Received: Tues, Oct 5, 2021 Accepted: Tues, May 31, 2022 Published: Thurs, July 7, 2022
DOI: 10.36283/pjr.zu.11.2/023

OPEN ACCESS

Pakistan Journal of Rehabilitation
Volume 11(Issue 2), 2022 | Page No. 167-178

ORIGINAL ARTICLE

DESIGN AND DEVELOPMENT OF A STROKE REHABILITATION GLOVE FOR MEASURING AND MONITORING HAND MOTIONS

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ABSTRACT

Muscular weakness tends to increase very rapidly due to various medical illnesses such as stroke, paralysis, fibromyalgia, etc. In order to keep tracks of the rehabilitative progress of patients who are suffering from such diseases, it is necessary to acquire data pertaining to finger movements including flexion and extension. Along with range of motions of proximal interphalangeal (PIP), distal interphalangeal (DIP) and meta-capo phalangeal joints, pinching strength is also vital in assessing the progress of rehabilitative therapies. Hence, our objective is to develop an assistive technology in the form of a smart glove comprising of flex and force sensors for measuring flexion and extension movements as well as the pinching strength. To the best of author's knowledge, commercially available rehabilitation gloves are expensive and have some limitations such as being non-portable, having an antenna mount on the gloves facing upward and so on. The smart glove was able to measure the flexion and extension of finger movements and pinch strength with low-power requirements and low cost associated with production. The flexion and extension of finger movements along with pinching strength of stroke survivors was measured with the aid of the glove and showed promising outcomes. Through the results achieved by our developed glove, we were able to analyze the rehabilitative progress of stroke survivors. Moreover, the data is monitored continuously through liquid crystal display for rehabilitation purposes. Notably, this low cost glove was designed with the aid of flex sensors and force sensors that enabled the effective measurement of flexion, extension and pinching strength of stroke survivors.

Conflict of Interest: The author (s) have no conflict of interest regarding any of the activity perform by PJR

Keywords: *Paralysis, stroke, rehabilitation, assistive technology, flexion, extension, smart glove.*

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Introduction

Hand motion abilities and functions are significant for executing daily routine activities and they encapsulate different types of movements such as extension and flexion[1]. In order to assess the different types of movements executed via the hand, measuring the range of motion (ROM) and pinch strength is vital[2,3]. It has been observed that any variation in ROM and disability of the arm, shoulder and hand can exert an influence on pinch strength[2]. Data pertaining to pinch strength and ROM is useful for diagnosis and pre and post planning of the rehabilitative treatment[4]. Furthermore, acquiring sufficient data relating to joint ROM via different assistive technology (AT) products can lead to an assessment about the treatment progress, patient's condition and information about patient's willingness to return to normal daily activities[5]. Therefore, measurements of joint ROM are one of the main quantitative methods for assessing hand abilities[6].

Each year, thousands of people all over the world tend to experience difficulties due to serious brain injuries, articulation traumas and chronic diseases[7]. Among many types of brain trauma, the major causes of disorders are stroke, paralysis and fibromyalgia in adults[8]. Stroke, a leading cause of adult disability can be handled with adequate AT products and rehabilitative treatment in order to restore patient mobility and limb functions[9, 10]. It is predicted that in 2030 the population over 65 years of age will constitute 20% of the total population and will require some kind of AT and rehabilitative product. Under these circumstances, the increasing demand for rehabilitation treatments would rise significant[11].

Conventionally, goniometers have been used to measure ROM with the first one being developed in France that could measure plane angles[12]. Following this, the cervical goniometer was developed to measure the ROM of elbow, forearm, ankle and the foot[13]. The universal goniometer is being used today for the measurement of ROM however, its use has been limited due to missing of relevant description about patient positioning and device placement[14]. The first electro goniometer, which converts angular motion of the joint into an electric signal, was developed. The use of electro goniometer is however limited due to their enhanced production cost and the time needed to calibrate and place them onto a patient[15, 16].

