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A Low-Cost Hand Trainer Device Based On Microcontroller Platform

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Abstract. Conventionally, the rehabilitation equipment used in the hospital or recovery center to treat and train the muscle of the stroke patient is implementing the pneumatic or compressed air machine. The main problem caused by this equipment is that the arrangement of the machine is quite complex and the position of it has been locked and fixed, which can cause uncomfortable feeling to the patients throughout the recovery session. Furthermore, the harsh movement from the machine could harm the patient as it does not allow flexibility movement and the use of pneumatic actuator has increased the gripping force towards the patient which could hurt them. Therefore, the main aim of this paper is to propose the development of the Bionic Hand Trainer based on Arduino platform, for a low-cost solution for rehabilitation machine as well as allows flexibility and smooth hand movement for the patients during the healing process. The scope of this work is to replicate the structure of the hand only at the fingers structure that is the phalanges part, which inclusive the proximal, intermediate and distal of the fingers. In order to do this, a hand glove is designed by equipping with flex sensors at every finger and connected them to the Arduino platform. The movement of the hand will motorize the movement of the dummy hand that has been controlled by the servo motors, which have been equipped along the phalanges part. As a result, the bending flex sensors due to the movement of the fingers has doubled up the rotation of the servo motors to mimic this movement at the dummy hand. The voltage output from the bending sensors are ranging from 0 volt to 5 volts, which are suitable for low-cost hand trainer device implementation. Through this system, the patient will have the power to control their gripping operation slowly without having a painful force from the external actuators throughout the rehabilitation process.

1. Introduction

The National Stroke Association of Malaysia (NASAM) recently has reported that stroke is now the third largest cause of death in Malaysia. It can abruptly change the life of a healthy and vibrant individual in an instant. The patients need to learn how to do basic daily tasks, such as self-feeding, and this activity can be an overwhelming physical hurdle to them. When they have lost the dexterity of their hands due to the stroke, the hand movements such as grasping and releasing objects for daily activities seem like insurmountable challenges. However, there are some helpful exercises provided by the rehabilitation center with the help of the therapist to help the stroke patients to reclaim their dexterity with these hand exercises during stroke recovery.

With the help of the positive and rapid growing of the technology, the machine-guided hand trainer or hand therapy device has been invented to help the stroke patients in exercising the essential muscles to bring back their dexterity and the use of their fingers. These low-impact exercise tools can be performed either in the rehabilitation center or at home in helping them to restore the motion of the hands after a stroke. In normal practice, the existing hand exercising equipment in the most rehabilitation is using pneumatic pressure during the valve or joint movement operation of this assisted hand machine. One of the disadvantages of the pneumatic-operated hand trainer is that the handling of the system is difficult as the trainer need to be there to assist the movement of the patient all the time as the harsh movement of the hand trainer could harm the patient due to the pneumatic actuator. Furthermore, this machine is also heavy and difficult to be lifted and moved from one space to another. The used of a soft pneumatic actuator for hand trainer has caught a lot of interest recently. However, the device is not yet widely commercial across the globe and the source to get it from is quite limited. Furthermore, by equipping the hand trainer device with game and music can make the therapy session become more interesting and the rehab less boring. In fact, the clinically testing has proven that by linking the hand movement with the music or game motivates more repetitive hand movement during the rehab session, which has improved the finger dexterity faster [20]. Figure 1 shows the main parts and joints of a hand that has been researched for the hand trainer device invention.

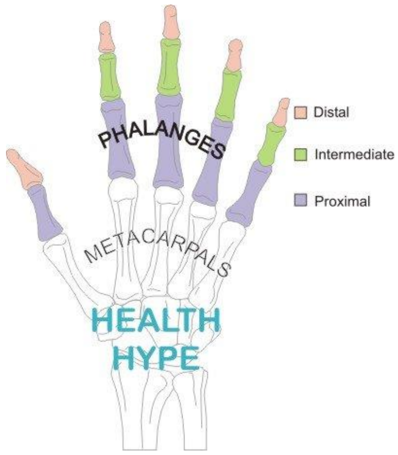

Figure 1. The skeleton segmentation of a hand.

