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IoT-Enabled Instrumented Glove for Real-Time Monitoring of Finger Pinch Strength

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ABSTRACT

The critical issue of academic misconduct is of utmost importance in the field of education and understanding whistleblowing behaviour can be a potential measure to effectively address this issue. This paper highlights the benefits of using the Tree-based Pipeline Optimization (TPOT) framework as a user-friendly tool for implementing machine learning techniques in studying whistleblowing behaviour among students in universities in Indonesia and Malaysia. The paper demonstrates the ease of implementing TPOT, making it accessible to inexpert computing scientists and showcases highly promising results from the whistleblowing classification models trained with TPOT. Performance metrics such as Area Under Curve (AUC) are used to measure the reliability of the TPOT framework, with some models achieving AUC values above 90% and the best AUC was 99% by TPOT with a Genetic Programming population size of 40. The paper's main contribution lies in the empirical demonstration and findings that resulted in achieving the optimal outcomes from the whistleblowing case study. This paper sheds light on the potential of TPOT as an easy and rapid implementation tool for AI in the field of education, addressing the challenges of academic misconduct and showcasing promising results in the context of whistleblowing classification.

Keywords:

Instrumented glove; pinch strength; force-sensitive resistor; IoT; rehabilitation; hand function assessment

1. Introduction

Stroke is a major public health issue, ranking as the second leading cause of death worldwide. It is a primary driver of lifelong disability among adults [1]. In the United States, stroke is a major cause

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of long-term disability [2]. Projections indicate a concerning rise in ischemic stroke cases to 9.62 million globally by 2030, which will significantly burden healthcare systems [3]. Stroke often leads to motor deficits in the hand, frequently resulting in diminished grip and pinch strength. Alarmingly, one-third of stroke survivors develop wrist and hand contractures within six months of a major stroke and over half of those with impaired hand function fail to regain sufficient capacity for daily activities [4]. Restoring hand motor control is crucial for stroke survivors to perform everyday activities independently and improve their quality of life [5-7], for example, enabling self-care tasks and reclaiming the ability to manipulate objects with dexterity [8-11].

The pinching function entails the flexion and extension movements of the fingers, allowing for the application of force on an object and the subsequent lifting of the object [12]. Measuring pinch strength is important in fields like occupational therapy, ergonomics and rehabilitation [13]. It is a critical measure of hand function and a predictor of independence in daily activities, as it quantifies the force when the thumb and index finger are pressed together. Additionally, grip strength, pinch strength and range of motion are commonly used to plan treatment for rheumatoid arthritis, a hand condition [14]. Traditionally, the assessment of improvements in pinch strength has been based on the use of pinch meters or gauges, which provide standardized measurements [13,15,16]. While these devices reliably measure maximum grip and pinch strength, a sensory glove can offer immediate visual feedback on grip or pinch application, allowing users to adjust their grip strength or pinch force during exercises. This is particularly beneficial in motor learning and rehabilitation, as patients can make real-time adjustments to their grip.

The limited availability of stroke services in rural areas in Malaysia [17] poses significant challenges for providing timely and effective treatment. Sensory gloves can be used remotely to assess and track patients' pinch strength and fine motor control, supporting remote rehabilitation. Several studies have explored different approaches to measuring hand forces, including sensor-equipped gloves [18-22] and gauge-based systems [23,24] using various sensor technologies to capture force distributions across the palm and individual digits, including force sensitive resistor sensors [18-22], Velostat pressure sensors [25], six-axis force or torque transducers [23] and custom sensor integration techniques such as small load cells and pressure-sensing fabric, coupled with mechanical pinch gauges [24].

While the prior studies have measured the forces exerted by individual digits, they have not converted this data into the specific pinch strength measurements typically obtained using a standard pinch meter. This could result in unreliable assessments of hand strength and dexterity, potentially leading to inaccurate evaluations of an individual's capabilities [13,26]. The data on individual digit forces may not be sufficient in clinical settings where the assessment of precise pinch strength is crucial for rehabilitation or ergonomic evaluations.

