 https://doi.org/10.24191/jeesr.v29i1.024

Real-Time Finger Counting System for Thrombotic Recovery: A Sensor Based Rehabilitation Approach

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***Abstract*—Thrombosis, the formation of blood clots within blood vessels, poses significant health risks including deep vein thrombosis (DVT), pulmonary embolism and stroke. Traditional monitoring methods are often invasive, costly and require specialized medical staff. This study proposes a non-invasive, low-cost monitoring system based on finger counting exercises using flex sensors integrated with an ESP32 microcontroller. The system detects finger movements during rehabilitation exercises, processes data wirelessly via ESP32 and displays results in real-time on an LCD interface. Visual feedback is provided through NeoPixel LEDs, enhancing patient engagement. The project demonstrates the feasibility of using finger motion analysis as a rehabilitation tool for thrombotic patients, offering improved efficiency for physiotherapists and reducing reliance on invasive monitoring techniques.**

***Index Terms*—ESP32, flex sensor, rehabilitation, thrombosis monitoring, wireless communication**

I. Introduction

Thrombosis, the pathological formation of blood clots is a leading cause of stroke and cardiovascular complications [1]. Rehabilitation is essential for recovery, with handgrip strength serving as a predictor of disability and mortality [6]. However, hospitals face challenges including limited staff availability and high patient loads [4].

Recent studies emphasize the role of finger movement exercises in elderly rehabilitation. [5] demonstrated that finger movement and weight lift training improved handgrip strength and Activities of Daily Living Scale (ADLS) scores in individuals aged ≥80 years. Dermatological rehabilitation research further underscores the importance of functional hand exercises in improving patient outcomes [7].

Physiotherapists play a crucial role in the rehabilitation of patients recovering from thrombotic events, stroke or other neurological impairments. Their responsibilities include guiding patients through structured exercises, monitoring progress and recording rehabilitation data. However, many clinics and hospitals face a shortage of physiotherapists, resulting in challenges in providing individualized attention to every patient. This shortage often leads to inefficiencies in data collection and delays in treatment monitoring.

This manuscript is submitted on January 22, 2026, revised on April 26, 2026, accepted on May 25, 2026 and published on October 31, 2026.

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A sensor based monitoring system can help address this gap by automating the process of recording patient performance during exercises such as finger counting. With real-time feedback displayed on an LCD or LED interface, patients can independently track their progress without constant supervision. This not only reduces the workload of physiotherapists but also ensures that data is collected systematically and efficiently. Consequently, physiotherapists can focus on clinical decision-making while patients benefit from more accessible and consistent rehabilitation support.

II. Literature Review

A. Thrombosis and Rehabilitation

Thrombosis defined as the pathological formation of blood clots within blood vessels is a major contributor to global morbidity and mortality. When clots obstruct blood flow, they can lead to severe complications such as DVT, pulmonary embolism, myocardial infarction or ischemic stroke. These conditions often result in long-term disability, reduced quality of life and increased healthcare burden. According to global cardiovascular statistics, thrombotic events remain among the leading causes of hospitalization and death, particularly in aging populations [6].

Rehabilitation following thrombotic events is therefore critical. Beyond pharmacological management with anticoagulants, patients require structured rehabilitation programs to restore motor function, prevent recurrence and maintain independence. One of the most widely recognized indicators of rehabilitation success is handgrip strength, which serves as a surrogate measure of overall muscle strength and functional capacity. Research has consistently shown that handgrip strength correlates with general health outcomes, including cardiovascular risk, bone density and frailty [8]. Importantly, diminished handgrip strength is associated with higher rates of disability, longer hospital stays and reduced ability to perform activities of daily living.

Moreover, handgrip strength has predictive value for mortality. Longitudinal studies in elderly populations demonstrate that individuals with weaker grip strength have significantly higher all cause mortality rates compared to those with stronger grip capacity [9]. This makes handgrip strength not only a rehabilitation target but also a prognostic marker for long term survival.

In the context of thrombotic rehabilitation, monitoring handgrip strength provides clinicians with a simple, non-invasive tool to evaluate patient progress. Rehabilitation strategies such as finger-movement exercises, resistance training and sensor-based monitoring systems can enhance grip strength, improve dexterity and support neurological recovery. These interventions are particularly valuable in resource-

limited settings, where advanced exoskeletons or robotic rehabilitation devices may be unavailable.

