Grab Force Measurement for Hand Orthosis

Rajesh Kannan Megalingam, Senior Member, IEEE, Haritha T and Urmila.O

***Abstract*—Rehabilitation is a key element in the recovery process of stroke survivors. As one part of the body is paralyzed, the recovery process takes time depending on the severity of the stroke. Mild stroke patients might be able to recover fast. Our research work is for such patients who have lost partial control of their hands due to mild stroke. Many of the existing studies does not take into account, the grab force for feedback to make a closed loop system. They only consider the opening and closing of the orthotic devices. The proposed system introduces a design to measure the grab forces of the fingers and thumb while grabbing an object. The measurement of the forces will be helpful in determining the torque requirements of the actuators used in hand orthotic devices.**

Index Terms—Grip, orthosis, force sensitive resistor, MATLAB, Actuators.

I. Introduction

ORTHOSIS is a mechanical device which can be brace, splint, or in any other form of a device in supporting the limbs to assist relative movement. A simple orthotic device is a wearable one that can have only two moving parts controlled by an actuator for opening and closing of the hands. There are two types of orthotic devices: static and dynamic. Static orthotic devices are used to support the joints to reduce pain, facilitate function and avoid bends. Dynamic orthotic devices serve as a mechanical assistance to move paralyzed or fragile muscles.We have two different types of grips which aid to pick an object [1]: pinch (precision) grip and power (cylindrical) grip.Pinch grip is commonly used for picking up smaller, lighter objects. The two fingers are pointer and middle finger while the thumb supports to hold the object. The power grip is the most commonly used grip force. The fingers are curled towards the palm to create a fist formation. Power grip operate in three different modes: passive mode, active mode and interactive mode. In passive mode, it is opening and closing of the fingers continuously moved from a highest position to the lowest. In this case, the system operates in open loop. Various parameters like the physical limits, number of repetitions etc. can be measured. In active mode, the system is integrated with sensors to create and closed loop and actively monitor the function of hand. The patient can influence the applied force and velocity of the movement of the hand. In the third mode, i.e., in interactive mode, a game is offered to the patient, and through the use of sound, visuals, touch and other sensory aids, the device interacts with the patient giving them response on their performance. The rest of this paper section II and III is describes the Motivation and Literature survey. System Architecture is discussed in Section IV. Simulation and Implementation results are explained in Section V and VI. finally concludes the paper in Section VII.

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II. Motivation

Previous researches on hand orthotic devices mainly focus on fingers and wrist only. As such they provide only a partial picture of movement dysfunction as they ignored the grab force acting between the finger and thumb. It's really worth if we can locate the force between the finger and the thumb while grabbing an object, so that a closed loop hand orthotic device be designed with appropriate actuators. One important aspect of the hand orthosis device is the torque requirement of the actuators used in the device design. The torque requirement of actuators will be high during the initial stages of the therapy as the motor control function of the hands of the stroke patients is severely impacted. As the therapy continues the required torque of the actuators need be reduced as the motor control function improves in the hand. This can be effectively done if the device is a closed loop system by measuring the grab force of the patients' hands. This paper presents a prototype designed to evaluate finger – thumb grab forces i.e. isometric flexion forces produced by the fingers and thumb to pick an object.

III. Literature Review

Authors in the paper [1] propose the design of an orthotic device for performing the daily activities of a hemiparesis patient with diminished hand functions. In paper [2], authors discuss about the design of a Wrist /Finger Force Sensing (WFFS) module which is an upper limb device that is attached to the distal end of forearm. Using WFFS they show that wrist/finger and thumb flexion forces varies drastically with respect to shoulder abduction and shoulder flexion levels. In paper [3] development and design of a new orthotic device called Pneumatic Actuated Finger Exoskeleton (PAFEx) which can control the movement of hand and finger is presented.In paper [4] the orthotic device presented consists of crank mechanism attached to four servo motors which is useful in flexing and extending the fingers. With the help of proposed device, the patient would have the opportunity to practice and perform key aspects of their rehabilitation program with the supervision of a therapist. For the rehabilitation of stroke patients immediately after stroke, authors in paper [5] proposes an exoskeleton design called the SCRIPT Passive Orthosis (SPO). The SPO assists patients suffering from impairment caused by spasticity and abnormal synergies. This device also interacts with the patient and gives them feedback based on their performance. Another paper [6] explains about usingsurface electromyography (sEMG) signals to control the position of hand. The authors have developed a prototype called Wrist Exoskeleton Prototype (WEP) used to estimate torque in different levels of sEMG pattern [6]. Authors in paper [7] designed a wearable light weight device that can be opened during therapy. This device can supports all the degrees of freedom of the wrist.In the paper [8] the design of an orthotic device that consist of force controlled trajectories produced by elastic actuators of the fingers, which keeps an interaction with the patient during training, is proposed. Authors in the

