaptability under frequent use without compromising comfort makes it suitable for rehabilitation gloves. Findings indicate that TPU’s resilience extends device longevity and maintains effectiveness, addressing limitations of traditional materials in wearables that often degrade quickly with repeated use.

2.5 Customized Rehabilitation Gloves Using CAD and 3D Printing

The paper discusses the customization benefits of Computer-Aided Design (CAD) and 3D printing in creating rehabilitation gloves. Tailored to fit individual hands, these gloves provide targeted support to affected areas, essential for stroke recovery. The study highlights how CAD modeling and 3D printing enable personalized thickness and flexibility adjustments, improving user comfort. Customization ensures the device adapts precisely to patient needs, enhancing therapy success.

2.6 Hand Function Recovery in Stroke Rehabilitation through Wearable Devices

This study examines wearable devices that assist in hand function recovery post-stroke. It notes that these devices support hand movement exercises and coordination improvements. The research finds that wearable devices provide a practical way to rebuild strength and motor skills, with better outcomes than traditional methods. Comfort and usability are emphasized, as these factors contribute to sustained device use during recovery.

2.7 3D Printing in Creating Low-Cost Rehabilitation Solutions

This paper explores how 3D printing reduces costs in rehabilitation equipment production. It shows that low-cost materials and rapid prototyping can yield effective solutions. The study advocates for 3D printing as a viable method for affordable and accessible rehabilitation tools, especially for patients with limited resources. Additionally, the customizable nature of 3D printing offers tailored solutions without significant additional costs.

2.8 Enhancing Dexterity through Variable Resistance in Rehabilitation Devices

Focusing on the importance of adjustable resistance, this study investigates how variable resistance in rehabilitation devices improves hand dexterity. It shows that targeted resistance strengthens specific hand muscles, aiding fine motor skills. Findings suggest that incorporating adjustable resistance helps patients regain hand control more effectively, as tailored resistance levels adapt to individual needs throughout recovery.

2.9 Effectiveness of Tailored Fit in Rehabilitation Wearables

This paper highlights the advantages of a tailored fit in rehabilitation gloves and wearables. It finds that a well-fitted device minimizes muscle strain and increases comfort, both of which are essential for effective rehabilitation. The tailored fit allows for extended use without fatigue, which is particularly beneficial for hand movement recovery in stroke patients. The study concludes that personalized wearables lead to better patient compliance and outcomes.

2.10 Future Prospects: Sensor-Based Technology in Stroke Rehabilitation This study discusses the potential of integrating advanced sensor technology in rehabilitation wearables for stroke patients. By tracking precise hand movements and muscle activities, sensors provide data-driven insights for clinicians to refine treatment plans. The paper emphasizes how sensor integration could lead to real-time monitoring, allowing therapists to customize therapy dynamically. Future innovations may enhance patient independence, making sensor-equipped wearables an exciting avenue for stroke recovery.

3.Methodology:

3.1 Understanding Rehabilitation Needs and Glove Design Requirements: The first step involves gathering insights into the specific rehabilitation needs of stroke patients, particularly those relating to hand and finger movement recovery. By consulting medical research and speaking with rehabilitation specialists, we identified essential exercises and movements that the glove should support. This initial research helped establish criteria for the glove's fit, flexibility, durability, and safety, forming the basis for our design.

3.2 3D Modelling and Design Customization: Using CAD software, we created a virtual model of the glove. This model was crafted to mimic the natural shape and structure of the human hand, enabling a comfortable fit that allows full movement range. Each section of the glove was adjusted to meet specific needs—some areas were made more rigid to support larger muscle groups, while others were left more flexible to allow fine motor movements. Additionally, the model was designed to be adjustable, so the glove can be customized for different hand sizes and therapy stages.

3.3 Selecting and Testing TPU Material: We chose Thermoplastic Polyurethane (TPU) as the glove's primary material due to its flexibility, durability, and skin-friendly properties. TPU's elasticity allows it to comfortably conform to the hand while providing enough resistance for therapeutic exercises. Before proceeding to production, we tested TPU samples for durability and flexibility, ensuring the material would withstand repeated bending and stretching without losing shape or function.

3.4 3D Printing of the Glove Prototype: With the 3D model finalized and TPU selected, we used 3D printing technology to produce the prototype. The printing process allowed for precise control over the thickness and flexibility in different areas of the glove. For instance, sections requiring more resistance were printed with thicker layers, while more delicate areas were kept thin to allow finer movements. The flexibility of TPU in printing also allowed us to create a glove that is lightweight, easy to wear, and suitable for extended use.

3.5 Prototype Testing and Adjustment After the initial prototype was printed, it was time for rigorous testing. We invited individuals to wear the glove and perform common rehabilitation exercises. Feedback was gathered on fit, comfort, and functionality, helping us pinpoint any necessary adjustments. Based on this input, we refined the design by adjusting certain areas to improve flexibility, enhancing fit, and reinforcing sections prone to wear.

3.6 Finalizing the Design and Preparing for Extended Testing
With the feedback integrated, we produced an updated prototype ready for extended testing. This stage involved observing patients over longer periods to ensure the glove's durability and effectiveness. We also evaluated ease of use, as the glove needs to be simple enough for patients to wear independently.

3.7 Future Integration of Sensor Technology (Planned)
For the future, we plan to incorporate sensors into the glove to track movement and provide real-time feedback. This enhancement will enable clinicians to monitor a patient's progress remotely and fine-tune exercises based on individual performance data.

3.8 Flow chart of the work flow

3.8.1G**love Design (CAD Modeling)**
The process begins with designing the rehabilitation glove using Computer-Aided Design (CAD). This allows the glove to be tailored to fit the unique hand size and movement requirements of each patient.

3.8.2 Customization via 3D Printing
The glove is then produced using 3D printing technology. This enables precise customization of glove thickness, flexibility, and overall fit, ensuring comfort and suitability for targeted hand movements essential for rehabilitation.