The instrumented gloves reported in prior studies also lacked the functionality to retrieve and compare data from previous rehabilitation sessions, which would hinder clinicians' ability to monitor and evaluate patients' improvements in strength over time. Therefore, an integrated system that can concurrently measure pinch strength, track progress and provide real-time biofeedback is essential to enhance stroke rehabilitation. To address this need, we propose the development of an IoT-enabled instrumented glove that can offer real-time monitoring of pinch strength in a manner compatible with standard clinical assessments.

2. Methodology

2.1 System Block Diagram and Flowchart

The instrumented glove system, as shown in Figure 1 and Figure 2, incorporates a block diagram and a breadboard arrangement for the real-time assessment and monitoring of finger pinch force. FSR sensors were used to detect the pressure exerted by the user's thumb and index finger. The microcontroller processed the pressure data and then transmitted it wirelessly using an ESP8266 module. The processed data were also displayed on a 16x2 liquid crystal display. Additionally, the ESP8266 module forwarded the data to a connected device for monitoring and storage, allowing the data to be visualized in the Blynk mobile application.

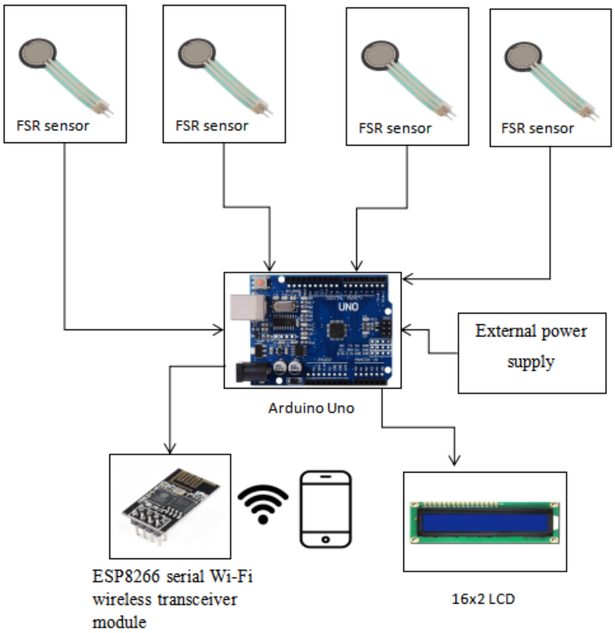

Fig. 1. Block diagram of the proposed system

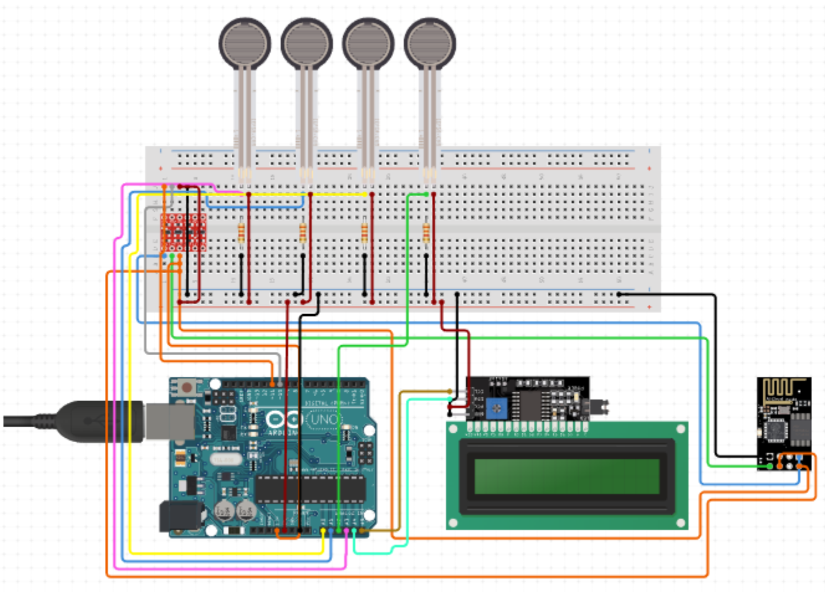

Fig. 2. Breadboard view of the proposed system

The proposed system, as illustrated in Figure 3, is divided into two components: the sensing operational system and the monitoring operational system.

