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A Device for Handmotor and Cognitive Rehabilitation

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Abstract: Stroke and other neurological disorders often result in both motor and cognitive impairments, particularly affecting hand movement, coordination, attention, and memory. Conventional rehabilitation approaches generally address these aspects separately, which may limit the overall recovery process. To address this limitation, the device for hand Motor and cognitive rehabilitation system is developed as an integrated solution that simultaneously evaluates and trains both hand motor and cognitive functions. The device incorporates force-sensitive resistor (FSR) sensors, RGBLEDs, and a microcontroller-based control unit to detect finger pressure, provide visual feedback, and guide users through interactive rehabilitation tasks. The system operates in two modes: Evaluation Mode and Training Mode. Evaluation Mode measures important parameters such as finger strength, reaction time, and memory performance, providing objective data for clinical assessment. Training Mode introduces structured and interactive exercises that help improve motor coordination, grip strength, attention, and cognitive response through repeated practice and real-time feedback. The device is designed with a modular and ergonomic structure, allowing independent monitoring of each finger while ensuring user comfort during rehabilitation sessions. In addition, the device integrates wireless communication and a web-based interface for real-time monitoring and data recording. This enables clinicians to track patient progress, analyze performance metrics, and adjust rehabilitation programs accordingly.
Keywords: Stroke, ESP32 microcontroller, FSR sensrs, Handmotor rehabilitation, Cognitive rehabilitation , Website.

I. INTRODUCTION

Stroke is one of the main causes of disability in adults, with about 12.2 million new cases reported each year. Around 80 percent of stroke survivors experience some level of motor impairment in their upper limbs, which reduces their ability to carry out daily activities over time.[1], [2], [8]. These changes often affect function of hand by causing difficulties with hand positioning, altering muscle tone, or limiting precise finger movements.[3], [4], [8]. In addition to motor problems, cognitive impairment is common after a stroke. About 80 percent of stroke survivors have issues in one or more cognitive areas, with attention, short-term memory, and executive function being the most affected. Moreover, over 20 percent of survivors show both motor and cognitive impairment in the long term.[3], [5], [7]. These two issues may be linked because there are common neural pathways that connect motor and cognitive functions.[2], [6], [4]. Several studies suggest a connection between motor performance and overall cognition, memory, and executive function**.** Impairments in executive and attentional functions following a stroke influence the extent to which hand motor function improves with training.[3], [6], [8]. Furthermore, impairments in executive and attention functions after a stroke affect how much hand motor function improves with training.[1], [2]. Traditionally, post-stroke rehabilitation has focused separately on motor and cognitive functions.[1], [3], [4]. These methods, which are delivered at different intensities by various professionals, have not fully recognized their possible connections.[1], [5], [6]. However, more research is suggesting that there are overlapping effects between the two. For example, hand strength training has positive effects on cognition in healthy adults and those with mild cognitive impairment.[3], [6], [8]. Therefore, a rehabilitation program after a stroke that includes both motor and cognitive elements is essential for achieving the best recovery and quality of life.[1], [7], [8]. This is particularly important during the first three months, which is seen as a key period where the ability of brain to adapt enhances recovery of strength and motor control after a stroke.[1], [6], [8].

Hand Motor and Cognitive Rehabilitation Device offers a groundbreaking improvement in neuro-rehabilitation by combining hand motor training with cognitive exercises in a single portable device.[1], [6], [8]. It solves the problems of current rehabilitation tools by being affordable, easy to use, and accessible remotely.[1], [2], [8]. It has solved the limitations of previously existed model by incorporating battery and including the fifth finger thumb. Its simple design, wireless connection, and dependable data recording make it suitable for both clinical and remote settings. The device gives clear feedback on patient progress, allowing clinicians to make informed decisions about treatment plans.[1], [6], [8]. While more studies, especially involving clinical groups like stroke survivors, are needed to confirm its effectiveness, early results are encouraging.[1], [4], .

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The innovative method of Hand Motor and Cognitive Rehabilitation Device responds to modern healthcare needs, where technology should be flexible, accessible, and focused on the patient.[3], [6], [8]. By integrating cognitive and motor rehabilitation, the device not only improves care quality but also broadens the availability of rehabilitation services, ultimately leading to better recovery outcomes for patients and reducing the long-term impact of post-stroke disability.[3], [5], [8].