Thus, thrombosis management must extend beyond acute treatment to include comprehensive rehabilitation programs that emphasize functional recovery. By integrating clinical evidence with technological innovation, such as flex sensor–based monitoring systems, healthcare providers can better assess patient outcomes, reduce disability and improve survival rates. Handgrip strength as a surrogate marker, remains central to this effort, bridging the gap between clinical rehabilitation and long-term patient well-being.

B. Functional Hand Exercises

Hand function plays a pivotal role in maintaining independence, self-care and quality of life across diverse patient populations. Evidence from [5] demonstrated that finger movement exercises combined with weight lift training significantly improved handgrip strength and ADLS values among very elderly individuals. These exercises enhanced dexterity, pinch force control and manual speed [10], thereby reducing functional decline associated with aging. The findings highlight the importance of structured, skill based finger training as a rehabilitation strategy to preserve autonomy in elderly care.

Similarly, the [7] study emphasized the role of functional hand exercises in dermatological rehabilitation, particularly for patients with chronic skin conditions that impair mobility and manual performance. Dermatological disorders often lead to stiffness, discomfort or reduced hand flexibility and targeted exercises were shown to restore functional capacity and improve patient outcomes. This underscores the interdisciplinary relevance of hand rehabilitation, extending beyond neurology and geriatrics into dermatology and other clinical domains.

Taken together, these studies illustrate that functional hand exercises are not only effective in elderly populations but also beneficial in dermatological contexts. Both highlight the centrality of hand function in rehabilitation, where improvements in grip strength and dexterity directly translate into enhanced independence and selfcare. Integrating sensor-based monitoring systems, such as flex sensor gloves, could further optimize these interventions by providing real-time feedback, ensuring compliance and tailoring exercise intensity to individual patient needs. Thus, functional hand exercises represent a versatile, cross-disciplinary rehabilitation approach with broad clinical applications.

C. Sensor Based Monitoring Systems

Sensor based monitoring systems have emerged as a transformative approach in healthcare and rehabilitation, offering non-invasive, real-time insights into patient progress. Among these technologies, flex sensors are particularly valuable due to their ability to measure bending and angular displacement. When embedded in wearable gloves, flex sensors can capture subtle finger movements, making them suitable for applications such as gesture recognition, robotic control and rehabilitation monitoring [2]. Their lightweight design and affordability further enhance their practicality in clinical and home based settings.

The integration of flex sensors with ESP32 microcontrollers significantly expands their functionality. The ESP32 is equipped with built-in Wi-Fi and Bluetooth capabilities, and through the ESP32 protocol, it enables low-latency, peer-to-peer communication between devices without requiring a router [3]. This feature is critical in rehabilitation contexts, where immediate feedback can motivate patients and assist physiotherapists in tracking progress. For example, finger-counting exercises monitored via flex sensors can be transmitted wirelessly to a display unit, providing both visual and auditory feedback.

Such systems not only improve patient compliance but also reduce the workload of healthcare professionals by automating data collection and monitoring. Compared to traditional rehabilitation methods, sensor based systems offer objective measurements, minimizing human error and ensuring consistency. Furthermore, they can be scaled for remote monitoring, aligning with global trends in telemedicine and personalized healthcare.

Sensor based monitoring systems that combine flex sensors with ESP32 microcontrollers represent a cost-effective, efficient and scalable solution for rehabilitation. They bridge the gap between engineering innovation and clinical practice, supporting precision medicine and enhancing patient outcomes.

III. HARDWARE IMPLEMENTATION

A. Flex sensor

A flex sensor is a resistive device that changes its electrical resistance depending on the degree of bending. Typically constructed from a thin strip of conductive material layered on flexible substrates, the sensor operates on the principle that mechanical deformation alters the conductive path length and thickness, thereby modifying resistance. When the sensor is straight, its resistance is relatively low (e.g., ~10 kΩ). As it bends, the resistance increases proportionally, often reaching values of 30–50 kΩ depending on the bend angle. This property makes flex sensors ideal for detecting finger, wrist or joint movements in wearable rehabilitation systems.

Functionally, flex sensors convert mechanical motion into electrical signals. When integrated into a glove or rehabilitation device, they provide continuous feedback on finger positions, enabling monitoring of exercises such as finger counting or grip strength. The sensor's output can be processed by microcontrollers to quantify movement and trigger visual or auditory feedback.

Threshold levels are established to distinguish between different states of motion. For example, a threshold resistance value may be set to determine whether a finger is fully bent or extended. By calibrating these thresholds, the system can reliably interpret gestures or exercise repetitions. Thresholds are often determined experimentally by measuring sensor resistance at specific bend angles and mapping them to digital values.