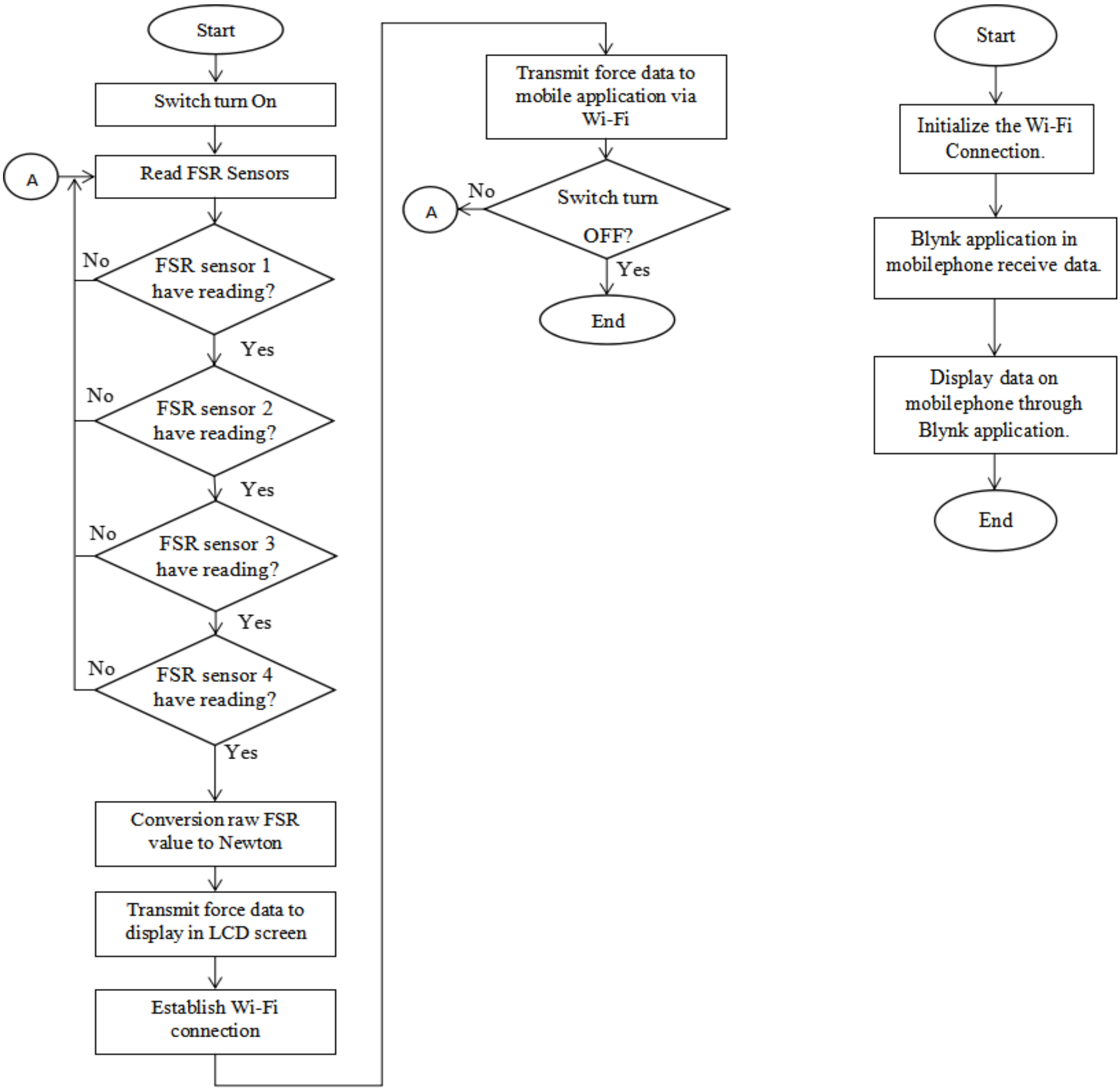

Fig. 3. Operational system flowchart for sensing and monitoring system

The FSR sensors were positioned on the glove's thumb and index finger regions, as illustrated in Figure 4. All FSR sensors were connected to the analogue input ports of the Arduino Uno microcontroller, while the ESP8266 Wi-Fi module was interfaced using a serial communication protocol and a 16x2 liquid crystal display was linked to the output ports.