II. METHODOLOGY

The Hand Motor and Cognitive Rehabilitation Device was designed to evaluate and train both motor and cognitive hand functions simultaneously. It has five modular finger units with Force Sensitive Resistor (FSR) sensors and RGB LEDs, all controlled by an ESP32 microcontroller. The system works in two modes: Evaluation Mode (EM) and Training Mode (TM). Evaluation Mode (EM) measures strength, reaction time and memory. Training Mode (TM) helps in improving these skills through gamified tasks. It collects data during user interactions and allows clinicians to monitor through a web interface. The tasks are simple and can be adjusted for different levels of difficulty, making the device suitable for various abilities. It can be used with either the left or right hand and is designed for comfort. This approach ensures consistent data collection and personalized rehabilitation.

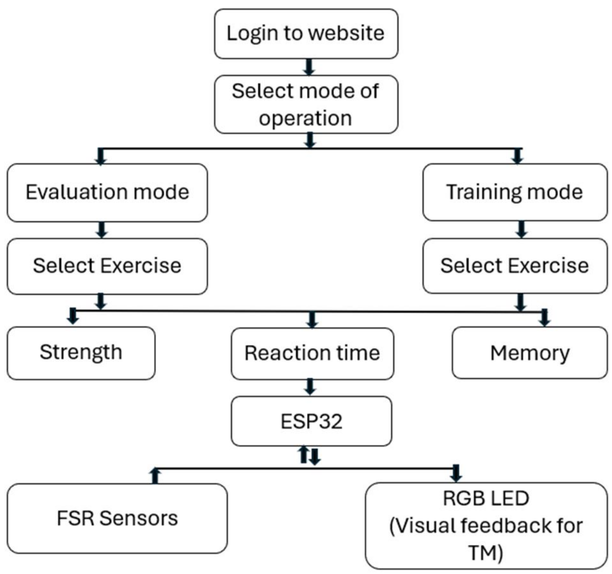

Fig.2.1 : Block Diagram of Hand Motor and Cognitive Rehabilitation Device

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The block diagram of hand motor and cognitive rehabilitation device shown in figure 2.1, explains how the Hand Motor and Cognitive rehabilitation system works from the user's point of view and how the software and hardware interacts. The process starts when the user log into the web platform and choose the required mode of operation.

The system offers two options: evaluation mode and training mode, depending on whether the goal is assessment or rehabilitation. The device is developed for the simultaneous evaluation and training of hand motor and cognitive functions, especially in stroke survivors. It has five cylindrical modules, each equipped with a Force Sensitive Resistor (FSR) and an RGB LED. These modules correspond to each finger, including the thumb, and connect to a central ESP32 microcontroller. Users interact with the device by responding to visual LED cues, applying finger pressure, and repeating color sequences to complete the tasks

A. *Evaluation Mode*

Evaluation Mode (EM) measures strength by recording the maximum force applied on each FSR. Reaction time is evaluated by tracking how quickly the user presses the correct module after a light cue appears. Memory is tested by presenting a sequence of colored lights that the user needs to reproduce. Each test is conducted three times to ensure reliability and accuracy. All response data, including force, timing, and correctness, is captured and stored for further analysis. This mode gives clinicians a baseline measurement about the abilities of the patient and helps to identify specific motor or cognitive issues for targeted rehabilitation

B. Training Mode

Training Mode (TM) builds on the evaluation framework by introducing repetitive, gamified tasks to boost user engagement and support functional recovery. As the user progresses, task difficulty increases by adjusting response time limits, force thresholds, or sequence lengths. This mode encourages neuroplastic adaptation and improves hand-eye coordination. The clinicians can assign exercises and track performance of the patients remotely via a cloud-based interface, making the device suitable for clinical or remote operation. The modular, ergonomic design ensures comfort and works well for users. The structured approach of Hand Motor and Cognitive Rehabilitation Device promotes consistent progress tracking, personalized therapy, and a unified method for cognitive-motor rehabilitation.

C. Circuit Diagram

The circuit diagram of hand motor and cognitive rehabilitation shown in fig 2.2 gives the circuit diagram for hardware setup used in the Hand Motor and Cognitive rehabilitation system, where sensing of force from hand and visual feedback are controlled using an ESP32 DevKit V1. The main purpose of the circuit is to sense pressure applied by each finger during exercises and provide immediate visual feedback, along with sending accurate data for evaluation and training tasks.