These traditional methods of measuring ROM used in clinical settings are often not that appropriate to plan and evaluate rehabilitation treatments. Hence, for accurate measurements, gloves using different sensors have been designed for measuring ROM of hand joints[17]. Fifth Dimension Technologies (5DT) has manufactured a glove which can communicate wirelessly with a nearby computer[18, 19]. The White Hand Group has developed a cost effective glove incorporating two sensors per finger with the help of fiber optics. The glove is mainly for virtual reality (VR) and gaming purpose rather than for correcting rehabilitation measurements[18]. A glove for measuring the flexion of hand joints with the help of potentiometers mounted at the back of the hand was introduced. Nonetheless, it was not durable for long term use. Flexion and hand gestures measurement in real time using inductive length encoders embedded in a cotton glove was developed. Limitations pertaining to this glove are the difficulty the user has to face while donning it on and the sensors can move around relative to the joint position and hence, can lead to inaccurate readings[20]. A glove known as Cyber Glove has been developed and contains five to twenty-two patented bend-sensor technology strain gauges to measure movements of individual joints. However, this glove is very expensive and difficult to don for stroke survivors[21].

To the best of the knowledge of authors, commercially available rehabilitation gloves are expensive and have some limitations such as being non-portable and encapsulating the requirement for an antenna mounted on the gloves that should be facing upward. Therefore, in this work an innovative smart glove which comprised of flex and force sensors has been designed for measuring the range of motion pertaining to the hand motions of the patient. This glove has the ability to measure the flexion and extension of finger movements and pinch strength with low-power requirements and low cost associated with production.

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Methodology

Architectural Design

The design and development of the smart glove has been divided in to three distinct regions which are sensing, signal conditioning and output display. The block diagram presented in Fig. 2.1 demonstrates the generic flow of this work.

Figures with captions

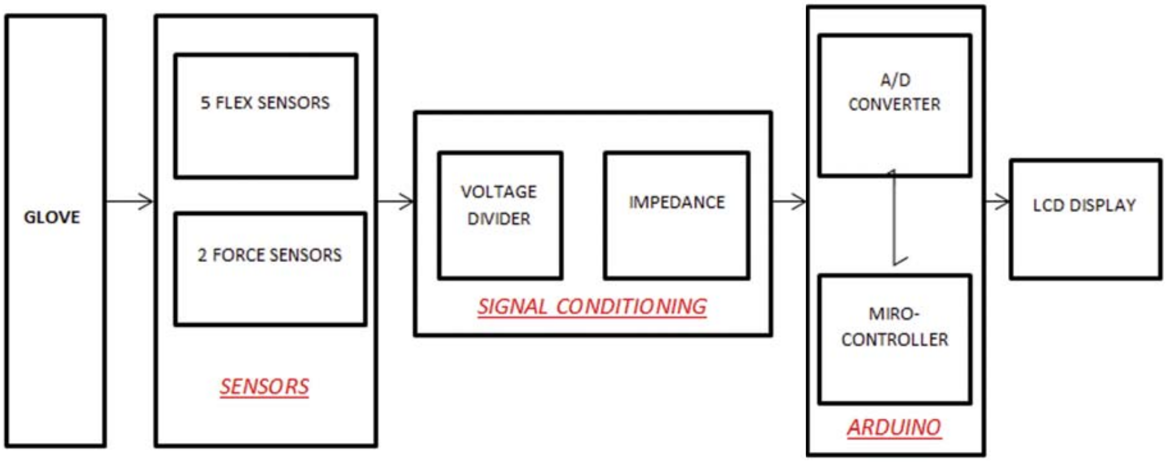

Fig. 2.1: Block Diagram of Architectural Design

For selecting a comfortable material for glove fabrication, different materials such as nylon, Lycra, woolen and cotton have been tested as a glove material. However, woolen has found to be most appropriate material for glove fabrication because of its light weight, comfort and durability among the other aforementioned materials. Also, woolen material has good heat retention characteristics. Hence, we have used woolen as the glove material.