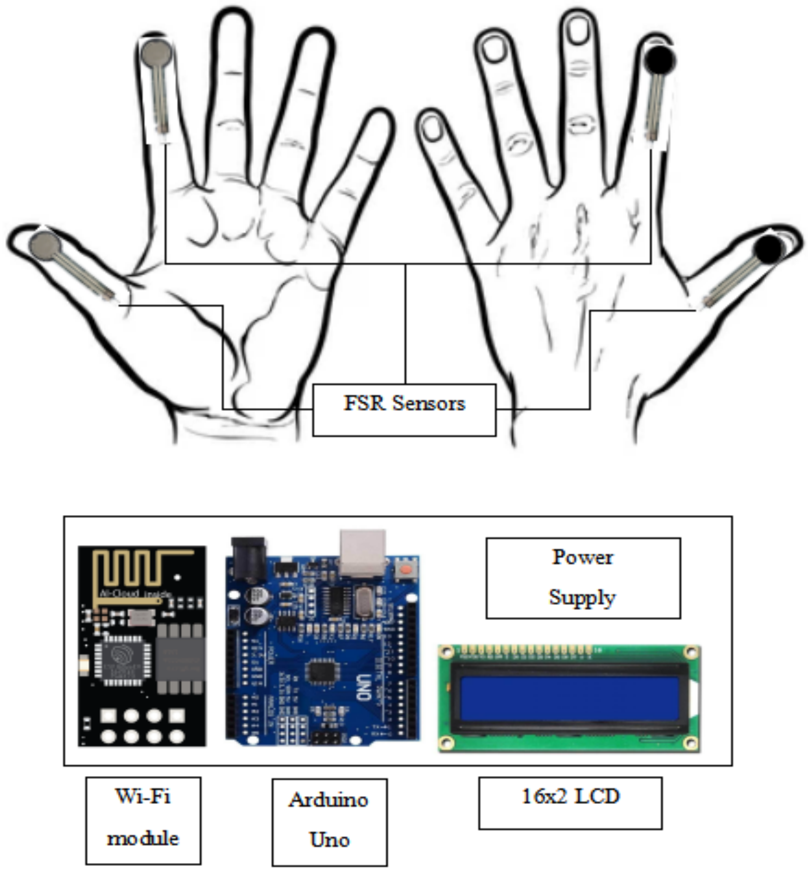

Fig. 4. Placement of the components on the glove

2.2 Equations

As outlined by Eq. (1), the digital value displayed in the Arduino IDE's serial monitor, ADC_{value} spanning from 0 to 1023 with 1024 discrete levels, can be used to calculate the output voltage of the voltage divider circuit, V_{out}. This voltage corresponds to the variation in resistance of the FSR sensor, R_{FSR} which is induced by the different forces applied by the user at the finger and thumb, as derived from the voltage divider circuit formula.

$$V_{out} = \frac{ADC_{value}}{1023} \times V_{in} \tag{1}$$

where V_{out} is the output voltage of voltage divider circuit, ADC_{value} is the FSR voltage in digital value and V_{in} is the input voltage of voltage divider circuit, 5V.

The resistance of the FSR sensor, R_{FSR} can be derived from the provided equation Eq. (2) once the corresponding voltage output, V_{out} has been calculated.

$$R_{FSR} = \left[\frac{R_F(V_{in} - V_{out})}{V_{out}}\right] \tag{2}$$

where R_{FSR} is the FSR resistance and R_F is a fixed resistor used in the voltage divider circuit, 10 kΩ.

The conductance value can then be calculated using the corresponding equation, Eq. (3) which can then be used to determine the individual finger force in Newtons.

$$G[mhos] = \frac{1000000}{R_{FSR}} \quad (3)$$

where G is the conductance.

When the conductance value is less than or equal to 1000, Eq. (4) is employed, while an Eq. (5) is utilized if the conductance exceeds this threshold.

$$F_{FSR}\,[N] = \frac{G}{80} \quad (4)$$

Where;
F_{FSR} is the individual finger force

$$F_{FSR}\,[N] = \frac{G-1000}{30} \quad (5)$$

These mathematical expressions were integrated into the program code to facilitate the conversion of the FSR sensor readings into quantifiable pinch force values, measured in Newtons. This enables the effective monitoring and assessment of the user's pinch strength capabilities. Ultimately, the total pinch force is determined by summing the individual force values obtained from the thumb and index finger sensors.