978-1-5386-7595-3/19/$31.00 ©2019 IEEE

paper [9] designed an orthotic device for hand function rehabilitation of stroke patients especially, grasp and release. In paper [10] a light weighted, compatible wearable device that helps the stroke patients capable for significant extension and flexion forces is discussed. Authors in paper [11] designed a prototype EXTEND which is used in an open loop system. It assists the user to compensate a linear joint stiffness of 0.15 to 0.33Nm/rad. The researchers have developed and tested an electroencephalogram (EEG) with Brain-Computer Interface (BCI) to perform hand grasping and to achieve continuous online control of orthotic device [12]. Assistive hand orthotic device in paper [13] mainly focuses on two methodologies to develop and control active orthotic device. The first is to determine the minimum values of hand positions. And the second is to determine optimal set of hand positions that is obtained by controlling sEMG sensor locations. In paper [14] the authors presented a design of an extending device that is controlled by EMG pattern and enables functional motions like pick and place. Authors in paper [15] discussed a thumb-based exoskeleton for pediatric disorders like cerebral palsy (CP) and stroke. In paper [16-18] the authors proposed a hand orthosis device for stroke and spinal cord injury (SCI) patients who had mild stroke or less severe SCI. For such patients, the hand functions can be retrieved by physiotherapy during their rehabilitation process. With the help of Human Computer Interface (HCI), the patients can undergo therapy without much effort. In our research work, we focus on the method to measure the required force to be applied by the user while using the hand orthosis.

IV. System Architecture

Fig. 1 shows the prototype system architecture designed to calculate the grab force of stroke patients post the stroke, during the rehabilitation. The architecture mainly consists of wearable prototype, Force sensitive resistor, Stepper motor unit, control unit, MATLAB simulator and RGB led.

A. Wearable prototype

This consists of a rubber glove fitted with two force sensors, one near the tip of the thumb and the other near the tip of the index fingers. When the patients/users grab any object, both the sensors become active and send the applied force values to the control unit which processes the data to find the exact force applied while grabbing an object.

B. Sensor unit

The sensor unit used here is the force sensitive resistor (FSR). The actuation force is very low at 0.1 N with the sensitivity in the range, 0 N to 10 N. It has a repeatable actuation system and Repeatable Force Reading is very low at 2%. It is simple and easy to integrate. While doing therapy the patient is instructed to put the orthotic device, in which two force sensors are placed at finger and the thumb. The person is then instructed to grab an object, in order to grab it the patient may give some force/pressure to the finger and thumb which is measured by the force/pressure sensors.

C. Stepper motor

The stepper motor provides a good amount of torque with in-traction torque at 34 mN.m, self-positioning torque of 34 mN.m, and pull-in torque of 300 gf.cm. With four phases, it operates at 5 V. It provides a stride angle of 5.625^{o} /64. This is very much suitable for the proposed application in this research work.

D. Control unit

The control unit uses Arudino Uno with ATMega microcontroller; it is an open source microcontroller board based on ATmega328P microchip. With 14 digital pins and 6 analog pins, this microcontroller is programmable with the Arudino Integrated Development Environment (IDE). The control unit displays the corresponding grab force required to hold the objects in serial monitor of the Arduino IDE. It helps in interfacing the stepper motor with the force sensors and varies the step per revolution according to the force applied.

E. RGB led

It is used to indicate the therapist the amount of force applied by the patient. If the force is below the previously set threshold (explained in Section V) red light glows. If the force is above the threshold green light glows, else if the force is very high the blue light is indicated. It is also interfaced with the control unit.

F. MATLAB simulator

The force values collected by the control unit from different users are given as input to the MATLAB. By using matrix manipulation technique, the values are converted to matrix form. A MATLAB code is created and is used to calculate and simulate the corresponding force versus voltage and net torque versus voltage plots.