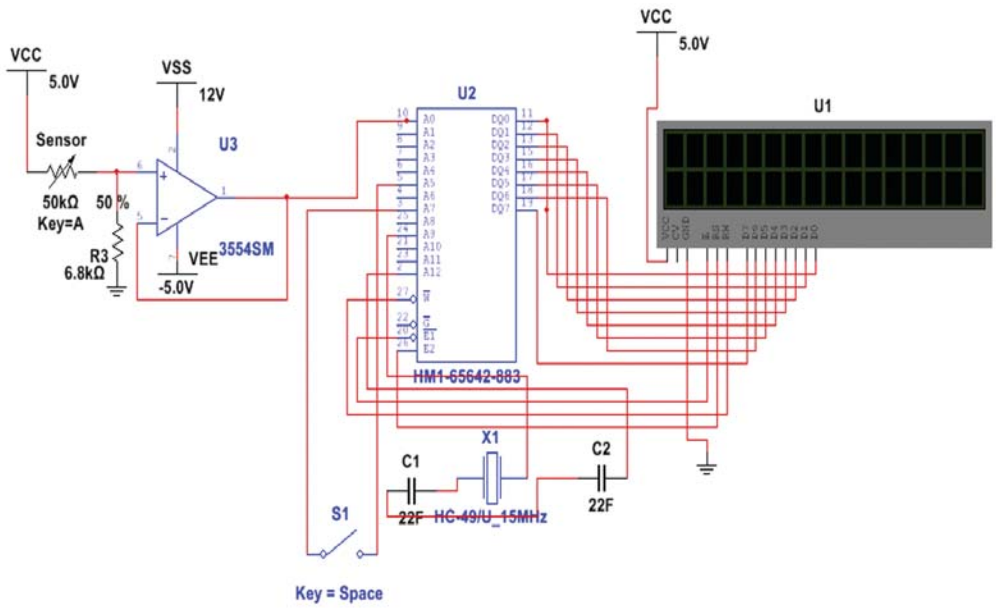

Fig. 2.2: Schematic Diagram of Architectural Design

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The sensing of the smart glove is made by using two sensors that are force sensor and flex sensor. There are 5 flex sensors and 2 force sensors have been employed on the glove. The working principle of flex sensor is that upon bending of sensor the resistance produces as per the change in the bending radius of the sensor. In this work, 5 flex sensors of 2.2" have been stitched in to gloves. The force sensor is a passive element and works as a variable resistor. In this work, 2 force sensors of 10 mm each have been stitched in to glove at thumb position.

The schematic diagram of architectural design is shown in Fig. 2.2. The signal conditioning is carried out using voltage divider circuit. The precise resistance values that are used in the voltage divider circuit (Fig. 2.2) are R1 = variable resistance (i.e., 10 KΩ to 40 KΩ) and R2 =67 KΩ. Further, impedance circuit is used in signal conditioning module for minimum deflections and maximum power delivery at output. The impedance circuit that is shown in Fig. 2.2 is used for improving the signal condition.

The Arduino UN0 microcontroller is used. The microcontroller is connected with the sensing glove for retrieving the signals from flex and force sensors in order to get the results. The microcontroller has AD converter which converts the analogue results into digital and displays it on LCD (liquid crystal display).

Mechanical Assembly
The mechanical assembly of sensing glove includes three primary steps that are:
• Architecture of Arduino
• Interfacing of sensors with Arduino,
• Assembling of circuit on the glove.

Fig. 2.3: Components of Mechanical Assembly

The tools that are required for the mechanical assembly of smart gloves are Arduino, soldering wire, soldering iron, resistance, force sensors; flex sensors, amplifier and LCD which is exhibited in Fig 2.3.

