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Development of Hand Exoskeleton for Recuperation

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***Abstract:** About half a million people across the globe suffer from different types of hand injuries and hand impairments. These impairments reduce the quality of living. The present system demands a physician to perform the physiotherapy on the mutilated hand of the patient. Nowadays it has become difficult for the physiotherapists to cater to all their patients given time constraints and increasing numbers of patients. A Hand Exoskeleton was developed for the rehabilitation of the mutilated hand which enables the patient to conduct physiotherapy himself without having to go to a rehabilitation centre. The exoskeleton provides a convenient and cost-effective mechanism for physiotherapy since the patient can do the physiotherapy himself at a time of his convenience and any number of times he wants to. With the exoskeleton, the movement of the good hand is replicated in the mutilated hand of the patient. This exoskeleton can supervise the bidirectional movement of the mutilated fingers. That way, the injured fingers are provided with some movement by the help of the servo motors. The gyroscope attached to the stroke hand determines the angular deflection. This exoskeleton can be used for repetitive, intensive and continuous physiotherapy exercises. It can treat many patients daily with minimum supervision. In the long term, the patient would be rewarded physically, emotionally and economically. The exoskeleton is lightweight and economically affordable for everyone. In this manner, patients are no more dependent on physiotherapists for the exercise. No external help is required by the patients for their daily exercise.*

***Keywords:** Arduino UNO, Flex sensors, MPU6050, Physiotherapy.*

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I. INTRODUCTION

Hand injuries are very common and frequent injuries to occur, it can be due to an automobile accident or any other injury. These injuries can leave temporary or even long-lasting effects. These injuries can hamper the productivity of a person and thus can cause economic losses. So we employ various rehabilitation techniques.

The goal of rehabilitation is to simplify the treatment of tendon injuries or to reduce painful post-surgery trauma. For this purpose, hand exoskeleton is developed. The hand is a very compound part of the body with several joints, various sorts of tendons, ligaments, as well as nerves. Trauma to the hand is a frequent and common thing to happen. Sprains are the result of forcing a joint to perform against its normal range of motion. The fractures and dislocations in the hand tend to cause deformity, swelling, discoloration, tenderness, weakness in the hand. The injuries to the ligaments around joints cause dislocations. Fracture of the finger happens when the finger hits a hard object. Thus to deal with this by Physiotherapy a hand exoskeleton is designed and developed.

Physical therapy treats the injuries that have a limiting action on a person's abilities to move and perform daily life activities. Hand therapy programs are tailored to reduce the symptoms and help retrieve the skills required for daily activities. Whether it is recuperating from an injury or surviving with any long term state like arthritis, therapists nurse a wide range of upper frontier criticism by providing specialized treatments and robustness intensifying exercises. The hand therapy plan duration is resolved by factors such as age and other health aspects and healing required time and patience. The exoskeleton aims to remove the burden from physiotherapists and aid the common man to increase the reach towards physiotherapy.

Fig. 1. Image of the working model

As shown in Fig. 1, the fingers of the working hands are moved. This movement is mapped through flex sensors that send this data to the Arduino board.

This data is then sent to servo motors connected to the stroke hand which then replicates the same motion in the stroke hand. A Microprocessor Unit 6050 is used to analyze the movement. Also proposed design contains digital image processing to observe the progress of a fracture patient during the rehabilitation phase. The block diagram of the proposed hand exoskeleton model is depicted in Fig. 2.

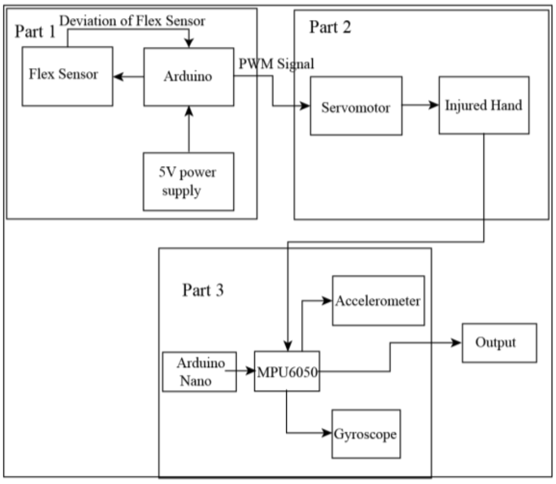

Fig. 2. Block diagram of the proposed hand exoskeleton

II. HARDWARE DESCRIPTION

A.. Flex Sensor

Flex Sensor is a variable resistor whose terminal resistance changes when the sensor is bent. The change in sensor resistance depends on surface linearity and it senses the changes in linearity. Flex sensors are generally available in two different sizes such as one of them is 2.2 inch and another is 4.5 inch**.** While the sizes are distinct the primary function persists to be the same. They are also divided based upon the resistance there are low resistance, medium resistance and high resistance types. Operating voltage of flex sensors lies between 0-5V and can even operate on low voltages. However, the power rating of the flex sensor is 1W and operating temperature lies between -45ºC to +80ºC. The flex sensors are combined with 22kΩ resistor to form a voltage divider circuit. The voltage divider circuit shown in Fig. 3 is used to give an output voltage that is a fraction of its input reference voltage.