To interface flex sensors with microcontrollers, a voltage divider circuit is commonly used. The sensor is connected in

series with a fixed resistor and the output voltage is taken from the junction between them. The voltage divider equation is:

$$V_{out} = V_{in} \times \frac{R_{fixed}}{R_{fixed}+R_{flex}} \quad (1)$$

Here, R_{flex} varies with bending, producing a corresponding change in . This analog voltage is read by the microcontroller's ADC (Analog to Digital Converter), enabling precise measurement of finger movement as shows in Fig. 1.

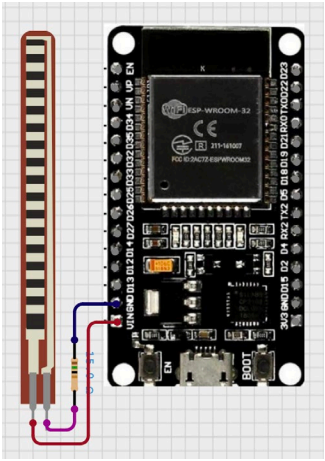

Fig. 1. ESP32 with flex sensor.

Thus, flex sensors combined with threshold calibration and voltage divider circuits, provide a simple yet powerful mechanism for motion detection in rehabilitation monitoring systems.

B. Block Diagram

Fig. 2 illustrates block diagram of wireless rehabilitation monitoring system comprising two ESP32 microcontrollers connected via WiFi. The transmitter ESP32 is integrated with a hand glove embedded with five flex sensors, each aligned to detect the bending motion of individual fingers. These sensors capture real-time data during finger exercises and transmit it wirelessly to the receiver ESP32. The receiver unit processes the incoming data and activates three output components: an LCD display for visual feedback, a buzzer to signal round completion and eight LEDs that indicate finger grip accuracy.

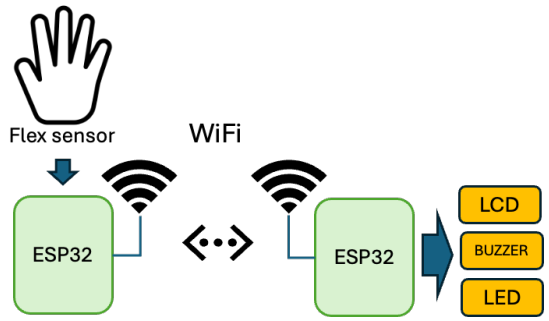

Fig. 2. Block diagram system.

The system is composed of two main modules: a transmitter unit and a receiver unit, both powered by ESP32 microcontrollers. The transmitter section is equipped with five calibrated flex sensors embedded in a wearable glove worn by the patient as shown in Fig. 3. Each sensor corresponds to one finger and is responsible for detecting bending motion during hand exercises. As the patient performs finger movements such as gripping and releasing a change in resistance is registered, allowing the system to capture real-time rehabilitation data.

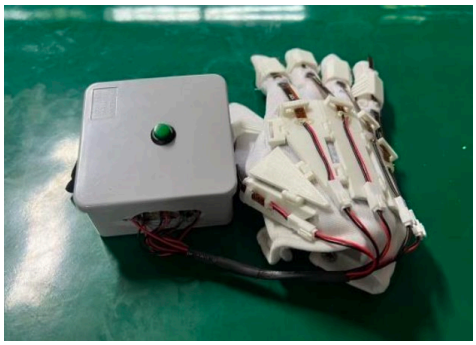

Fig. 3. Transmitter box with hand glove (flex sensor).

The receiver unit consists of another ESP32 microcontroller connected to three output components: an LCD screen, a set of eight LEDs, and a buzzer as shows in Fig. 4. The LCD serves as a visual interface, displaying the number of successful grips and rounds completed, which helps both patients and physiotherapists monitor progress efficiently. The eight LEDs provide immediate feedback: all LEDs illuminate green when the patient successfully grips all five fingers, indicating proper execution. If any finger fails to bend correctly, the corresponding LED turns red, signaling incomplete or incorrect movement. Additionally, the buzzer activates at the end of each round to notify the patient that a set of 15 repetitions has been completed.