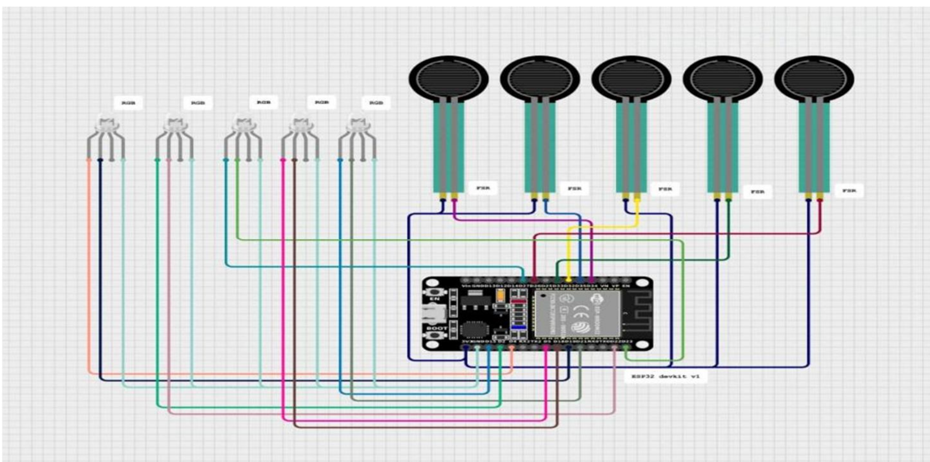

Fig 2.2 Circuit Diagram of Hand Motor and Cognitive Rehabilitation Device

At the centre of the circuit is the ESP32 DevKit V1, which acts as the control unit of the system. It handles sensor data acquisition, processes user inputs, and controls the output feedback. The ESP32 was chosen. because it supports multiple analog inputs, PWM outputs, and wireless communication, all of which are essential for this application.

Five Force Sensitive Resistors (FSRs**)** are connected to the digital pins (25,32,33,34,35) of ESP32 to measure the pressure applied by each finger. Each FSR changes its resistance based on the amount of force applied. One terminal of each FSR is connected to the supply voltage, while the other terminal is connected to an ESP32 analog input pin. When the user presses on the sensor, the voltage at the analog pin changes accordingly. This allows the ESP32 to continuously monitor finger force levels during hand movements or gripping tasks.

On the output side, five RGB LED**s** are connected to the ESP32 to provide visual feedback. Each RGB LED has three control lines corresponding to the red, green, and blue channels. These lines are connected to ESP32 GPIO pins configured for PWM operation. By varying the PWM signals, the ESP32 can control the color and brightness of each LED. This visual feedback is used mainly during training mode to guide the user, indicate correct responses, or signal task completion.

All sensors and LEDs share a common ground with the ESP32 to ensure stable and accurate operation. The wiring layout allows each sensor and LED to be independently controlled and monitored, enabling multi-finger interaction and parallel task execution. This design supports exercises related to strength measurement, reaction time, and memory by combining physical input with real-time feedback.

Overall, this circuit creates a smooth interaction between the user and the system. The ESP32 continuously reads force inputs from the FSR sensors, processes the data based on the selected rehabilitation task, and responds instantly through RGB LED feedback. This integrated setup makes the system suitable for both evaluation and training, while remaining simple, compact, and reliable for clinical or remote-based rehabilitation use.

The methodology presents Hand Motor and Cognitive Rehabilitation Device as a portable device that evaluate and improve both hand motor function and cognitive performance. It uses a finger-level sensing cylinder, an Arduino-based control module, and a web-based interface for remote operation and data management. The study outlines specific requirements for the device, including ergonomics, adaptability, portability, affordability, and independent operation. It also describes two operational modes: Evaluation Mode and Training Mode, which feature three parallel tasks covering strength, processing speed, and memory to collect detailed hand-cognition data. The evaluation protocol includes a reliability assessment focused on hardware, testing retest measures for strength, tapping speed, and memory. Additionally, the methodology explains how data is handled, with CSV storage on a secure web platform. It discusses choices made in interface design and plans for statistical analyses, including ICC interpretation, Bland-Altman limits of agreement, SEM, and correlation thresholds. Lastly, the approach notes limitations such as battery life and grip challenges, while suggesting future improvements to boost reliability, validity, and clinical use.

III. SIMULATION AND RESULTS

A Proteus-based simulation was performed to verify the functional operation of the proposed system before proceeding to ESP32-based hardware development. This preliminary simulation allowed the behaviour of the sensing circuitry, data acquisition process, and controller logic to be examined in a controlled environment, thereby ensuring reliable system performance prior to physical implementation.