3.8.3 Sensor Integration
Various sensors are embedded into the glove to monitor critical metrics during rehabilitation exercises:

Oxygen Level Sensor monitors blood oxygen levels.

Flex Sensor tracks hand movements, helping to monitor progress in motor skills.

SOS Button provides an emergency alert feature, allowing patients to signal for immediate assistance if needed.

3.8.4 App Connectivity
The glove connects to a mobile app, which serves as a communication hub between the patient and healthcare provider. The app collects data from the

glove's sensors, including hand movement details, oxygen levels, and emergency alerts.

3.8.5 Doctor-Patient Communication

Through the app, clinicians can review sensor data, monitor patient progress, and adjust rehabilitation exercises as needed. Real-time data and alerts allow doctors to make timely decisions, enabling a more personalized therapy experience and improving patient outcomes.

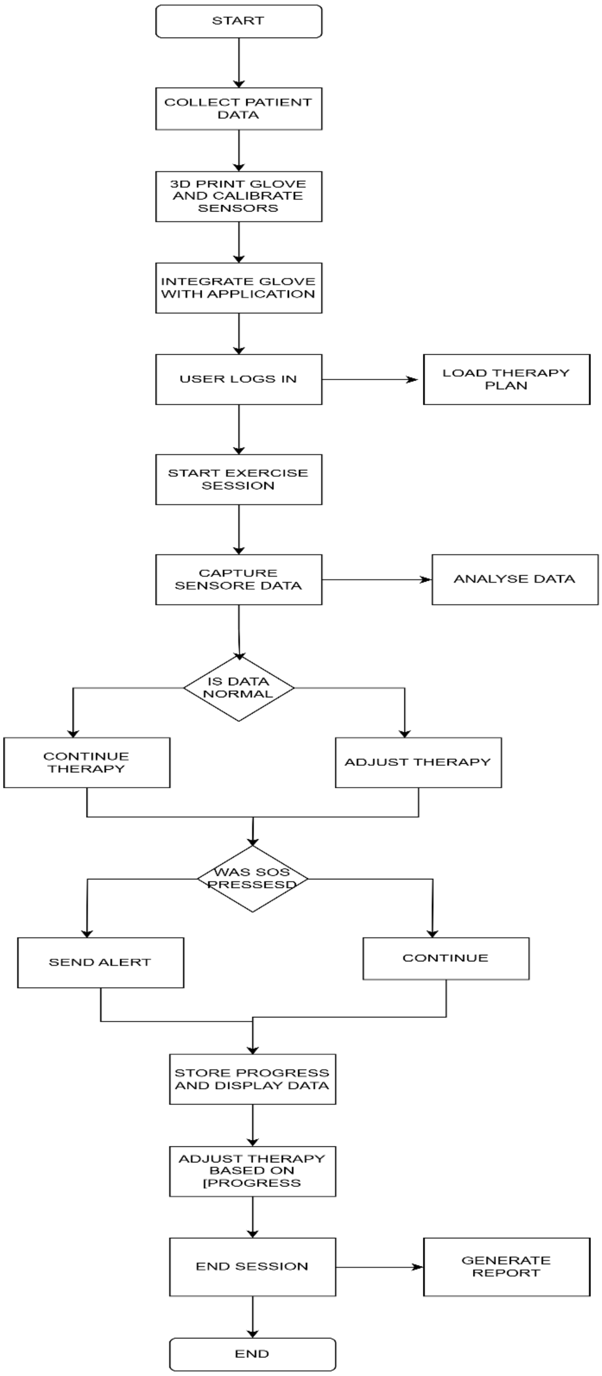


FIGURE 1: WORKFLOW DIAGRAM OF THE PROPOSED DESIGN.

3.9 Glove design

A smart glove using an ESP32, flex sensors, and a pulse oximeter enables health monitoring and gesture control. The ESP32 processes data from the flex sensors, which detect finger movements for gesture recognition, and the pulse oximeter, which monitors heart rate and blood oxygen levels (SpO2).

The device can transmit this data wirelessly to a smartphone or IoT platform. Applications include healthcare for continuous monitoring, physiotherapy for tracking hand movements, gaming and VR for gesture-based control, and robotics for controlling devices via hand gestures.

Analog-to-Digital Conversion: The ESP microcontroller converts analog signals (from sensors like the flex sensor) into digital data that can be processed.

Temperature sensor: The analog signal corresponding to temperature changes is converted into a digital value.

Heartbeat sensor: Pulse rate data from the pulse oximeter is processed, and oxygen saturation is measured.