Software Implementation
The software comprises of a standard programming language compiler and a boot loader that runs on the microcontroller. The software system used in this work consists of an angle calculation code developed on Arduino IDE (Integrated Development Environment). The angle calculation code is used to calculate the range of motions (ROMs) of patient's fingers. The Arduino code for this work contains serial prints and delays to see the readings.

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Algorithmic Approach

The algorithmic approach is based on the input which is acquired through glove when user moves the fingers, signal is read by microcontroller. Continuous analog signal is converted into digital value which is displayed on LCD. If the input is constant it will show the same value till the changes occur. The flow chart of final algorithmic approach is shown in Fig. 2.4.

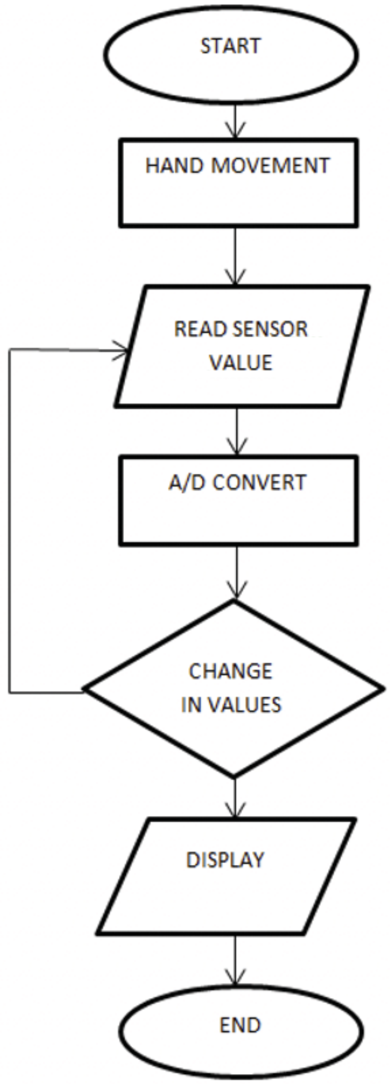

Fig. 2.4: Flow Chart of Algorithmic Approach

Data Collection from Hospital Site

After successful fabrication of the smart glove, the pilot study was performed on fifteen stroke patients and their flexion readings were acquired. The data of seven patients were reported in this study. They were undergoing different rehabilitation therapies and data was recorded at the end of the activities. After 15 days, the second hospital visit was executed and flexion readings of the same seven stroke patients, involved during first data collection, were acquired. The results of data collection have been reported in subsequent section.

Ethical Concerns

Ethical concerns related to this study are to take the consent of an individual patient for pilot study

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in accordance with the Declaration of Helsinki. For this purpose, authors have performed the standard procedure required for ethical approval before performing the pilot study.

Results

A flex sensor was used to observe the change in LED (light emitting diode) brightness with the change in resistance when the sensor was subjected to bending. LED and flex sensor were connected to pin 3 and pin A0 of Arduino respectively. Increase in the bending of sensor increases the resistance and intensity of LED. Table 3.1 demonstrates the standard and observed value of flex sensor. Standard value has been acquired via datasheet whereas observed value corresponds to the millimeters reading.

Valu e	Resistance when sensor is straight	Resistance when sensor is fully bend
Standard value	30kΩ	70KΩ
Observed value	25KΩ	60-70KΩ