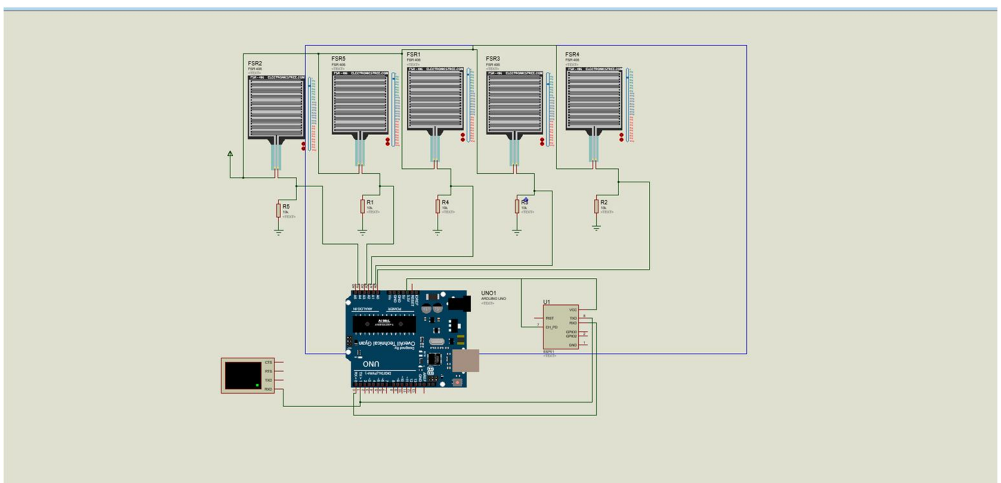

Fig 3.1 Simulation of Hand Motor and Cognitive Rehabilitation Device

The simulation is shown in figure 3.1. In this simulation, an Arduino Uno was used as the controller to represent the system logic, as Proteus offers robust support for Arduino-based designs. Although the final hardware prototype is implemented using an ESP32, the Arduino-based simulation allows effective verification of core functionalities such as multi-channel force sensing, voltage divider operation, and serial data monitoring. The insights obtained from this simulation ensure that the sensing architecture and control strategy are validated before transitioning to the ESP32-based hardware platform.

The entire system is designed to be portable and cost-effective, making it suitable for both clinical and remote-based rehabilitation programs. This is especially beneficial for patients recovering from neurological conditions like stroke or for those with impaired hand function. By providing immediate feedback on finger performance and overall hand function, the system helps therapists and users set measurable goals and adjust interventions. This approach enables more personalized rehabilitation, encourages user engagement, and supports evidence-based evaluation of hand recovery over time.

A. *Simulation Result*

The Proteus simulation was successful in validating the functionality of the proposed sensing system. Five force-sensitive resistors (FSRs) were simultaneously observed using separate analog input channels, and the system showed stable and consistent voltage responses to applied pressure. The differences in the force applied to each sensor resulted in corresponding changes to the analog values, ensuring proper voltage divider functioning and signal acquisition.

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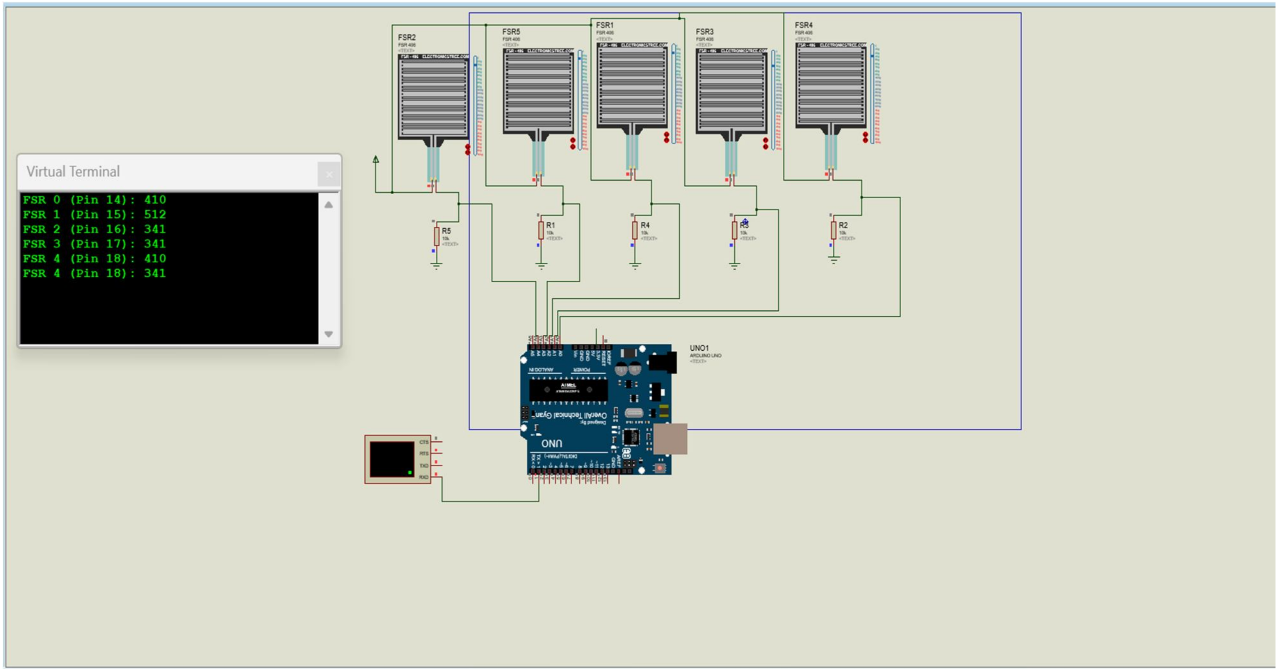