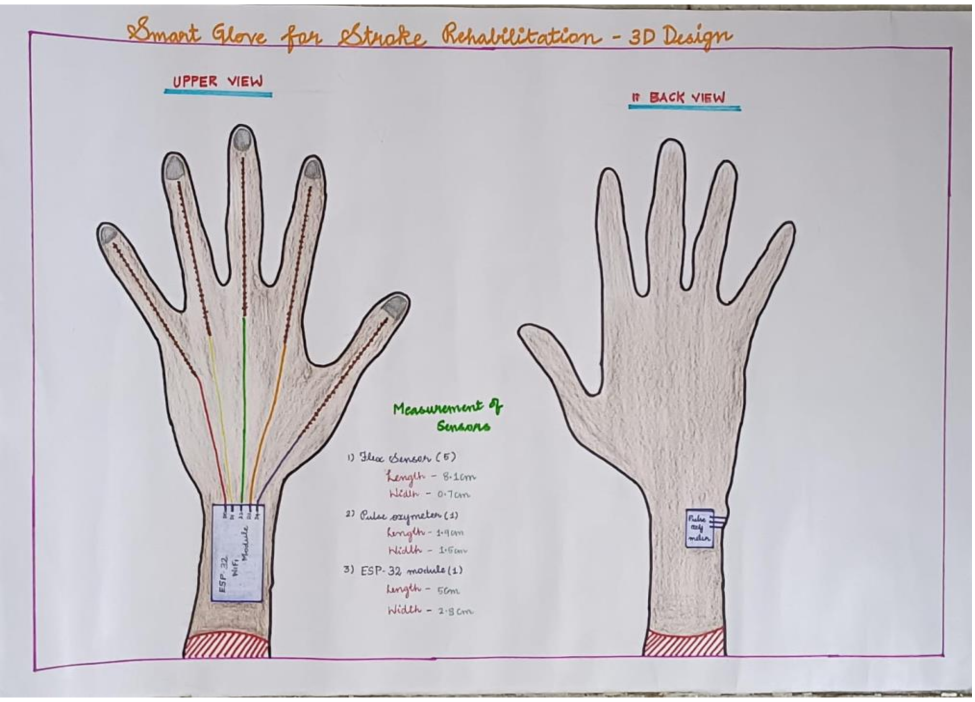


FIGURE 2: Rough drawing of Glove

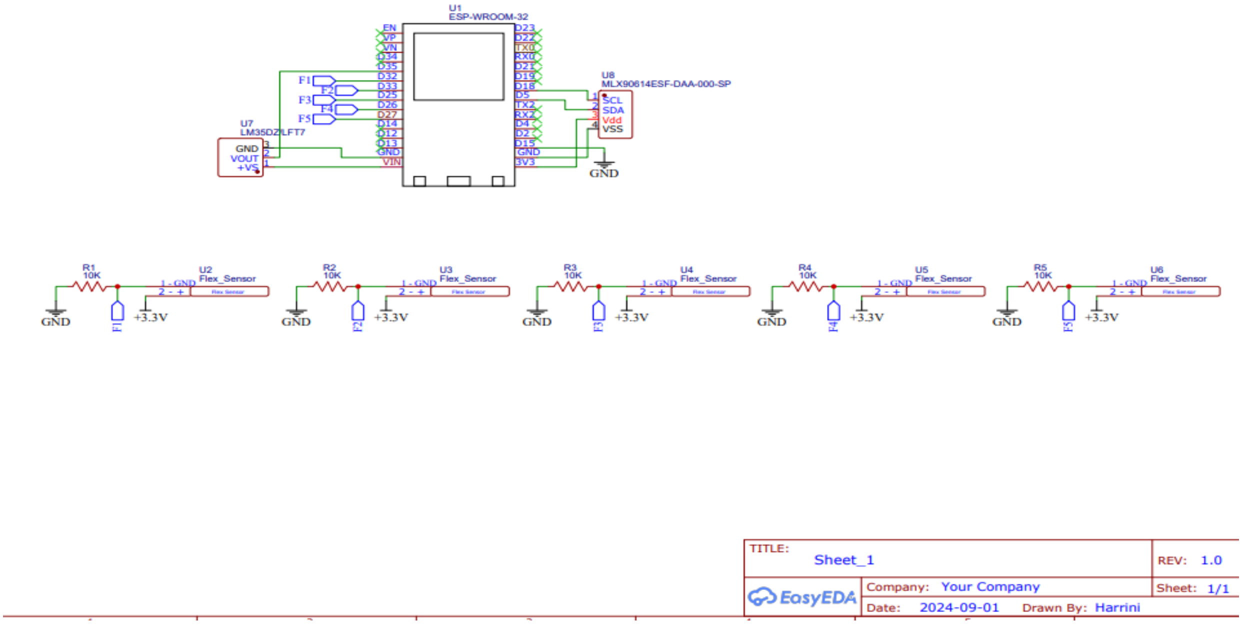
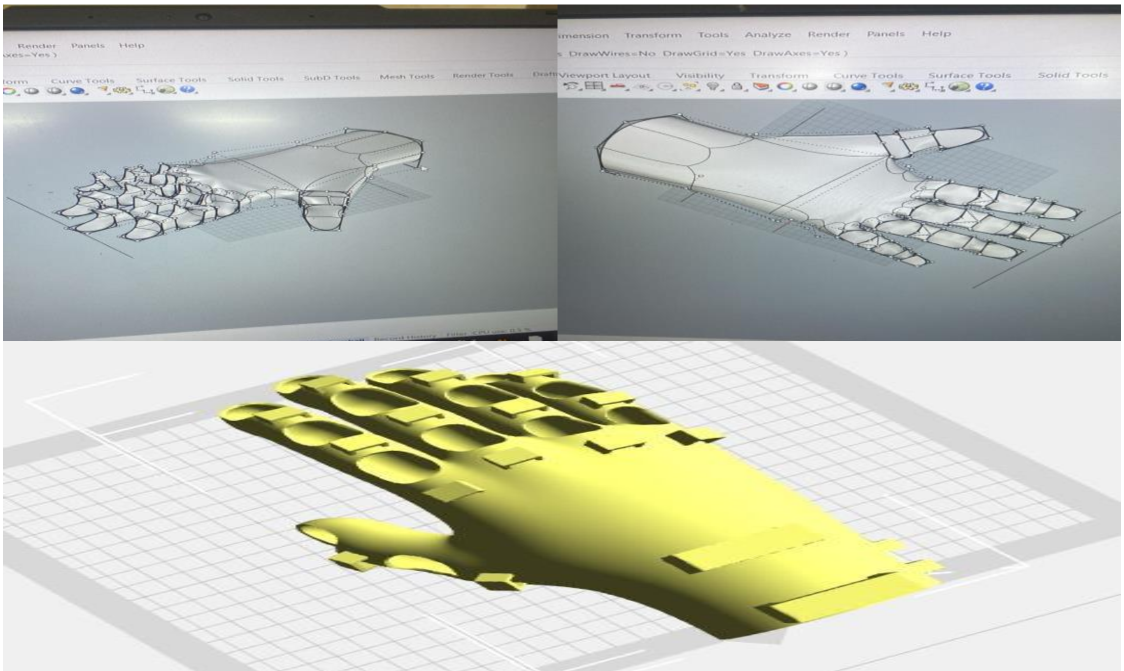