Table 3.1: Measurements of Flex Sensor

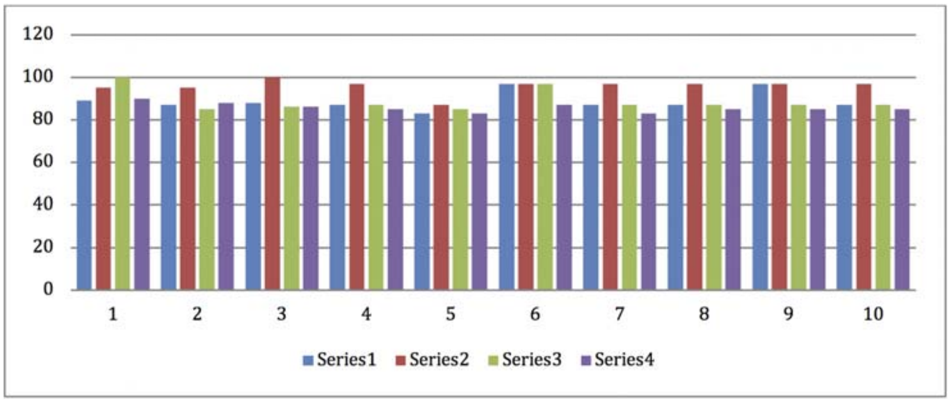

Fig 3.1: Bar Chart Representing Hand Flexion Readings Of Healthy Individuals In Degrees.

Fig 3.1 represents the data of 10 healthy subjects in the form of a bar chart Person 5 is observed to exhibit the lowest reading and person 6 has highest of all readings. It represents the bar chart where different colors of the bars pertain to flexion readings in degrees acquired from the four fingers of healthy individuals. The four fingers include the index, middle, ring and baby finger.

Finger Name	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10
Index	78	78	78	78	66	85	78	78	85	78
Middle	85	85	90	85	78	86	85	85	85	85
Ring	90	73	78	78	72	85	78	78	78	78
Baby	84	78	78	73	66	78	67	72	72	72

Table 3.2: Flexion Readings of Healthy Individuals

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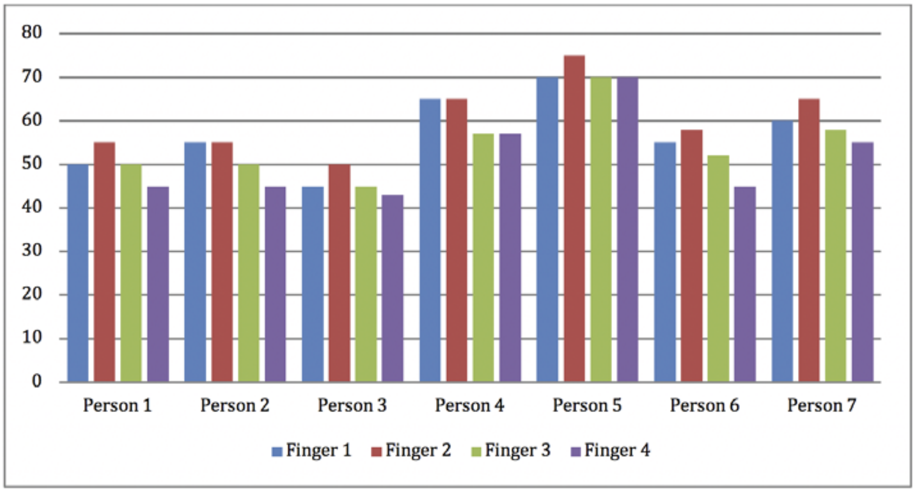

Fig 3.2: Bar Chart Representing Seven Stroke Patients' Flexion Readings in Degrees.

Table 3.2 exhibits flexion readings of ten healthy individuals in degrees measured from this smart glove. Table 3.2 demonstrates that flexion readings of ten healthy subjects were observed to be between seventy and ninety degrees. It exhibits the flexion readings in the form of a bar chart. It can be observed that the lowest flexion reading was generated by subject 3 and the highest by subject 5.