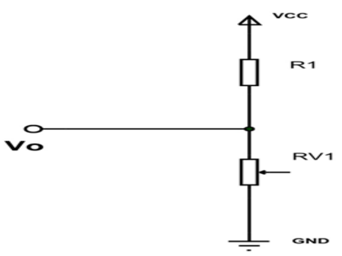

Fig. 3. Voltage divider circuit

As shown in Fig. 3, the constant resistance is R1, and variable resistance is a flex sensor. V_o is the output voltage and also the voltage across the flex sensor.

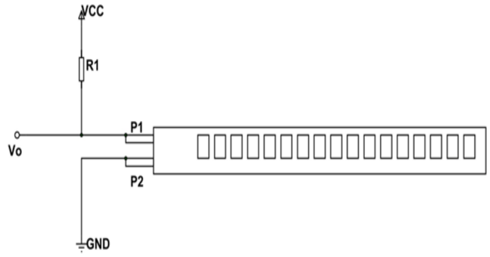

Fig. 4. Connection of flex sensor

Here, $$V_o = V_{cc}\left(\frac{R_x}{R_1 + R_x}\right)$$

where R_x stands for flex sensor resistance when the flex sensor is bent the terminal.

B. MPU 6050

The Micro Processing Unit (MPU) 6050 consists of an accelerometer and a gyroscope. It has 6 degrees of freedom. There are three axes in the gyroscope namely gx, gy, gz and three axes in the accelerometer namely ax, ay and az. In this way, it gives an ordered pair of 6 axes. This means that the MPU sensor gives a very precise value. The accuracy of the sensor is more if it is a combination of both accelerometer and gyroscope. Individually the accelerometer and gyroscope do not have much accuracy, so this sensor gives a more accurate and precise value which makes the system precise and cost effective. MPU6050 is based on the Micro Electro Mechanical System (MEMS).

The MPU 6050 sensor module consists of 8 pins and these pins are used for different configurations. Power is provided to this sensor by VCC pin and 3-5V dc voltage to power on this sensor. The second one is the GND pin which is connected to the source ground. The third is the serial clock pin, connected to the Serial Clock (SCL) microcontroller pin. Fourth pin is SDA i.e. serial data pin, attached to the supplementary I2C interface sensors to enable its pin from the MPU sensor module. The fifth one is XDA pin i.e. auxiliary data pin. It is connected to the XDA pin of the microcontroller. The sixth one is an XCL (Auxiliary clock) pin which is also connected to other I2C interface sensors which enable its pin from this sensor module. The seventh one is the AD0 which is an I2C slave address LSB pin. This pin is directly connected to the VCC pin for changing the slave address and reading logic. Similarly, the last one is an INT (interrupt) pin which interrupts the digital output pin and gives any interruption to the MPU 6050 sensor module.

C. Arduino NANO

Arduino is an open source computer which uses a variety of microprocessors and microcontrollers. The board contains analogue and digital input and output pins which can be interfaced to other circuits. They have a 16 MHz crystal oscillator. The Arduino UNO is a complete, small and bread board-compatible board based on the ATmega328P microcontroller. Its programming is done using Arduino IDE.

Its operating voltage is 5V. The recommended input voltage is 7 to 12V. It has 14 digital input and output pins. There are 8 analogue input pins. It's flash memory is 32KB. The DC current per input-output pin is 40mA. The clock speed is 16 MHz.

D. Servo Motor

The servo motor works as a rotary actuator which has control over the angular position of the movement of its shaft. The servo motor used in the proposed design is MG945. Servo Motors have a sensor which acts as a feedback to the circuit. Metal gears are used in MG945. The operating voltage ranges from 4.8V to 4.6V. The power is supplied to the servo motor through an external adapter. The servo wire length is usually 32 cm. It draws current at the idle position which is equivalent to 10 mA. Its dead bandwidth is 1 microsecond. The usual revolution cutoff of servo motors ranges from 90° to 180°. The revolution cutoff of a few servo motors goes up to 360° or more. But the rotation of servo motors is not consistent. Fixed angles limit their rotation.

III. SYSTEM DESIGN

The flex sensors are attached to the uninjured hand. The uninjured hand is connected to the Arduino nano which moves when the supply of 5V is given to it. When the fingers of the uninjured hand are moved, there exists a change in the resistance. This change is then added as an input signal for the Arduino where it is then converted to its digital counterpart. These digital signals are sent to the servo motors which are connected to the injured hand in the form of PWM signal. So, when the uninjured hand moves, the injured hand also moves accordingly.