FIGURE 3: Circuit Diagram of Flex Sensor Implementation

Design of product (3D GLOVE):

The below samples indicates the design made in CAD



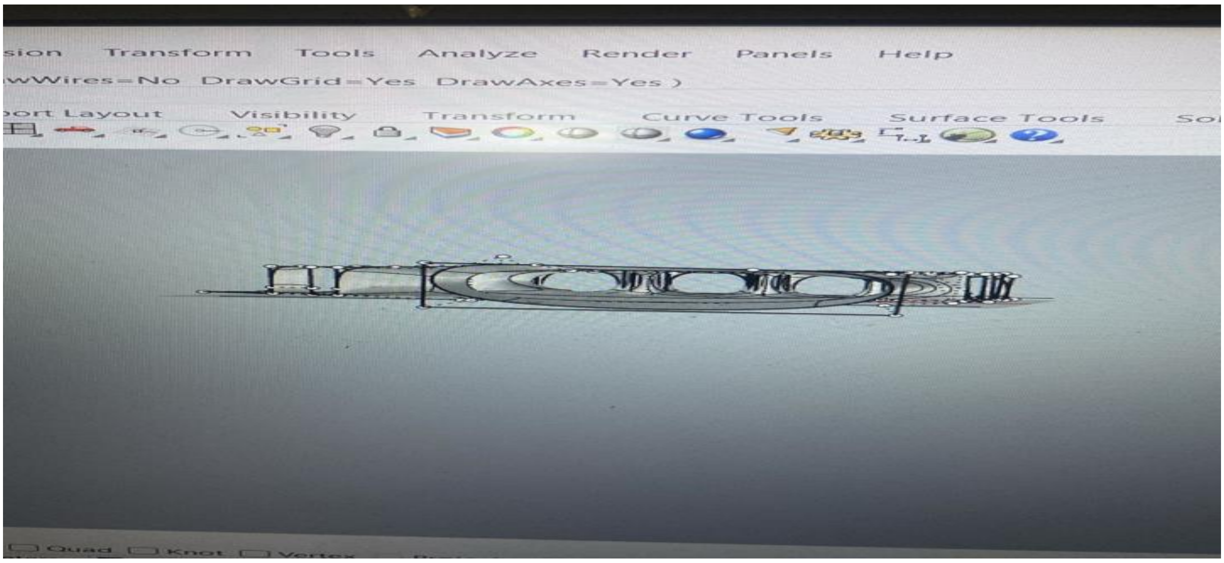


FIGURE 4: Views of Glove in CAD

<u>Hardware Circuit Connection:</u>

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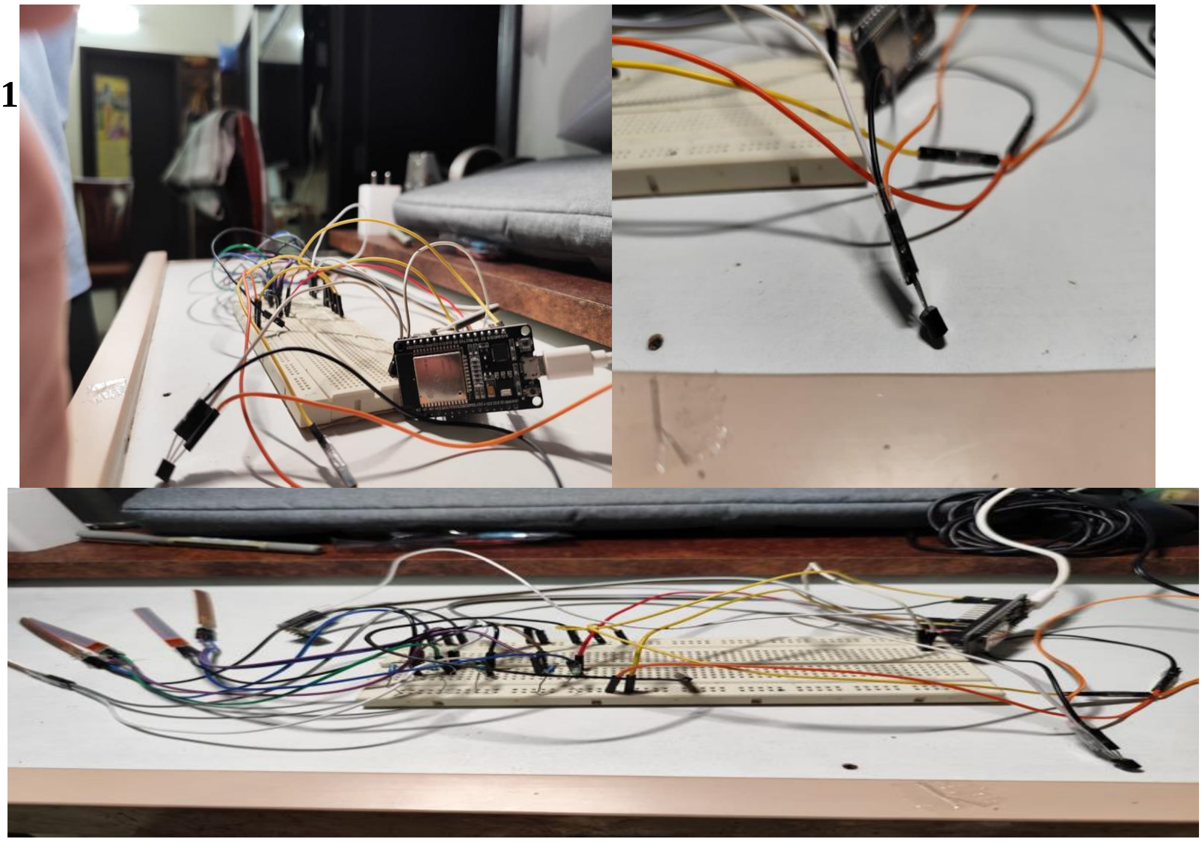


