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Intensity Based Fiber Optic Sensor for Remote Measurement of Human Joint Movements

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Abstract: *With the increase in the number of digital devices and ever increasing use of the frequency spectrum, our environment is susceptible to a variety of electromagnetic noise signals. These signals pose a real threat to the accurate functioning of the various electronic sensors. The requirement of a sensor system immune to these noises is becoming a must in various fields like biomedical engineering and cutting edge robotics. Fiber optic sensors, being immune to other radiations are a viable alternative. There has been a rapid increase in the use of optic fiber sensors for various biomedical applications. Goniometers are devices which are used to measure the degree of recovery after an injury to an elbow, knee or finger by finding to what extend the patient can move these parts without pain. This paper aims to calibrate a goniometer device with the help of optical fiber sensors.*

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I. Introduction

The ability of fiber optic sensors to displace traditional sensors for rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, chemical measurements, and a host of other sensor applications has been enhanced. The inherent advantages of fiber optic sensors, which include their ability to be lightweight, of very small size, passive, low power, and resistant to electromagnetic interference, high sensitivity, bandwidth and (4environmental ruggedness, were heavily used to offset their major disadvantages of high cost and end-user unfamiliarity [1]. The general structure of an optical fiber sensor system is shown in figure 1.

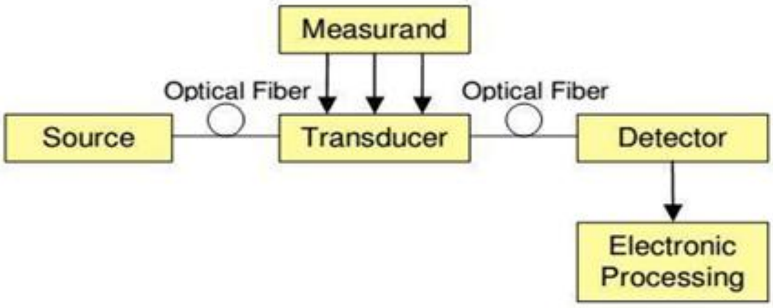


Figure 1

It consists of an optical source (Laser, LED, Laser diode etc.), optical fiber, sensing or modulator element (which transduces the measured value to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyser etc.) [2]. Even though a variety of techniques was proposed to the measurement of hand posture – such as optical tracking with external cameras, acoustic and magnetic tracking, and electromyography, – glove-based sensors present advantages in terms of real-time response and portability, and are unaffected by latency and fingers occlusion. However, the design of such instrumentation must take account of certain operational requirements, including accuracy comfort to the user with low mechanical load or movement restrictions, fast calibration and relative low cost. Most of the transducers applied on glove-based devices make use of electrical, magnetic or optical measurements to the estimation of finger joints displacements. However, most of these approaches are susceptible to electromagnetic interferences, and can exhibit limitations in terms of response linearity. On the other hand, optical fiber sensors present attractive characteristics for motion detection systems, like flexibility, lightweight, high sensitivity, multiplexing capability and immunity to electromagnetic interference [9].

FIBRE LONGITUDINAL DISPLACEMENT LOSS

Optical fiber displacement loss sensors were used to build a goniometer setup. The displacement loss was the light intensity loss caused due to the separation between two fibers. Both input and output fibres end were polished with a flat end tip. The emitting fibre was attached on a static stage while the other fibre was placed on the micro meter positioning stage (moveable part) using an adhesive tape. The receiving fibre was moved in a longitudinal direction and the change of the output intensity of the detector was measured at every 0.25 mm movement.

Fibre tilt angle loss: This type of configuration is based on the changes of the light intensity as the angle between the emitting fibre axis and the receiving fibre axis is increased.

To accurately define the light attenuation characteristic of the fibre bending angle, both fibre tilt angle and fibre gap (displacement) were measured separately. The measurements of light intensity versus fibre gap and fibre tilt angle are presented in figures the intensity of the light is in linear relationship with the fibre gap at three different slope degrees.