2.3 Measurement Setup

The study participants, aged 20 to 24 years, underwent an evaluation of their pinch strength. The dominant hand of each individual was measured, with hand lengths ranging from 16.5 to 18.5 cm and circumferences between 17.8 and 18.2 cm. As shown in Figure 5, the subjects were seated comfortably with their arms elevated to a 90-degree angle.

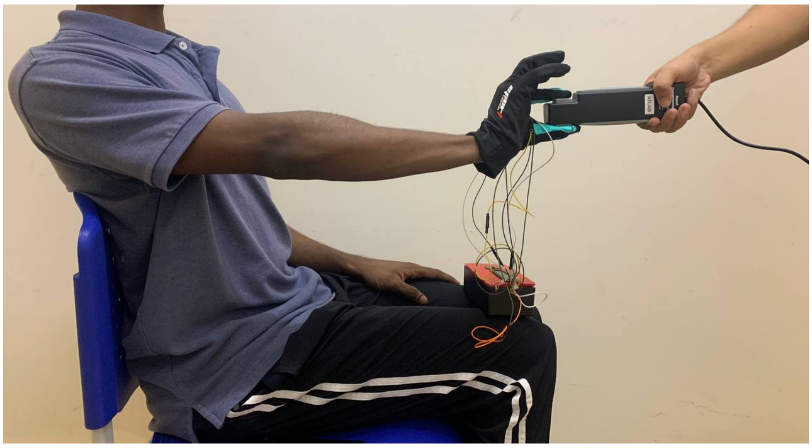

Fig. 5. Pinching and seating posture for pinch strength measurement by using hand dynamometer by Vernier

The users were instructed to use a tip-to-tip pinch grip with their thumb and index finger, positioning the hand dynamometer securely between these digits. This arrangement ensured the fingertips applied appropriate pressure on the dynamometer jaws, enabling accurate measurements of pinch strength. Participants were then directed to exert maximal force on the hand dynamometer and maintain the grip for a brief duration. Both the instrumented glove and hand dynamometer pinch strength readings were recorded meticulously. Each individual's measurements were repeated five times, with brief rest intervals between attempts to enhance the precision and reliability of the data.

2.4 Mobile Application Monitoring System

The Blynk mobile application gathers pinch strength data and enables real-time remote monitoring on a personalized dashboard. The instrumented glove and the Blynk application communicate through the Blynk cloud platform, which facilitates secure wireless sensor data monitoring for IoT devices like the ESP8266. The graphical user interface displayed in Figure 6 presents the instantaneous pinch strength applied by the fingers, measured in Newtons. The Blynk cloud-based platform facilitates communication between the graphical interface and the microcontroller. This allows users to remotely monitor the pinch strength data. The ESP8266 Wi-Fi module transmits the sensor data to the Blynk server, automatically updating the corresponding visual elements in real-time.

Fig. 6. Blynk application mobile dashboard user interface

3. Results and Discussion

This section presents the findings and analysis of the proposed system, evaluating the accuracy of the FSR sensors by comparing the pinch strength measurements obtained from the developed instrumented glove and a traditional pinch dynamometer. The prototype of the IoT-Enabled Instrumented Glove for Real-Time Monitoring of Finger Pinch Strength is depicted in Figure 7. The key components, including the Arduino Uno microcontroller, a 10K resistor, the ESP8266 serial Wi-Fi wireless transceiver module and a 16x2 LCD, are housed in an external enclosure. The jumper wires for the various sensors have been soldered and connected to the breadboard and Arduino Uno to facilitate easy connection and disconnection.

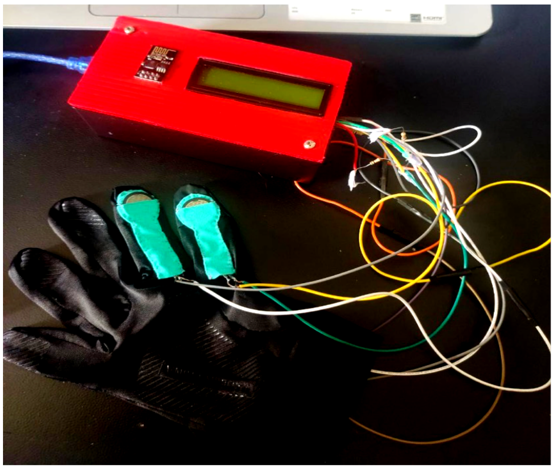

Fig. 7. The instrumented glove system prototype

The results of measuring the pinch strength of three subjects, Subjects A, B and C, with five trials each, are shown in Figure 8 through Figure 11. The data is presented in tabular and graphical formats.