FIGURE 5: Hardware Connection using Breadboard

4. Result and Discussion:

The glove, made from Thermoplastic Polyurethane (TPU), was designed to closely fit each patient’s hand. User feedback indicates that the TPU material provided a snug yet comfortable fit, supporting prolonged use without discomfort. TPU’s elasticity allowed the glove to conform naturally to the hand's shape, offering gentle resistance that aided muscle strengthening. Over multiple sessions, the glove demonstrated resilience, maintaining elasticity and form without significant wear. Using 3D printing, the glove could be uniquely tailored to each user’s specific hand dimensions, ensuring precise support. Patients expressed satisfaction with the individualized fit, which contributed to ease of use and effectiveness. Patients found the glove easy to put on and remove independently, enhancing its usability in a daily rehabilitation routine. The gentle resistance provided by the TPU glove was particularly effective in strengthening hand muscles, especially for patients with limited hand mobility. The flexibility allowed gradual improvement without causing strain.

The glove’s snug fit allowed patients to feel secure during exercises, though future adjustments in material thickness may further balance flexibility and resistance based on each patient's rehabilitation stage. The ability to 3D print each glove based on specific measurements improved adherence to rehabilitation routines, as patients were more inclined to wear a device that felt uniquely fitted. While effective on a small scale, 3D printing for large numbers of gloves may face time and cost challenges. Addressing these concerns could involve semi-customized designs for scalability without compromising personalization.

The app’s guided exercise feature was well-received, offering patients structured routines tailored to hand therapy needs. Many patients noted increased confidence in performing exercises due to clear, step-by-step instructions. The app allowed patients and caregivers to monitor daily progress. Visualized data, including metrics on hand movements and exercise completion, provided clear indicators of improvement, which encouraged continued engagement. The SOS button added a significant safety measure for independent users. Although seldom activated, patients reported feeling reassured, knowing they could call for help if needed.

Remote Monitoring by Healthcare Providers: Healthcare professionals were able to review patient progress remotely, which facilitated timely adjustments to therapy without requiring frequent in-person visits. The app's positive feedback loop, coupled with visual progress indicators, played a critical role in keeping patients motivated. Such features reinforced the idea of small, incremental progress, which is crucial in a long recovery journey.

The SOS feature provided psychological comfort, empowering patients to practice independently with a safety net. This feature could be expanded in future versions, possibly by adding more specific types of assistance or automatic monitoring for signs of discomfort. Remote access to patient data allowed therapists to make informed adjustments, ensuring personalized and adaptive therapy. However, ensuring data privacy and seamless app-patient integration will be essential for maintaining trust. Feedback highlighted that additional interactive features, such as virtual coaching or community support, could enhance user engagement and satisfaction. Further refinements in the user interface could also improve accessibility, particularly for elderly users or those less familiar with mobile apps.