Finger Name	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7
Index	45	50	40	60	70	50	60
Middle	50	50	45	60	75	55	65
Ring	45	45	40	55	70	45	55
Baby	40	40	35	55	70	40	50

Table 3.3: Flexion readings of seven stroke patients

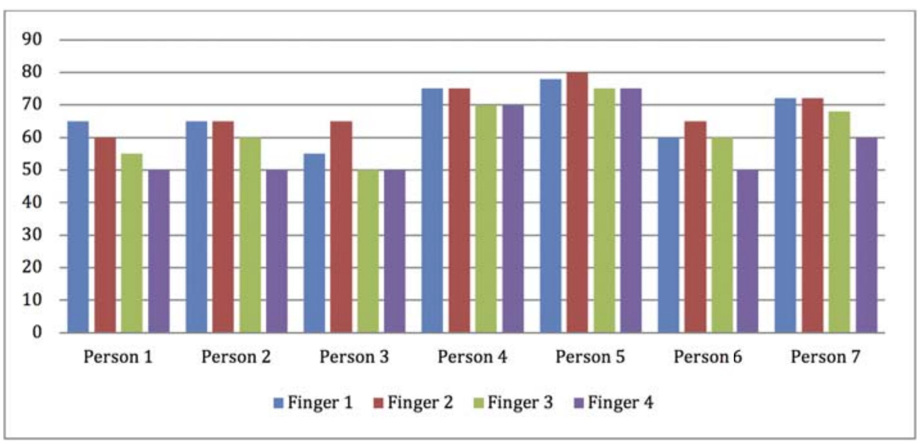

Fig 3.3: Bar Chart Representing Flexion Readings of Seven Stroke Patients after Receiving Rehabilitative Treatment for 15 Days.

It can be observed from Table 3.3 that subject 3 generated the lowest flexion reading and subject 5 generated the highest reading. The readings of the seven stroke subjects were found to be in range of 35 and 75 degrees.

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Finger Name	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7
Index	55	55	45	65	75	50	65
Middle	50	55	55	65	80	55	65
Ring	45	50	40	60	70	50	55
Baby	40	40	40	60	70	40	50

Table 3.4: Flexion readings of the seven stroke patients after receiving rehabilitative treatment for 15 days

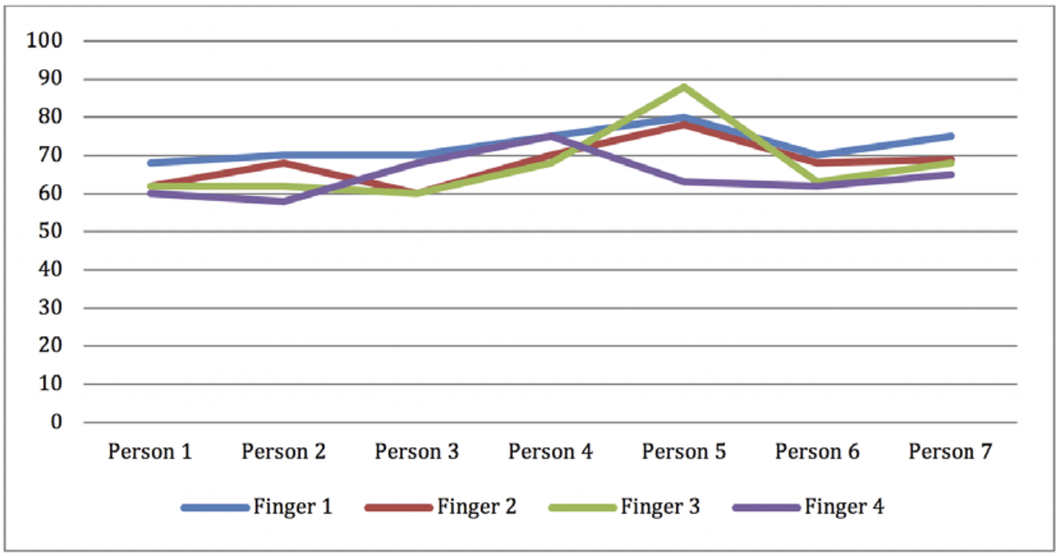

Fig 3.4: Line Chart Exhibiting Comparative Analysis Of Data Points Acquired From Patients Before And After 15 Days Of Therapy