The uninjured hand has flex sensors attached to it, each finger is named as A, B, C, D, E and a flex sensor is attached to each finger. The finger is inclined inwards and if the radius of curvature is small, there is an increase in resistance. A resistor of 22kΩ is merged with the flex sensor to create a voltage divider circuit to generate a variable voltage. As compared to the reference voltage, a voltage divider circuit provides lesser voltage which gives the desired voltage to the circuit. F1, F2, F3, F4, F5 are the flex sensors corresponding to the fingers A, B, C, D, E. The corresponding voltages are sent to the Arduino Nano, as the flex sensors are inclined. The analogue signal received by the Arduino nano is then converted to a digital signal with the help of analogue to digital converters. The PWM signal is sent to the servo motors of each finger. The servo motors S1, S2, S3, S4 and S5 are the servo motors corresponding to fingers A, B, C, D, E with their flex sensors F1, F2, F3, F4 and F5. If the finger A is bent, the flex sensor F1 is bent and the servo motor S1 starts moving after receiving the signal. With the help of nylon strings, all the servo motors are attached to the fingers of the injured hand. The MPU6050 sensor is used to measure the deflection of the fingers. It has a gyroscope sensor and accelerometer sensor in it for measuring the acceleration and angular velocity of the moving object. The MPU sensor is kept on any servo motor to determine angular deflection. The MPU sensor is also connected to the Arduino Nano and the final output is obtained in the form of a deviation of the finger. These deviations of fingers of the injured hand are measured. However, the digital image processing is then carried out which observes the progress of a fracture in the patient during the rehabilitation phase. With on-going physiotherapy, the x-rays will be scanned at regular intervals to detect any possible minor fracture in bones. The design process of the proposed hand exoskeleton is shown in Fig. 5.

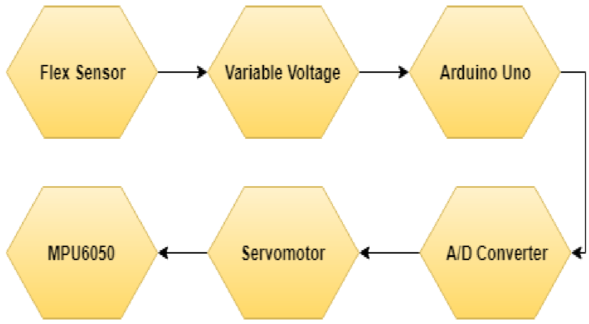

Fig. 5. Design of the proposed hand exoskeleton

IV. RESULT

There is a library in Arduino which has servo.h, which has servo pre-installed function. There are five fingers to which five flex sensors are fettered. The first finger gives the first sensor S1 as its value. Similarly, the second finger gives S2 as its value, the third as S3, fourth as S4 and fifth as S5. To gather data from the sensor the method is to use analog Read ( ), which is attached to an analog pin of the Arduino. The output range which is received from analog Read ( ) function is plotted between 0 to1023. The calculation for the voltage is given by, voltage = sensor value * (5.0÷1023.0). The sensor values are plotted now. Each finger has dissimilar minimum and maximum values. So every finger is calibrated suitably.

TABLE - I: Calibration of flex sensors

Servomotor	Min(0°)	Max(180°)
S1	880	900
S2	878	891
S3	823	841
S4	827	802
S5	759	770

The readings here are of the flex sensors which are attached to the uninjured hand. These readings are in voltage. The graph shown in Fig. 6 depicts the output of the flex sensor. However the deviation of the servomotor corresponding to the finger S1 is also illustrated in the simulated graph of servo motor shown in Fig. 7.

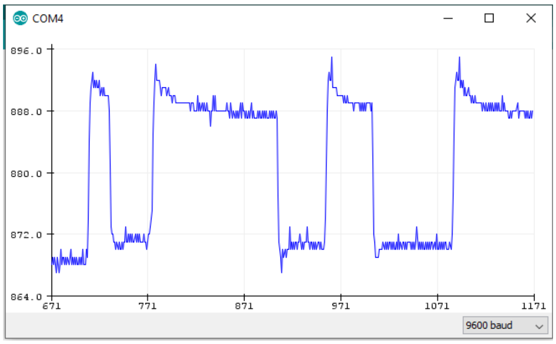

Fig. 6. Simulated graph of flex sensor

Fig. 7. Simulated graph of servomotor

V. CONCLUSION

The deviation of the fingers is calculated using MPU 6050. The movement of the uninjured hand is replicated in the injured hand. This movement is rendered in all the fingers of the injured hand. The graph of each finger movement was plotted. The deviation and position of the fingers were seen and calculated using a gyroscope and accelerometer sensor. Hence the proposed hand exoskeleton enables physiotherapists to carry out physiotherapy treatment for patients.

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