Measurement of joint angle for physical therapy using a wearable carbon nanotube based sensor

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Presented in International Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering held at Indian Institute of Technology Ropar (IITR), Rupnagar, during December 5-7, 2019.

ABSTRACT

KEYWORDS:

Angle of Elevation,
Solidworks,
Proteus,
MWCNT,
Human Motion Monitoring and Physiotherapy.

This work presents the simulation and analysis of the circuit designed to capture angle of elevation of joint of index finger using flexible Multi walled Carbon Nano Tubes (MWCNT) / silicone vulcanized rubber composite. To determine the location of optimum strain on index finger, a 3-D model of the index finger is created using CAD tool. For joint angle measurement, an electronic circuit comprises of wheatstone bridge, microcontroller and LCD is designed using Proteus software. One arm of the Wheatstone bridge is replaced with wearable sensor and rest is fixed resistors. Simulation result shows that the resistance of sensor varies linearly with the joint angle of index finger. Joint angle measurement upto 60° is displayed on LCD. This work will be used to model a wearable human motion monitoring device, which will assist the physiotherapists in observing the angle of movement of joints, thereby, aiding rehabilitative health.

1. Introduction

Recent advances in research on material science and bio-medical engineering based applications show a rapid rise in the employment of composite materials. The use of composite materials is to incorporate the advantageous properties of two or more components. In recent years, polymer nanocomposite has been an area of industrial interest in bio medical healthcare devices. Polymer nanocomposite is formed by reinforcing a filler material in nanometric dimension into polymer matrices. Most commonly used filler materials are CNT, graphene, clay, silica and zinc oxide. Among all the filler materials, CNT is preferred as it is dispersed uniformly and enhances the properties of polymer at very low filler loading. CNT/polymer based nanocomposite yield an excellent response characteristic owing to its considerably high Young's modulus (i.e. 1 TPa), high tensile strength (i.e. 100GPa), very high electrical conductivity (i.e. ~ 10^{13} A/cm^2) and very high thermal conductivity (~3500 W/mK) [1-2]. These properties arise due to the in-plane linking of the graphitic carbon atoms.

The increase in intensity of research in material science has led to the over whelming innovations and advancements in the healthcare domain. It narrows the discussion to recent developments in the field of wearable sensors. As the contemporary times suggest modern problems, modern solutions, having minimally invasive, unobtrusive health care services on the go such as hexoskin biometric shirts, flexible wireless Electro Cardio Gram (ECG) sensors and Jawbone UP fitness trackers. Hexoskin biometric shirt monitors heart rate, variability of the heart rate, respiratory rate, number of steps, distance traveled, pace, maximal oxygen consumption, and calories burned. ECG sensor with a fully functional microcontroller captures and transmits data with the help of a low power radio. And a Jawbone UP fitness tracker records sleep stages (Rapid Eye Movement (REM) sleep, light and deep), Heart Rate (HR), food & liquid intake, number of steps and the distance traveled.

These devices also captivate real time data and measure physiological signs like ECG, Electro Myo Graphy (EMG), Electro Dermal Activity (EDA), arterial oxygen saturation, Blood Pressure (BP) and Respiratory Rate (RR) [3-4]. Detection of an early outbreak of cardiovascular,

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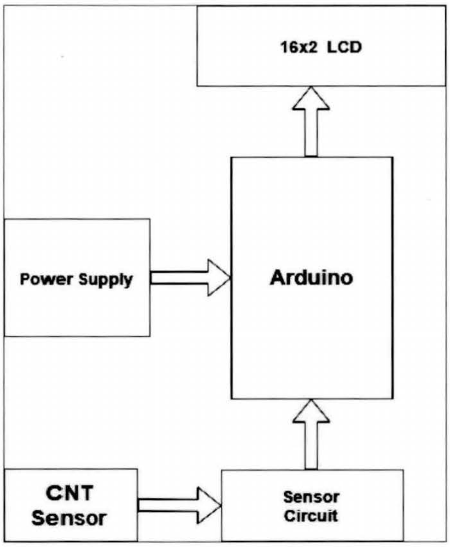

Fig. 1. Schematic representation of wearable flexible CNT sensing unit.