The readings are demonstrated in Table 3.4. Significant changes were observed because of the continuous rehabilitation therapies that the subjects were adhering to. Table 3.4 exhibits that the seven subjects are recovering rapidly as significant change in flexion values has been observed. Fig 3.4 is used for drawing a comparative analysis. Flexion readings in degrees have been represented on y axis and x axis represents subjects. For subject 1 the angle of first finger increases after 15 days showing significant improvement in flexion. Same improvement is seen for other fingers. It is concluded that angle increases as a result of continuous physical therapy activities. Improvement can be observed through our designed glove and future hand assessment can also be executed effectively. Results also show that angle of flexion is greater for index finger as compared to baby finger.

Gender	Subjects 1 Male	Subjects 2 Male	Subjects 3 Female	Subjects 4 Female	Subjects 5 Female	Subjects 6 Female	Subjects 7 Male	Subjects 8 Male	Subjects 9 Female	Subjects 10 Male
Pinching Force in N	147	156.8	127.4	98	166.6	117.6	127.4	186.2	137.2	156.8
Pinching Force in kg	15	16	13	10	17	12	13	19	14	16

Table 3.5: Pinching strength in Newton and Kilograms

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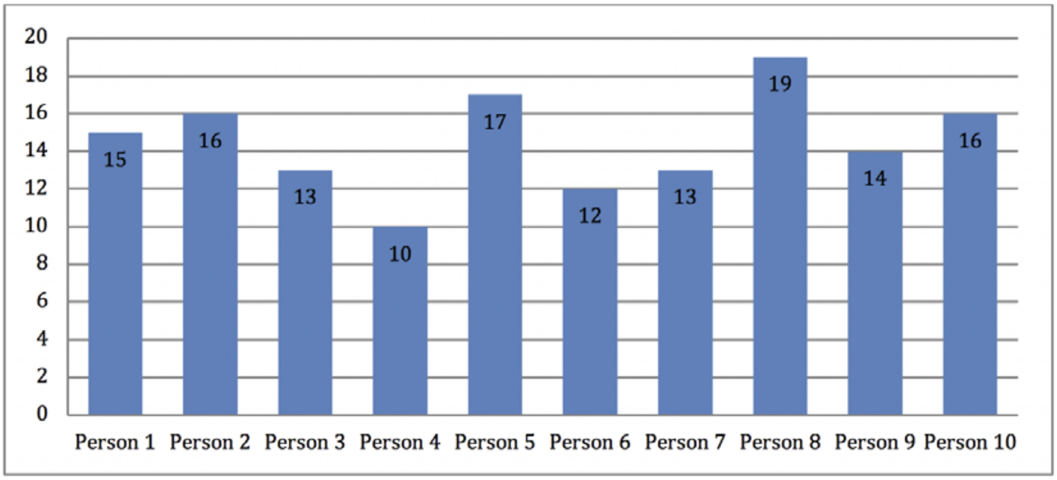

Fig 3.5: Pinching Strength Expressed In Kilograms (Kg)

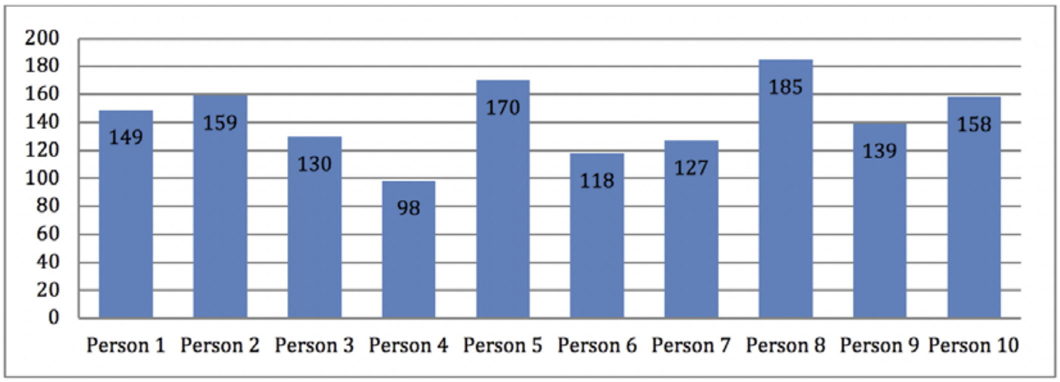

Fig 3.6: Pinching Strength Expressed In Newton

Table and Fig 3.5 exhibit the pinching strength in Kilograms while Fig 3.6 demonstrates the results in Newton.