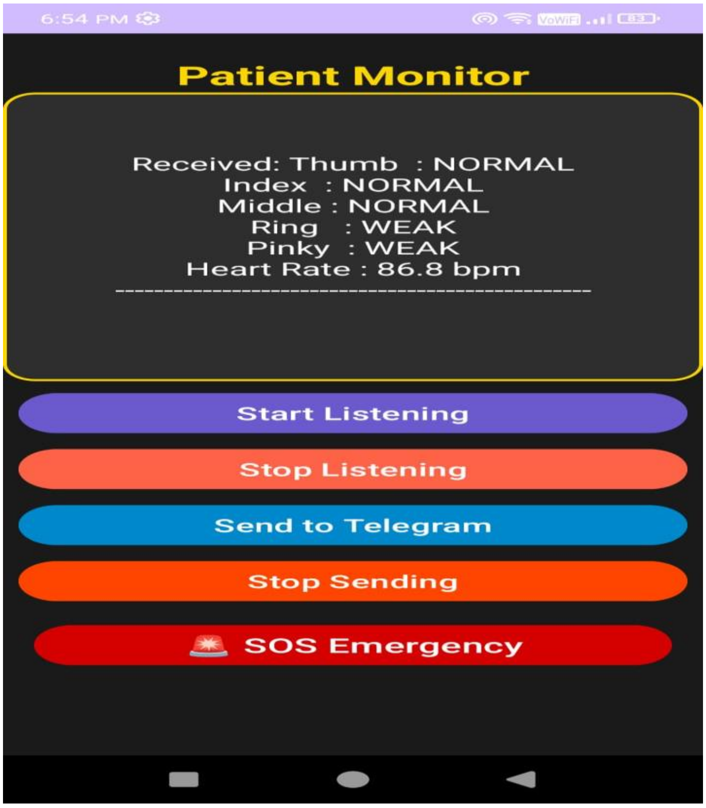


FIGURE 6: VIEW OF THE APP DEVELOPED

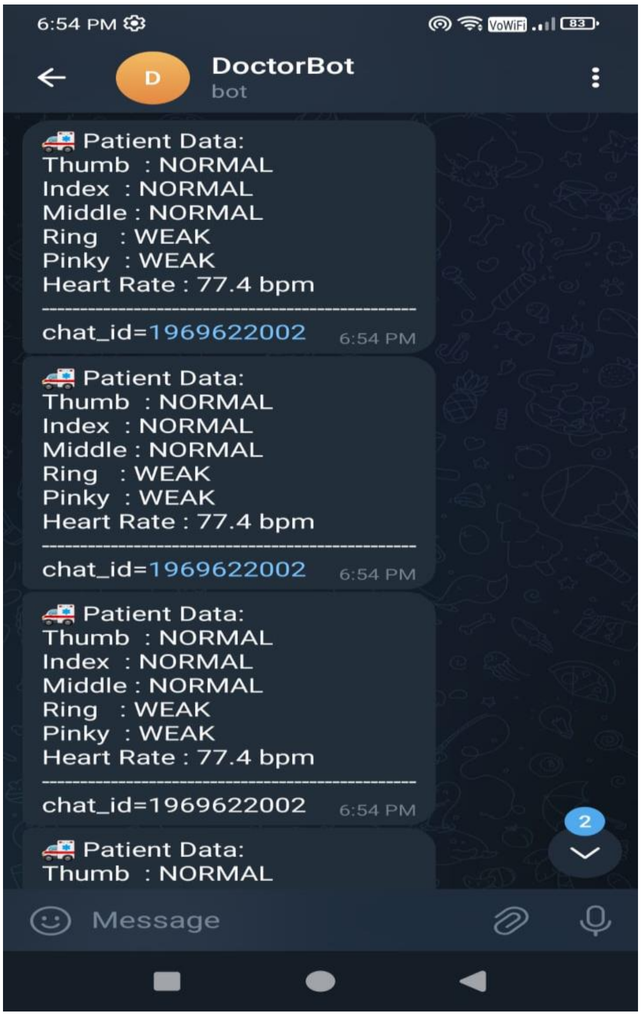


FIGURE 7: SEND TO TELEGRAM FEATURE RESULT

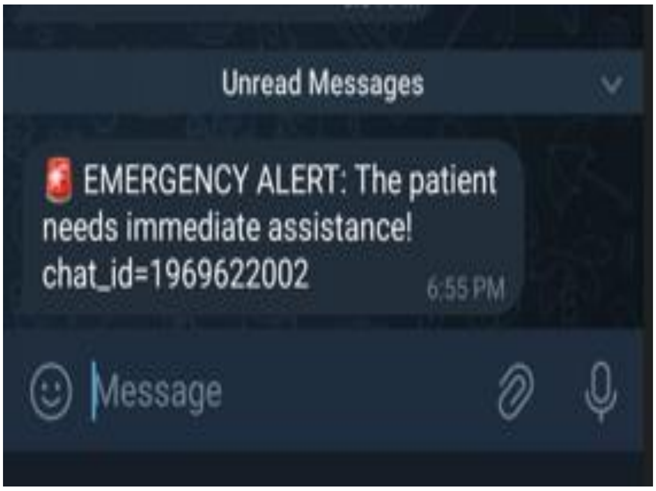