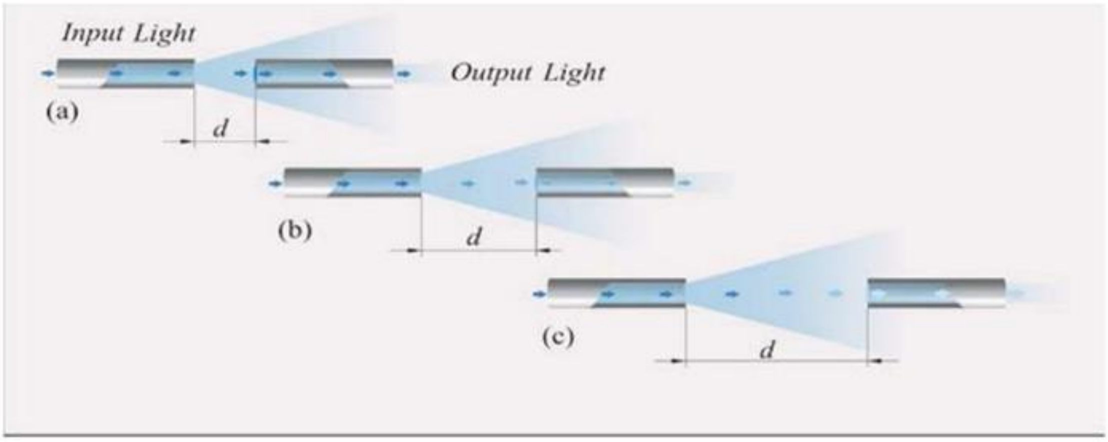


Figure 2: Intensity variations generated by the bending of the joint

Types of coupling losses caused in displacement type sensor can be due to axial displacement, gap displacement, angular displacement and due imperfections on the fiber opening. Losses in intensity are caused also by bending. These are classified into Macrobending and Microbending losses. When the optic fiber is bend beyond a particular radius, the light in the core escapes through the cladding. The resulting loss is called macrobending loss.

II. Results And Discussion

A. Experimental Setup

Fiber optic sensors are light weight and chemically inert and their immunity to radiations make them the apt choice to act as sensors in the biomedical field. In this paper, the movement or bending of the human finger and elbow are measured using a displacement type intensity based optic fiber sensor. The earlier stage of the work deals with the identification of a suitable optic fiber. The variation of intensity with displacement was studied for fibers with different core diameters. The fiber with the maximum available core diameter was chosen. Displacement type sensors were setup on a glove and on an elastic elbow band. Variation of the intensity was noted with the movement of the parts and a relation was established to calculate degree of bending. The analog voltage variation was received into an Arduino Uno board and this data was processed and converted into digital values and transmitted using a Bluetooth module to a mobile application. The live variations of the angle were plotted using an application called Arduino Excel.

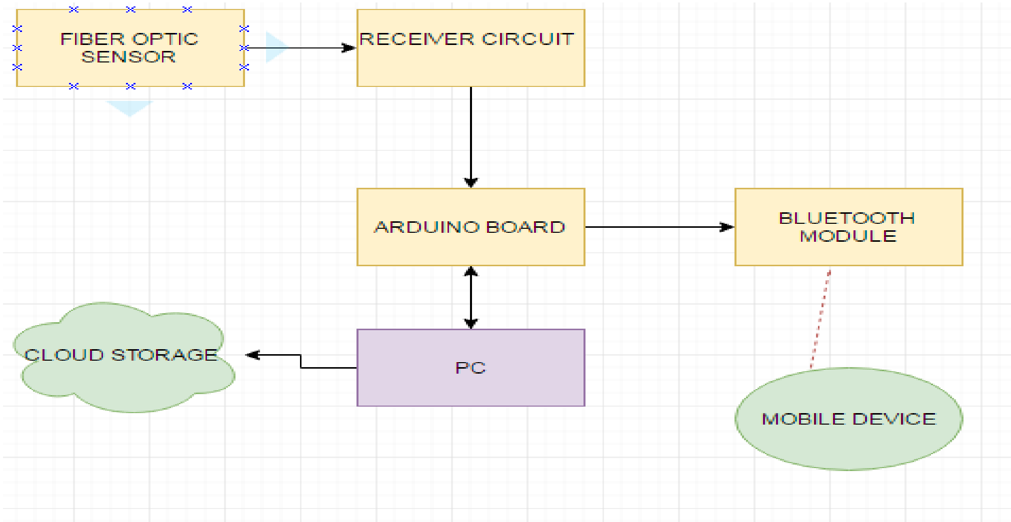


Figure 1 : Optic Fiber Goniometer

The main challenge is to select the optical fiber cable for the sensing purpose. The fiber with high light carrying capability is needed for the sensor design. So to select a fiber with good core radius is the essential design part. For doing the sensor design initially select the different optical fiber have different core diameter. Then conduct an intensity test to select the fiber. For doing that test two fiber with core diameter 200µm and 400µm is selected. Then, one end of the fiber is coupled to the laser source and the other end focused to a mirror. A photo detector assembly is setup to catch the reflected light from the fiber. The measurements are taken by moving the fiber backward and notice the intensity of light falling in the photo transistor. A Bevel Protractor was used to manually measure the angle made by the finger and elbow and the corresponding voltage levels were plotted.