Fig 3.2 : Simulation Result

Real-time sensor data was viewed using the virtual serial terminal, where each FSR channel was distinctly labeled and updated in real-time. The data obtained confirmed that changes made to one sensor did not influence the output of other channels, ensuring proper electrical isolation and multi-channel stability. This confirms that the system is capable of accurately extracting finger-specific force data in real-time, which is critical for hand motor evaluation and training applications.

The simulation was successful in confirming that the controller is capable of accurately acquiring, processing, and transmitting multi-sensor data without signal interference or instability. These findings confirm the proposed sensing system's appropriateness for strength evaluation, reaction time analysis, and cognitive training applications, thus providing assurance for the transition of the validated design to the ESP32-based hardware platform.

IV. HARDWARE IMPLEMENTATION

A. Hardware Architecture

The Hand Motor and Cognitive Rehabilitation Device is implemented using an embedded hardware architecture designed to support integrated hand motor and cognitive rehabilitation within a compact and portable system. The system emphasizes modular sensing, real-time processing, and intuitive feedback while maintaining low power consumption and cost efficiency, suitable for both clinical and remote-based use.

The digitized sensor data are processed in real time by the ESP32 to compute motor performance indicators such as peak applied force, response timing, and inter-finger coordination. These parameters are utilized to support both assessment-oriented and training-oriented rehabilitation tasks. The high processing capability and multitasking support of the ESP32 enable synchronized data acquisition and low-latency system response during user interaction.

Cognitive engagement and task guidance are provided through RGB light-emitting diodes controlled by the ESP32’s digital output pins. The LEDs present predefined colour cues and illumination sequences that function as visual stimuli for reaction time and memory-based exercises. During training tasks, the visual outputs operate as real-time feedback indicators, reinforcing correct actions and promoting motor learning through closed-loop interaction. The use of RGB LEDs enables versatile cue representation without increasing circuit complexity.

The system is powered via a low-voltage USB supply, allowing operation from standard adapters or portable power banks. This power configuration enhances user safety and supports mobile deployment. Passive electronic components, including fixed-value resistors, are incorporated to stabilize sensor outputs, suppress electrical noise, and prevent floating input conditions at the ESP32 analog pins, thereby ensuring consistent performance during extended operation.