Referring to Figure 1, the skeleton of a human hand consists of 27 bones that are organized into proximal row and distal row, which articulates the bases of the metacarpal bones. This bone will each turn articulates with the phalanges of a thumb and the fingers. The thumb only consists of three phalanx bones, which are the distal and proximal phalanx. Whereas, the other four fingers consist of three phalanx bones, namely, proximal, intermediate and distal. To move them, the muscles of the forearm are used for this purpose. Due to this unique structure of a hand, researchers have invented a hand glove that consists of bending sensors such as soft actuators and flex sensors to detect the bending angle of the fingers for the rehabilitation purpose.

Therefore, the objective of this work is to propose a prototype of hand glove with the used of bend sensors to detect the movement of the fingers for rehab purpose. Secondly, the movement of this hand glove will synergize the movement of the artificial hand which copies the motion of the hand.).

2. Previous work

In this section, the available research works in hand trainer device for rehabilitation purpose are discussed. There are a number of machines that available commercially to aid in the rehabilitation of the hand. For an instance, the MRC-Glove, which is a Function Magnetic Resonance Imaging (fMRI) compatible soft robotic glove for hand rehabilitation [2] as shown in Figure 2. It has been designed

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and fabricated by using soft robotic glove which can be used with fMRI during the hand continuous passive motion (CPM) in the rehabilitation process. This device used two major components, namely, a) soft pneumatic actuator and b) a glove. The soft pneumatic actuators are made from silicon elastomer. It generates a bending motion and actuates the finger joints upon pressurization. The fMRI has been widely used to investigate the brain activity and reorganization in response to dynamic environments. Recent advances in neuroscience research by using fMRI have increased the understanding of brain neural plasticity and its relationship to motor recovery [5]. It gives important insights into brain mechanisms controlling voluntary movement as well as provides supporting evidence for optimal rehabilitation interventions and the development of rehabilitation robotics which can assist in the execution of motor task and study of brain responses using the fMRI machine. Unfortunately, the fMRI is a huge machine and will need high maintained continuously and costly. This is clearly become the main disadvantage for portable and low-cost hand trainer system.

Figure 2. An MRC-Glove prototype [2].

Therefore, the MRC-Glove is used together with the fMRI machine to investigate the brain responses and understand the motor performances of the brain during the hand CPM exercises during the rehabilitation period. The soft actuators have drawn increasing research interest due to their low inherent stiffness as well as high customizability and compliance [6]. Several research groups have adopted a soft robotic approach to design soft rehabilitation devices that are more lightweight and wearable [7-8]. Another interesting characteristic of soft actuators is that they are made from soft elastomeric materials which are non-ferromagnetic, thus they remain functional and do not affect the MR environment as shown in Figure 3.

Figure 3. Actuator bent and actuated the finger joint upon pressurization [2].

Based on Figure 3, the glove is attached with a Velcro hook straps with four soft pneumatic actuators on it. These actuators are corresponded to the index, middle, ring and small fingers, respectively. Silicone connecting tubes of the actuators are then connected to an external pneumatic source. The entire prototype weighs less than 200g. Upon pressurization, the prototype actuates and conforms to a hand grasping profile. This design is really useful in realizing the portable hand trainer, unfortunately, the used of external pneumatic source might jeopardize its portability as the weight of it could hinder it to be carried away freely.

An Actuated Finger Exoskeleton (AFX) which has been invented by the researchers from Northwestern University [3], has built the hand trainer to facilitate patient with the movement of a pinch, by making an exoskeleton to permit independent actuation of each of the three joints of the index finger as depicted in Figure 4. Separate actuators are used for flexion and extension, with the closed-loop control of either force or position. As the hand is exceedingly complex, which is more than 20 degrees-of-freedom, it focuses on the important function of the hand such as pinching movement. This specific hand trainer consists of three parts, namely, the mechanical exoskeleton, actuation with motors, and a local control using feedback loop provided by the sensors.