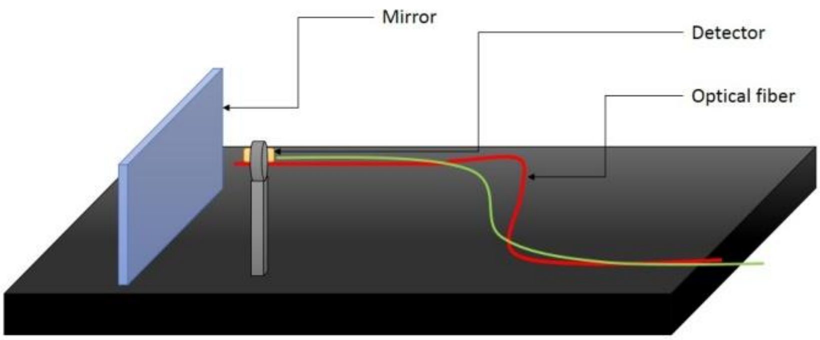


Figure 2: Setup to choose fiber diamter

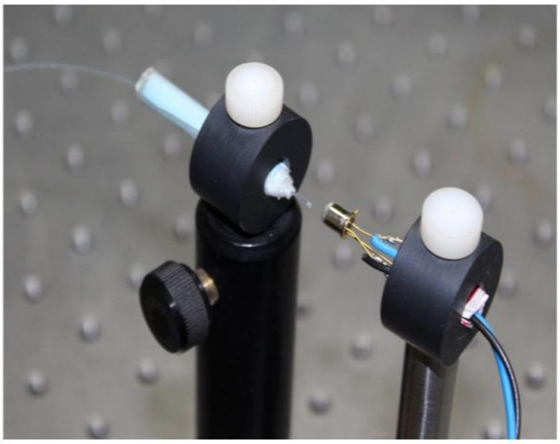


Figure 3 : Photo detector circuit

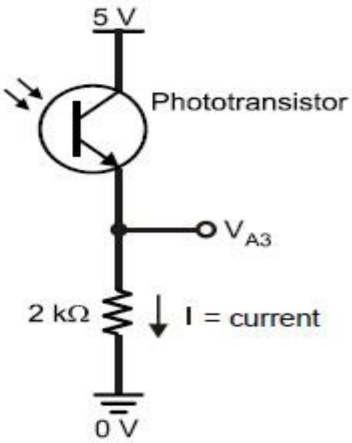


Figure 4 : Receiver circuit

The photo detector is used to detect the optical intensity variations of sensor. Here, we use optical detector assembly for detecting the sensor output. Figure 5 shows the detector circuit. An NPN photo transistor is used as a photo detector. When the photons get emitted at the base of the photo transistor, the resistance of the base region decreases and more current flows through the collector to the emitter region. The voltage drop across the 2 Kilo Ohm resistor is taken as the output voltage.

An Arduino Uno board was used to convert the analog voltage values received into digital values and map them into bending values in degrees. This processed data is then transmitted to the mobile application via Bluetooth. The data is also stored in an excel file where it is possible to see live variations of the angle in a real time basis. The excel file is then stored and uploaded into the cloud storage.

FIBER OPTIC SENSOR:

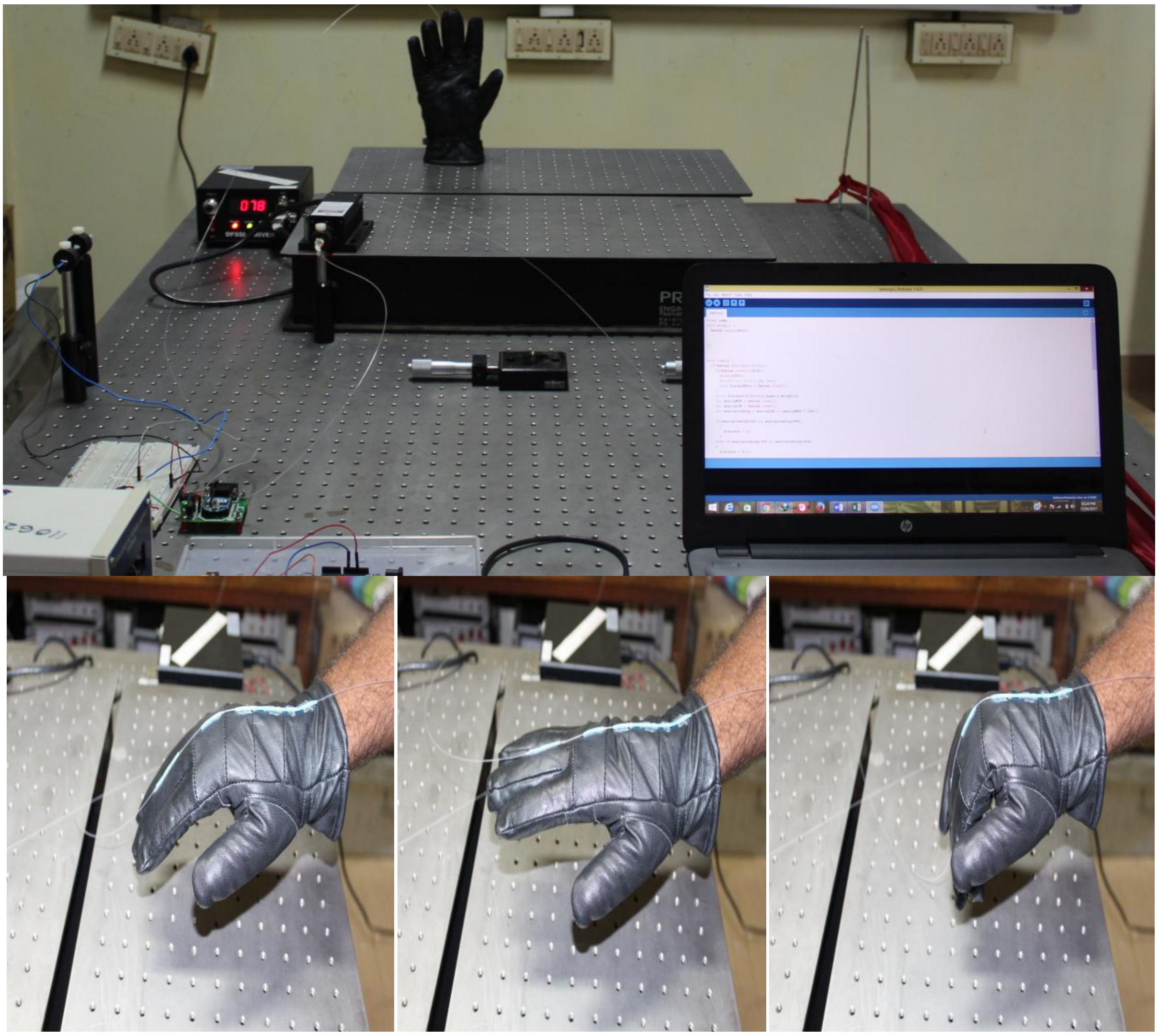
Two displacement type optical fiber sensors are calibrated one for finger and another for the elbow of the human arm using the 400 micrometer core optic fiber.

Figure 5: Sensor for elbow

The sensor for the elbow motion is a displacement type of optic fiber sensor. The maximum intensity output is obtained when the arm is outstretched as the elbow angle decreases from 180 degrees to 90 degrees the output of the displacement sensor reduces

Figure 6: Sensor for Finger

The finger sensor is designed for two types of motion. The initial position is the relaxed arm position for which the maximum intensity is obtained at the output.



B. Experimental Results

i.Selection of optical fiber:

The plot shows the relationship between the output voltage at the detector versus the distance from the mirror. From the graph it's clear that as the distance is increased the reflection intensity is reduced and hence the output voltage from the detector is also reduced. This graph also shows the intensity variation in different core diameters. From the graph the optical fiber with higher core diameter have more intensity reflection compared to optical fiber cable with low core diameter.