FIGURE 8: SOS EMERGENCY MESSAGE RESULT

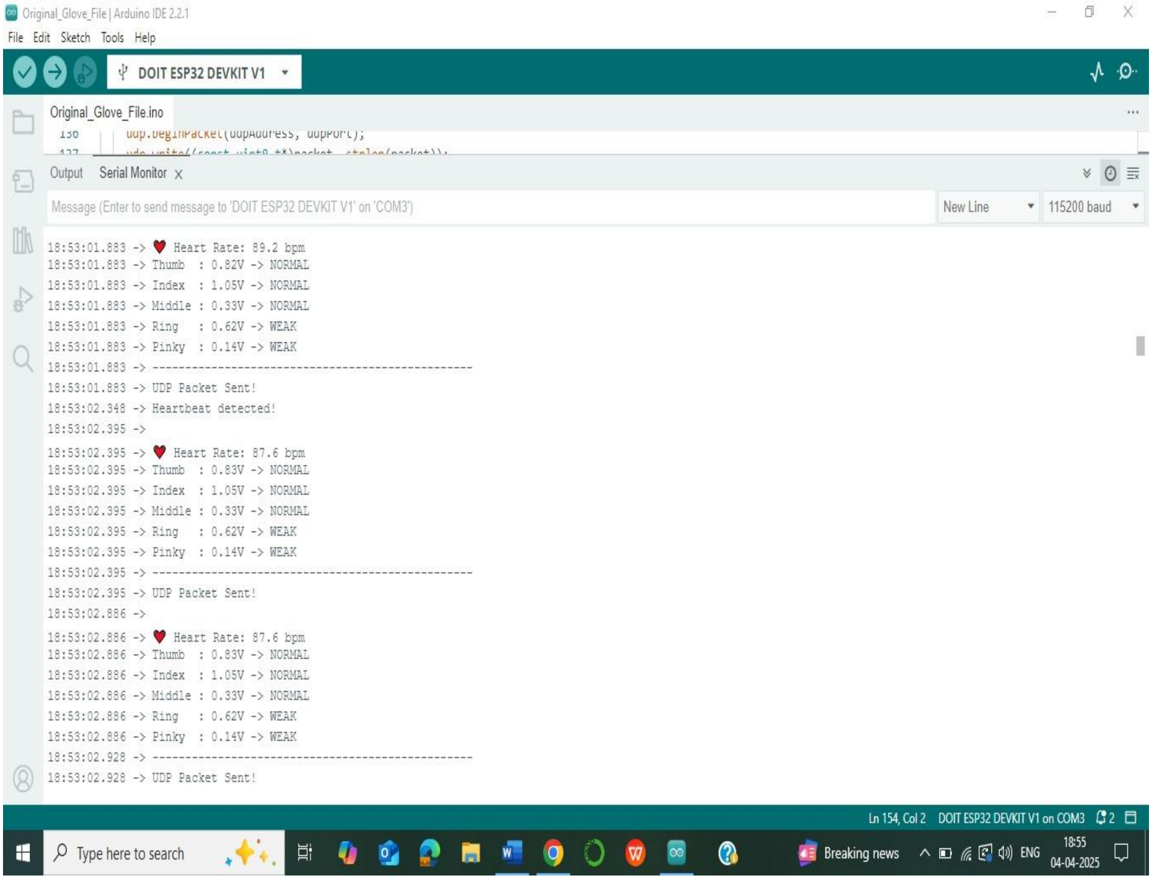
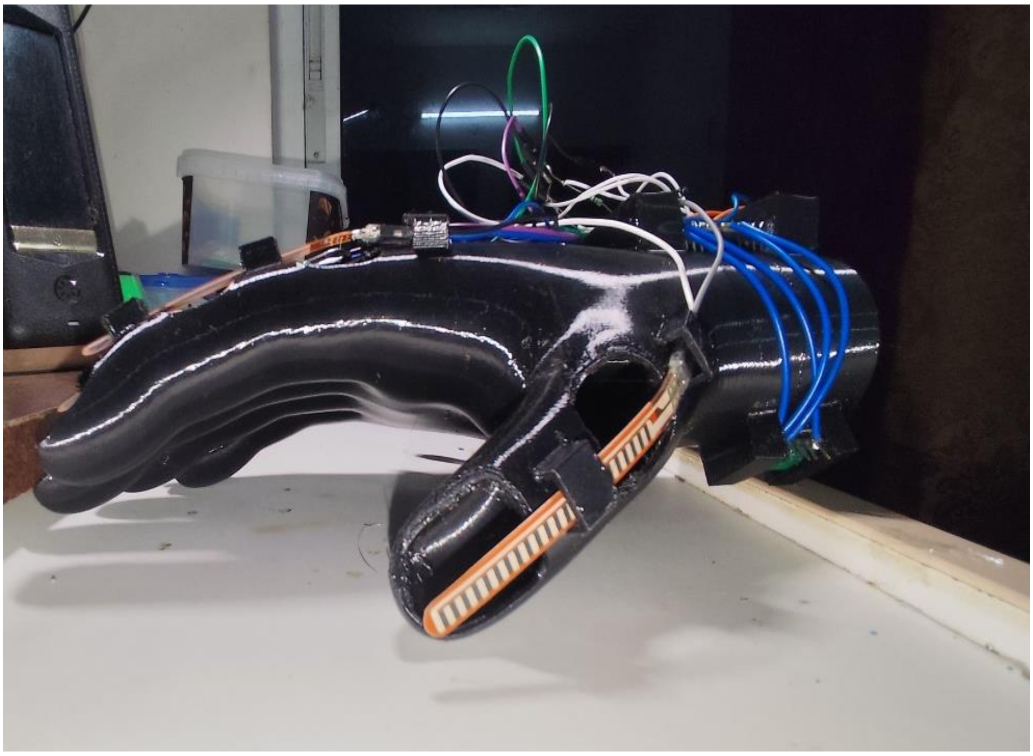
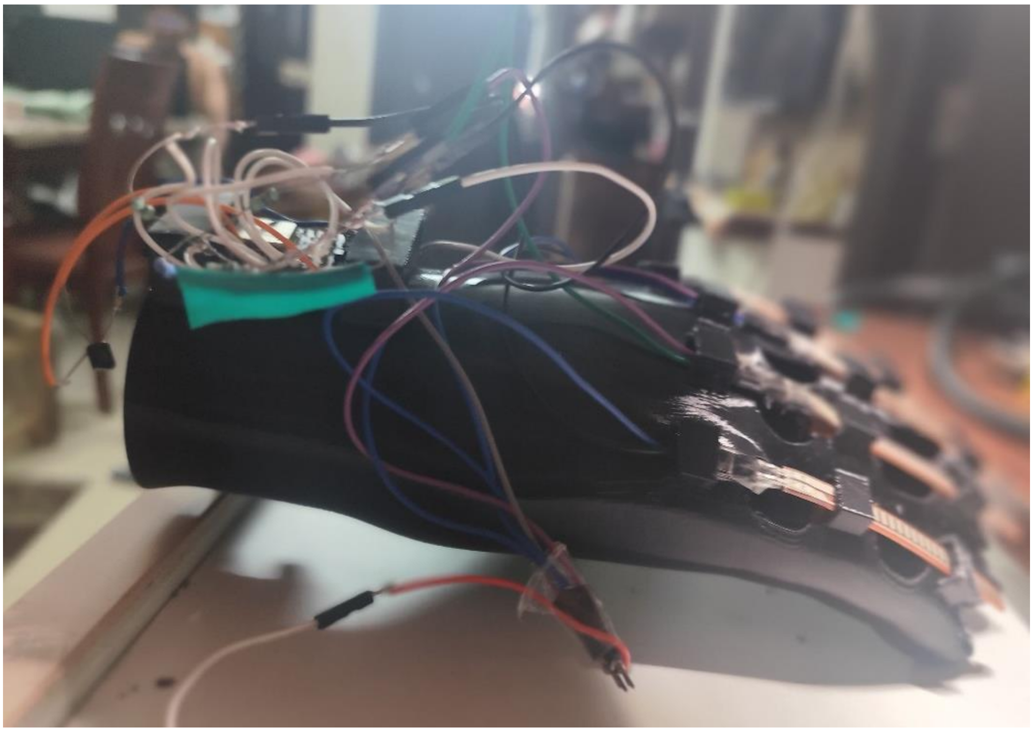


FIGURE 9: ARDUINO SENSOR RESULT (FLEX AND ESP MODULE)