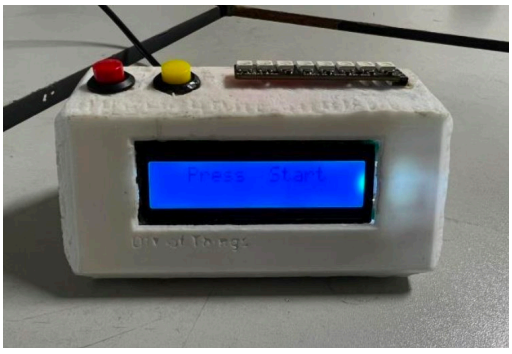

Fig. 4. Receiver box (output).

C. Standard Operating Procedure

The operation begins by powering on the system and ensuring that the patient wears the flex sensor glove on the hand designated for rehabilitation. This glove contains embedded flex sensors that detect finger bending during exercise. Refer Fig. 5 for the flowchart of the process.

Next, the communication between the WiFi transmitter system (connected to the flex sensor and ESP32

microcontroller) and the WiFi receiver system (connected to the display and feedback components) must be verified. This ensures that data can be transmitted wirelessly via ESP32 protocol without interruption.

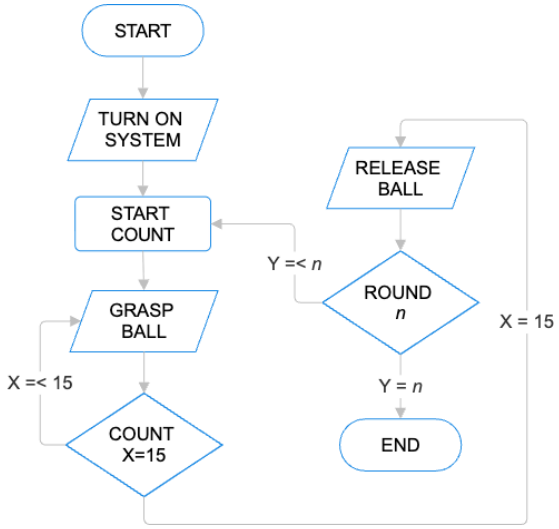

Fig. 5. Flowchart of the process.

Once the connection is established, the user selects the "Start" button on the receiver box to initiate the session. The rehabilitation exercise begins with the patient grasping and releasing a soft ball. This action is repeated 15 times, with each grip detected by the flex sensor and counted by the system.

After completing 15 repetitions, the system checks whether the patient wishes to continue with additional rounds. If the patient is capable, they may proceed with further sets of 15 repetitions. This flexibility allows the therapy to be tailored to individual endurance levels.

Throughout the session, the ESP32 receiver processes the data and displays the grip count and round progress on the LCD screen. This real-time feedback helps both the patient and physiotherapist monitor performance.

IV. Result

Table I presents the raw data collected from five flex sensors embedded in a rehabilitation glove worn by the patient. Each sensor corresponds to a specific finger; thumb, index, middle, ring, and little and captures analog signals as the fingers bend during exercise. The data is recorded in real-time, with each entry time-stamped in milliseconds to ensure accurate temporal tracking. The ADC values represent the electrical signal generated by the sensor, which varies depending on the degree of finger flexion. These values are sampled at a consistent rate of 100 Hz, providing high resolution data suitable for motion analysis.

The voltage column shows the converted signal strength using a 10-bit ADC with a 5V reference, calculated using the formula $V = \frac{ADC \times 5}{1023}$. This conversion is essential for interpreting sensor behavior and calibrating thresholds for grip detection. By analyzing these raw signals, researchers and clinicians can assess finger movement patterns, detect anomalies and monitor rehabilitation progress. The table provides foundational data for further processing, including bend angle estimation and grip classification. It also supports system validation, ensuring that the sensors respond accurately and consistently to patient movement.

TABLE I. RAW FLEX SENSORS SIGNALS PER FINGER

Timestamp (ms)	Finger	ADC Value	Sampling Rate (Hz)	Voltage (V)
0	Thumb	512	100	2.50
0	Index	478	100	2.34
0	Middle	490	100	2.39
0	Ring	505	100	2.47
0	Little	520	100	2.54
100	Thumb	620	100	3.02
100	Index	590	100	2.87
100	Middle	600	100	2.93
100	Ring	615	100	3.00
100	Little	630	100	3.08

Table II illustrates the processed output derived from raw flex sensor data, showing how ADC values are translated into meaningful biomechanical metrics. Each row corresponds to a finger with its respective ADC reading converted into resistance (in kilo ohms) and then mapped to a bend angle (in degrees). This transformation is achieved using a calibration curve, typically modeled as $\theta = a \times R + b$, where θ is the bend angle and R is the sensor resistance. The constants a and b are determined experimentally during system setup.