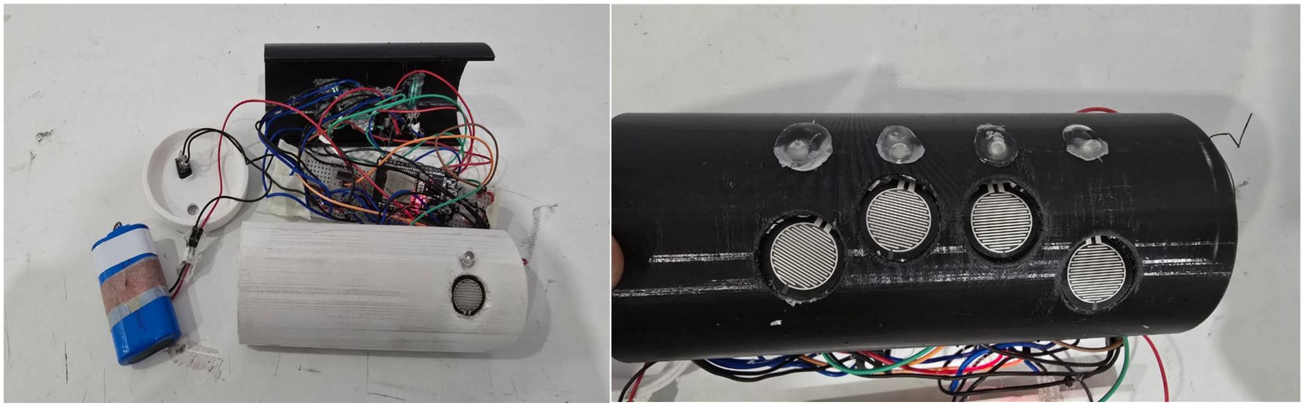

Figure 4.1 Hardware of Handmotor and Cognitive Rehabilitation device

All electronic components are housed within a custom-fabricated 3D-printed enclosure that provides mechanical protection, electrical insulation, and ergonomic support. The enclosure incorporates accurately positioned openings for sensor placement and visual indicators, ensuring reliable finger interaction and user comfort. Its modular design facilitates ease of assembly, maintenance, and future hardware expansion.

In summary, the proposed hardware architecture integrates multi-channel force sensing, real-time processing, and visual feedback using an ESP32-based embedded platform. This configuration provides a reliable, scalable, and cost-effective solution for combined motor and cognitive rehabilitation in both supervised and unsupervised environment.

B. 3D Model of device

The body of the device is 3-D printed as a modular cylindrical enclosure that supports both hand motor and cognitive rehabilitation tasks. Its shape allows the user to grip the device comfortably while enabling independent interaction of individual fingers during exercises. Smooth edges and a rounded profile are used throughout the design to improve ergonomics and ensure comfort during repeated or long-duration use.

The principal portion is the cylindrical shape that acts as active surface of grip and include accommodated apertures for integrating it to force sensors and visual feedback means. These apertures are designed with respect to finger placement naturally, so the force is applied accurately and interaction becomes intuitive during evaluation or training. Smaller openings are for indicators and larger circular cut-out to accommodate sensing components without compromising mechanical integrity.

Fig 4.2: 3-D Printed Body of Hand Motor and Cognitive Rehabilitation Device

The assembly is finished with two round end caps to protect the electronics and wire. The first end cap is used for mounting components and installing electrical connections, while the second end cap serves as a secure seal and mechanical support. This split body design makes it easy to assemble, maintain or change the design.

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The enclosure, which is 3D-printed, allows for quick production and customization for different hands or users. The system is compact and lightweight, allowing usage in clinic as well as remote setting. In sum, the enclosure combines ergonomics, functionality and sturdiness to enable convincing motor and cognitive rehabilitation in a small and user-friendly system

C. Software Architecture

The Live FSR Monitoring Website is an interactive platform designed to display real-time readings from a Force Sensitive Resistor (FSR) sensor. The primary objective of this system is to visualize the amount of pressure or force applied to the FSR in a clear and understandable graphical format. By continuously receiving sensor data, the website plots the FSR values against time, allowing users to observe live variations in pressure levels.