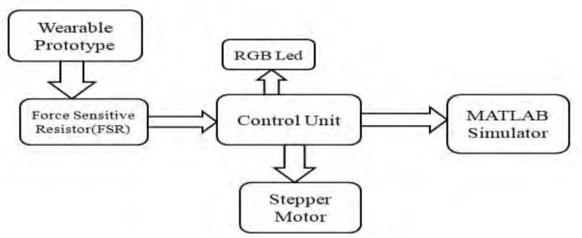

Fig. 1. Block diagram of the proposed prototype system

The force sensitive resistors (FSR) are attached to the glove that is to be worn by the user. The user here is the stroke survivor who is undergoing therapy and rehabilitation. Two force sensors are attached to the thumb and index finger part of the glove, outside. The user is asked to wear the glove and grab an object and lift. The force applied by the user while grabbing the object is measured by the FSRs and given to the control unit. The Arduino based MCU uses the corresponding forces measure to control the stepper motor interface to drive the stepper motor. We also set a force threshold value in order for the system to decide to apply more or less torque as per the strength of the stroke affected hand. As the stroke patients of the initial stage will have very less strength in their hands, force required will be high to grab an object. As the therapy continues, the patients gain strength in their hands gradually. After a certain period, the amount of force required to grab an object by the user becomes less.If the applied force is less than the default threshold value to grab an object, then the stepper motor will rotate with higher steps per revolution and the torque output will increase. This in turn will provide enough strength in the hand of the users to grab an object. If the applied force is greater than the default threshold value, (which means the user/patients are able to exert more strength) then the steps per revolution will be lowered to reduce the torque output of the stepper motor. If the force applied is below the threshold, it is indicated by red led, or by green led is the force applied is higher than the threshold. A blue led light indicates that the force applied is nominal.

V. Implementation

A rubber glove is used as wearable in this prototype. The FSRs are attached to the thumb and index finger part of the glove. This is shown in Fig. 2. The FSR in the index finger can be clearly seen in the figure. The electronics and the control part is also shown in the figure. The system with Arduino MCU, stepper motor, stepper motor driver and the circuitry can be clearly seen. The user is shown holding the object i.e. a pencil in this case. The force sensor is shown pressed over the pencil. Two FSRs press against the pencil, one on the index finger and the other on the thumb.

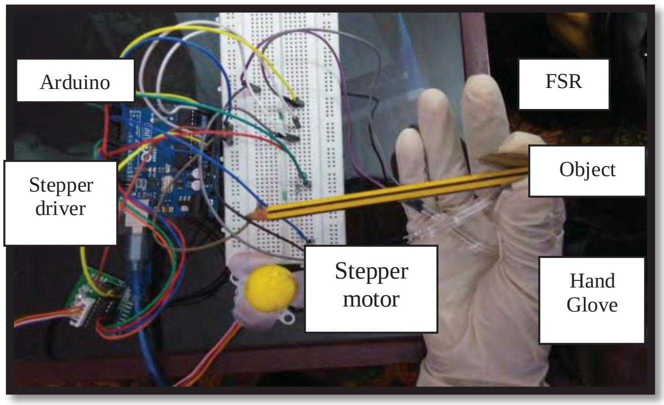

Fig. 2. Prototype implementation of the propose system.

Flow chart of the Arduino programming is shown in Fig. 3. The Arduino reads the analog values of the FSR connected to the control unit. This force value is compared to the threshold value which is prefixed as explained in simulation and results section. If the compared value is lesser than the threshold value, then the number of steps per revolution of the stepper motor is increased. After this again the Arduino will start reading the FSR values and the entire process repeats. If the compared value is greater than the threshold value, then there is no change in the stepper motor steps. The control goes back to the beginning of the flow where the Arduino starts sampling fresh FSR values. This continues as long the system is in use.

VI. Simulation And Results

The grab force threshold has to be set properly in the device before the use of the device. For this purpose, two of the users from our team were chosen. These users are not stroke patients. These users were requested to wear the prototype and grab an object. Based on this experiment, the threshold force in the device is set. Once the threshold is set, the prototype was given to a group of 10 users and was asked to grab an object. Depending on the force applied by these users, the result was categorized under sense of touch (light/ medium) as shown in Table. I.

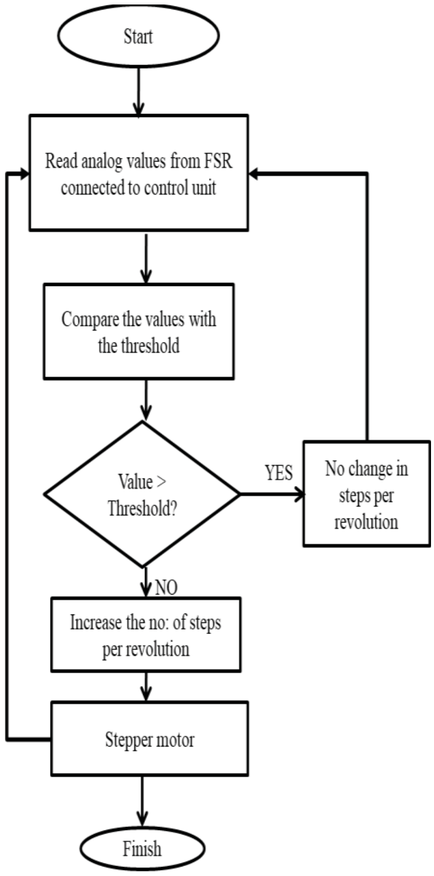

Fig. 3. System level flow of events

TABLE I

GRAB FORE MEASUREMENTS

Users	Thumb Force (N)	Index Finger Force (N)	Total Force (N)	Sense of touch
1	10	13	23	Light touch
2	18	17	35	Medium touch
3	8	14	22	Light touch
4	25	29	54	Medium touch
5	23	25	48	Medium touch
6	12	21	33	Medium touch
7	10	12	22	Light touch
8	23	19	42	Medium touch
9	10	15	25	Light touch
10	15	11	26	Light touch