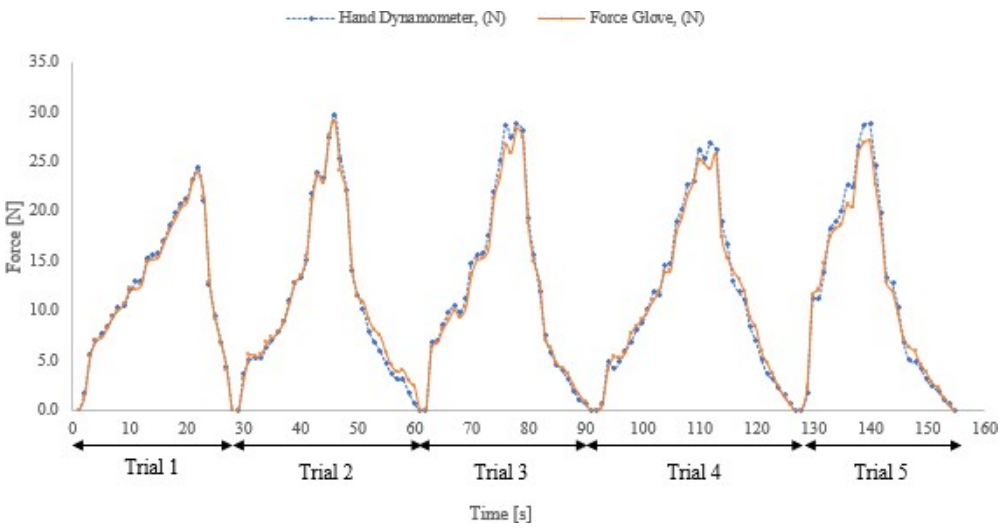

Fig. 8. Pinch strength data measured from Subject A using an instrumented glove and hand dynamometer in 5 trials

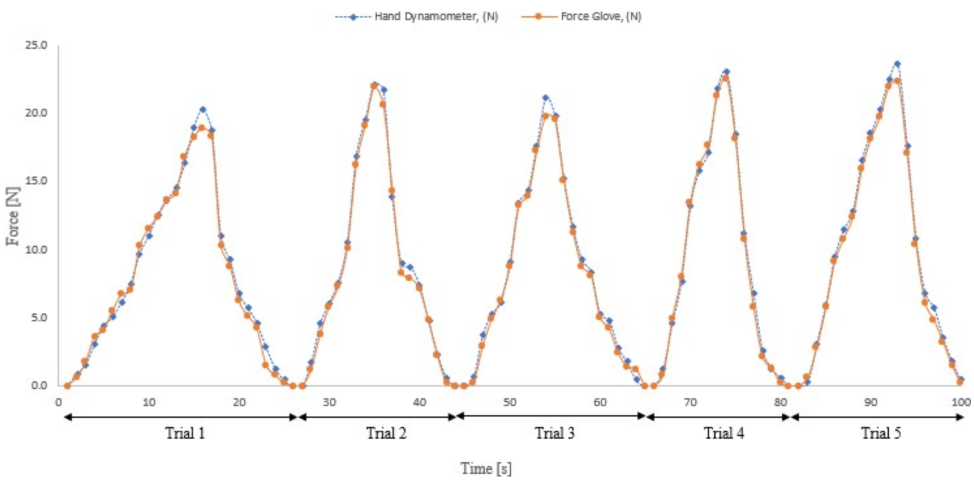

Fig. 9. Pinch strength data measured from Subject B using an instrumented glove and hand dynamometer in 5 trials