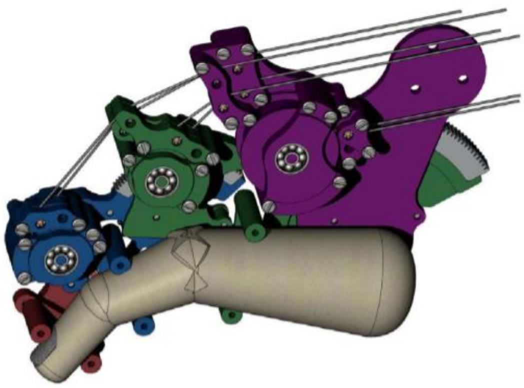

Figure 4. Pairs of metal rods connect to the AFX to each of the finger segment [3].

According to Figure 4, AFX is a metal exoskeleton, which is built from aluminum and D2 steel and is connected to the proximal, middle, and distal segments of the finger through pairs of rods. Specifically, pairs of rods contact the ventral and dorsal sides of each segment of the digit to control the movement of that segment about the proximal joint. The AFX also has three pin joints which match the metacarpophalangeal (MCP) proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints of the finger. To avoid the potential difficulties associated with remote centers of rotation, each of the rotational axes of the exoskeleton is aligned with the anatomical joint of the digit as shown in Figure 5.

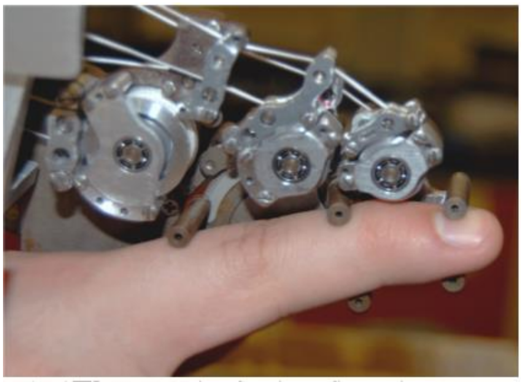

Figure 5. AFX located radial of the index finger with parallel post- interfacing with each finger segment [3].

All components are fabricated from aluminum or steel to withstand the relatively high torques required of the device. Thrust bearings at the MCP and PIP joints serve to accommodate potentially significant off-axis moments. The exoskeleton was designed to allow large ranges of motion: -15 to 75°, 0 to 90° and 0 to 90° for the MCP, PIP and DIP joints, respectively. The angle of the joint of the fingers is manipulated by the used of optical encoders as shown in Figure 6. This angle is computed by using the data obtained from these optical encoders that are attached to the DC motors. As the pulley sizes and gear ratios at each joint are fixed, motor shaft rotation can be translated into the joint angle. Sensors will also be used to measure the tension of the cable. As the cable is spooled from the motor, it runs over a small pulley mounted on a cantilever beam.

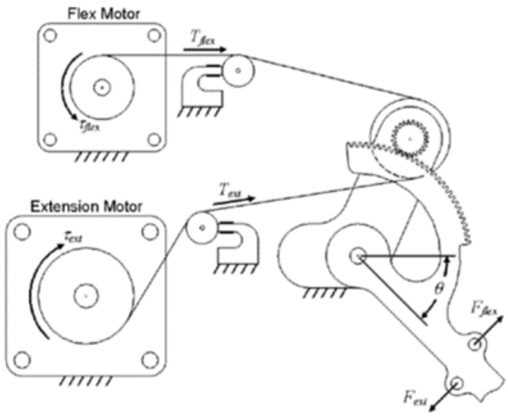

Figure 6. Schematic of one joint of the manipulator [3].

This particular beam is instrumented with strain gages to determine the force applied by the cable. The joint torque is calculated from the height information of the above the joint and the gear ratio. Unfortunately, there could be a backlash due to imperfect mating between the gears and therefore, it could put a patient in danger situation.

3. Methodology

In this work, flex sensors have been used to detect the bending angle of the fingers. These sensors are stitched and attached to the glove for this purpose as depicted in Figure 7. Only four fingers are used in this experiments to move an artificial hand as shown in Figure 8. The artificial hand is used as the hand movement emulator which will imitate the movement made by the hand trainer device.

The flex sensor and 22kΩ resistor are connected in series to the Arduino Mega 2560 development board as illustrated in Figure 9. The analog data, which is the bending force voltage value from these sensors are fed to the Arduino. This signal is converted into digital values through the Analog-To-Digital (ADC) converter for further processing operation in the microcontroller-based platform.