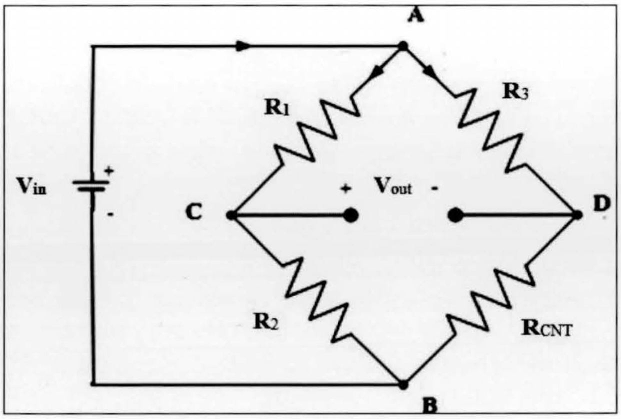

Fig. 2. Signal conditioning unit of CNT sensor.

neurological and pulmonary diseases symptoms gives them a high ground over other conventional methods. The ultimate goal is to provide quick and precise remote health monitoring, ensure safety and contribute towards the rehabilitative health measures [5-6].

In this paper, a model of wearable CNT based sensor for measurement of angle of elevation of joint of index finger is reported [7]. The proposed sensor is simulated in the Proteus software. The stress analysis of the fabricated sensor is done using CAD toolbox which verifies the location of optimum strain on index finger.

2. Wearable Flexible Strain Sensor

According to piezo resistivity property of CNT its resistance varies with the change in applied strain and hence, it is used as strain sensor [8]. To use a wearable flexible CNT based strain sensor, MWCNT is reinforced into vulcanized rubber composite [9]. The schematic of a wearable flexible CNT based strain sensing unit is shown in Fig. 1.

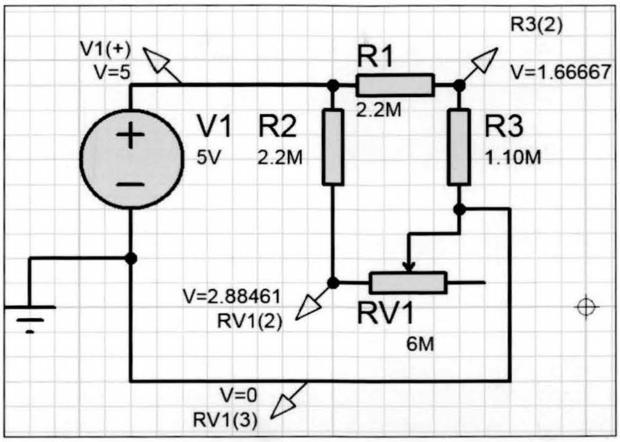

Fig. 3. Simulation of a quarter-bridge circuit in proteus environment.

To convert change in resistance of CNT sensor with respect to strain into change in voltage signal, signal conditioning circuitry is required as shown in Fig. 2.

Wheatstone bridge is used as a signal conditioning unit in which one arm of the bridge is CNT sensor and initially bridge is said to be in balanced state. For bridge to be in balanced state, it must satisfy the relation given in equation 1.

$$\frac{R_1}{R_2} = \frac{R_3}{R_{CNT}}$$

.... (1)

Where 'R_1','R_2','R_3' and 'R_{CNT}' are the resistances which form the arms of bridge unit. When the strain is applied on CNT sensor its resistance changes and bridge is in unbalanced state and an output voltage appears across the bridge. The output voltage 'Vout 'across the bridge is given by:

$$V_{out} = \frac{V_{in}}{4} GF \in$$

.... (2)

Where 'V_{in}' is the input voltage of Wheatstone bridge, 'GF' is the gauge factor of CNT sensor and 'ϵ' is the applied strain. Gauge factor of CNT sensor is the measure of strain sensitivity of CNT sensor and it is given by:

$$GF = \frac{\Delta R_o}{R_o}$$

..........................(3)

Where 'R_o' is the original resistance of CNT sensor and 'ΔR_o' is the change in resistance of CNT

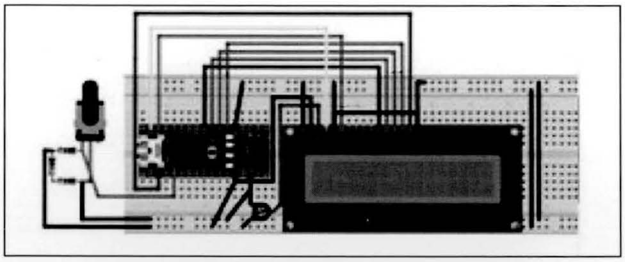

Fig. 4. Fritzing schematic representation of the electronic circuit.

sensor with respect to the original resistance.