The bend angle provides a quantifiable measure of finger flexion, which is crucial for evaluating grip quality and rehabilitation performance. In this example, all fingers exhibit bend angles above 60°, indicating a successful full-hand grip. The final column, "Grip Status," classifies each finger as either "Bent" or "Unbent" based on predefined angle thresholds. This classification enables real-time feedback via LEDs and supports automated tracking of exercise repetitions.

By converting electrical signals into biomechanical data, Table II bridges the gap between engineering and clinical interpretation. It allows physiotherapists to monitor patient progress objectively and adjust therapy protocols accordingly. This data driven approach enhances rehabilitation precision and supports personalized recovery strategies.

TABLE II. ESTIMATED BEND ANGLES FROM FLEX SENSOR CALIBRATION

Finger	ADC Value	Resistance (kΩ)	Bend Angle (°)	Grip Status
Thumb	620	30.2	65	Bent
Index	590	28.7	60	Bent
Middle	600	29.3	62	Bent
Ring	615	30.0	64	Bent
Little	630	31.0	67	Bent

Fig. 6 demonstrates the correct method for performing a therapeutic grip using a reference object a soft ball. The patient wears a flex sensor embedded glove that detects finger movement during the exercise. By gripping the ball, the patient engages all five fingers in a coordinated motion, ensuring

proper flexion and pressure. The ball acts as a tactile guide, helping the patient maintain consistent grip posture and force. This approach improves rehabilitation accuracy, allowing the system to detect full-hand engagement. It also supports physiotherapists in validating movement quality while enabling patients to perform exercises independently with reliable feedback.



Fig. 6. Handgrip method with soft ball.

Fig. 7 and Fig. 8 illustrate the operation of a sensor based rehabilitation glove system. The patient wears a glove embedded with flex sensors and grips a soft ball to perform therapeutic exercises. When the hand is correctly clenched around the ball, all five flex sensors detect sufficient bending, triggering a green LED light, indicating a successful grip and registering one COUNT. If the grip is incomplete or the hand is released prematurely, the system activates a red LED, signaling an error or improper movement. This real-time feedback helps patients perform exercises accurately and allows physiotherapists to monitor progress efficiently and systematically.

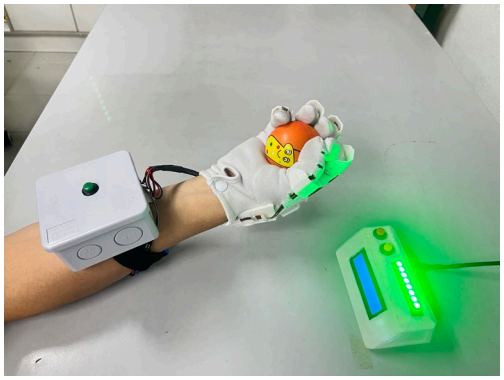

Fig. 7. Output for handgrip (green).

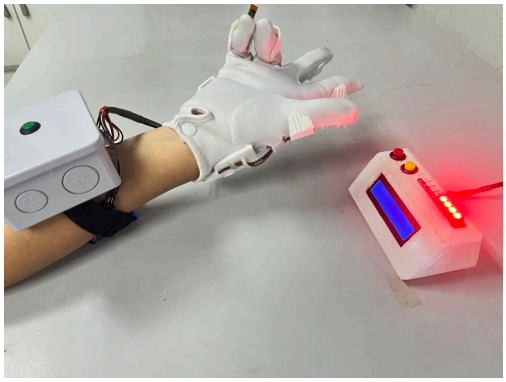

Fig. 8. Output for hand release (red).

V. Conclusion

The development of this flex sensor based finger counting system using ESP32 microcontrollers was successfully implemented and tested. The project demonstrated reliable performance in detecting finger movements, providing real-time feedback through LCD, LED and buzzer outputs. It effectively supports physiotherapists by automating grip monitoring, reducing manual data collection and enabling patients to perform rehabilitation exercises independently. This system addresses the shortage of physiotherapists in clinics and hospitals by streamlining rehabilitation workflows and enhancing patient compliance. Overall, the project offers a practical, low-cost solution that bridges engineering innovation with clinical needs in thrombotic recovery and hand function rehabilitation.

Acknowledgment

The authors would like to express their sincere gratitude to Mr. Khairizan Hairiri, a physiotherapy staff member at Hospital Sultanah Bahiyah, for his valuable input and practical insights in guiding the rehabilitation aspects of this project.

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