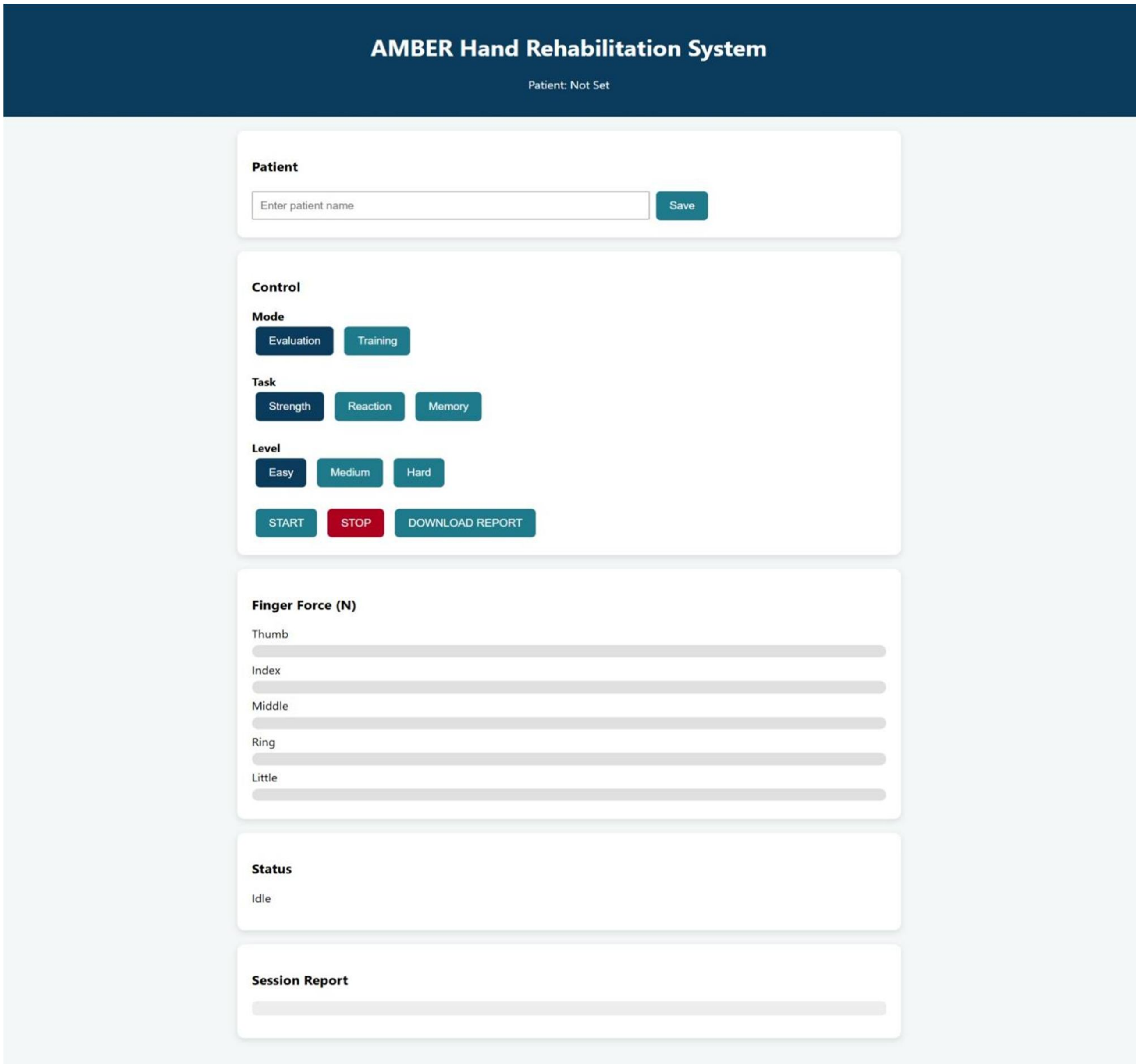

Figure 4.3: Live FSR Monitoring Website

The Force Sensitive Resistor (FSR) is a sensor whose resistance changes when force or pressure is applied. This property makes it ideal for various applications such as biomedical devices, robotic grips, pressure-sensitive control systems, and user-interactive interfaces. The data captured from the FSR is processed in real time and transmitted to the website through a connected microcontroller or data acquisition system.

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D. Hardware Result

The hardware implementation of the handmotor and cognitive rehabilitation device demonstrates the successful integration of force-sensitive resistor (FSR) sensors, RGB LEDs, and a microcontroller-based control unit. In the developed setup, five FSR sensors are positioned to correspond with the thumb, index, middle, ring, and little fingers. These sensors detect the force applied by each finger during grip or pressing actions. The sensors are connected to the analog input pins of the microcontroller through a voltage divider configuration using resistors, which ensures stable voltage variation corresponding to the applied pressure.