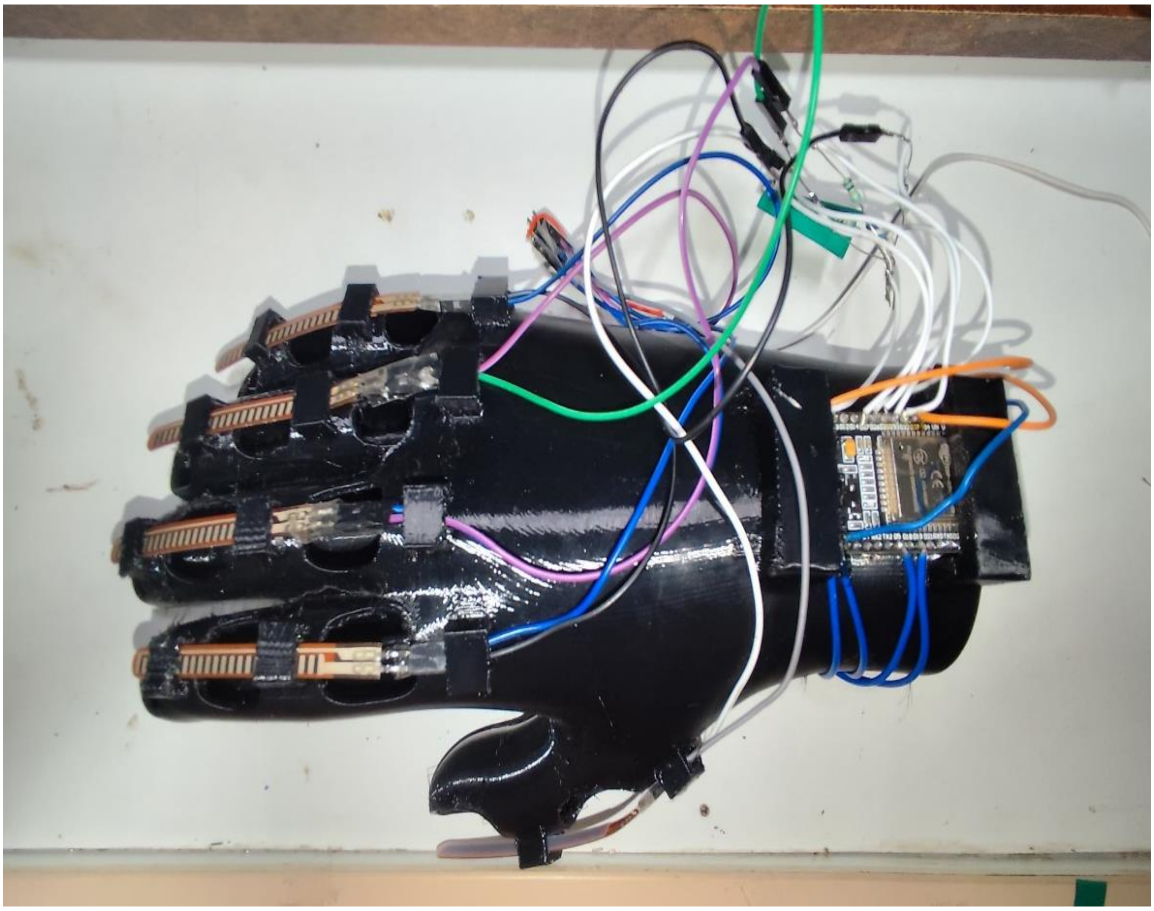
<u>LEFT VIEW:</u>



RIGHT VIEW:



TOP VIEW:



BOTTOM VIEW:

USER EXPERIENCE:

FIGURE 10: Views glove after soldering circuit connections inside the glove for monitoring.

5. Conclusion and Future Work:

The 3D-printed glove, combined with a companion mobile app, presents a significant advancement in stroke rehabilitation by merging personalized physical support with digital engagement. This project addresses critical gaps in current rehabilitation devices by providing a tailored, adaptable solution that supports both the physical and psychological aspects of recovery. The glove's design, using TPU, offers a unique blend of comfort, flexibility, and resistance suited to the gradual strengthening required in stroke rehabilitation. TPU's compatibility with skin and its durability make it ideal for prolonged use, while 3D printing enables the creation of gloves customized to each patient's hand shape and recovery needs. This ensures the glove fits comfortably and provides effective resistance, adapting as the user regains strength and flexibility.

The mobile app enhances the glove's functionality by creating a structured rehabilitation environment. It guides patients through a series of exercises, tracks their progress, and uses motivational feedback to keep them engaged. These digital features help overcome common challenges in rehabilitation, such as lack of motivation or uncertainty about proper exercise techniques. Moreover, the app's SOS button serves as a valuable safety feature, enabling patients to call for assistance if they experience discomfort or require help during exercises. This level of support not only increases patient confidence in practicing independently but also provides reassurance to caregivers and healthcare providers that assistance is readily available if needed.

The real-time tracking capabilities within the app also offer a unique advantage for both patients and healthcare providers. Patients can monitor their own progress, which can be highly motivating, while healthcare providers can remotely assess patient data and make informed decisions on adjustments to the therapy plan. This remote monitoring could be especially beneficial for patients with limited access to rehabilitation facilities, as it brings professional oversight into the home environment. The ability to adjust therapy based on real-time data makes the rehabilitation process more responsive to each patient's unique progression, offering a level of personalization that traditional in-person therapy sessions may not always provide.

Looking forward, the integration of additional features and advanced technologies could further enhance the glove’s effectiveness and reach. For instance, embedding sensors within the glove could provide detailed data on hand movement, muscle engagement, and pressure distribution during exercises. Such data could offer valuable insights into the quality of each movement, helping therapists refine exercise routines to improve recovery outcomes. These sensors could also enable the glove to detect improper hand movements or postures, providing corrective feedback in real-time through the app. This feature could be invaluable in ensuring that patients perform exercises correctly, minimizing the risk of strain or injury.

In terms of the app’s future scope, integrating AI-driven analytics could improve the adaptive capabilities of the therapy program. By analyzing trends in a patient’s data, the app could suggest new exercises or adjustments to existing routines based on individual progress patterns. This personalization could make rehabilitation more efficient, targeting specific areas that need improvement and reducing repetitive exercises that may not be necessary. Additionally, by developing a database of anonymized patient data, the app could potentially identify common progress patterns, offering benchmarks for recovery and allowing therapists to compare individual cases against broader trends.

The future of this glove and app system could also involve expanding access to more patients by making the solution affordable and easy to use. Collaborations with healthcare providers, insurance companies, and rehabilitation centres could help distribute the technology more widely. Moreover, educational content within the app could be developed to train caregivers and family members in supporting patients’ rehabilitation, further extending the solution’s impact.

In conclusion, this innovative glove and app system not only provides immediate benefits for stroke patients but also holds promising potential for the future of personalized rehabilitation. By addressing both physical and motivational aspects of recovery, this project enhances the rehabilitation experience, offering patients greater independence, confidence, and engagement in their healing process. As the system evolves with new technologies, it could play a transformative role in stroke rehabilitation, creating a more accessible, data-driven, and patient-centred approach to recovery.

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