Simulation of the wheatstone bridge circuit is performed in Proteus software as shown in Fig. 3. In a quarter-bridge circuit, CNT composite sensor forms one arm of the bridge and fixed resistors make up the other three arms. Therefore, any change in the resistance of CNT composite sensor result in unbalance of the bridge to produce a non-zero output voltage / electrical signal that is a function of tensile strain (or compressive strain). [10-14]

The parameters chosen for quarter-bridge circuit are as follows: Input voltage V_{in}= 5 volts, three fixed resistors R_1= 2.20MΩ, R_2=2.20MΩ, R_3=1.10MΩ, Potentiometer RV_1 ranging from 0MΩ to 10MΩ. Output voltage V_{out} appears in the range of 0V to 2V.

3. Joint Angle Measurement

This work presents measurement of a parameter of Functional Range Of Motion (FROM), i.e. the joint angle, of Proximal Inter Phalangeal (PIP) joint in evaluating rehabilitation programs. The user wears a glove that has the flexible MWCNT/ vulcanized rubber composite strain sensor on it [15-17]. Now when the user bends the joint at which the sensor is attached, the sensor creates different resistances, corresponding to the bending angles, for the fourth arm of the Wheatstone bridge. The Wheatstone bridge converts mechanical strain to voltage signal input for the analog input pin of Arduino. The Arduino is programmed to display the joint angle in degrees with a least count of 1 degrees of the index finger, corresponding to the digital input, on the Liquid Crystal Display (LCD), connected to output pins of the Arduino as shown in Fig 4.

This work can be extended to other joints of the human body corresponding to different sizes of the flexible sensor [18-19]. The voltage signal in the range 0 to 2V is fed to analog pin of Arduino Nano microcontroller. Arduino boards contain a multichannel, 10-bit analog to digital converter. This means that it will map input voltages between 0 and the operating voltage i.e. 5V into integer values between 0 and 1023 as shown in Table 1. This yields a resolution between readings of 5 volts /1024 units i.e. 0.0049 volts per unit.

Table 1
Analog to digital conversions.

Analog Voltage Signal (V)	Digital Integer Values (0-1023)
0	0
0.20	41
0.50	102
0.80	164
1.00	205
1.50	307
2.00	409
2.50	511
3.00	613
3.50	716
4.00	818
4.30	880
4.60	941
5.00	1023

4. Results and Discussions

To find the optimum location of attaching flexible sensor on index finger joint stress strain analysis is performed. To perform the stress-strain analysis of the index finger joint, an anthropomorphic artificial finger model is developed in Computer Aided Design (CAD) software.

After modeling the artificial index finger joint in CAD tool, stress analysis is performed on the joint. After applying a material on the model, the base of the finger is taken as fixture, similar to the fixed part of metacarpophalangeal joint of the index finger, as shown in Fig. 5. To simulate a force of 10 N is applied near the proximal interphalangeal joint as the joint flexes when the index finger is bent. Simulation result in Fig. 6 shows the deformed state of finger and

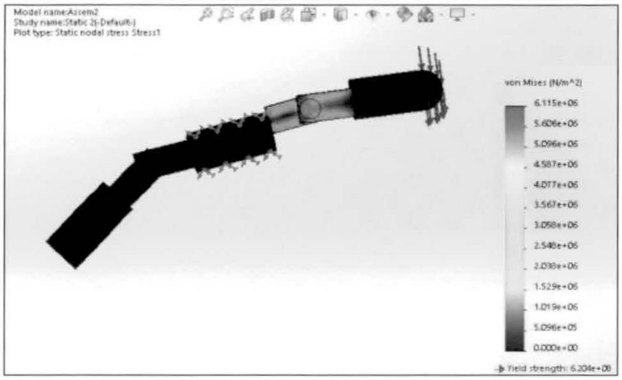

Fig. 5. Simulation of index finger model for verifying optimum location of strain using stress analysis study.

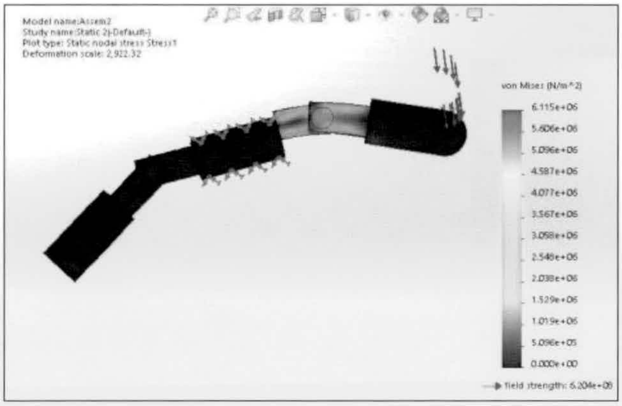

Fig. 6. Deformed state of the finger after the application of the 10N force.