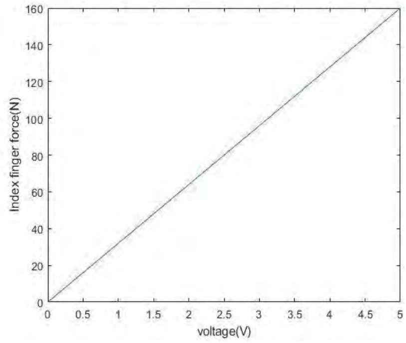

Fig. 4. Finger force versus voltage of a healthy person

Fig 3 to 6 show the force variations of index fingers and thumbs of a healthy and elderly person. These are the results of the experiments we did for finding the threshold force to be used in the proposed system. The Fig. 3 shows the index finger force of healthy person plotted against voltage. We see the linear relationship between the index finger force and the voltage. This is an expected outcome as the healthy person is able to apply required force depending on the object size and weight.

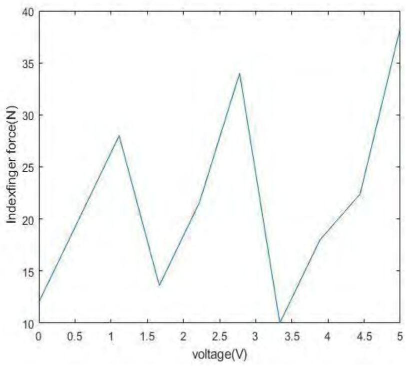

Fig. 5. Finger force versus voltage of an elderly person

The Fig 4 shows the finger force of an elderly person. We can see that there relationship between the index finger force and the voltage is no more linear. This shows that the elderly person hand strength is not the same as that of an healthy person. As people age, strength in their hands to hold object decreases.

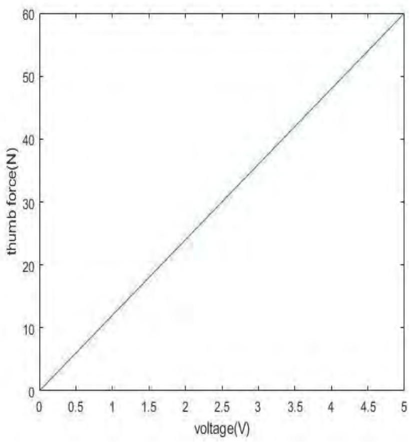

Fig. 6. Thumb force versus voltage of a healthy person

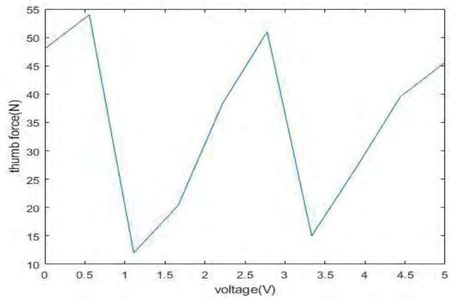

Fig. 7. Thumb force versus voltage of an elderly person

Fig 5 and 6 shows the thumb force of the same healthy person and elderly person respectively, while grabbing or picking an object. Here too we see that the force variations in healthy and elderly person. In healthy person the thumb force is linear in nature when plotted over voltage where as in elderly person the thumb force is very unstable.

VII. Conclusion

In this work, we have presented a prototype system that can measure the grab force while picking an object which can be very useful in design of hand orthotic devices. This can be very useful for the stroke patients and patients with partial paralysis to improve their hand functions. We analysed various existing hand orthotic devices currently used in the therapy of patients who have lost fine control of their hand functions. We presented the design method of using FSRs in a hand glove to measure the force applied while grabbing/picking up an object. We also tested with various users and controlled the stepper motor steps as per the forces applied by these users. We also compared the force applied by healthy person with that of old people who might have lost the strength in their hand due to old age.

Acknowledgement

We are very much indebted to Electronics and Communication Department of Amrita School of Engineering, Amrita Vishwa Vidyapeetham University, Amritapuri campus, Kollam, India for providing us all the necessary lab facilities and support towards the successful completion of the project.

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