Figure 7. The flex sensors are stitched and attached to the hand trainer glove.

Figure 8. An artificial hand is used to emulate the movement detected by the flex sensors on the hand trainer device.

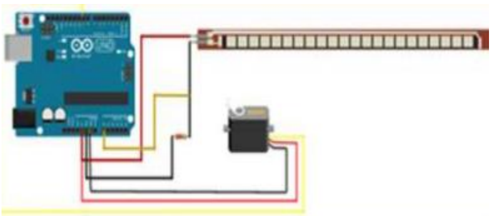

Figure 9. The flex sensor is connected to the Arduino development board.

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Finally, the fingers on the artificial hand will be stretched and moved according to the rotation of the servo motor. Figure 10 shows the architecture of the artificial fingers. It uses cylindrical plastic pipes which have been segmented into phalanges part of the fingers. A nylon thread is filling through the drilled hole of each segmented phalange to act as the joint of the fingers. This nylon thread is connected to the servo motor and will be extended and contracted during this movement.

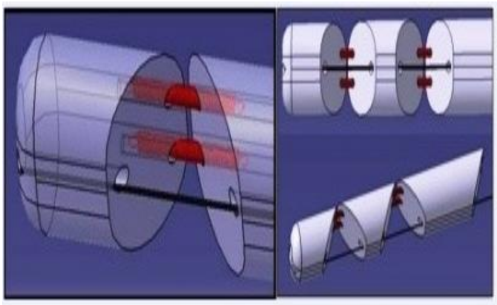

Figure 10. The connection of the fingers on the artificial hand.

4. Result and discussion

The voltage value received at this point depends on the position of the flex sensors as shown in Table 1. When the flex sensor is straight or unbend, the obtained digital value is 720 V. The value is decreasing whenever the flex sensors are bent. The digital value for 45, 90, 135 and 180 degrees are 702, 695, 682 and 670, respectively. These values are really useful in energizing the servo motor that is attached on the artificial hand to be rotated at the same angle, simultaneously. To do this, the pulse-width signals are generated by the Arduino platform. Table II shows the pulse width modulation required by the servo motor to be rotating in various angles.

Table 1. The digital value of ADC output and Motor angle.

Digital Value	Motor Angle(°)
720	0
702	45
695	90
682	135
670	180

Table 2. Relation between pulse width and angle of rotation motor.

Pulse Width(ms)	Rotation of motor(°)
1	0
1.5	90
2	180

Table 3. Bending of flex sensor and rotation servo motor.

Bending of flex sensor (°)	Rotation of servo motor (°)
0	0
30	60
45	90
60	120
75	150
90	180

The relationship between the degrees of the bent flex sensor on the hand trainer glove with the rotation of the servo motor at the artificial hand is stated in Table III, respectively. The initial angle for both of flex sensor and the servo motor is 0 degree. From this table, it can be analyzed that, the total degree turn of the servo motor is doubled than the bending angle of the flex sensor. This discrepancy could be attributed to the nylon string attached to each servo motor at the artificial hand. The tension produced by the strings is quite firm and therefore, more effort is needed by the servo motor to tight or to release it during hand releasing and grabbing movements. The linear relationship between the bending angle of the flex sensors and rotating angle of the servo motors is graphically plotted in Figure 11 for a clearer view.

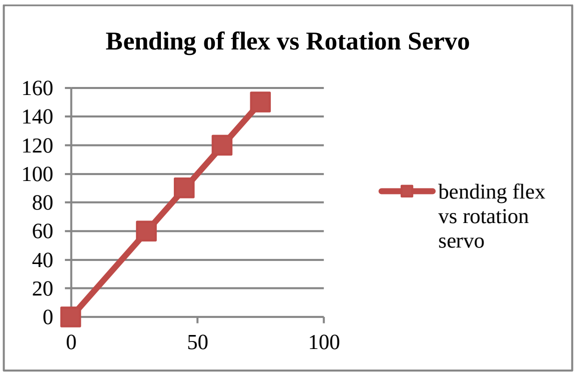

Figure 11. Plot bending sensor with respect to rotation.