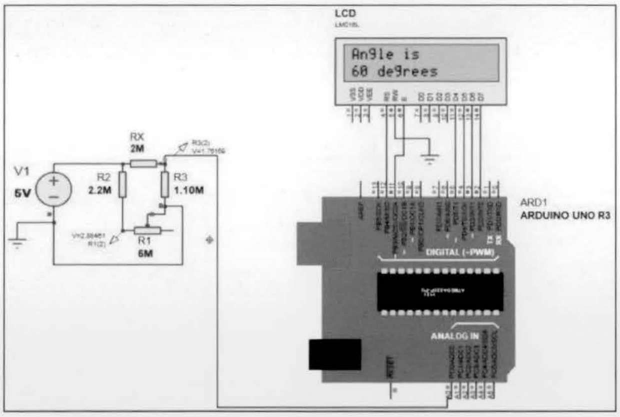

Fig. 7. Schematic diagram of the joint angle measurement circuit in Proteus environment.

Table 2

Simulation circuit parameters.

Parameters	Values
Supply Voltage(V_1)	5 Volts
Output Voltage(V_2)	1.76 Volts
CNT Sensor Resistance(R_x)	2 MΩ

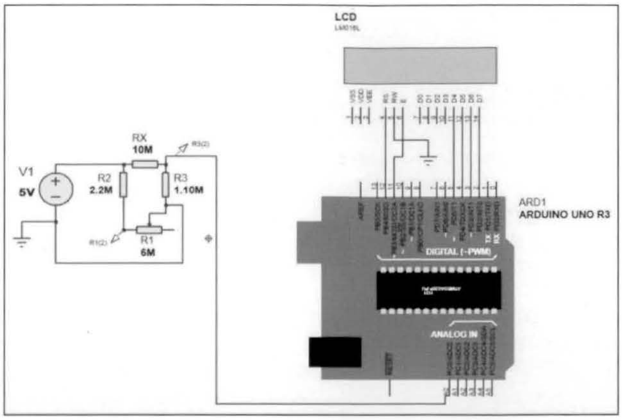

Fig. 8. Simulation of joint angle measurement circuit in Proteus environment.

the optimum strain location on the index finger model.

Before implementing the hardware circuit in real time the performance is analysed by simulating the circuit in proteus design suite software as shown in Fig.7. Main components in schematic are: a DC voltage source (V1), fixed resistances R_1=6MΩ, R_2=2.2MΩ, R_3=1.1MΩ, Arduino Uno microcontroller and LCD.

From the design parameters, the micro controller converts the output voltage to digital integer values using the built in A/D converter. Further, the microcontroller displays the joint angle corresponding to that digital value as per the code as shown in Fig. 8.

5. Conclusion

In this paper, simulation of joint angle measurement circuits using proteus design suite is reported. Simulation circuits comprises of input supply voltage, wearable flexible MWCNT/ vulcanized rubber composite strain sensor as one arm of wheatstone bridge, fixed resistances as three arms of bridge, Ardunio microcontroller and LCD display. CNT sensor resistance varies from 0 to 10 MΩ on bending the joint. Based on the variation of CNT sensor resistance joint angle measurement upto 60° is displayed, on LCD. To identify the optimum location of attaching sensor on index finger joints, stress-strain analysis is performed in CAD software. A 3D model of index finger is created and force of 10N is applied. Result shows that optimum location of pasting sensor is near the fixed end of index finger joints. This circuit can be implemented as a healthcare device for rehabilitation or for smart human motion monitoring at a low cost.

Acknowledgement

Authors acknowledge the support of Director, UIET, Panjab University, Chandigarh and Director, CSIO, Chandigarh. Authors thank Department of Science and Technology, New Delhi for providing INSPIRE faculty award to Dr. Parveen Kumar. "This paper is a revised and expanded version of an article entitled, 'Measurement of Joint Angle for Physical Therapy Using a Wearable Carbon Nanotube Based Sensor' presented in '7th International Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering' held at Indian Institute of Technology Ropar, Rupnagar, India during December 5-7, 2019".

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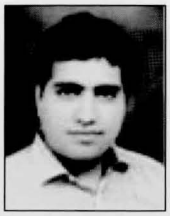

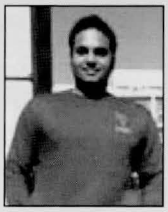

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