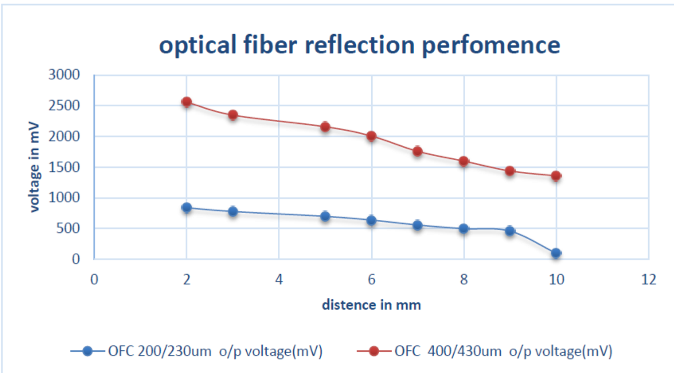


Figure 7: Optical fiber cables reflection behaviour

In the sensor designing part we emphasised primarily on to the selection of an optical fiber. The sensor should be capable of high sensitivity and must be flexible and display significant loss. Out of two glass fibers of 50 and 62.5 micro meter, we were able to select 62.5 micro meter core fiber as it displayed more sensitivity. The two plastic fibers of core diameter 200 and 400 micro meter had less sensitivity and were not that flexible but were most suitable for the displacement sensor as they had higher output intensity

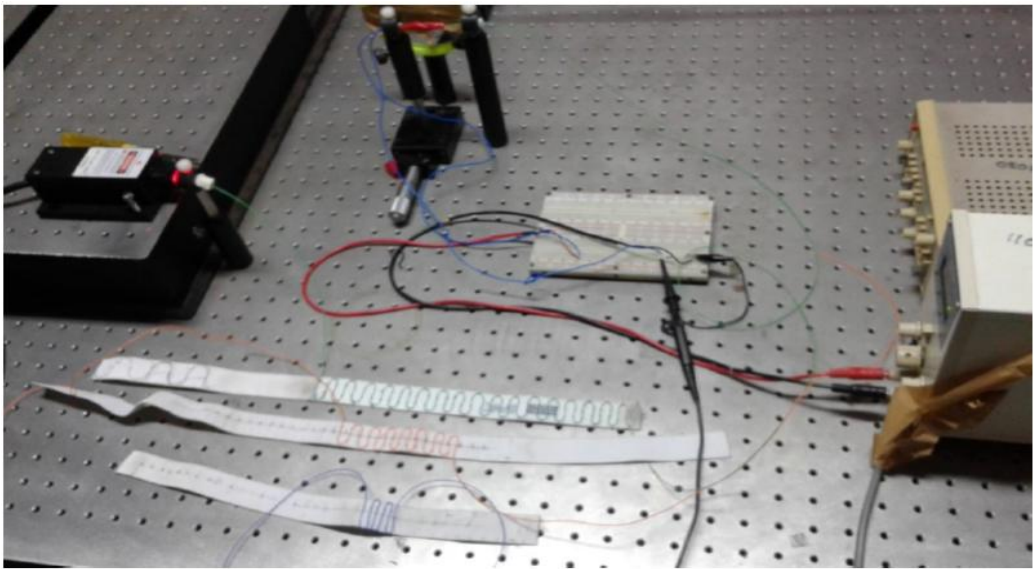


Figure 8: Setup to select optical fiber depending on core radius

From the above study it was concluded that the 400 micrometer fiber had a greater intensity output and was more suitable for sensor application.