During operation, the microcontroller continuously reads the analog signals from the FSR sensors and converts them into force values. Based on the measured force levels, the system evaluates the hand motor performance of the user. The RGB LEDs connected to the digital output pins provide visual feedback, indicating the activity or response of each finger during rehabilitation exercises. This feedback mechanism supports interactive training by guiding the user to apply the required pressure or perform specific finger movements.

```
Patient: ALEENA JOSEPH

EVALUATION
 STRENGTH
  EASY :     Thumb  : 33.0 N
    Index  : 34.0 N
    Middle : 30.0 N
    Ring   : 12.0 N
    Little : 33.0 N
    Avg    : 28.4 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Evaluation mode clinical assessment.)
  MEDIUM :     Thumb  : 31.0 N
    Index  : 25.0 N
    Middle : 24.0 N
    Ring   : 15.0 N
    Little : 39.0 N
    Avg    : 26.8 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Evaluation mode clinical assessment.)
  HARD :     Thumb  : 25.0 N
    Index  : 29.0 N
    Middle : 21.0 N
    Ring   : 22.0 N
    Little : 33.0 N
    Avg    : 26.0 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Evaluation mode clinical assessment.)
 REACTION
  EASY : TIMEOUT (Partial Data)
    Avg Reaction : 4061 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Evaluation mode clinical assessment.)
  MEDIUM :     Avg Reaction : 4968 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Evaluation mode clinical assessment.)
  HARD :     Avg Reaction : 2891 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Evaluation mode clinical assessment.)
 MEMORY
  EASY :     Accuracy : 100 %
    Doctor AI Comment: Memory performance is strong. Cognitive function stable. (Evaluation mode clinical assessment.)
  MEDIUM :     Accuracy : 75 %
    Doctor AI Comment: Memory recall is moderate. Improvement noted. (Evaluation mode clinical assessment.)
  HARD :     Accuracy : 40 %
    Doctor AI Comment: Memory performance is poor. Rehabilitation recommended. (Evaluation mode clinical assessment.)
```

Figure 4.4: Hardware result of evaluation mode

```
TRAINING
 STRENGTH
  EASY :     Thumb  : 21.0 N
    Index  : 14.0 N
    Middle : 13.0 N
    Ring   : 9.0 N
    Little : 24.0 N
    Avg    : 16.2 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Training mode observation.)
  MEDIUM :     Thumb  : 23.0 N
    Index  : 28.0 N
    Middle : 25.0 N
    Ring   : 12.0 N
    Little : 31.0 N
    Avg    : 23.8 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Training mode observation.)
  HARD :     Thumb  : 31.0 N
    Index  : 26.0 N
    Middle : 31.0 N
    Ring   : 16.0 N
    Little : 34.0 N
    Avg    : 27.6 N
    Doctor AI Comment: Grip strength is within acceptable range. Recovery progressing well. (Training mode observation.)
 REACTION
  EASY :     Avg Reaction : 2577 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Training mode observation.)
  MEDIUM :     Avg Reaction : 2893 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Training mode observation.)
  HARD :     Avg Reaction : 3222 ms
    Doctor AI Comment: Reaction time is delayed. Neuromuscular coordination needs improvement. (Training mode observation.)
 MEMORY
  EASY :     Accuracy : 66 %
    Doctor AI Comment: Memory recall is moderate. Improvement noted. (Training mode observation.)
  MEDIUM :     Accuracy : 75 %
    Doctor AI Comment: Memory recall is moderate. Improvement noted. (Training mode observation.)
  HARD :     Accuracy : 100 %
    Doctor AI Comment: Memory performance is strong. Cognitive function stable. (Training mode observation.)


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OVERALL DOCTOR AI SUMMARY
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Overall performance indicates reduced functional ability. Continued rehabilitation is advised.
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Figure 4.5: Hardware result of training mode

The result obtained from hand motor and cognitive rehabilitation device is shown in figure 4.4 The hardware output is also recorded in a system log file that displays the measured force values for each finger and the corresponding evaluation results. As shown in the generated report, the measured grip force values for all fingers are approximately 40 N under the medium difficulty level, indicating that the user's grip strength falls within an acceptable range. The automated evaluation module further provides a clinical-style summary stating that recovery is progressing well while recommending continued rehabilitation exercises. Overall, the hardware results confirm that the device is capable of accurately detecting finger force, providing real-time feedback, and generating performance assessments. This demonstrates the feasibility of the proposed system for supporting both hand motor rehabilitation and cognitive training in a structured and interactive manner.

V. CONCLUSIONS

The Hand Motor and Cognitive rehabilitation Device stands out because of its ergonomic design, adaptability, robustness, and reliability as a tool for measuring force, memory, attention, and coordination. It holds promise for therapists, helping them conduct reliable evaluations and address motor and cognitive issues in patients with a single, portable, and cost-effective device. It can offer flexible programming and create stronger links with more complex cognitive evaluations. Unlike other hand rehabilitation devices, Hand Motor and Cognitive rehabilitation Device includes cognitive rehabilitation tasks, a feature missing in existing options. The hardware of the Hand Motor and Cognitive rrehabilitation device is reliable, accurate, and user-friendly, effectively capturing motor and cognitive responses with modular sensor-equipped finger units. The Arduino Uno provided smooth control and data management, and the system aligned well with standard clinical tools. Its compact, ergonomic design makes it suitable for both clinical and remote use, offering a practical solution for stroke rehabilitation.

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