Outcome Measures

Ten Patients of the same hospital were recruited for observing their tip pinch strength. 5 were male and 5 were female. Table 3.5 and Fig 3.5 and Fig 3.6 show that male subjects have greater pinch strength as compared to female subjects. Person 1, 2, 7, 8 and 10 are male subjects while person 3, 4, 5, 6 and 9 are female subjects. It also concluded that pinch strength decreases with increasing age. Fig 3.5 exhibits the pinching strength in Kilograms while Fig 3.6 demonstrates the results in Newton.

Discussion

The objective of this study was to design a glove possessing the ability to measure the ROM and the pinch strength with the aid of flex sensors and force sensors. The glove is able to evaluate the effectiveness of rehabilitative treatments pertaining to a patient functional impairment. Furthermore, the glove generates readings readily and reduces the execution time.

Accurate measurement of ROM of the fingers and pinching strength is necessary in analyzing upper limb therapies pertaining to functions for diagnosis, pre and post planning of the rehabilitative treatment including prescription about drugs, stroke, surgeries and physical therapies. The measurements are vital for assessing treatment progress and patient condition. The examination of ROM of the fingers includes analysis of finger ROM involving assessment of the

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Metacarpophalangeal joints (MCP) and Proximal interphalangeal joints (PIP).
An overview pertaining to robotic and mechanical assistive devices being used for post stroke thumb rehabilitation was emphasized. Traditional methods of rehabilitation tend to enhance the costs involved and exert labor intensive strategies which are time consuming. Mechanical devices are being used for assessing rehabilitation outcomes of patients particularly, stroke survivors. However, the full potential of such devices is yet to be unveiled[22]. Comparing our results with[22], it can be concluded that we have designed an effective AT device that can measure both ROM and pinching strength following rehabilitative therapies. Hand prosthesis referred to as. A study proposed upper limb prosthesis referred to as the BrightArm Duo for analyzing the grasp strength and wrist position of chronic stroke survivors. Results of the study exhibited improvement in shoulder ROM and shoulder grasp strength among seven participants[23]. Inertial sensors were utilized for measuring the lower limb joint ROM of healthy adults, stroke survivors and in patients with knee osteoarthritis. The results of these studies exhibited that an inertial sensor system is able to measure major joint angles as well as the ROM for stroke survivors and patients suffering from knee osteoarthritis [24, 25, 26]. Comparing [24, 25, 26] with our work, it can be concluded that our designed smart glove is effective in evaluating the ROM of stroke survivors both before and after adhering to rehabilitative treatment regimens.

Conclusion

There are numerous tools for monitoring and measuring ROM of the joints of finger as well as the pinching strength. Nonetheless, these devices require assistantship for the patient, are time consuming, expensive and tend to be less accurate. Also, these devices can measure only one joint at a time and cannot be used if there is any injury in the finger or in hand. A smart glove based measurement system for monitoring ROM and pinching strength is proposed. The smart glove consists of flex and force sensors that can be used to generate accurate readings of ROM and pinching strength for stroke survivors following post stroke rehabilitation therapies. This smart glove has several advantages in terms of accuracy, time and comfort. The smart glove can be easily used by less skilled individuals and does not require sufficient training. Also, this smart glove is very comfortable to use, as it is light in weight and easy to don and doff without causing any injury and discomfort to the patient.

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