When the sensor is bending, the values of the resistor and output voltage change immediately. Table IV shows the values of the flex sensor resistance and the obtained output voltage with the bending angle of the flex sensors. The value of the resistor is comparatively increased whenever the flex sensor is relatively bending. Similar to the output voltage. When the flex sensors are bending, the upper body of it is expanded. More voltage is needed to across this resistance. And therefore, the output voltage is incremented directly with the increment of the resistance as shown Figure 12 and Figure 13.

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Table 4. Bending of flex sensor and flex sensor resistor.

Flex sensor resistor (kΩ)	Flex sensor bending angle.	Vout
2.8	0	0.564 V
3.283	45	0.6492 V
4.022	60	0.7728 V
4.769	90	0.8907 V
5.013	135	0.9279 V

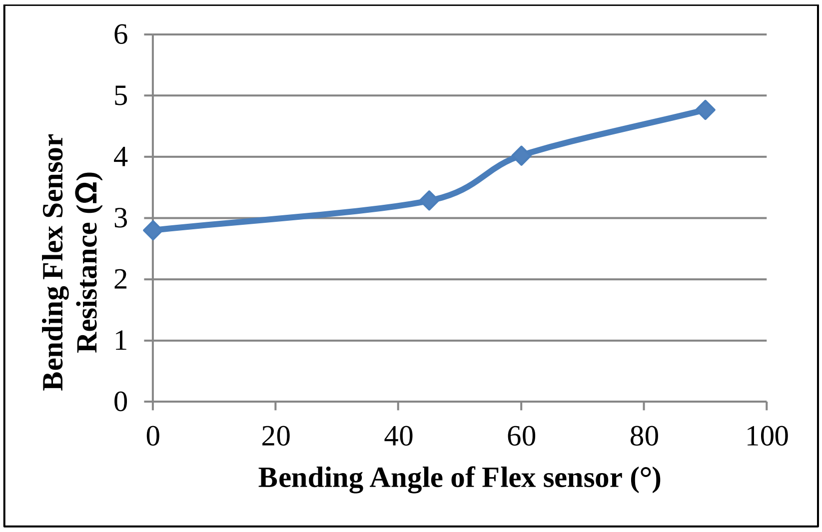

Figure 12. The relationship between the bending of the flex sensors with respect to the resistance.

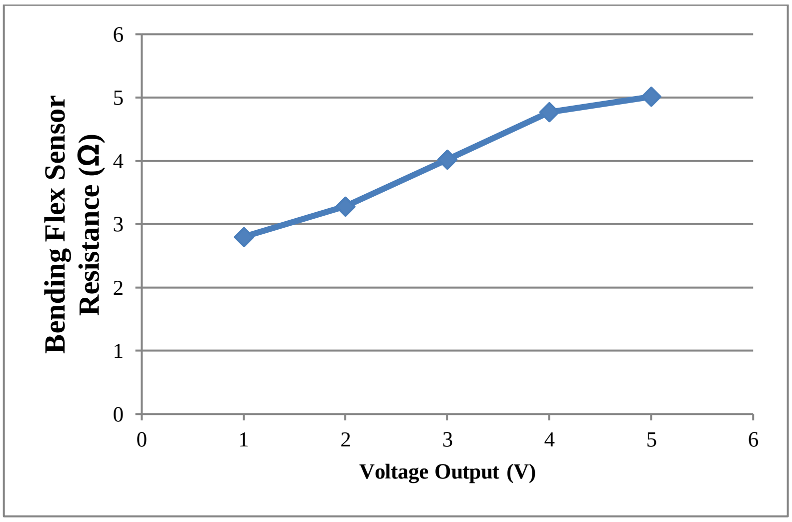

Figure 13. The relationship between the bending of the flex sensors with respect to the voltage output.

5. Conclusion

This project has come out with the working glove for hand trainer device by using flex sensors as the main input. The movement of the hand, either releasing or grabbing movements are mimicking by the artificial hand through the manipulation of the servo motor rotations and the nylon string that attached to each single artificial finger. It is one way to indicate the patient whether their hand movement is strong and sufficient by looking at the movement of the artificial hand during the rehabilitation process. This prototype could be enhanced by replacing the servo motor with the higher torque motor so that the artificial hand could grab and lift a heavier material such as ball during the hand exercise process and making the rehabilitation more interactive and interesting.

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