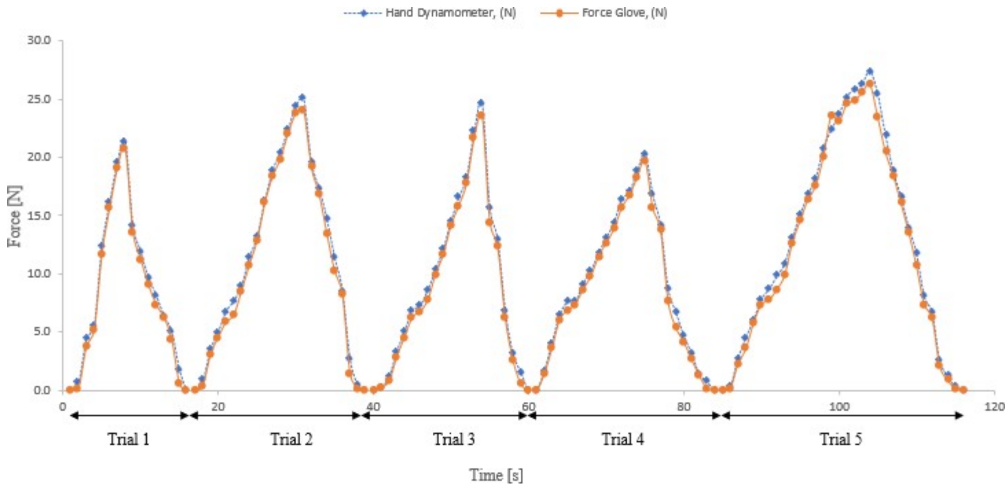

Fig. 10. Pinch strength data measured from Subject C using an instrumented glove and hand dynamometer in 5 trials

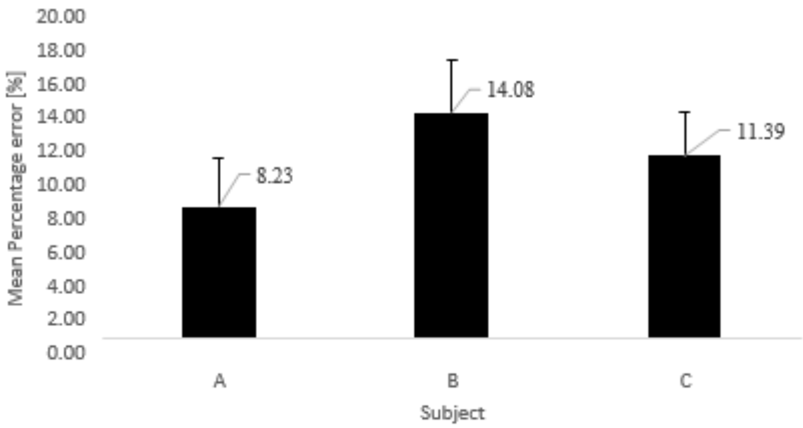

Fig. 11. Mean percentage error and standard deviation visualization of all subjects

Subject A had the lowest average mean percentage error, ranging from 2.92% to 10.60%, as indicated in Table 1. For Subject C, the average mean percentage error varied between 8.33% and 15.37%, with an overall average of 11.39%. Subject B exhibited the highest average mean percentage error, falling between 10.58% and 18.06%. While the maximum mean percentage error of 18.06% for Subject B suggests a significant level of inaccuracy between the observed and expected values, the similarity in the trend lines of force measured from the instrumented force glove and hand dynamometer makes this level of error acceptable.

Table 1
Mean percentage error, average of mean percentage error and standard deviation of mean percentage error data

Subject	Age	Mean Percentage Error [%]					Average	Standard Deviation
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
A	24	2.94	9.52	8.93	9.18	10.60	8.23	3.03
B	21	12.64	10.58	18.06	12.10	17.02	14.08	3.27
C	21	15.37	12.48	8.33	10.59	10.19	11.39	2.67

4. Conclusions

The assessment of pinch strength has become a crucial component in occupational health and ergonomics, enabling researchers and practitioners to evaluate an individual's physical capacities and identify potential risk factors associated with work-related activities. The objectives of this study were successfully met and the pinch strength glove system can be implemented as an alternative tool for rehabilitation assessment, particularly where portability is essential. The system can assess and quantify the pinch strength of the fingers for stroke patients or individuals with related disabilities, representing an advancement over previous research. Physiotherapy exercises can be efficiently conducted with real-time monitoring through a dedicated application, facilitating the evaluation of pinch strength with graphical representation. Furthermore, it is recommended to minimize sensing errors and enhance the user interface of the monitoring application by incorporating intuitive controls, clear visualizations and user-friendly features.

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