ii. Variations of output voltage for elbow and finger bending

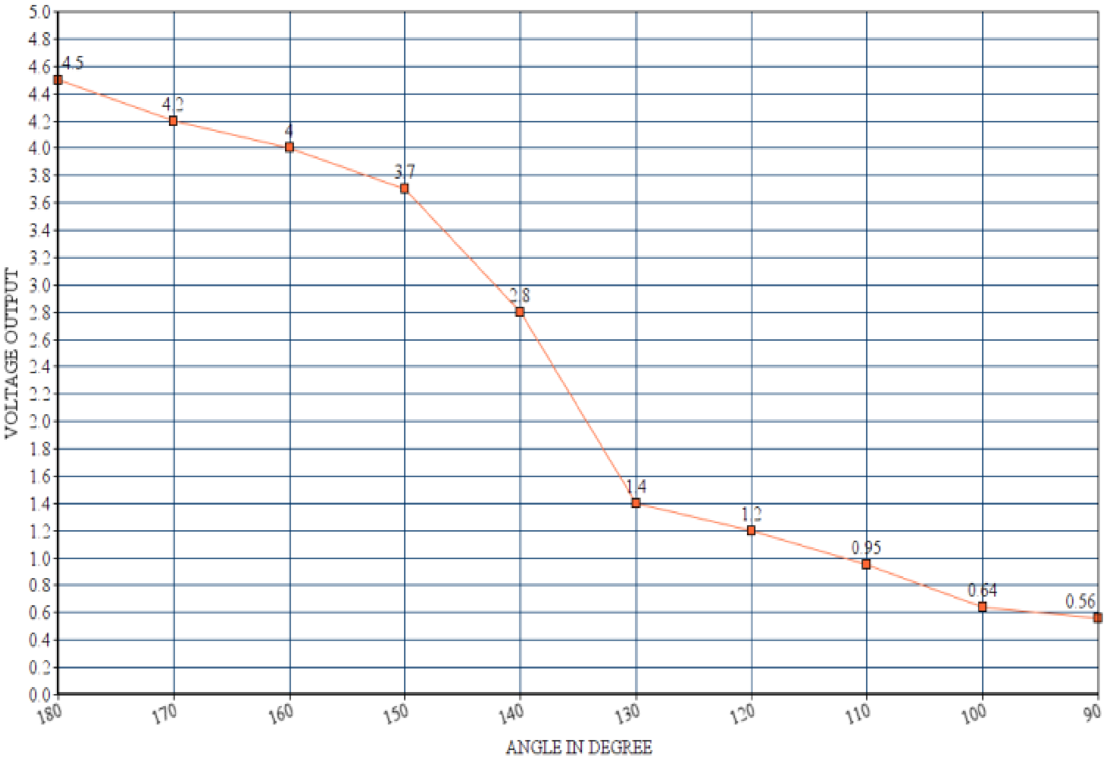


Figure 9: Graph showing Elbow bending vs output voltage

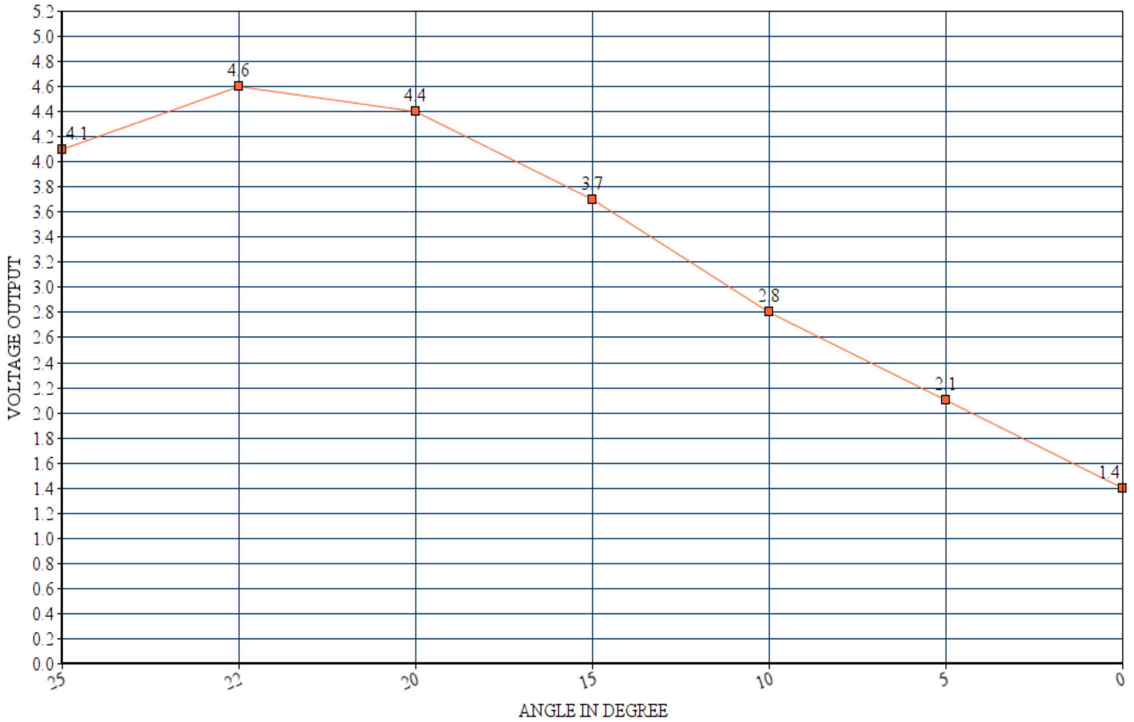


Figure 10: Graph Showing Finger extending vs output voltage

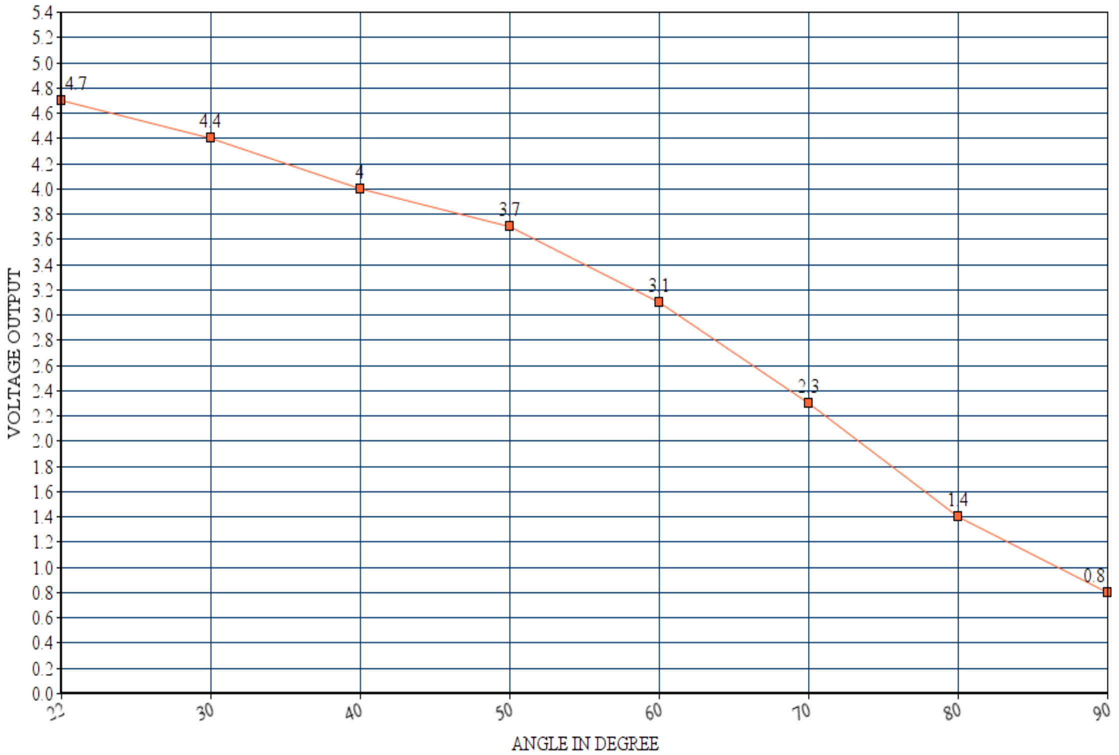


Figure 11: graph showing finger bending vs output voltage

From the above graphs it is clear that an almost linear variation is obtained for the finger bending sensor for both upward and downward bending from the relaxed position. Using the bevel protractor we found that the relaxed position is 22 degrees downward bend from the outstretched position. The maximum intensity is obtained for the relaxed position.

In the case of elbow bending there is a sudden drop of intensity from 150 degree to 130 degree. It is noted that the intensity of the source must be increased to get readings for up to 90 degree bend.

III. Conclusion

The above described model could be further updated in future works. The displacement optical fiber sensor could be replaced with an LPG-FBG combination which would greatly increase the sensitivity of the apparatus. The use of LPG-FBG combination sensor will open doors to greater possibilities and the model could be transformed to measure all angle related parameters.

Therefore we can transform this apparatus into a fully operational spirometer with the help of LPG-FBG sensor. These sensors have many advantages which include chemical inertness, small size, high sensitivity, ultra-fast response, electrically passive operation, insensitivity to radio frequency, immunity to electromagnetic interference. These advantages make it apt for use in medical diagnosis. Laser source can be replaced with LED source which will greatly reduce the cost.

Two different displacement type optical fiber sensors were setup for measuring finger bending and ankle bending of the human arm. The data was processed and stored in an excel file and uploaded into the cloud. A wireless sensor network based on Bluetooth controlled by an Arduino board was set up and the measured values were transmitted live to a mobile device. Live variation of the data was displayed in excel sheet.

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